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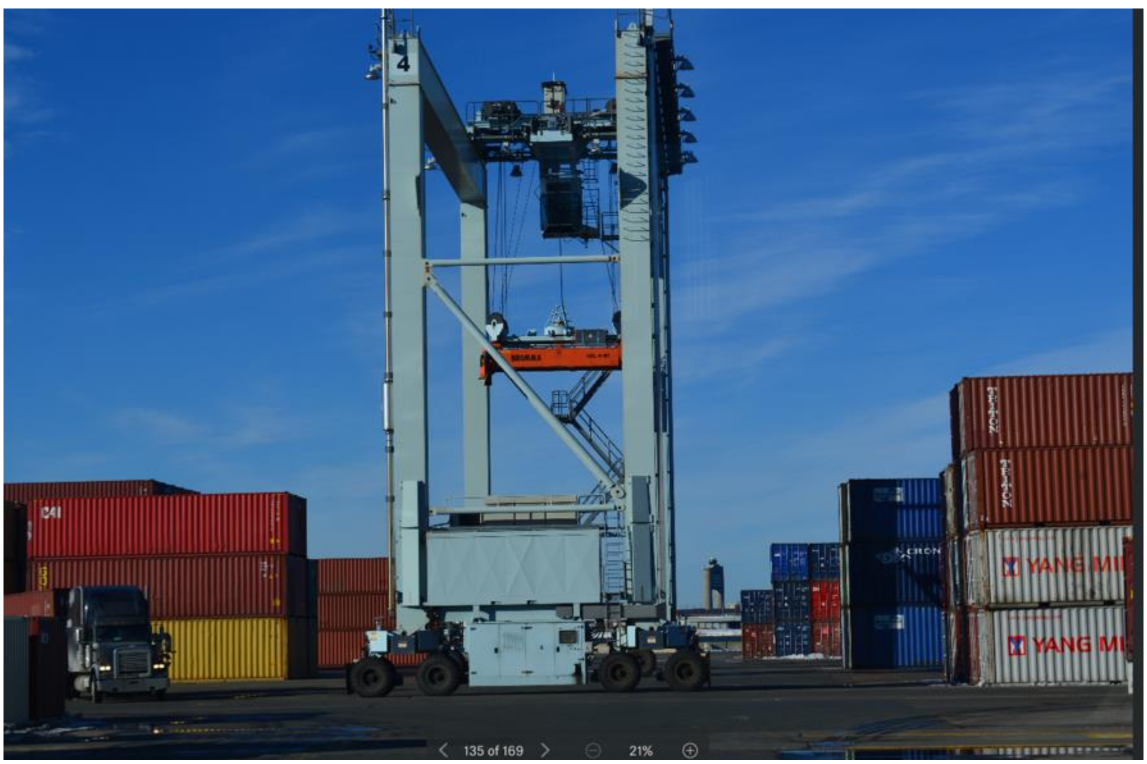
Measuring Climate and Extreme Weather Vulnerability to Inform Resilience

Report 1: A Pilot Study for North Atlantic Medium- and High-Use Maritime Freight Nodes

R. Duncan McIntosh, Elizabeth L. Mclean, and Austin Becker

November 2019



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Report 1: A Pilot Study for North Atlantic Medium- and High-Use Maritime Freight Nodes

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Report 1 of 2

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Vicksburg, MS 39180-6199

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Abstract

This research identified vulnerability indicators from open-data sources that represent the three components of vulnerability, as outlined by the Intergovernmental Panel on Climate Change: exposure, sensitivity, and adaptive capacity. With input from experts knowledgeable in port operations, planning, policy, and data, researchers refined a set of high-level vulnerability indicators to answer the following key questions: (1) how sufficient is the current state of U.S. seaport sector data for developing expert-supported vulnerability indicators for a regional sample of ports and (2) how can indicators be used to measure the relative vulnerability (i.e., exposure, sensitivity, and adaptive capacity) of multiple ports? Using open-data sources, this study developed an Indicator-Based Vulnerability Assessment methodology that integrates multiple vulnerability indicators for ports in the North Atlantic region. The Analytic Hierarchy Process, a technique for organizing and analyzing complex decisions using pairwise comparisons, was used to develop a ranking that matched 3 of the top-4 most vulnerable ports that were subjectively identified by port experts. This demonstrates strong promise for this methodological approach to measure seaport vulnerability to climate and extreme weather events. Indices of seaport relative vulnerability to climate and extreme weather can advance goals for a resilient Marine Transportation System by informing efforts and plans to prioritize and allocate limited resources.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE), Navigation Systems (NavSys) Research Program. NavSys is administered at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), under the USACE Navigation Systems Research and Development Program. The Program Manager of the NavSys Program was Mr. Charles E. Wiggins. This contract report was prepared by an interdisciplinary team at the University of Rhode Island, Kingston, RI, at the direction of Dr. Julie Rosati and Ms. Katherine Chambers at ERDC-CHL, Vicksburg, MS, and was funded by the Broad Agency Announcement Category CHL-11: Coastal Inlets and Navigation Channels. A full proposal was submitted to the ERDC CHL, Vicksburg, MS, through the Vicksburg Consolidated Contracting Office. This work was performed under Work Unit 33143; Project W912HZ-16-C-0019.

At the time of publication of this report, Mr. Jeffrey R. Eckstein was the Deputy Director of CHL, and Dr. Ty V. Wamsley was the Director.

COL Teresa A. Schlosser was the Commander of ERDC, and the Director was Dr. David W. Pittman.

Executive Summary

The third U.S. National Climate Assessment indicates that seaport infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat, and research suggests damage rates will continue to increase (Melillo et al. 2014). National and global economies depend on ports as over 90% of global trade is transported by sea (IMO 2012). Because climate and extreme weather affect most coastal infrastructure in the United States (IPCC 2013), it is important that knowledge of the regional distribution of vulnerability to climate and extreme weather inform transportation resilience and climate-adaptation planning.

This work is part of the U.S. Army Corps of Engineers (USACE) Project W912HZ-16-C-0019 entitled “Measuring Climate and Extreme Weather Vulnerability to Inform Resilience.” This report captures the first of a two-part study. In this first part, experts ranked higher the use of *exposure* and *sensitivity* indicators as measures of ports vulnerability. The second part of the study (Mclean and Becker [2019], *Measuring Climate and Extreme Weather Vulnerability to Inform Resilience: Report 2: Port Decision Makers’ Barriers to Climate and Extreme Weather Adaptation*) focuses on *adaptive capacity* – the third component of vulnerability—and in particular on barriers to adaptation.

This project develops and pilots a methodology to measure climate and extreme weather vulnerability for North Atlantic Medium- and High-Use seaports by aggregating weighted indicators into composite indices. The approach developed by the University of Rhode Island with the support of the U.S. Army Engineer Research and the Development Center at the U.S. Army Corps of Engineers (USACE), integrates multiple vulnerability indicators. The composite indices resulted from a process that first identified candidate indicators from open-data sources, used experts’ evaluation of the candidate indicators, and weighted a selection of the highest ranking indicators.

The vulnerability indicators identified from open-data sources were sought for their potential to represent one of the three components of vulnerability outlined by the Intergovernmental Panel on Climate Change (IPCC): exposure, sensitivity, and adaptive capacity (IPCC 2012). To help ensure scalability, the project relied on open-data sources rather than creating bespoke datasets or obtaining proprietary data.

Based on the availability of open-data sources, this study developed an Indicator-Based Vulnerability Assessment (IBVA) methodology; the generated indices of seaport relative vulnerability to climate and extreme weather can advance the goals of the Marine Transportation System of the USACE by informing efforts and plans to prioritize and allocate limited resources to increase the climate resilience of seaports.

This report outlines the process of identification of candidate indicators for describing seaport vulnerability, the subsequent narrowing down to a manageable set, and the process of weighting and ranking indicators applied to a sample of ports. Of the 108 initially identified candidate indicators, 48 were supported by sufficient data for the selected 22 ports within the USACE North Atlantic Division geographic boundary. Through an expert elicitation process, experts ranked each indicator's correlation with the components of vulnerability (i.e., exposure, sensitivity, and adaptive capacity); indicators that did not have a high perceived correlation with the components of vulnerability were removed at this stage. This left 34 candidate indicators, of which the top-12 ranking indicators were weighted by experts in a final step via an Analytic Hierarchy Process (AHP).

The AHP resulted in relatively low levels of perceived correlation with adaptive capacity, compared to that for exposure and sensitivity. Therefore, the resulting seaport composite indices of vulnerability do not include indicators for adaptive capacity. Regional distribution of port vulnerability was measured with the composite indices of seaport exposure and sensitivity to climate and extreme weather resulting from aggregating the selected weighted indicators. The results of the IBVA methodology were validated by comparison to a subjective expert-ranking of ports by perceived vulnerability to climate and extreme weather. The AHP-generated ranking matched three of the top-4 most vulnerable ports as assessed subjectively by port experts showing strong promise as a methodological approach for measuring seaport vulnerability to climate and extreme weather events.

In conclusion, a new methodology to measure relative vulnerability to climate and extreme weather can advance the goals of the USACE by informing efforts and plans to prioritize and allocate limited resources to increase the climate resilience of seaports. Results of the research reported here suggest that while indicator-based methods show promise for differentiating outlier ports among a sample in terms of climate vulnerability, challenges remain. For instance, adaptive capacity indicators lacked expert-perceived correlation with the open-data indicators identified, suggesting that improvements in the standardized reporting and sharing of port data or identifying other less quantitative means of assessing adaptive capacity may be warranted.

Results of this research point to several next steps needed to enhance the ability to compare and assess seaport climate vulnerability. Researchers recommend that future efforts focus on the development of methods to comparatively measure ports' adaptive capacity. Port experts weight adaptive capacity high in importance with respect to seaport climate vulnerability, yet adaptive capacity lacks expert-supported representation in the available data. Because results of the Visual Analogue Survey indicate that port-specific data are preferred by experts for representing adaptive capacity, researchers recommend that non-open (i.e., proprietary) port-specific data be explored for this purpose where possible. Additionally, researchers recommend that next steps involve the investigation of what types of bespoke data (e.g., Geographic Information System analysis of port elevation or proprietary non-open-data sources) might be synthesized into new, additional, or supplementary indicators.

1 Introduction[1]

At a national and regional scale, understanding how climate and storm events at maritime freight nodes (i.e., coastal ports) can help decision-makers evaluate how port-related investments impact the greater economy, the ecosystems in which ports reside (NRC 2009), and the level of resilience inherent to a port system. This understanding can lead to better decisions to increase resilience and coastal protection.

The vulnerability of seaports to climate and extreme weather can be measured in different ways; some studies have focused on the assessment of *exposure* only (Hanson et al. 2010; Nicholls et al. 2008); others have assessed port vulnerability at the single-port scale (NOAA 2015; Sempier et al. 2010; Morris and Sempier 2016); others have enlisted indicators as measures of relative port-performance. However, difficulty remains for describing the distribution of relative port climate vulnerability across multiple ports in a region. Climate and extreme weather are already affecting coastal infrastructure in the United States (Melillo et al. 2014). The threats include sea level rise, heavy downpours, and extreme heat. Impacts are expected to worsen over time; thus, the regional distribution of relative vulnerability of seaports in the North Atlantic to these impacts can assist planning priorities toward more resilient marine transportation.

How sufficient is the current state of data reporting for and about the seaport sector to develop expert-supported vulnerability indicators for a regional sample of ports?

When comparing vulnerabilities of multiple disparate systems, Indicator-Based Vulnerability Assessment (IBVA) methods can (1) provide a (semi) objective measure based on an aggregate of experts' opinions of an indicator's value, which is then applied to a group of ports, as opposed to an individual person guessing about the vulnerability of any one particular port; (2) allow measurable comparison that can be applied to other ports or used to evaluate level of

[1] Portions of this chapter reproduced from Duncan McIntosh, R. Duncan, and A. Becker. 2017. "Seaport Climate Vulnerability Assessment at the Multi-port Scale: A Review of Approaches." *Resilience and Risk: Methods and Application in Environment, Cyber and Social Domains*, edited by I. Linkov and J. M. Palma-Oliveira, 205-224. Springer Netherlands, Dordrecht.

vulnerability over time; and (3) allow investigations of the components and determinants of vulnerability levels. These standardized metrics allow for high-level analysis to identify areas or systems of concern. To advance IBVA for the seaport sector, this study investigated the suitability of publicly available open-data sources, generally collected for other purposes, to serve as indicators of climate and extreme-weather vulnerability for 22 major seaports in the Northeast United States, addressing the following question: Can the current state of data be utilized to develop expert-supported vulnerability indicators for a regional sample of ports?

This research contributes to a better understanding of the regional distribution of climate and extreme weather vulnerability across 22 North Atlantic ports to inform transportation resilience and climate and extreme weather adaptation planning. Results will serve as an entry point to inform the Marine Transportation System (MTS) decision-makers in the U.S. Army Corps of Engineers (USACE) and other agencies about the nature of seaport vulnerabilities to climate and extreme weather, the components and determinants of those vulnerabilities, the mechanisms through which a port is vulnerable, and the suitability of available data to serve as high-level indicators of seaport climate and extreme weather vulnerability.

Although this report focuses specifically on ports, these ports form part of a larger multi-modal network (i.e., the MTS). This approach considers the port as a *system* composed of on-site port infrastructure and equipment, water side components (approach channels), hinterland road and rail connections, as well as the surrounding natural environment and its local communities.

1.1 Report organization and research design

This contract report is organized into six chapters.

Chapter 1 provides background, terminology, and a description of the research design for the development of the composite indices of seaport vulnerability.

Chapter 2 describes the process of identifying and refining a set of candidate indicators from open-data sources. The search for candidate indicators was driven by the definition of climate vulnerability as defined by the Intergovernmental Panel for Climate Change (IPCC). *Indicators* are measurable, observable quantities that serve as proxies for an aspect of a system that cannot itself be directly, or precisely, measured (Gallopin 1997; Hinkel 2011). Indicators were identified by reviewing the Climate Change Vulnerability Assessment (CCVA) and seaport studies literature. Indicators were sought for their potential to represent one of the three components of vulnerability outlined by the IPCC: *exposure, sensitivity,* and *adaptive capacity* (IPCC 2012). From the initial literature search, 108 candidate indicators were identified within 20 open-source databases (hosted in seven federal agencies and one higher education institution webpage). Of these, 48 candidate indicators were found to contain data for the USACE North Atlantic Division (CENAD) sample of ports. These 48 candidate indicators were then presented to members of the U.S. Committee for Marine Transportation System, Resilience Integrated Action Team (RIAT). The MTS RIAT was established to focus on cross-federal agency knowledge co-production and governance to incorporate the concepts of resilience into the operation and management of the U.S. MTS (Touzinsky et al. 2018). Using a *Mind map©,* an organized diagram that allows the visualization of ideas (Mindmap.com 2017), the RIAT could visualize each candidate indicator hierarchically linked to the components of climate vulnerability. The RIAT experts helped the researcher team eliminate candidate indicators with low perceived correlation with the components of climate vulnerability for seaports. Thirty-four indicators were selected via the *Mind mapping©* exercise with the RIAT team of experts.

Chapter 3 describes the process of evaluating the set of 34 candidate indicators via a Visual Analogue Scale (VAS) survey where experts evaluated each indicator for perceived correlation with each of the three components of vulnerability, as mentioned above. This chapter present a measure of expert-perceived correlation with the components of seaport climate vulnerability for each of the 34 candidate indicators.

Chapter 4 describes the application of the expert Analytic Hierarchy Process (AHP) to develop weights for the top-scoring vulnerability indicators as evaluated via the VAS survey described in Chapter 3. Because the port expert respondents found stronger correlation between candidate indicators for the exposure and sensitivity vulnerability components of a port than for indicators for the adaptive capacity, the AHP exercise did not include this last component.

Chapter 5 discusses how the weighted indicators were aggregated to generate a prototype composite index of seaport exposure and sensitivity to climate and extreme weather for the 22 ports in this study. From the initial assessment, the results were validated by comparing the rank order to a subjective expert-ranking of ports based on perceived vulnerability to climate and extreme weather. The AHP-generated ranking matched three of the top-4 most vulnerable ports as assessed subjectively by port experts.

Chapter 6 summarizes the conclusion from this study, which found that the development of weighted algorithms and composite indices, based on open-data, for seaport relative vulnerability to climate and extreme weather can advance the goals of the Marine Transportation System (MTS) of the USACE by informing efforts and plans to prioritize and allocate limited resources to increase the climate-resilient seaports.

1.2 Background

1.2.1 Vulnerability of seaports[1]

The primary function of a port is the transfer of cargo and/or passengers between a waterway and the shore (Talley 2009), but today's ports are more than simply a system of channels, wharves, and multi-modal connections. Ports link international supply-chains and are critical to the global economy and trading system (Figure 1). At the same time, many U.S. ports are highly vulnerable to a range of climate-related impacts, including temporary and permanent flooding arising from sea level rise, high winds, and storm surges (Hanson et al. 2010; Asariotis et al. 2017). Service disruptions alone can cause total economic losses in the billions of dollars (Haveman and Shatz 2006; Lloyds 2017) and can have second-order consequences, not only for the regional economy and the quality of life of those who depend on the port's functionality but also for the operation of supply chains (Figure 1).

[1]Portions of this chapter reproduced from Duncan McIntosh, R. Duncan, and A. Becker. 2017. "Seaport Climate Vulnerability Assessment at the Multi-port Scale: A Review of Approaches." *Resilience and Risk: Methods and Application in Environment, Cyber and Social Domains*, edited by I. Linkov and J. M. Palma-Oliveira, 205-224. Springer Netherlands, Dordrecht.

Figure 1. Ports are critical to the U.S. national economies, global trade, and national security. Photo: Port of Camden-Gloucester, N.J. (photo by Elizabeth L. Mclean, 2018).

Seaports represent spatially defined, large-scale, coast-dependent infrastructure with high exposure to projected impacts of global climate change and extreme weather impacts (Becker et al. 2013; Hanson et al. 2010; Melillo et al. 2014). Since 90% of global trade is carried by sea (IMO 2012), a disruption to port activities can interrupt supply chains and have far-reaching consequences (Becker et al. 2011; Becker et al. 2013; IPCC 2014a).

Among climate change vulnerability, resilience, and risk assessment methods applied to seaports, most efforts to date have been limited in scope to exposure-only assessments (Hanson et al. 2010; Nicholls et al. 2008; Klein et al. 2003), limited in scale to a single port (either as case studies (Koppe 2012; Cox et al. 2013; USDOT 2014; Messner et al. 2013; Chhetri et al. 2014; Stenek et al. 2011; Peris-Mora et al. 2005) or as self-assessment tools (Sempier et al. 2010; Morris and Sempier 2016; Roos and Kliemann Neto 2017; NOAA 2015).

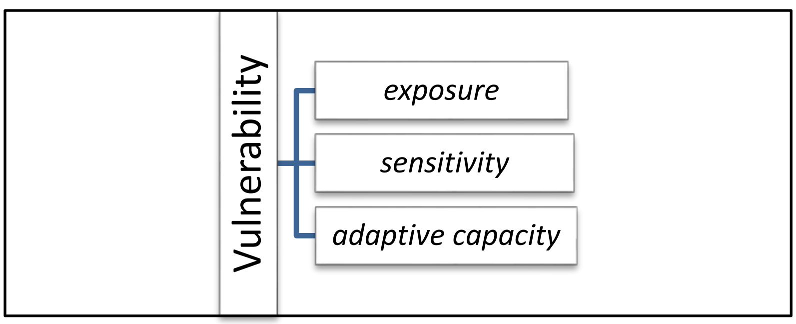
The stakeholders who depend upon the port functionality are diverse, as ports serve as profit centers for a variety of businesses, including shippers, shipping agents, energy companies, importers and exporters, and port authorities. They facilitate the transport of energy resources, building materials, finished products, and chemicals. Ports also share ecologically sensitive coastlines with other stakeholders, such as commercial and recreational users. Ports may also be considered a cultural element, embedded within and held accountable for the goals of a larger society (Burroughs 2005).

1.2.2 Terminology

In port's IBVA, *indicators* are measurable, observable quantities that serve as proxies for an aspect of a system that cannot itself be directly, adequately measured (Gallopin 1997; Hinkel 2011). Indicator-based assessment methods are generally applied to assess or measure features of a system that are described by theoretical concepts. Directly immeasurable, concepts such as resilience and vulnerability are instead made operational by mapping them to functions of observable variables called indicators (McIntosh 2018).

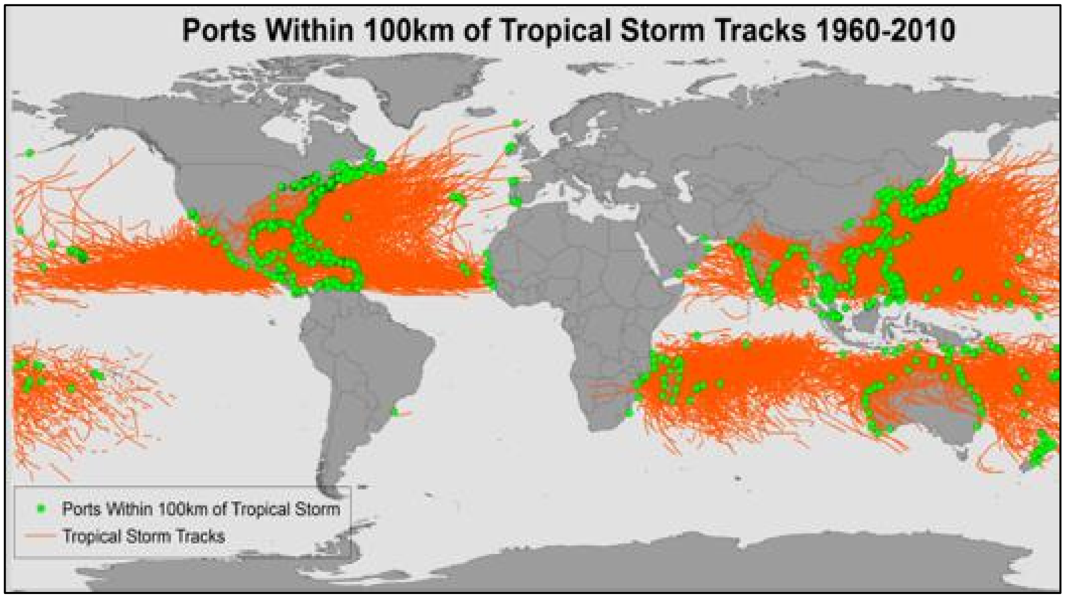
Vulnerability is defined as a function of the character, magnitude, and rate of climate and extreme weather change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2001) (Figure 2).

Figure 2. The three components of vulnerability.



Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC 2014a). For ports, high exposure to climate and extreme weather events would be one that, for example, when the port is in an area prone to hurricanes or with a higher than average rate of sea level change. For example, U.S. East Coast ports are thought to have higher exposure to tropical storms than U.S. West Coast ports (Figure 3) whereas West Coast ports have higher exposure to earthquakes.

Figure 3. Exposure of ports relative to proximity of historical tropical storms.



Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC 2001). An example of a port structure with a high level of sensitivity to climate and extreme weather events would be an old wooden pier built over a century ago and in poor repair. This pier would be more susceptible to damage from a future storm event. A low level of sensitivity would be a newly constructed cement pier built to today's design standards (Figure 4). Note that in this example, the exposure for both structures could be the same, but due to its higher sensitivity, the wooden pier would be more vulnerable.

Figure 4. Examples of high (left) and low (right) levels of port sensitivity relative to its infrastructure construction materials and age.

Adaptive capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC 2014a). For ports, higher adaptive capacity could be represented by a higher level of resources available to invest in resilience (Figure 5), or a port with a robust resilience plan and a staff position dedicated to resilience might be considered to have a higher adaptive capacity. A port that is struggling to make a profit with short planning horizons might be thought of as having a lower adaptive capacity.

Figure 5. Decision-makers use resources to plan for resilience.

Risk: A measure of the potential for consequences where something of value is at stake and where the outcome is uncertain (IPCC 2014b). Risk can be quantitatively modeled as *Risk = p (L)*, where *L* is potential loss and *p* the probability of occurrence. However, both can be speculative and difficult to measure in the climate-risk context. Risk, in the context of climate change, is often defined similarly to vulnerability (Preston 2012; IPCC 2014a), but — as seen in the equation — with the added component of *probability,* thus making vulnerability a component of *risk*. From the risk analysis perspective, the indicators developed by this research focus on measuring the potential loss "*L*" rather than the probability "*p*." From the CCVA perspective, indicators are developed to measure vulnerability based on the three components, but not in relation to likelihood nor probability of occurrence.

Resilience: As defined by the IPCC, resilience is "the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function" (IPCC 2014b). More recently, Schultz and Smith (2016) defined it as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." Most working definitions of resilience involve a process that begins before a hazardous impact occurs, including temporal periods for during and after the impact. While this research will further the development of indicators of seaport climate and extreme weather vulnerability, the objective is that by increasing the understanding of the regional distribution of seaport climate and extreme weather vulnerability, the overall resilience of the MTS[1] can be enhanced.

The focus on individual port scale assessments presents a challenge for how to assess the regional distribution of climate and extreme weather vulnerabilities across multiple ports.

Other terminology used in this study is defined in Appendix A.

1.2.3 Vulnerability assessments

The IPCC describes the vulnerability and risk assessment as "the first step for risk reduction, prevention, as well as climate adaptation in the context of extremes." (IPCC 2012). Similarly, the U.S. National Climate Assessment considers vulnerability and risk assessment as an "especially important" area in consideration of adaptation strategies in the transportation sector (Melillo et al. 2014).

Port decision-makers, including port managers and federal agencies, manage risks for a diverse array of stakeholders, not only in ports but also in private firms and areas of public interest. In the context of climate change and extreme risks, port managers may consider the uninterrupted operations of their port the number-one priority. However, at the multi-port (regional or national) scale, policy-makers will need to prioritize competing port adaptation needs to maximize the efficiency of limited physical and financial resources, and to address the resilience of the marine transportation system as a whole.

[1] The MTS consists of waterways, ports, and inter-modal land-side connections that allow the various modes of transportation to move people and goods to, from, and on the water MARAD. 2016. *Marine Transportation System (MTS)* [Online]. Washington, DC: Maritime Administration. Available at https://www.marad.dot.gov/ports/marine-transportation-system-mts/. Accessed 5/25/2016..

1.2.4 Single vs. multi-seaport assessments

In 2010, Hanson et al. (2010) made positive progress in the area of climate change vulnerability assessment by looking at the exposure of 136 international port cities with over one million inhabitants exposed to flooding in 2005. Their case study considered exposure for present day 100-year floods including six additional predicted future flooding scenarios. Using semi-empirical values of the number of people and 2005-dollar value of assets, researchers were able to calculate exposure. However, producing more concrete calculations was difficult due to scale.

This is one of many examples of seaport vulnerability and risk assessment methods that are limited to exposure-only assessments (Hanson et al. 2010; Nicholls et al. 2008), limited in scale to a single port, presented as case studies (Koppe et al. 2012; Cox et al. 2013; USDOT 2014; Messner et al. 2013; Chhetri et al. 2014), or presented as self-assessment tools (NOAA OCM 2015; Sempier et al. 2010; Morris and Sempier 2016). While single-port scale CCVA inform decisions within the domain of one port (e.g., Which specific adaptations are recommended for my port?), a CCVA approach that objectively compares the relative vulnerabilities of multiple ports in a region could support Climate Impact Adaptation and Vulnerability decisions at the multi-port scale (e.g., Which ports in a region are the *most* vulnerable and urgently in need of adaptation?). The focus on individual port scale assessments presents a challenge for how to assess the regional distribution of climate and extreme weather vulnerabilities across multiple ports.

While self-assessment methods can yield valuable stakeholder insight into the state of an individual seaport, they are context-specific and therefore, not readily applicable to comparative analyses across seaports. Mixed quantitative and qualitative methods allow for a deeper understanding of individuals' or groups' perceptions of vulnerability.

At the multi-port scale, an evaluation of *relative* climate and extreme weather-vulnerabilities or the distribution of those vulnerabilities among a regional or national set of ports requires standard measures (i.e., indicators or metrics). As an example, the Port Performance Indicators: Selection and Measurement program aims to develop indicators that allow the port industry to measure, assess, and communicate the impact of the European port system on society, the environment, and the economy (ESPO 2010).

Resiliency of systems are routinely measured at the engineering level. These efforts are challenged by difficulty of agreement on a quantifiable measure and the integration of uncertainty (Yodo and Wang 2016). Concepts of resilience and risk can be mapped using functions of observable variables called indicators. Given that indicators serve as proxies (Gallopin 1997; Hinkel 2011), indicator-based assessment methods are generally applied to assess or measure features of a system that are described by theoretical concepts.

To measure relative vulnerability across multiple ports, or to predict a port's climate and extreme weather resilience, port vulnerability indicators are considered. The indicator-based assessment process consists of two or sometimes three steps: (1) defining the response to be indicated, (2) selecting the indicators, and (3) aggregating the indicators (Hinkel 2011). Step three is sometimes omitted, but it is fundamental for generating a numerical *score* or creating a comparative index.

The Value of Seaport Climate and Extreme Weather Vulnerability Indicators

On a national and regional scale, evaluation of port-related investment proposals for restoring ecosystems and sustaining navigation will require an understanding of how climate and storm events at maritime freight nodes (i.e., coastal ports) impact the greater economy and ecosystems in which ports reside (NRC 2009) and the level of resilience inherent to a port system. For comparative studies, the data used as indicators need to hold similar standards and scale. By identifying and refining a set of high-level vulnerability indicators of seaport climate and extreme weather vulnerability, the availability and suitability of data to differentiate ports' relative vulnerability within a region can be better understood.

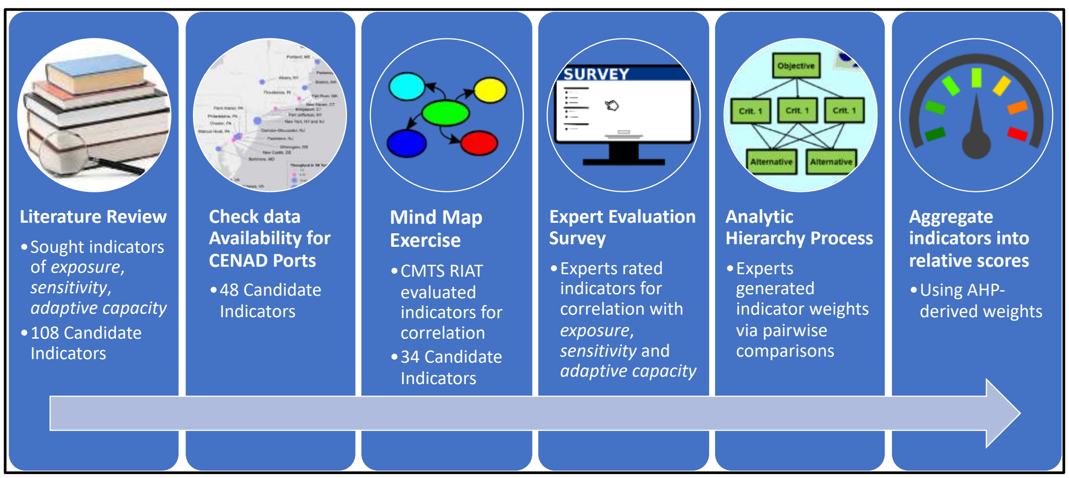
The remainder of this report describes the methods developed and tested to identify, evaluate, and implement the vulnerability index approach.

2 Identification of Candidate Indicators of Seaport Vulnerability to Climate and Extreme Weather

2.1 Introduction

This Chapter 2 describes the method for identifying candidate indicators for seaport vulnerability (i.e., exposure, sensitivity, and adaptive capacity, Figure 6). It begins with a description of approaches to indicator-based assessment and applicability to the seaport sector. Next, it describes the method used to identify candidate indicators through a web and literature-based search and the verification of data availability for the studied ports. It then provides an overview of how experts participated in a *Mind mapping*© exercise (see Appendix B) to vet the candidate indicators and narrow the list to a size that could be evaluated through a VAS process in an online survey described in Chapter 3.

Figure 6. Research design with steps allocated into four chapters of this report. Chapter 2 focuses on the first three steps.



2.1.1 Indicator-based assessments

The indicator-based assessment process (Hinkel 2011) consists of two or sometimes three steps: (1) defining the response to be indicated, (2) selecting the indicators, and (3) aggregating[1] the indicators. (Hinkel 2011) describes three kinds of arguments for developing vulnerability indicators and notes that development of indicators generally combines different

[1] This step is sometimes omitted but necessary to yield a heat map or create a comparative index.

types such as (1) deductive indicators that are based on existing theory, (2) inductive indicators that are based on data of both the indicating variables as well as observed harm, and (3) normative indicators that are based on stakeholder's value judgments.

Accordingly, the approach described in this work begins with the application of a deductive argument, meaning that the selection of vulnerability indicators is grounded in the framework established in the third assessment report of the Intergovernmental Panel on Climate Change (IPCC 2001). The IPCC report defined climate change vulnerability in terms of three components: exposure, sensitivity, and adaptive capacity. The expert-elicitation process can be described as a normative approach because it seeks experts' consensus based on the value judgments required to determine perceived correlation between the candidate indicators and the components of vulnerability initially identified.

2.1.2 Expert elicitation

Expert elicitation has become a common approach for the indicator development process, and examples include the "new indicators of vulnerability and adaptive capacity" (Adger et al. 2004), "determinants of vulnerability and adaptive capacity at the national level" (Brooks et al. 2005), climate change vulnerability for South Korea (Kim and Chung 2013), performance appraisal indicators for mobility of the service (Seijger et al. 2014) industries (Kuo and Chen 2008), and indicators for fisheries management (Rice and Rochet 2005) among others. Additionally, research indicates that involving stakeholders in the process of developing knowledge systems (White et al. 2010; Schroth et al. 2011) (i.e., decision support tools) can lead to improvements in their perceived credibility, salience, and legitimacy (Seijger et al. 2014; Akompab et al. 2012)

This investigation contributes to the ongoing work of developing climate change vulnerability assessment indicators by applying expert-elicitation methods to develop and evaluate a set of indicators for each of the three components of seaport climate vulnerability.

The IPCC considers indicators an important part of vulnerability and risk analysis and recommends that quantitative approaches be complemented with qualitative approaches to capture the full complexity of climate vulnerability in its different dimensions (environmental, social, economic)

(IPCC 2014a). This investigation contributes to the ongoing work of developing CCVA indicators by applying expert-elicitation methods to develop and evaluate a set of indicators for each of the three components of seaport climate vulnerability.

To date there have been relatively few examples of comparative CCVA for the seaport sector (McIntosh 2018). Most indicator-based assessments for ports have stopped short of a comparative CCVA[1] (e.g., the elevation-based exposure-only assessment of global port cities [Nicholls et al. 2008]) or have focused on assessing other concepts (e.g., which aimed to measure port performance [ESPO 2012]). While understanding how a port or a port-city's elevation affects its exposure to climate-impacts like sea level rise (SLR), it is only one piece of the puzzle that describes how a port is or is not vulnerable to climate and extreme weather. By assessing the sensitivity and adaptive capacity of a port along with its exposure to a wide array of impacts in addition to SLR, a more complete picture of the mechanisms and drivers of seaport climate vulnerability may be better understood.

As port decision-makers face climate and extreme weather impacts and make adaptation and vulnerability[1] decisions, CCVA support those decisions (IPCC 2014a). This process can generate dialog among stakeholders and practitioners on planning and implementation of needed adaptation measures. Such assessments can be made at the single-port scale, or at the multi-port scale, with each approach having benefits for different decision-makers.

2.2 Methodology

Rather than taking a purely theoretical approach to developing indicators (e.g., that used in the development of the Social Vulnerability Index [SoVI] [Cutter et al. 2003]), this work takes a stakeholder-driven approach to a vulnerability indicator development by including port experts in the selection, evaluation, and weighting of the indicators. According to previous works, stakeholder-driven approaches increase the creditability of the indicators as tools (Barnett et al. 2008; Sagar and Najam 1998). By including stakeholders in the design-stage of decision-support tools or boundary-object development, the stakeholders'

[1] CCVA decisions are choices, the results of which are expected to affect or be affected by the interactions of the changing climate with ecological, economic, and social systems.

perceptions of the credibility, salience, and legitimacy of the tool can be increased (White et al. 2010).

For evaluating candidate indicators of seaport vulnerability, this research took a holistic approach to vulnerability assessment by considering impacts that extend beyond the borders of the port property. To that end, this research, in the identification and evaluation of the candidate indicators, considered potential multimodal vulnerabilities at the port location as well as impacts to a port's surrounding community and economy (socio-economic systems) and ecological and environmental surroundings (environmental systems).

The selection and evaluation of indicators involved three steps, which will be described in the following sections:

Step 1. Literature review to compile candidate indicators
Step 2. Vetting for data availability
Step 3. *Mind mapping©* exercise.

This research focuses on the 9 high-use and 13 medium-use ports (Table 1) found in the CENAD[1] as the sample population for which to develop indicators (Figure 7). The U.S. Army Engineer Research and Development Center has expressed an interest in piloting port resilience and vulnerability assessment methods with high-use ports[2] and by adding medium-use ports and restricting the selection to the Northeast region, researchers were able to create a manageable sample of 22 ports.

[1] The North Atlantic Division is one of nine USACE divisions and encompasses the U.S. Eastern Seaboard from Virginia to Maine (USACE 2019).

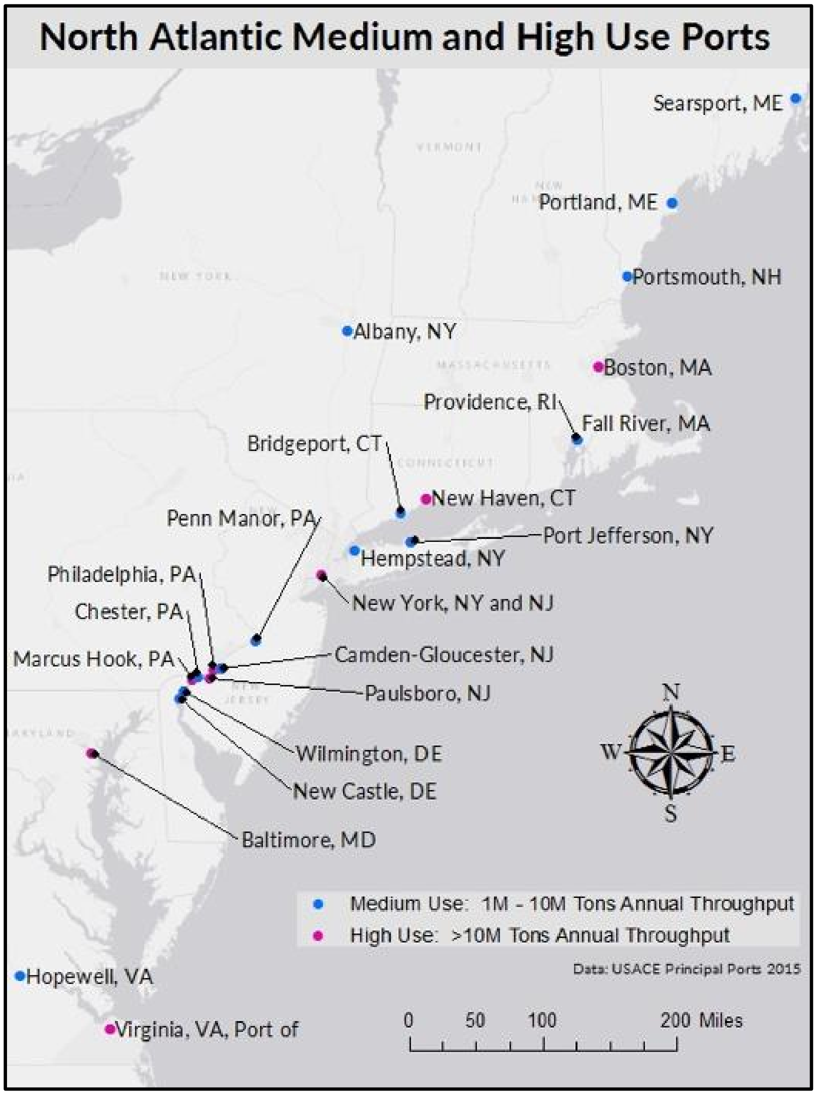
[2] Dr. Julie Rosati, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Personal communication, February 2015.

Table 1. Nine high-use ports (> 10 million tons, dark blue) and 13 medium-use ports (1 to 10 million tons, light blue) in the North Atlantic Region, 2015.

NO.	PORT NAME	STATE	TOTAL TONS
1	New York	NY and NJ	123,323,000
2	Norfolk Harbor	VA	48,893,600
3	Baltimore	MD	36,578,800
4	Philadelphia	PA	26,046,300
5	Paulsboro	NJ	19,122,100
6	Boston	MA	17,087,800
7	Portland	ME	12,039,600
8	Marcus Hook	PA	11,925,400
9	Albany	NY	11,021,200
10	New Haven	CT	8,350,900
11	Providence	RI	7,749,520
12	New Castle	DE	6,918,900
13	Wilmington	DE	6,146,100
14	Camdem-Glaucester	NJ	5,536,810
15	Portsmouth	NH	2,679,150
16	Penn Manor	PA	2,586,130
17	Bridgeport	CT	1,805,580
18	Searsport	ME	1,457,540
19	Port Jefferson	NY	1,437,880
20	Falls River	MA	1,366,630
21	Chester	PA	1,306,040
22	Hopewell	VA	1,027,150

Source: http://www.navigationdatacenter.us/wcsc/portname15.html

Figure 7. The 22 medium-use (blue dots) and high-use (magenta dots) ports in the North Atlantic based on USACE CENAD data from 2015.



The proximity of these ports to the University of Rhode Island allowed the team to ground-truth some of the research through site visits and interviews. Results of these interviews will follow in a subsequent report. Though this assessment was tailored for the New England region, the framework was developed with the intent that it could be applicable (with modifications) to other regions.

2.2.1 Step 1: Literature review to compile candidate indicators

Candidate indicators of seaport climate and extreme weather vulnerability were first identified from an extensive literature review of the CCVA and seaport studies researched in the literature. Indicators were sought for their potential to represent one of the three components of vulnerability: exposure, sensitivity, and adaptive capacity. These three components were considered in terms of weather extremes, variability, projected climate changes, and the impacts of these stressors on seaports and their associated socioeconomic and environmental systems.

The exposure component of vulnerability captures the geographic proximity of a port to projected climate and extreme weather impacts, while the sensitivity component captures the degree to which a port is affected by those impacts. Adaptive capacity indicators are not specific to individual climate impacts (USDOT 2014) but capture a port's ability to cope with and respond to stress by measuring redundancies within the port, duration of downtime, and ability to bounce back quickly. Other examples of candidate indicators for adaptive capacity include *port throughput value, budgets, planning processes,* and *resilience budgets*. The 108 candidate indicators are described in more detail in a spreadsheet linked through the University of Rhode Island Digital Commons online repository (for access, visit hyperlinked address at URI – Digital Commons). The 48 candidate indicators found to contain appropriate data for analysis of the North Atlantic ports in this study are further described in Appendix C of this report.

2.2.2 Step 2: Vetting for data availability

Any candidate indicators identified in the literature review were vetted for data availability. Several criteria were necessary for data to qualify for use in this study. First, the indicators and their dataset needed to be available from open-data sources. Next, datasets needed to be represented across the sample set of ports. If a particular dataset was not available across at least 16 of 22 ports, it was left out of the analysis. New data were not created or collected for this research, although future studies could enhance this assessment through the addition of new data such as age of structures, slope and elevation, individual port plans, and individual port budgets. Collecting such data was outside the scope of the project and presents numerous questions. For example, to collect age of structures or conduct a ground elevation analysis, decisions would need to be made about what *is* and *is not* part of the port. Since this study considered the port to be a system, numerous terminals and facilities might be included in each port. An elevation analysis would need to determine the bounds for each of these facilities, as well as which should be considered part of the port. Individual port plans or budgets would similarly need to be assessed in a way that could facilitate inter-port comparisons.

Once identified, candidate indicators were vetted for their data availability from open-data sources. Adopting open-data for indicator development increases transparency, facilitates reproducibility, and can enhance reliability when using standardized data sources (Janssen et al. 2012; CMTS 2015). Only those indicators with data available for at least 16 of the study's sample of 22 ports were retained for further study. The 108 candidate indicators of seaport climate-exposure, sensitivity, and adaptive capacity that were investigated during this first step, as well as each indicator's preliminary categorization, were presented in the University of Rhode Island's URI – Digital Commons and its open-data source are in Appendix C. Additionally, a summary and description of the open-data sources are also presented in Appendix D and Appendix E.

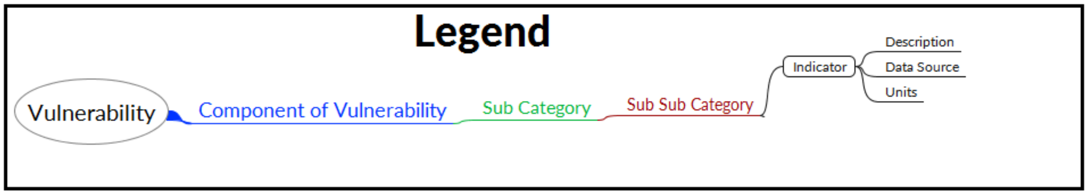
These candidate indicators include a mix of "place-based" indicators that measure vulnerability of place at the county scale, as seen in the "hazards-of-place" model of vulnerability (Cutter 1996b; Cutter et al. 2008; Cutter et al. 2010), e.g., *population inside floodplain*, and *port-specific* indicators that measure vulnerability via a characteristic of the port itself, e.g., *containership capacity*. For a comprehensive review of the data sources used, see the metadata spreadsheet in the URI – Digital Commons. Of the 108 candidate indicators originally compiled, 48 (24 place-based and 24 port-specific) were found to have sufficient data available for the 22 sample ports.

2.2.3 Step 3: *Mind mapping*© exercise to refine the set of candidate indicators

After compiling the 48 candidate indicators that were deemed to have sufficient data availability, researchers mapped them to the components of seaport climate vulnerability using the *Mind mapping*© software *FreeMind*[1]. On the *Mind maps*©, each of the 48 candidate indicators with available data was hierarchically mapped to one of the three components of vulnerability, and for each indicator, the research team provided its description, data source, and units (Figure 8).

[1] Muller, J., D. Polansky, P. Novak, C. Foltin, and D. Polivaev. 2013. *FreeMind – Free Mind Mapping and Knowledge Building Software*. http://freemind.sourceforge.net/wiki/index.php/Main_Page

Figure 8. *Mind map* legend presenting each indicator hierarchically mapped to a component of vulnerability. The *Mind map* also listed a description, data source, and units for each indicator.



Researchers held a workshop on 9 November 2016[1] with nine members of the RIAT[2] of the United States Committee on the Marine Transportation System[3] (U.S. CMTS) in Washington, DC, to elicit MTS-experts' opinions on which of the candidate indicators to include in the VAS survey instrument. For each candidate indicator, experts denoted with a plus or a minus whether an increase in that indicator correlates to an increase or decrease in the component of vulnerability it was mapped to, or with a zero if no correlation could be determined. In addition to evaluating the 48 candidate indicators with sufficient data availability, participants brainstormed other potential data sources for those indicators without sufficient data and suggested additional indicators that may have been overlooked (Appendix F).

The *Mind mapping* exercise concluded with 14 candidate indicators marked as having no correlation to vulnerability, 25 marked as having positive correlation, and 9 as having negative correlations. Because of the *Mind mapping* exercise, 34 candidate indicators were selected to be evaluated in the next round, which consisted of a VAS expert survey (described in Chapter 3) distributed to a larger group. Of these 34 indicators, 14 were port-specific and 20 were place-based indicators. They are listed alphabetically, along with descriptions, units, and data sources in (Table 2). For a more comprehensive description of each of the 34 indicators see the summary compilation in URI – Digital Commons.

[1] Workshop notes were submitted to USACE on 11/10/2016.

[2] The MTS RIAT was established to focus on cross-federal agency knowledge co-production and governance to incorporate the concepts of resilience into the operation and management of the U.S. MTS.

[3] The U.S. CMTS is a federal Cabinet-level, inter-departmental committee chaired by the Secretary of Transportation. The purpose of the CMTS is to create a partnership of federal departments and agencies with responsibility for the MTS.

Table 2. Thirty-four candidate indicators selected via *Mind mapping* exercise for inclusion in the VAS survey, with each indicator's description, units, and data source. Port-specific candidate indicators in bold.

Indicator	Description	Units	Data Source
Air.Pollution.Days	Number of Days with Air Quality Index value greater than 100 for the port city	Days	U.S. Environmental Protection Agency (EPA) Air Quality Report
Average.Cost.of.Hazmat.Incidents	Average cost per incident of total damage from the 10 most costly Hazardous Materials Incidents in the port city since 2007	$	U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration
Average.Cost.of.Storm.Events	Average cost of property damage from storm events in the port county since 1950 with property damage > $1 Million	$	National Oceanic and Atmospheric Administration (NOAA) Storm Events Database
Channel.Depth	The controlling depth of the principal or deepest channel at chart datum	A (over 76 feet [ft]) to Q (0 – 5 ft) in 5 ft increments	World Port Index (Pub 150)
Containership.Capacity	Container Vessel Capacity	calls x Dead Weight Total (DWT)	Marine Administration (MARAD): Vessel Calls at U.S. Ports by Vessel Type
Disaster.Housing.Assistance	The total disaster housing assistance of Presidential Disaster Declarations for the port county since 1953	Declarations	Federal Emergency Management Agency (FEMA): Disaster Declarations
Entrance.Restrictions	Presence or absence of entrance restrictions	Tide, Swell, Ice, Other	World Port Index (Pub 150)
Environmental.Index	Environmental Sensitivity Index (ESI) shoreline sensitivity to an oil spill for the most sensitive shoreline within the port	ESI Rank (1.00 - 10.83)	NOAA Office of Response and Restoration
Gas.Carrier.Capacity	Gas Carrier Capacity	calls x DWT	MARAD: Vessel Calls at U.S. Ports by Vessel Type
Harbor.Size	Harbor Size	Large, Medium, Small, Very-Small	World Port Index (Pub 150)
Hundred.Year.High.Water	1% annual exceedance probability high water level which corresponds to the level that would be exceeded one time per century, for the nearest NOAA tide station to the port	meters above mean higher high water (MHHW)	NOAA Tides and Currents: Extreme Water Levels

Indicator	Description	Units	Data Source
Hundred.Year.Low.Water	1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century	meters below mean lower low level (MLLW)	NOAA Extreme Water Levels
Marine.Transportation.GDP	County Marine Transportation Gross Domestic Product (GDP)	$	NOAA Office for Coastal Management
Marine.Transportation.Jobs	Number of Marine Transportation Jobs in the port county	number of jobs	NOAA Office for Coastal Management
Number.of.Critical.Habitat.Areas	Number of Critical Habitat Areas within 50 miles of the port	Areas	U.S. Fish and Wildlife Service
Number.of.Cyclones	Number of cyclones that have passed within 100 nautical miles (nm) of the port since 1842	Number of cyclones	NOAA Historical Hurricane Tracks Tool
Number.of.Disasters	Number of Presidential Disaster Declarations for the port county since 1953	Disaster Type	FEMA: Disaster Declarations
Number.of.Endangered.Species	Number of Threatened or Endangered Species found in port county	Species	U.S. Fish & Wildlife Service
Number.of.Hazmat.Incidents	Number of Hazardous Materials Incidents in port city since 2007	Number of Incidents	U.S. DOT Pipeline and Hazardous Materials Safety Administration
Number.of.Storm.Events	Number of storm events in port county w/ property damage > $1M	events	NOAA Storm Events Database
Overhead.Limits	Presence or absence of overhead limitations	Y/N	World Port Index (Pub 150)
Percent.of.Bridges.Deficient	Percent of bridges in the port county that are structurally deficient or functionally obsolete	%	US DOT FHA National Bridge Inventory
Pier.Depth	The greatest depth at chart datum alongside the respective wharf/pier. If there is more than one wharf/pier, then the one which has greatest usable depth is shown.	A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments	World Port Index (Pub 150)

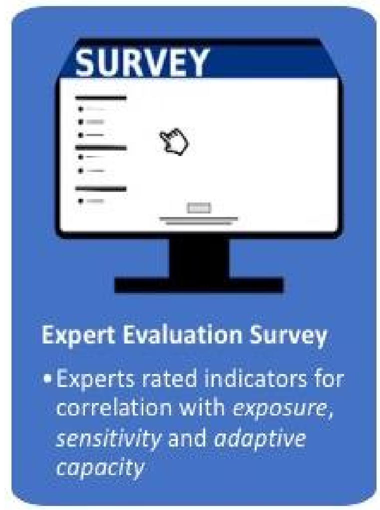
Indicator	Description	Units	Data Source
Population.Change	Rate of population change (from 2000-2010) in the port county, expressed as a percent change	%	NOAA Office for Coastal Management
Population.Inside.Floodplain	Percent of the port county population living inside the FEMA Floodplain	%	NOAA Coastal County Snapshots
Projected.Change.in.Days.Above.Baseline.Extremely.Hot.Temperature	The percent change from observed baseline of the average number of days per year above baseline “Extremely Hot” temperature projected for the end-of-century, downscaled to 12 km resolution for the port location	%	U.S. DOT Coupled Model Inter-comparison Project (CMIP) Climate Data Processing Tool
Projected.Change.in.Number.of.Extremely.Heavy.Precipitation.Events	The percent change from observed baseline of the average number of “Extremely Heavy” Precipitation Events projected for the end-of-century, downscaled to 12 km resolution for the port location	%	U.S. DOT CMIP Climate Data Processing Tool
Sea.Level.Trend	Local Mean Sea Level Trend	millimeters per year (mm/yr)	NOAA Tides and Currents: Sea Level Trends
Shelter.Afforded	The shelter afforded from wind, sea, and swell, refers to the area where normal port operations are conducted, usually the wharf area.	Excellent (5), Good (4), Fair (3), Poor (2), None (1)	World Port Index (Pub 150)
SoVI.Social.Vulnerability.Score	Port County Social Vulnerability (SoVI) Score	score number	SoVI® Social Vulnerability Index
Tanker.Capacity	Tanker Capacity	calls x DWT	MARAD: Vessel Calls at U.S. Ports by Vessel Type
Tide.Range	Mean tide range at the port	feet	World Port Index (Pub 150)
Tonnage	Total Throughput	Tons	USACE Navigation Data Center (ports)
Vessel.Capacity	Vessel Capacity (vessels > 10k (DWT)	calls x DWT	MARAD: Vessel Calls at U.S. Ports by Vessel Type

2.3 Conclusion

A total of 108 candidate indicators were identified via the literature review; of these, 48 (24 place-based and 24 port-specific) had sufficient data for the 22 studied ports and were used in a *Mind mapping* exercise with the RIAT team. For summary information on these 48 indicators, please see Appendix G. Thirty-four candidate indicators were mapped and marked as having correlation to vulnerability, 25 marked as having positive correlation, and 9 candidate indicators marked as having negative correlation. The 34 resulting candidate indicators from the *Mind mapping* exercise were selected to be evaluated via the subsequent VAS expert survey: 14 of these were port-specific indicators and 20 were place-based indicators. A comprehensive list of all 108 indicators is available at URI – Digital Commons (see also Appendix H).

3 Expert Evaluation of Seaport Climate and Extreme Weather Vulnerability Indicators

3.1 Introduction

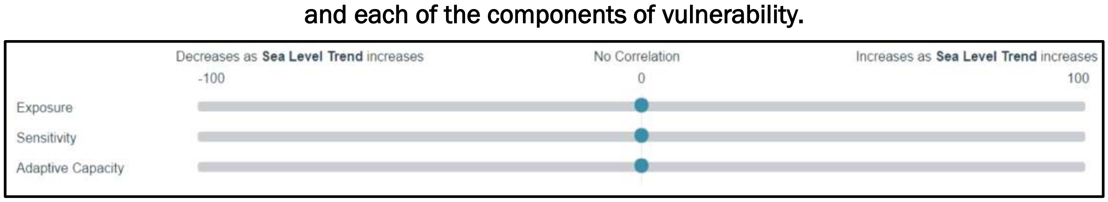


To refine a set of high-level indicators of seaport climate and extreme weather vulnerability identified in Chapter 2, and to determine the suitability of available open-data to differentiate ports within a region in terms of relative climate vulnerabilities, researchers developed a VAS survey instrument for expert-evaluation of selected candidate indicators of seaport vulnerability to climate and extreme weather impacts for the 22 medium and high-use ports of the USACE CENAD. Chapter 3 provides an overview of this process and the method for further narrowing down the indicators through expert elicitation.

3.2 Methodology

A VAS is an instrument that measures a characteristic or an attitude that is believed to range across a continuum of values and cannot easily be directly measured (Appendix I). A VAS is usually a horizontal line, 100 millimeters (mm) in length, anchored by word descriptors at each end, as illustrated in Figure 9. The respondent selects the point on the line that represents their perception of the question. The VAS score is determined by measuring in millimeters from the left-hand end of the line to the point that the respondent marks. As a continuous, or analogue scale, the VAS is differentiated from discrete scales such as Likert scale (Likert 1932) by the fact that a VAS contains a real distance measure, and as such, a wider range of statistical methods can be applied to the measurement.

Figure 9. VAS slider for indicating expert-perceived correlation between a candidate indicator and each of the components of vulnerability.



3.2.1 Selection of experts for Visual Analogue Scale (VAS) survey

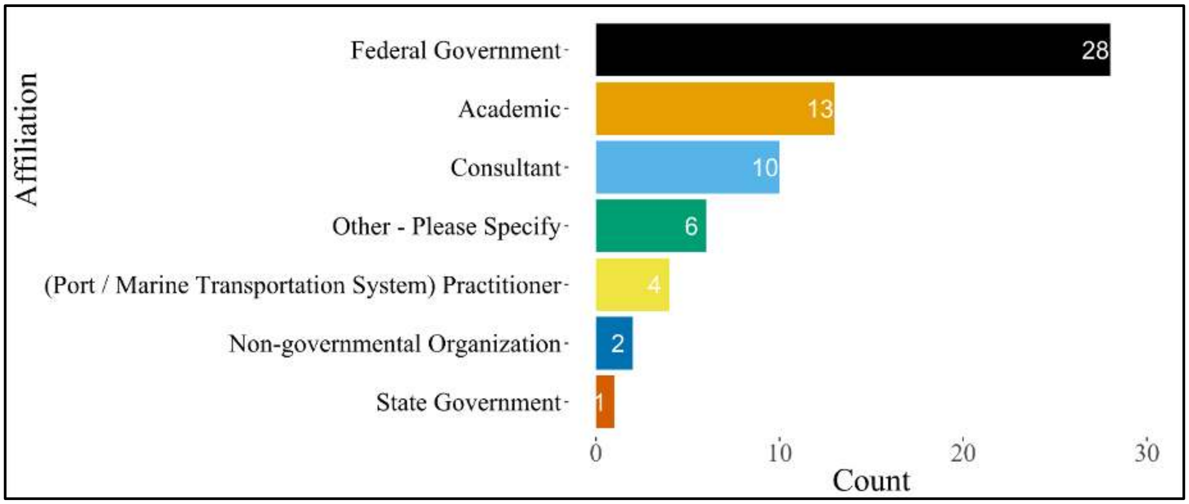
Because expert elicitation relies on expert's knowledge rather than a statistical sample, the selection of qualified experts is considered one of most crucial steps in the process for insuring the internal validity of the research (Delbecq et al. 1975; Hasson et al. 2000; Keeney et al. 2006; Okoli and Pawlowski 2004). Candidates for the port expert group were selected according to recommended best practices in expert selection developed by Delbecq et al. (1975) and expanded by Okoli and Pawlowski (2004). Researchers first prepared a Knowledge Resource Nomination Worksheet (KRNW) modified from Okoli and Pawlowski (2004) to help categorize the experts prior to identifying them and to help avoid overlooking any important class of expert.

The KRNW was then populated with names, beginning with the professional network of the research team and that of the RIAT and identifying other candidate experts via a review of the relevant literature. This initial group of 154 port experts was contacted and provided with a brief description of the study, queried for basic biographical information (e.g., number of papers published, length of practice, or number of years of tenure in government or non-governmental organization positions), and asked to nominate other potential experts for inclusion on the list. Experts were asked to nominate peers with expertise in the fields of seaport operations, planning, policy, seaport data, and/or the vulnerability of the Northeast U.S. MTS to climate and extreme weather impacts. This first round of contacts did not include invitations but was aimed at extending the KRNW to ensure that it included as many experts as could be accessed.

For this survey, of the 154 experts invited, 64 participated, for a response rate of 42%. Participating experts provided their predominant sector affiliation (Figure 10). These are divided into *Federal Government* (n=28), *Academic* (n=13), *Consultant* (n=10), *Port/MTS Practitioner* (n=4), *Non-governmental Organization* (n=2), *State Government* (n=1), and *Other* (n=6). The *other* category of expert affiliation was specified as Attorney (n=1), Contractor supporting the federal government (n=1), Consultant/port director/District engineer/Academic (n=1), Federal Government Academic (n=1), Port Authority (n=1), and Local Government (n=1) (Figure 10). These experts had between 14 to 40 years of experience in their fields, some were published, and all had affiliations to one or more of the following organizations: USACE, American Association of Port Authority, the American Society of Civil Engineers, Federal Highway

Administration, State Port Authorities, NOAA, U.S. Coast Guard (USCG), U.S. United States Coast Guard Academy, Environmental Protection Agency, Federal Emergency Management Agency, State Sea Grant, Transportation Management Areas, MARAD, and/or state universities (United States and Canada). Some of the experts serve as directors of port authorities, marine transportation recovery specialists, resilience directors at a port, professors, executive directors, directors of emergency management, civil engineers/marine consultants, etc.

Figure 10. Count of respondents' self-identified affiliations. Total n = 64.



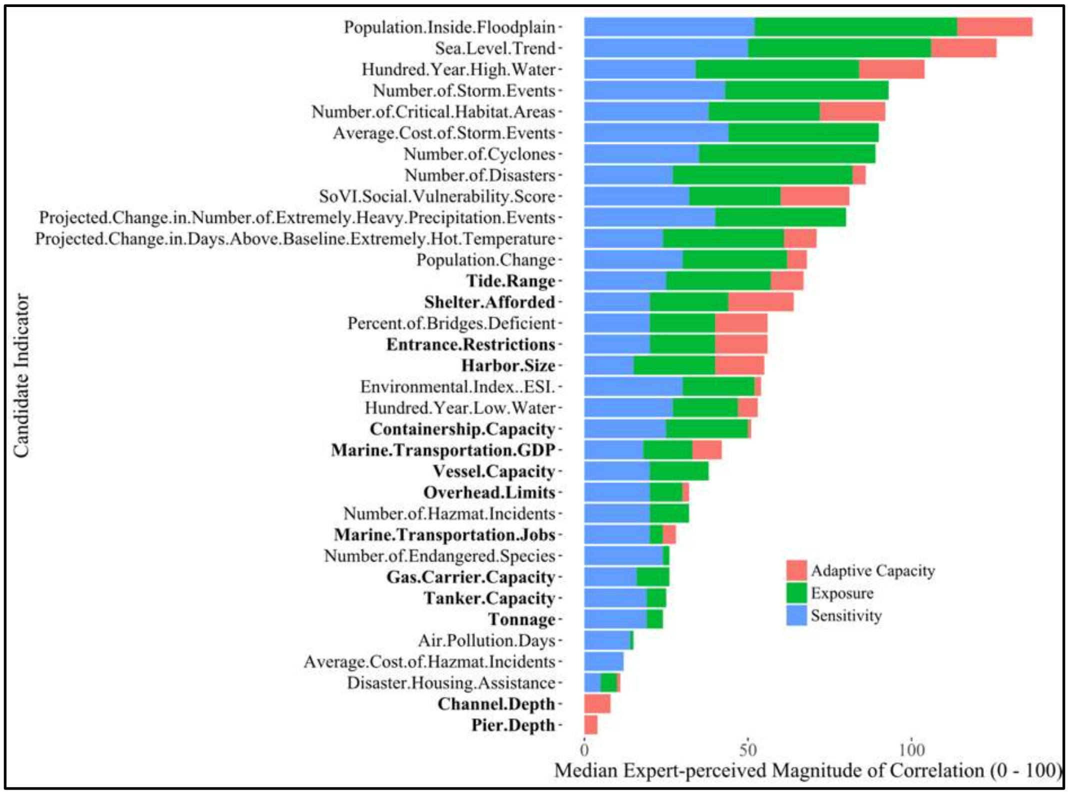
3.2.2 Online expert elicitation VAS survey

The objective of this survey was to measure port experts' perceptions of the suitability of available data to serve as indicators of seaport vulnerabilities to climate and extreme weather (Appendix J; for a webinar provided to participants with survey instructions see Appendix K). The VAS survey requested that participants evaluate 34 candidate indicators for correlation with the components of seaport vulnerability (for a summary description of the vulnerability indicators see McIntosh [2018]). In addition to evaluating candidate indicators, respondents were asked to rank --in their opinion-- the 10 *most* vulnerable ports and the 10 *least* vulnerable ports. The results of this question would be used in the final validation step of this project to compare subjective opinions of seaport vulnerability with the outputs of the model (see Chapter 5).

For each candidate indicator, respondents were given the indicator's description, units, data source, and example values, and respondents were asked to determine whether the candidate indicator correlated with the exposure, sensitivity, and/or adaptive capacity of ports in the study area. In evaluating candidate indicators, respondents were instructed to consider port vulnerability holistically, inclusive of the port's surrounding socioeconomic and environmental systems. Respondents indicated the magnitude and direction of correlation by dragging a slider along a VAS line segment (Figure 9). To indicate *no correlation*, respondents were to leave the slider in the center of the line. Dragging the slider to the left indicated a negative correlation, and dragging the slider to the right indicated a positive correlation. The distance measure of how far the slider was moved was indicative of the magnitude of perceived correlation. As a second verification on the comprehensiveness of the set of candidate indicators, experts were also asked to suggest additional candidate indicators and data sources.

The candidate indicators were presented with their metadata, without assignment to a single component of vulnerability (i.e., exposure, sensitivity, adaptive capacity) and then respondents denoted each indicator's correlation (or lack of correlation) for each component. In this way, some indicators scored high in correlation with more than one component of vulnerability (Figure 11).

Figure 11. Candidate indicators of seaport vulnerability to climate and extreme weather, sorted by total median expert-perceived magnitude of correlation with each of the three components of vulnerability. Port-specific candidate indicators in bold.



3.3 Results of VAS survey

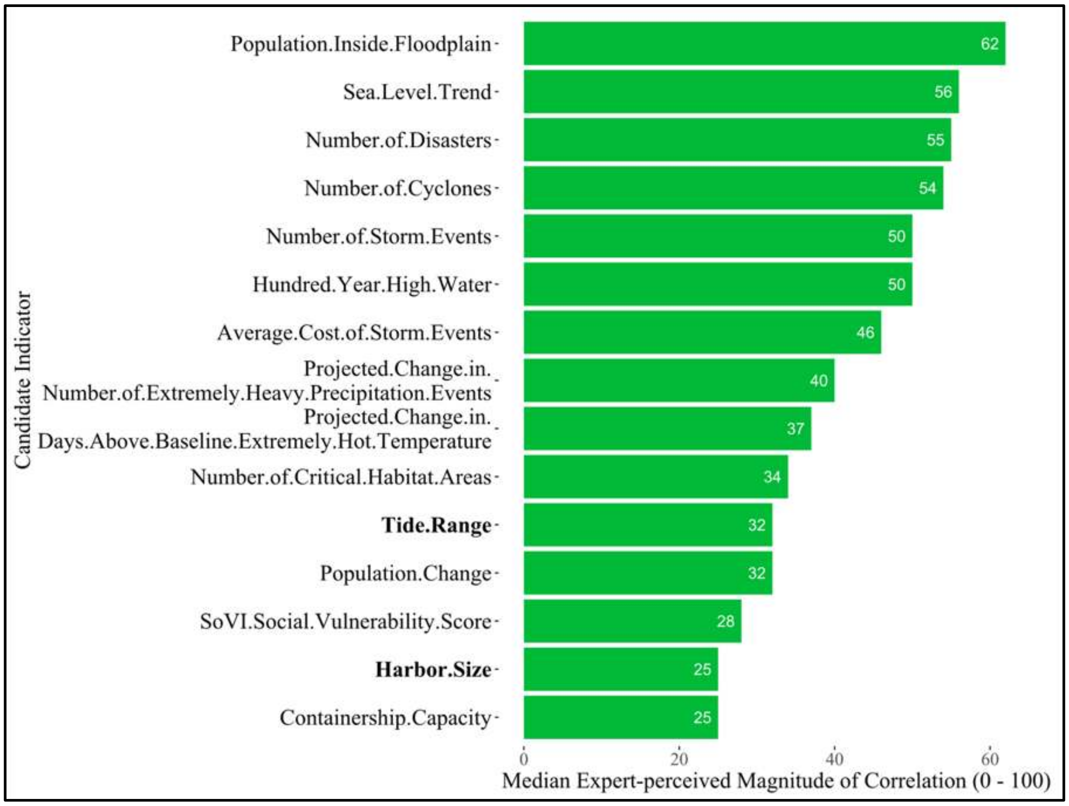
For each of the 34 candidate indicators evaluated, the median[1] expert-perceived magnitude of correlation was calculated for each of the three components of vulnerability (Figure 11). The graphs use the median[1] rather than the mean of responses when aggregating scores for each candidate indicator. Interestingly, when values were aggregated, respondents' highest levels of perceived correlation were for place-based indicators; although 14 of the 34 candidate indicators were port-specific, the top-12 candidate indicators ranked by all three components of vulnerability total correlation were all placed based (Figure 11). Also, noted is the low level of perceived correlation with adaptive capacity (pink) compared to exposure (green) and sensitivity (blue).

The indicator with the highest median expert-perceived correlation was the same for all three components of vulnerability; i.e., *population inside*

[1] The use of medians instead of the means reduces the effect of outliers (smaller or larger values) on the measure of central tendency.

floodplain. The indicator *sea level trend* also scored high, rated second highest in median correlation with exposure and sensitivity, and fourth highest with adaptive capacity. The highest scoring port-specific indicator (bold) was *tide range* (Figure 12), followed by *shelter afforded*, both metrics available from the World Port Index (NGIA 2015).

Figure 12. Top-15 candidate indicators for exposure, in descending order of median expert-perceived magnitude of correlation with seaport exposure to climate and extreme weather impacts. Port-specific candidate indicators in bold.

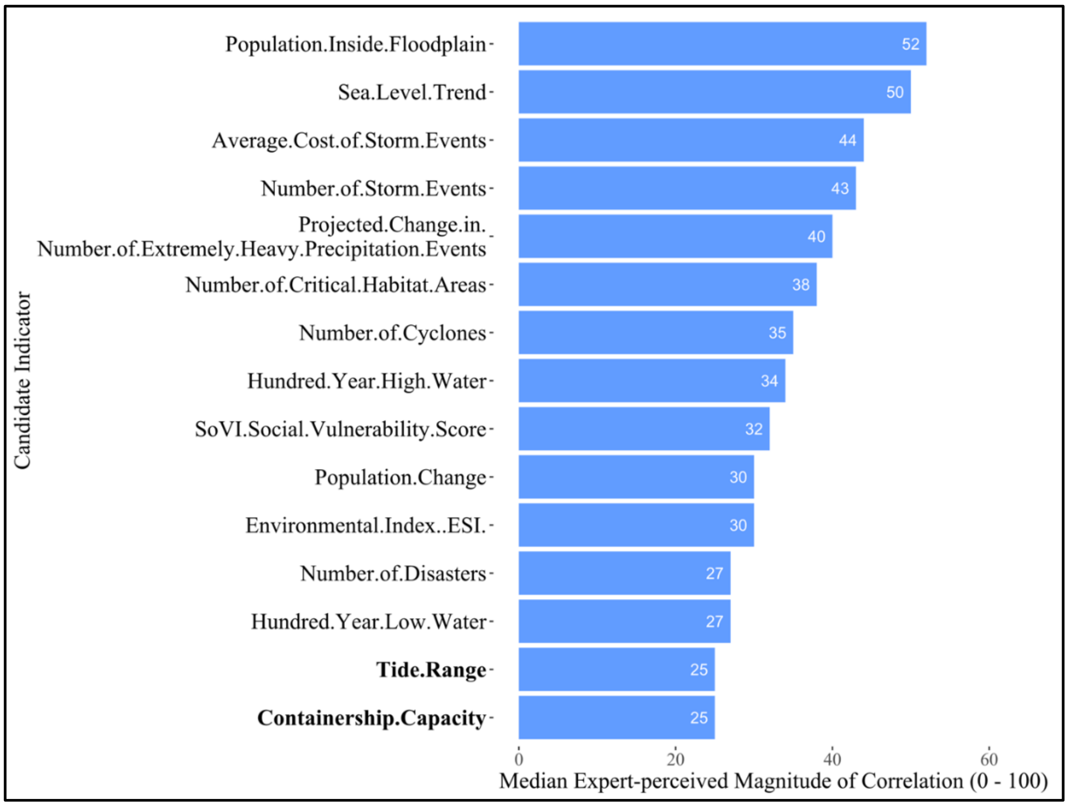


The median expert-perceived magnitude of correlation for each component of vulnerability reveals the experts' preferences for the most suitable candidate indicators to represent each concept for the sample set of CENAD ports (Figure 12 through Figure 14). The top-15 scoring indicators in descending order for correlation with exposure, sensitivity, and adaptive capacity can also be observed in Figure 12 through Figure 14.

The 10 indicators with the perceived highest median correlation with port exposure were all place-based (Figure 12). The port-specific indicator rated highest perceived correlation with exposure was tide range, ranked 11 of 34, followed by harbor size, ranked 14 of 34.

The top-13 indicators with the highest median perceived correlation with port sensitivity were all place based (Figure 13). As was the case with exposure in Figure 12, the two highest scoring indicators for correlation with sensitivity were also population inside floodplain and sea level trend, respectively. The port-specific indicators rated highest for perceived correlation with sensitivity was also the same as that for exposure. These indicators for sensitivity were tide range, ranked 14 of 34, followed by containership capacity, ranked 15 of 34.

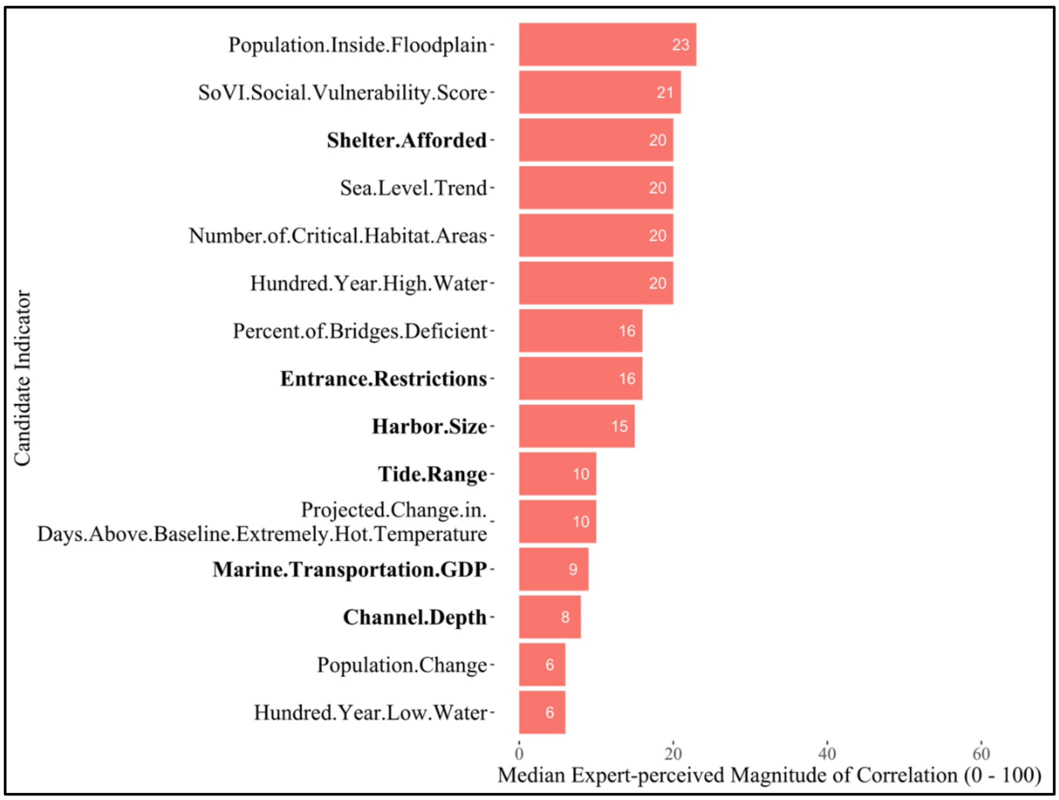
Figure 13. Top-15 candidate indicators for sensitivity, sorted by median expert-perceived magnitude of correlation with seaport sensitivity to climate and extreme weather impacts. Port-specific candidate indicators in bold.



While the top-10 scoring indicators with the highest median perceived correlation with port exposure and sensitivity were all place-based, the same was not true for adaptive capacity (Figure 14). For correlation with adaptive capacity, port-specific indicators scored relatively high. In general, the port-specific indicator for adaptive capacity had a lower score than the 16th and 17th place for exposure and sensitivity indicators. The indicators for adaptive capacity that rated highest were shelter afforded, ranked 3 of 34, followed by *entrance restrictions*, 8 of 34 (Figure 14)

Although the distance measure of the VAS sliders is unitless, the results indicate an overall low level of expert-perceived correlation between candidate indicators and seaports' adaptive capacity (Figure 14) significantly lower than that for exposure (Figure 12) and sensitivity (Figure 13). The highest scoring candidate indicator for adaptive capacity, population inside floodplain, only scored 23 on the unitless VAS, which is lower than 16th place for exposure and lower than 17th place for sensitivity. Although candidate indicators scored generally low with adaptive capacity, port-specific indicators fared much better with adaptive capacity than with the other two components of vulnerability, with four of the top-10 indicators representing port-specific indicators (Figure 14).

Figure 14. Top-15 candidate indicators for adaptive capacity, sorted by median expert-perceived magnitude of correlation with seaport adaptive capacity to climate and extreme weather impacts. Port-specific candidate indicators in bold. Overall, experts found significantly lower correlation with adaptive capacity than with the other two components of vulnerability.



Because the VAS expert group was disproportionately represented by those with federal affiliations (Figure 10), the median aggregate group response considered in the previous four figures is necessarily dominated by those experts. Further insights can be gained by filtering results by expert type, revealing differences in the perceptions of the differently affiliated experts. For example, academically affiliated experts found more and higher levels of correlation with adaptive capacity than did other types of experts. Practitioners found higher correlation with exposure and sensitivity indicators, with *Population inside Floodplains* and *SoVI Social Vulnerability Score* ranking highest (Figure 12 through Figure 14). This may be due to academically affiliated experts having more familiarity with the concept of adaptive capacity as it has become a more common subject in the academic literature, and/or reservations by others in defining a correlation for the more difficult or abstract indicators.

3.4 Seven additional indicators suggested by port experts

When asked to suggest additional candidate indicators, respondent port experts suggested seven indicators that may warrant further development but did not meet the data requirements (open data, coverage across the 22 ports in the study area) to be included in this study (Table 3). Some of the suggested indicators that currently lack sufficient data coverage could be synthesized from a combination of other available data sources, derived via geographic information systems (GIS) or compiled via additional computation for evaluation in future studies. For example, *robustness of transportation infrastructure,* measured in terms of the number of backup routes, may be determinable via GIS analysis of each ports' multimodal connections' elevations (Hategekimana et al. 2018); however, such indicators will be highly sensitive to the value judgment of how each port is delimited.

Port interdependencies also present potential for inclusion in indicator development (e.g., the suggested indicator *distance to nearest alternative seaport*), which would capture the availability of backup ports available to handle a port's primary cargo should that port experience downtime. Though not presently identifiable in openly available data sources, such an indicator could be synthesized from data records of port cargo types with a similar caveat that it will also require the value judgment of what qualifies as an alternative port in terms of ability to handle similar cargo.

Table 3. Expert-suggested candidate indicators of seaport vulnerability to climate and extreme weather impacts. While these suggested candidate indicators lacked the readily available data required to be included in the VAS survey, they may hold promise for further development provided data can be synthesized or compiled from identifiable sources.

Indicator	Units	Description	Data Source
Real estate values	% of tax base at risk	Sea level rise (SLR) changes in Nuisance and Repetitive Flooding	NA
Distance to nearest alternative seaport	Nautical or statute miles	Based on type of cargo received at the primary seaport	GIS, nautical charts, customs cargo records
Alternative freight transportation modes between seaports	Transportation modes for freight (Pipeline, rail, highway)	As paucity of alternative transportation modes increases, so does the criticality and therefore vulnerability of the primary port	U.S. DOT
Robustness of redundancy for transportation options	number of back-up routes	Robustness of port area to a shock to operations	GIS Mapping
land use	industrial/mixed use	low value vs. high value infrastructure	NA
Age of infrastructure	Years	Average age of critical port infrastructure	NA
Surface Transportation Vulnerability	NA	Ports are dependent on surface access	Local, perhaps Federal High Way Administration (FHWA)

3.5 Discussion of VAS results

To further IBVA development for the seaport sector and to determine the suitability of available open-data to differentiate ports within a region in terms of relative climate and extreme weather vulnerabilities, researchers applied expert-elicitation methods to refine and evaluate a set of high-level indicators of seaport climate vulnerability. Researchers first held a *Mind mapping* exercise with MTS experts to refine a set of candidate indicators, then developed and tested a VAS survey instrument for expert evaluation of the selected candidate indicators of seaport vulnerability to climate and extreme weather impacts for the 22 medium and high-use ports of the USACE North Atlantic Division. The results of the VAS survey reveal which indicators port experts found relatively more correlated with the components of climate vulnerability for seaports. The results can be used to aid in indicator selection for IBVA and CCVA development work in the seaport sector, and the indicators themselves can serve as high-level screening tools for quick comparative analyses among multiple ports.

3.5.1 Low expert-perceived correlation with adaptive capacity

> **From the selected 34 candidate indicators, respondents found higher levels of correlation with the components of vulnerability for place-based indicators than for port-specific ones.**

Results suggest that available open-data can be developed into expert-supported indicators of seaport climate exposure and sensitivity. However, results also suggest relatively little expert-perceived correlation between open-data and a port's adaptive capacity. For the 34 candidate indicators that were evaluated, none scored a median rating higher than 23 on the unitless VAS scale of correlation with adaptive capacity, compared to a high of 62 with exposure and 52 with sensitivity. This low level of perceived correlation with adaptive capacity suggests a dearth of open-data sources suitable for representing the adaptive capacity of seaports to climate and extreme weather impacts. It also suggests that the concept of adaptive capacity is considered by port experts to be more difficult to represent with quantitative data than the concepts of exposure or sensitivity.

3.5.2 Expert preference for place-based indicators

Results of the VAS survey also indicate that respondents reserve their highest levels of aggregate perceived correlation for place-based indicators; though 14 of the 34 candidate indicators were port specific, the top-12 candidate indicators ranked by total correlation were all place-based. While port-specific indicators scored low overall, they fared better with adaptive capacity than with exposure or sensitivity, which suggests that more or different port-specific data reporting may lead to improvements in the ability to measure a port's relative adaptive capacity.

While the 34 candidate indicators encompassed a combination of 14 port-specific indicators (i.e., those that capture a specific aspect of the port) and 20 place-based indicators (i.e., those that capture the hazards-of-place at the county scale), respondents found higher levels of correlation with the components of vulnerability for place-based indicators than for port-specific ones. For both correlation with exposure (Figure 12) and with sensitivity (Figure 13), the 10 highest rated candidate indicators were all place-based. For correlation with adaptive capacity, however, while noticeably lower in magnitude, four of the top-10 indicators were port specific, and a port-specific indicator scored second highest overall

(Figure 14). This suggests that of the 34 candidate indicators evaluated, respondents generally preferred the place-based indicators for representing the exposure and sensitivity of a seaport but preferred a mixture of place-based and port-specific indicators for representing a port's adaptive capacity.

This finding suggests that while adaptive capacity is considered by port experts to be the most difficult component of seaport climate vulnerability to quantify, if expert-supported indicators of seaport adaptive capacity are to be developed, they will most likely be developed from port-specific data rather than place-based data. This means that the adaptive capacity can be measured for the port facility by engaging with port stakeholders rather than relying on open-data indicators for the county where the port resides. As the current selection of port-specific data openly available for the CENAD sample of ports was found to have little expert-perceived correlation with the components of seaport climate vulnerability, efforts will have to be made to identify and share additional port-specific data that can better capture these concepts, and adaptive capacity in particular.

3.5.3 Variation of results for different expert-affiliation groups

Filtering responses by expert affiliation revealed differences in perceptions (Appendix J). Academically affiliated experts were more willing to indicate correlation with adaptive capacity than other types of experts while federally affiliated experts indicated the least amount of correlation with adaptive capacity. These differences may reveal variance in the willingness to assert correlation with complicated concepts, difficulty of presumption, or making statements about things that are uncertain. Whereas academic jobs allow for statements based on an individual's opinion, federally affiliated experts often are interpreted as pertaining to the organization. These findings highlight the importance of a diverse expert group when using expert-elicitation methods.

This body of work identified a set of 34 expert-evaluated indicators of seaport climate and extreme weather vulnerability from open data that can be monitored to assess relative vulnerabilities across ports.

3.5.4 Limitations and next steps

As the population of experts with the requisite knowledge of the climate vulnerabilities of northeastern U.S. seaports is limited, this study was limited by the sample size of respondent experts. While the total response rate was satisfactory, the total number of experts was not evenly distributed among the seven expert-affiliation categories (Figure 10). Accordingly, comparisons of responses by expert affiliation suffer from this small sample size. These expert-related limitations are a function of applying a stakeholder-driven approach, as opposed to a purely data-drive approach (e.g., SoVI [Cutter et al. 2003]). Instead of the purely data-driven approach described by the SoVI, this work takes a stakeholder-driven approach by including port experts in the development and weighting of the indicators, as this has been shown to increase the creditability of the index as a tool (Barnett et al. 2008; Sagar and Najam 1998).

An additional limitation stems from the difficulty of seeking and compiling a comprehensive list of candidate indicators for experts to evaluate. To lessen the risk of excluding potential candidate indicators, researchers asked experts *Mind map* to suggest additional or better indicators at both the *Mind map* stage and the VAS survey stage. The experts were able to suggest an indicator with a known data source with sufficient data availability for the sample of ports, suggesting that the search for open-data candidate indicators was suitably comprehensive. Next steps for future studies may involve furthering the development of those candidate indicators suggested by respondents in (McIntosh 2018), exploring non-open or proprietary sources of data for those indicators identified in (McIntosh 2018) but lacking available open-data sources, or synthesizing novel indicators from combinations of available data.

3.6 Conclusion

While the research literature currently lacks examples of multi-port, comparative CCVA for the seaport sector, this body of work has developed and contributed a set of 34 expert-evaluated indicators of seaport climate and extreme weather vulnerability from open data that can be monitored to assess relative vulnerabilities across ports. Further, this work quantified expert preferences for weighting indicators and the components of climate vulnerability for seaports and identified adaptive capacity as lacking representation in the available data. The stakeholder-driven method of identifying and evaluating candidate indicators could be replicated to develop new indicators for other port regions or other non-port sectors.

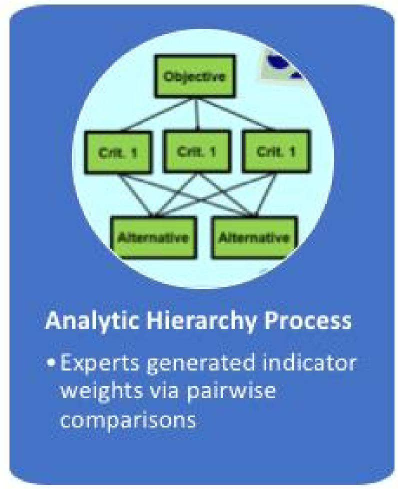
Expert-evaluation of 34 candidate indicators in the context of a sample of 22 CENAD ports resulted in port experts having found significantly stronger correlation with the exposure and sensitivity of a port than with the adaptive capacity, suggesting a lack of open-data sources available for representing the adaptive capacity of seaports in the sample. This finding also suggests that port experts consider the concept of adaptive capacity to be less amenable to representation with quantitative data than the remaining two components of vulnerability (i.e., exposure and sensitivity).

These results suggest an opportunity exists for further research and development of standardized, comparative CCVA methods for seaports and the MTS, with the objective of supporting climate impact, adaptation and vulnerability decisions with information products that allow decision-makers to compare mechanisms and drivers of climate change across multiple ports. Before a complete IBVA framework for seaports can be developed, however, further work on the development of indicators of adaptive capacity will be needed.

Results suggest that while *exposure* and *sensitivity* can presently be represented by expert-supported indicators, this research was unable to identify available open-data sources that could yield expert-supported indicators of *adaptive capacity*.

4 Weighting Indicators via Analytic Hierarchy Process (AHP)

4.1 Introduction



This chapter describes the process of deriving weights for the previously selected indicators through an AHP. Once the weights are generated, the weighted indicators are aggregated into a composite indicator that can inform MTS decision-makers in the USACE and other agencies about the nature of seaport vulnerabilities to climate and extreme weather, the components and determinants of those vulnerabilities, the mechanisms through which a port is vulnerable, and the suitability of available data to serve as high-level indicators of seaport climate and extreme weather vulnerability. Respondents were also asked to rank the 10 *most* vulnerable ports and the 10 *least* vulnerable ports (see Chapter 3). These results were used as final validation step to compare subjective opinions of seaport vulnerability with the outputs of the model (see Chapter 5).

4.2 AHP

The AHP is a method to support multi-criteria decision-making. Initially described by Saaty (1977), it is based on the solution of an eigenvalue problem. Participants quantify weights by using pairwise comparisons. Results are arranged in a matrix where the dominant normalized right eigenvector represents the ratio scale (weighting) and the eigenvalue determines the consistency ratio (Goepel 2013; Saaty 1977, 1990b, 2006). The AHP is a well-established form to aggregate individual judgments for group decisions (Ramanathan and Ganesh 1994; Dedeke 2013; Goepel 2013). Psychologists have noted that respondents have an easier time making judgments on a pair of alternatives at a time than simultaneously on all the alternatives (Ishizaka and Labib 2011). Using pairwise comparisons not only helps discover and correct logical inconsistencies (Goepel 2013), it also allows for translating subjective opinions into numeric relations, helping make group decisions more rational, transparent, and understandable (Goepel 2013; Saaty 2008a). Furthermore, AHP uses a ratio scale, which, unlike other methods using interval scales, does not require units in the comparison (Kainulainen et al. 2009; Hovanov et al. 2008).

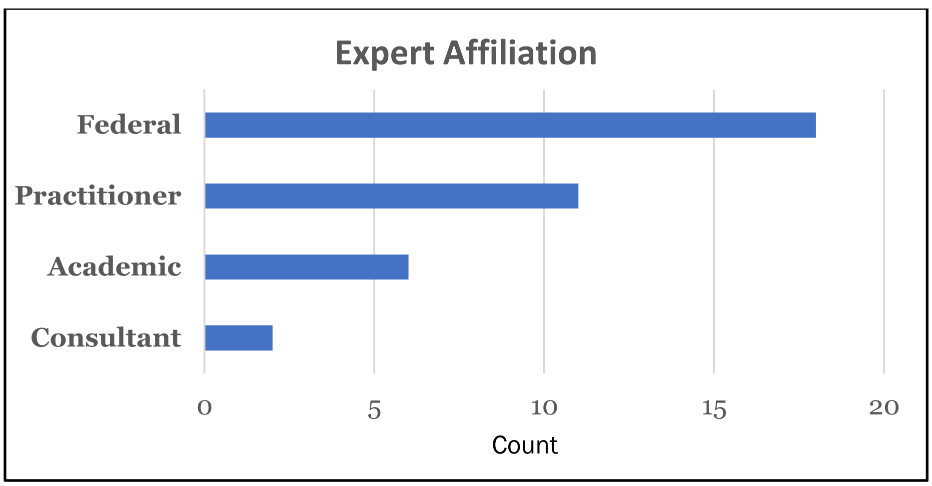
The AHP is useful as a standardized method for generating the weights of indicators in composite indices within a variety of different fields (e.g., environmental performance index [Dedeke 2013]), disaster-resilience index (Orencio and Fujii 2013), composite indicator of agricultural sustainability (Gómez-Limón and Riesgo 2009), flood hazards index (Hategekimana et al. 2018), and the urban public transport system quality (Pticina and Yatskiv 2015).

4.3 Methodology

4.3.1 Expert selection

Researchers invited the same group of 64 experts who contributed to the evaluation of candidate vulnerability indicators via the previous VAS survey (see Chapter 3) to participate in this AHP weighting exercise. These experts were sought for their specialized knowledge and experience in seaport operations, planning, policy, data, and the vulnerability of the U.S. MTS to climate and extreme weather impacts. This group of expert respondents was compiled via a KRNW and peer snowball sampling (see Chapter 3). Out of this expert pool, 37 experts participated in this AHP exercise, representing these affiliation categories: Federal (e.g., USCG, NOAA, USACE, MARAD), Practitioner (e.g., port authorities), Academic (e.g., professors, research analysts), and Consultant (Figure 15).

Figure 15. Count of participating experts' affiliations. Note: only 42% of the 64 invited experts participated in the survey.



4.3.2 AHP webinars with 37 port experts

In the spring and summer of 2017, researchers held 21 separate webinars with a total of 37 participating port experts (Appendix K). During each webinar, participants were guided through the steps of the AHP using a web-based AHP system (Goepel 2017). Experts were given a data dictionary with descriptions, units, data sources, and example values for each of the 12 indicators to be weighted (see Data Dictionary PDF in URI-Digital Commons). Note: As mentioned earlier, best practice for AHP recommends each category should have at least 4, but not more than 7-10 sub-categories (Goepel 2013); researchers selected the six highest scoring indicators for exposure (Table 4) and the six highest scoring indicators for sensitivity (Table 5) for inclusion in the AHP exercise. For the AHP exercise, as with the previous VAS survey, respondents were instructed to consider port vulnerability holistically, inclusive of the port's surrounding socioeconomic and environmental systems, and to focus on 22 ports of the CENAD (Figure 7).

Table 4. Top-6 indicators for seaport exposure as identified by experts in the VAS survey.

Indicator	Rank for Exposure (expert-perceived magnitude of correlation)	Description	Units	Data Source
Population.Inside.Floodplain	1 (62)	Percentage of the port county population living inside the FEMA Floodplain	%	NOAA Coastal County Snapshots
Sea.Level.Trend	2 (56)	Local Mean Sea Level Trend	mm/yr	NOAA Tides and Currents: Sea Level Trends
Number.of.Disasters	3 (55)	Number of Presidential Disaster Declarations for the port county since 1953	Disaster Type	FEMA: Disaster Declarations
Number.of.Cyclones	4 (54)	Number of cyclones that have passed within 100 nm of the port since 1842	Number of cyclones	NOAA Historical Hurricane Tracks Tool
Number.of.Storm.Events	5 (50)	Number of storm events in port county with property damage > $1M	Events	NOAA Storm Events Database

Indicator	Rank for Exposure (expert-perceived magnitude of correlation)	Description	Units	Data Source
Hundred.Year.Low.Water	6 (50)	1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century	m below MLLW	NOAA Extreme Water Levels

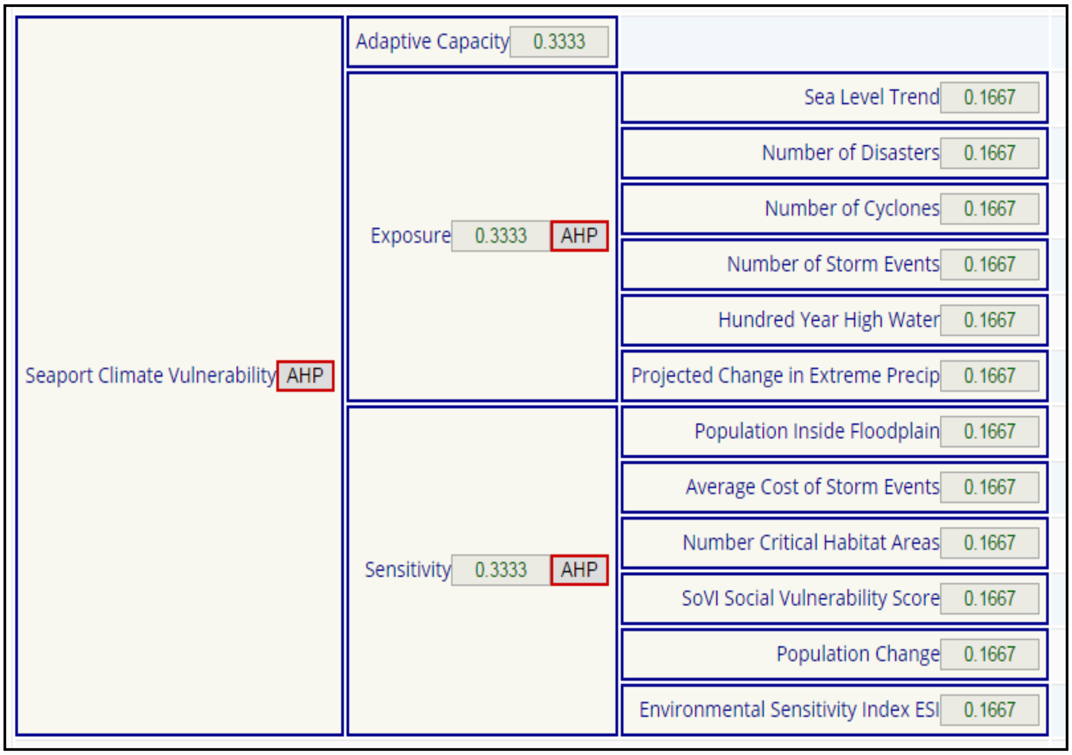
Table 5. Top-6 indicators of seaport sensitivity as identified by experts in the VAS survey.

Indicator	Rank for Sensitivity (expert-perceived magnitude of correlation)	Description	Units	Data Source
Population.Inside.Floodplain	1 (52)	Percentage of the port county population living inside the FEMA Floodplain	%	NOAA Coastal County Snapshots
Sea.Level.Trend	2 (50)	Local Mean Sea Level Trend	mm / yr	NOAA Tides and Currents: Sea Level Trends
Average.Cost.of.Storm.Events	3 (44)	Average cost of property damage from storm events in the port county since 1950 with property damage > $1M	$	NOAA Storm Events Database
Number.of.Storm.Events	4 (43)	Number of storm events in port county w/ property damage > $1M	Events	NOAA Storm Events Database
Projected.Change.in.Number.of.Extremely.Heavy.Precipitation.Events	5 (40)	The percent change from observed baseline of the average number of "Extremely Heavy" Precipitation Events projected for the end-of-century, downscaled to 12 km resolution for the port location	%	US DOT CMIP Climate Data Processing Tool

Indicator	Rank for Sensitivity (expert-perceived magnitude of correlation)	Description	Units	Data Source
Number.of.Critical.Habitat.Areas	6 (38)	Number of Critical Habitat Areas within 50 miles of the port	Areas	U.S. Fish and Wildlife Service

The AHP involved two levels; the first comprised weighting the three components of vulnerability (i.e., exposure, sensitivity, and adaptive capacity as described in the introduction to this report), and the second comprised weighting the six indicators of exposure and the six indicators of sensitivity (Figure 16). As AHP best practice recommends each category should have at least 4, but not more than 7 to 10 sub-categories (Goepel 2013), researchers selected the six highest scoring indicators for exposure (Table 4) and the six highest scoring indicators for sensitivity (Table 5) for inclusion in the AHP exercise described in the following sub-Chapter 4.4 "Results of AHP-generated weights." (See Chapter 3 for description of indicators and selection process.)

Figure 16. Equal weighting scores in the AHP prior to the pairwise comparisons. Each column represents a level of the AHP, and each red rectangle indicates a node (for which a priority vector will be calculated).



Because the earlier VAS survey failed to develop expert-supported indicators of adaptive capacity for seaport climate and extreme weather vulnerability (see Chapter 3), researchers did not include indicators of adaptive capacity for weighting in this AHP. The lack of indicators of adaptive capacity, however, did not prevent the derivation of weight for adaptive capacity as a component of seaport vulnerability to climate and weather extremes.

For the first level of the AHP, respondents weighted the three components of seaport vulnerability via pairwise comparisons. Respondents were given two components at a time and asked "With respect to seaport climate vulnerability, which criterion is more important, and how much more on a scale 1 to 9," where "1" represents equal importance (Figure 17).

Figure 17. Pairwise comparisons of the three components of seaport vulnerability.

	A - wrt *Seaport Climate Vulnerability* - or B?			Equal	How much more?
1	Adaptive Capacity	or	Exposure	1	2 3 4 5 6 7 8 9
2	Adaptive Capacity	or	Sensitivity	1	2 3 4 5 6 7 8 9
3	Exposure	or	Sensitivity	1	2 3 4 5 6 7 8 9

The second level of the AHP involved two nodes: weighting six indicators of exposure, and weighting six indicators of sensitivity. For the former, respondents were given two indicators at a time and asked "With respect to seaport climate exposure, which criterion is more important, and how much more on a scale 1 to 9?" For calculating the number of pairwise comparisons required, Equation 1 is used where n is the number of components or indicators (Saaty 1977, 1990a; Orencio and Fujii 2013).

Equation 1. Number of pairwise comparisons required for *n* indicators.

$$(n)(n-1)/2$$

For the six indicators of exposure (Table 4), respondents completed 15 pairwise comparisons, contrasting the relative importance of each indicator to every other indicator, one pair at a time. Similarly, the second node of this level of the AHP repeated this process with respect to sensitivity for the six indicators of seaport climate and extreme weather sensitivity (Table 5). For each respondent at each level of the AHP, the product of each paired comparison was recorded in a $n \times n$ square matrix, with n equaling the number of indicators or components.

Denoted here are the criteria that were ranked by experts as $[I_1, I_2, \ldots I_n]$, where n is the number of components of vulnerability or the number of indicators compared. Based on experts' responses, a preference matrix was derived for each respondent (Equation 2) of the form as follows:

Equation 2. Preference matrix for AHP.

$$A = [a_{ij}] \begin{bmatrix} 1 & a_{ij} & \cdots & a_{1n} \\ 1/a_{ij} & 1 & \ldots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

Where a_{ij} is the preference for indicator I_i over I_j when both were compared pairwise, for i, j = 1, 2, … n. If a respondent decided that indicator i was equally important to another indicator j, a comparison of $a_{ij} = a_{ji} = 1$ was recorded. If a respondent considered indicator i much more important than indicator j, the preference-matrix score was based on $a_{ij} = 9$ and its reciprocal given as $a_{ji} = 1/9$, where $a_{ij} > 0$.

After compiling a preference matrix for each expert for each node of the AHP, the dominant eigenvector of each matrix was then calculated using the power method (Larson 2016; Goepel 2013) with the number of iterations limited to 20, for an approximation error of 1×10^{-7} (Goepel 2013). This normalized principal eigenvector, also called a priority vector[1], gives the relative weights of the indicators and components of vulnerability that were compared.

The consistency of a respondent's answers was checked using the linear fit method (Equation 3) proposed by Alonso and Lamata (2006) to calculate the consistency ratio, CR, for each respondent's preference matrix for each node of the AHP, where λ_{max} represents the principal eigenvalue obtained from the summation of products between each element of the priority vector and the sum of columns of the preference matrix, and n represents the number of dimensions of the matrix.

Equation 3. Linear fit method of calculating consistency ratio.

$$CR = \frac{\lambda_{max} - n}{2.7699 \cdot n - 4.3513 - n}$$

If a respondent completed a node of pairwise comparisons that yielded a CR greater than 10%, the software prompted the respondent to correct the inconsistencies by highlighting the three most inconsistent judgments and allowing adjustments.

Aggregation of individual judgments (AIJ) was based on the weighted geometric mean (WGM) of all participants' judgments (Aull-Hyde et al. 2006). The software calculated the geometric mean and standard deviation of all K participants' individual judgments pwc_k to derive a consolidated preference matrix, a_{ij}^{cons}. The WGM-AIJ process consisted of summing individual judgements, pwc, over K participants, squaring the

[1] Because the vector is normalized, the sum of all elements in a priority vector is equal to 1.

sum, calculating the geometric mean of each *pwc*, and using the means to create a consolidated preference matrix (Equation 4).

Equation 4. Consolidated preference matrix based on the geometric mean of individual judgments.

$$a_{ij}^{cons} = (\Pi_{k=1}^{K} a_{ij})^{\frac{1}{K}}$$

To measure the consensus for the aggregated group result, the AHP software used Shannon entropy and its partitioning in two independent components (alpha and beta diversity) to derive an AHP consensus indicator based on relative homogeneity *S* (Goepel 2013). The consensus of the complete hierarchy was calculated as the weighted arithmetic mean of the consensus of all hierarchy nodes. This similarity measure, *S*, is zero when the priorities of all *pwc* are completely distinct and *S=1* when the priorities of all *pwc* are identical (Goepel 2013).

4.4 Results of AHP-generated weights

The aggregation of judgments from the first level of the AHP, which weighted the three components of seaport vulnerability to climate and extreme weather, resulted in exposure ranked most important, with a ratio scale (weight) of 0.394 (Table 6). Adaptive capacity was ranked a close second, with a weight of 0.390, which is noteworthy since the component of adaptive capacity lacks expert-supported indicators. Sensitivity was ranked least important of the three components, with a weight of 0.216. For this node, the maximum consistency ratio, *CR,* was 0.1% (highly consistent), and the group consensus, *S*, was 50.1% (low)[1].

Table 6. Results of AHP consolidated group preferences for the relative importance of the components of seaport climate and extreme weather vulnerability.

Component	Weight	Rank
Exposure	0.394	1
Adaptive Capacity	0.390	2
Sensitivity	0.216	3

[1] Goepel, K. D. "Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making in Corporate Enterprises–A New AHP Excel Template with Multiple Inputs." *Proceedings of the International Symposium on the Analytic Hierarchy Process*, 2013, 1-10, considers the following interpretation of AHP consensus; <50% (very low), 50%-65% (low), 65%-75% (moderate), 75%-85% (high), >85% (very high).

The second level of the AHP consisted of two nodes; the first evaluated six indicators for relative importance in terms of seaport exposure to climate and weather extremes, and the second node evaluated six indicators in terms of seaport sensitivity. The first node resulted in the indicator *number of disasters*, ranked most important for the component of exposure with a weight of 0.200 and resulted in weights for the remaining indicators of exposure (Table 7). For this node, the maximum consistency ratio, *CR,* was 0.3% (highly consistent), and the group consensus, *S*, was 53.6% (low).

Table 7. Consolidated group preferences for the relative importance of indicators of seaport *exposure* to climate and weather extremes.

Indicator of *Exposure*	Weight	Rank
Number of Disasters	0.200	1
Number of Storm Events	0.196	2
Sea Level Trend	0.180	3
Hundred Year High Water	0.163	4
Number of Cyclones	0.143	5
Projected Change in Extreme Precipitation	0.118	6

The second node of the second AHP level resulted in the indicator population inside floodplain, ranked most important for the component of sensitivity with a weight of 0.229 and resulted in the remaining indicators of sensitivity weighted (Table 8). For this node, the maximum consistency ratio, *CR,* was 0.5% (highly consistent), and the group consensus, *S*, was 61.1% (low).

Table 8. Consolidated group preferences for the relative importance of indicators of seaport *sensitivity* to climate and weather extremes.

Indicator of Sensitivity	Weight	Rank
Population Inside Floodplain	0.229	1
SoVI Social Vulnerability Index Score	0.213	2
Average Cost of Storm Events	0.210	3
ESI	0.125	4
Population Change	0.119	5
Number Critical Habitat Areas	0.104	6

These indicator weights were then used to generate a composite index of seaport vulnerability (minus adaptive capacity) to climate and extreme weather impacts with a Weight Sum Model (WSM) (see Chapter 5, Equation 5).

4.5 Discussion

The AHP resulted in adaptive capacity being ranked close to exposure in terms of importance with respect to seaport climate and extreme weather vulnerability. This suggests that port experts consider adaptive capacity to be more important than sensitivity and practically equal in importance to exposure with respect to seaport vulnerability. Though experts place a high degree of importance on adaptive capacity as a component of vulnerability, adaptive capacity may be the most difficult of the three components of seaport vulnerability to represent with quantitative data. This discrepancy points to a need to improve the data collection and sharing of metrics that can capture the concept of adaptive capacity for ports. It is also possible that the concept of adaptive capacity may be better captured by other, less quantitative assessment methods. This finding also suggests a disconnect between what experts perceive as an important component to understanding seaport vulnerability and the types of data that are currently being reported and available to represent that component.

Using the AHP expert-based survey, weights were developed for 12 indicators of seaport *exposure* and *sensitivity* (2 of 3 vulnerability components) to climate and extreme weather impacts. From this survey, although the indicators for *adaptive capacity* did not rank high, as vulnerability component, experts weighted *adaptive capacity* higher than *sensitivity* and nearly equal to *exposure* in importance with respect to seaport climate and extreme weather vulnerability.

A limitation of this AHP method can be the difficulty of achieving high levels of group consensus. For each of the three nodes of this AHP, the consensus indicator, S, was low (50.1%, 53.6%, 61.1%), suggesting low relative homogeneity of expert preferences. Improvements in group consensus may be achieved by using iterative approaches such as the Delphi method[1], in which participants are shown descriptive statistics of the group responses and given the opportunity to revise their answers during subsequent iterations of the AHP, as was employed in (Orencio and Fujii 2013). A drawback of this iterative approach, however, is the additional time required to complete the process. For this study, researchers held 21 different webinars lasting approximately 30 minutes to 1 hour. Experts may be reluctant to participate in a longer process. As the number of pairwise comparisons increases quickly due to the number required for *n* indicators (Equation 1), or the number of ports, even a single-round AHP can become an imposition on the time constraints of busy professional experts.

4.6 Conclusion

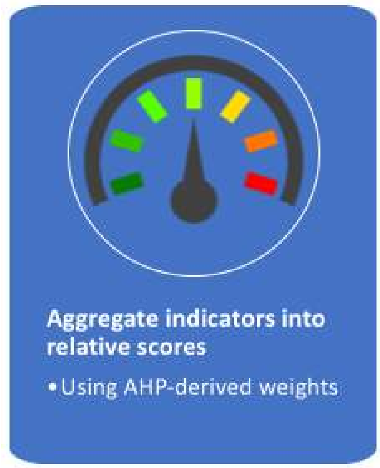
To further the development of IBVA methods for the port sector, this study performed an AHP with 37 port experts to develop weights for the three components of vulnerability (i.e., exposure, sensitivity, and adaptive capacity) and for a selection of 12 indicators of seaport exposure and sensitivity to climate and extreme weather impacts. The AHP weighted the importance of adaptive capacity higher than sensitivity and nearly equal to exposure with respect to seaport climate and extreme weather vulnerability. This finding suggests a disconnect between what experts believe is an important component to understanding seaport vulnerability to meteorological and climatological threats, and the types of data that are currently being reported and available to represent that component. An opportunity for future research exists to develop an answer to what types of data, if any, experts would accept as representative of the concept of seaport adaptive capacity.

[1] The Delphi method is a structured communication technique designed to obtain opinion consensus of a group of experts by subjecting them to a series of questionnaires interspersed with feedback in the form of a statistical representation of the group response. The goal of employing the Delphi method is to reduce the range of responses and arrive at something closer to expert consensus.

5 Trialing a Prototype Composite Index of Seaport Climate Vulnerability

5.1 Introduction

After generating the vulnerability indicator and the component's weights via AHP, the next step was to create a composite index of seaport vulnerability based on the port experts developed weights. This chapter describes the aggregation of indicators into weighted *scores* and the validation of the output through comparison to experts' subjective rankings of seaport vulnerability to climate and extreme weather events (Figure 6).



5.2 Methodology: Aggregating weighted indicators

Due to the lack of expert-supported indicators of adaptive capacity, the AHP-based composite index was limited to the aggregation of only two of the three components of vulnerability: exposure and sensitivity. This yielded a composite score that may be considered similar to vulnerability indicator minus the component of adaptive capacity. Researchers aggregated these indicators into a composite index of vulnerability using a WSM (Equation 5). In Equation 5, n represents the number of decision criteria (i.e., indicators or components), m represents the number of ports, w_j represents the relative weight of indicator I_j, and p_{ij} represents the performance of port A_i when evaluated in terms of indicator I_j.

Equation 5. WSM.

$$A_i^{WSM-score} = \sum_{j=1}^{n} w_j p_{ij}, for\ i = 1, 2, 3 \dots, m.$$

To create the composite index for the CENAD ports based on this WSM, researchers first compiled data on all 12 of the indicators used in the AHP for the 22 ports of the CENAD. Missing values were imputed with the indicator's mean value. Afterwards, the input variables were standardized using z-score standardization (Equation 6), generating variables with a mean of 0 and a standard deviation of 1. This standardization allows for indicators with disparate units to be combined (Cutter et al. 2003).

Equation 6. *Z*-score standardization.

$$z = \frac{X - \mu}{\sigma}$$

A composite indicator for exposure was created by summing the products of each exposure indicator and its weight. Next, a composite indicator for sensitivity was created by summing the products of each sensitivity indicator and its weight. The two composite indicators of exposure and sensitivity were then each multiplied by their respective component weights and summed together. The resultant composite indicator represents the combined exposure and sensitivity of the sample ports used to compile a composite index of seaport vulnerability (minus adaptive capacity) for the CENAD sample of ports. Afterwards, the port rankings generated by the composite index were compared to the experts' subjective ranking of port vulnerability obtained from the previous VAS survey.

5.3 Results of Weighted Sum Model (WSM): Composite indices of CENAD ports

Using the AHP-generated weights based on the WSM, researchers obtained a port's vulnerability ranking value. This value represents the port's level of vulnerability to climate and extreme weather. Additionally, researchers recorded a priori ranking generated[1] subjectively by the same participating experts. This allowed for a comparison between the two rank measurements. Next, researchers compiled composite indices for the CENAD sample of ports. Applying the AHP-generated indicator weights to the *z*-score-standardized input variables for 22 CENAD ports and aggregating them in a WSM yielded the following ranking (Table 9) where a larger number corresponds to a higher degree of vulnerability. Results can also be classified using quartiles or standard deviations to create

[1] As part of the VAS survey described in McIntosh, R. D., and Becker, A. 2018. *Expert Evaluation of Open-Data Indicators of Seaport Vulnerability to Climate and Extreme Weather for U.S. North Atlantic Ports*, University of Rhode Island, port experts were asked to rank the top-10 most vulnerable ports out of the sample of 22 CENAD ports. The rank distribution (Table 8) was generated from a sum of weighted values, which were weighted as the inverse of the number of ports the respondent chose to rank.

classes like *high*, *medium,* and *low* to illustrate the vulnerability scores as illustrated in the *hot spots* map (Figure 18).

Table 9. Model-generated ranking of USACE CENAD ports by vulnerability to climate and extreme weather events. A score of 1 indicates most vulnerable, and -1 indicates least vulnerable. Note that here, vulnerability includes exposure and sensitivity, but not adaptive capa*city*.

Port	Vulnerability Score
Virginia, VA	0.46
Boston, MA	0.24
Philadelphia, PA	0.11
New Haven, CT	0.10
Port Jefferson, NY	0.10
Portland, ME	0.10
Hopewell, VA	0.07
Searsport, ME	0.04
Fall River, MA	0.02
Camden-Gloucester, NJ	0.02
Baltimore, MD	0.00
Bridgeport, CT	-0.03
Hempstead, NY	-0.04
Paulsboro, NJ	-0.04
Albany, NY	-0.05
Wilmington, DE	-0.07
Marcus Hook, PA	-0.09
Chester, PA	-0.10
Penn Manor, PA	-0.11
Portsmouth, NH	-0.12
New York and New Jersey, NY	-0.12
Providence, RI	-0.13

With the exception the of the Port of New York and New Jersey, the model-generated port vulnerability rankings matched the subjective (validation) highest vulnerability ranking by experts in the VAS survey (Table 10). The model captured three out of four of the most vulnerable ports consistent with the experts' rankings.

Figure 18. Hotspots map presenting the vulnerability scores using three standard deviation classes. (Colors: green = low; yellow = medium; red = high vulnerability)

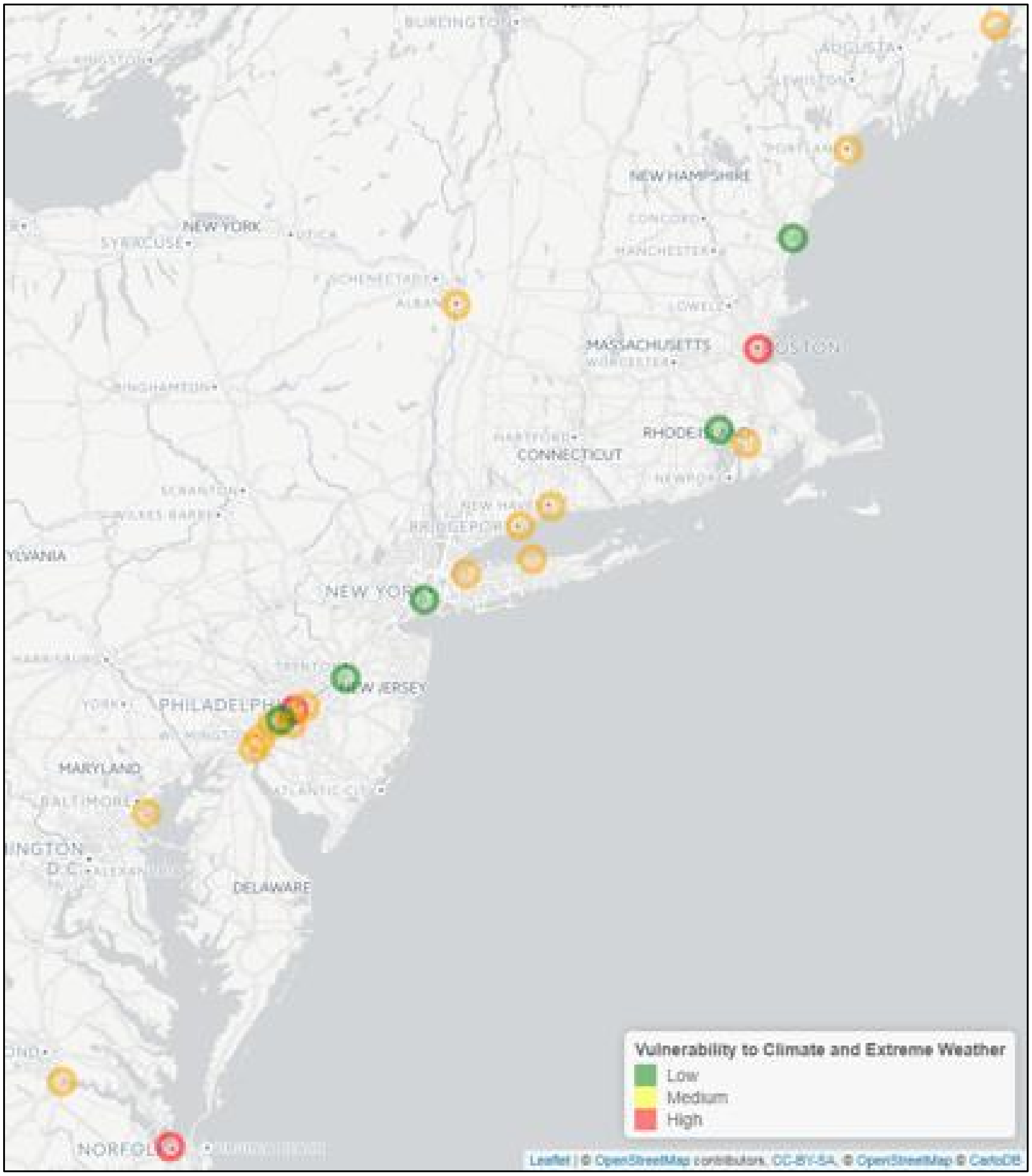
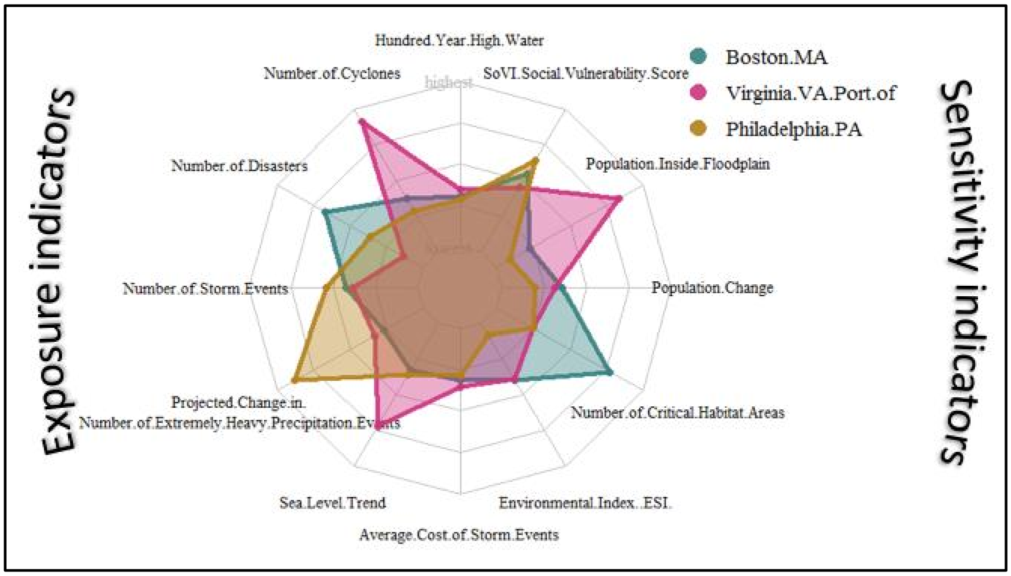


Table 10. Port experts' consolidated subjective ranking of the top-10 USACE CENAD ports most vulnerable to climate and extreme weather (from McIntosh 2018).

Port	Experts' Rank
Virginia, VA	1
New York and New Jersey, NY	2
Boston, MA	3
New Haven, CT	4
Baltimore, MD	5
Providence, RI	6
Portland, ME	7
Portsmouth, NH	8
Philadelphia, PA	9
Hempstead, NY	10

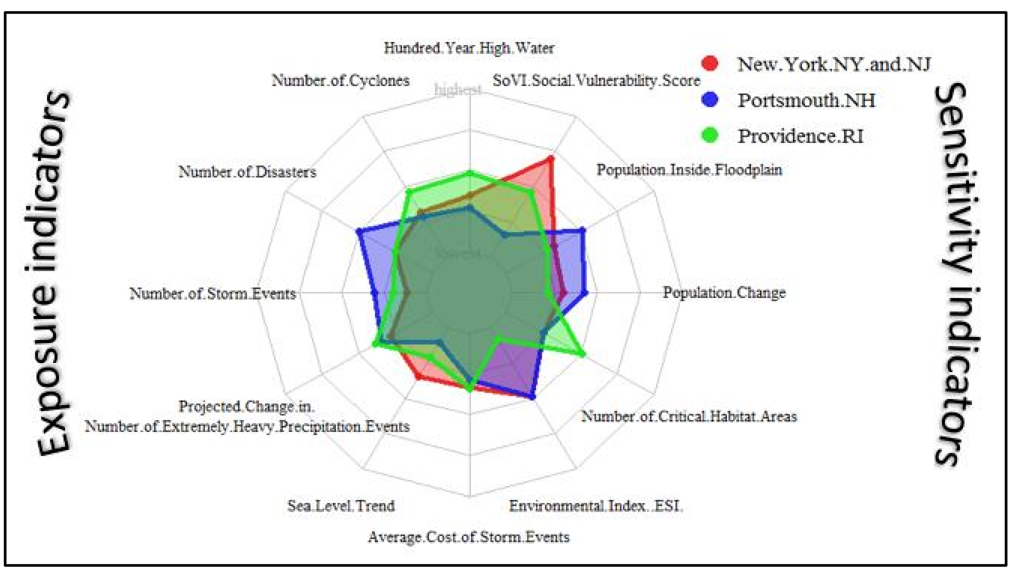
One benefit of indicator-based composite indices is their ability to synthesize multiple variables into a single, measurable concept while still retaining the ability to explore the disaggregated substructure behind the composite construct. As such, their users are able to ask "*Why* does a particular entity score high or low according to this index?" The disaggregated substructure behind the composite vulnerability scores can be used to explore the relative performance of a port in terms of the individual scores for the three highest scoring ports from the composite index indicators (Figure 19), or for the three lowest scoring ports from the composite index (Figure 20). In Figure 19, the Number of Critical Habitats (exposure) indicator scored highest for the Port of Boston, while the Number of Cyclones (exposure) and Population inside Floodplains (sensitivity) scored highest for the port of Virginia and the Projected Change in Number of Extremely Heavy Precipitation Events scored highest for the port of Philadelphia. Whereas the Port of Virginia scored high (i.e., relatively more vulnerable) in the "Number.of.Cyclones" indicator and relatively low with respect to the "Number.of.Disasters," the opposite is seen for the Boston (Figure 19).

Figure 19. Disaggregated substructure of the composite-index vulnerability scores of the three highest scoring ports. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half.



Comparison of the Ports of New York and New Jersey, Portsmouth (NH), and Providence (RI) shows differences in the underlying vulnerability concern of each port in terms of the individual indicators (Figure 20). This type of differentiation can assist decision-makers in understanding the mechanisms and drivers behind a composite score and give them more insights for better decisions.

Figure 20. Disaggregated substructure of the composite-index vulnerability scores of the three lowest scoring ports. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half.



The substructures created from the composite index scores of the three least vulnerable ports yield insight into the discrepancy between the index rankings and the subjective, expert-rankings (Figure 20). While the Port of New York and New Jersey was considered second most vulnerable according to expert perception, the weighted index scored it second *least* vulnerable. While the Port of New York and New Jersey scored high (i.e., relatively more vulnerable) in the SoVI indicator, it scored near the bottom of the sample in nearly every other indicator (Figure 20). This may be an artifact of the method of compiling the indicator data for the sample of ports. Most place-based indicators were gathered at the county level, and for this experiment, the Port of New York and New Jersey was represented solely by New York County. Similarly, the Port of Providence was subjectively ranked sixth most vulnerable by port experts yet scored least vulnerable of all in the composite index. While Providence scored near the middle of the sample for *number of critical habitat areas*, *hundred year high water*, and *number of cyclones*, it scored near the bottom of the sample for *number of disasters*, *number of storm events*, and ESI, and did not score higher than average for any indicator (Figure 20). Other radar plots for the 22 ports studied are shared in Appendix L.

5.4 Discussion

The method of generating indicator weights based on aggregated expert preferences using AHP described in this paper presents promise and limitations. Port rankings generated by a composite index based on a WSM using the AHP-derived weights was compared to an a priori subjective ranking generated by port experts. Though the model lacked indicators of adaptive capacity, it matched (Table 9) the experts' ranking for the most vulnerable port and also matched three of the four ports ranked most vulnerable by the experts (Table 10).

Previous climate vulnerability assessments of seaports have tended to focus on the single port scale as case studies (Koppe et al. 2012; Cox et al. 2013; USDOT 2014; Messner et al. 2013; Chhetri et al. 2014), or self-assessment tools (NOAA OCM 2015; Sempier et al. 2010; Morris and Sempier 2016; Stenek et al. 2011; Roos and Kliemann Neto 2017). Other studies focused on presenting general frameworks and guidelines for studying climate vulnerability (Scott et al. 2013; Mansouri et al. 2010). The contribution of this study is unique, as it proposes an indicator-based composite index for the purpose of developing seaport CCVA at the multi-port scale.

To the observed problem (i.e., the current difficulty of comparing relative vulnerability across ports), this work contributes a prototype composite index (and a method to replicate such an index for other sectors) that allows rudimentary quantitative comparisons of exposure and sensitivity levels across ports. This prototype index was able to capture relative outliers in the sample of ports (i.e., the main objective of composite-indices) and presents the promise of an indicator-based approach to address relative vulnerability.

5.4.1 Adaptive capacity considered highly important

Adaptive capacity is defined in the glossary of the IPCC Fifth Assessment Report as "The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2014b). As noted by Siders, this definition bears some resemblance to generally accepted definitions of resilience (Siders 2016) (i.e., the ability to bounce back from an impact[1]). As such, Siders recommends that adaptive capacity can be distinguished from resilience by ascribing resilience as maintaining stability by *bouncing back* to pre-shock conditions, and by taking adaptive capacity to refer to the broader ability of a system to self-organize, learn, and embrace change to limit future harms (Klein et al. 2003; Siders 2016).

As noted by Brooks et al. (2005), adaptive capacity is a component of vulnerability primarily associated with governance. Hence, next-step efforts to assess relative levels of seaport adaptive capacity should start by examining ports' governance structures to find measurable metrics to assess and compare the ports' ability to adjust, take advantage, or respond to climate and weather impacts.

5.4.2 Limitations

The aggregation of weighted indicators into a composite index was done as a means to validate the AHP-generated weights. By comparing the port-rankings that were generated through a WSM to the subjective port-ranking, this process produced insights into the benefits and limitations of such methods.

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[1] McIntosh, R. D., and A. Becker. Unpublished. "Expert Evaluation of Open-Data Indicators of Seaport Vulnerability to Climate and Extreme Weather for U.S. North Atlantic Ports." *Journal of Ocean and Coastal Management*.

As a means to identify relative outliers among a sample, this method successfully matched the most vulnerable port and three of the four most vulnerable ports as ranked subjectively by port experts. While partially successful at identifying the relative outliers among the sample of ports, the composite index also ranked several ports (e.g., Providence, New York and New Jersey) near the bottom of the sample that experts had subjectively ranked near the top.

Some of this discrepancy may be due to the sensitivity of indicator-based composite indices to differences in the interpretation of data used for the indicators. For example, an indicator for an entity that spans multiple counties, like the Port of New York and New Jersey, could be represented by a measure of central tendency of the data for the collection of counties, by the data from the county with most extreme value, or by a single representative county. In this experiment, the single county of New York was taken to represent the Port of New York and New Jersey for the purposes of compiling the indicator data, which may have resulted in lower than expected values for that port in some of the indicators. Additionally, indicator-based assessments will always be limited by the quality of data available to incorporate into them.

Although the AHP weighted all three components of vulnerability, including adaptive capacity, and the composite index incorporated the weights for the components of exposure and sensitivity into the WSM, it should be noted that this composite index of seaport vulnerability to climate and extreme-weather did not include indicators of adaptive capacity. As such, the composite index is more accurately described as a weighted measure of seaport exposure and sensitivity to climate and weather extremes. This may have also contributed to some of the discrepancy between model results and the subjective ranking of ports that was based on a definition of vulnerability that included all three components (e.g., exposure, sensitivity, and adaptive capacity).

Additionally, indicator-based methods are inherently limited by the availability of data. Chapter 2 of this report, which describes the identification, development, and evaluation of candidate indicators of seaport climate vulnerability, illustrates these data availability limitations in more detail. For example, the lack of openly available data to serve as indicators of adaptive capacity resulted in the reduction of the composite index described here from an assessment of holistic vulnerability to one of exposure and sensitivity only.

5.5 Conclusion

To validate the results of the AHP described in Chapter 4, the AHP-generated weighting scheme was applied using a WSM to create a composite index for 22 CENAD ports that was compared to a subjective ranking of the ports by the same experts. This comparison revealed that while the model is promising in fulfilling the main objective of generating composite indices, the potential for group consensus during the AHP is low. Potentially, implementing Delphi-style iterations can remedy this issue, but it would increase the time cost.

Variations in spatial scale and the given values of available data can require subjective choices regarding the compilation of indicator data for ports that span multiple counties. Because of the sensitivity and subjectivity of these decisions, researchers recommend a stakeholder-based approach for the early stages of indicator development such as the expert-elicitation methods applied in McLeod et al. (2015) and Teck et al. (2010).

This research has furthered the development of indicator-based assessment methods for the port sector by constructing and trialing a prototype composite index of seaport climate vulnerability. However, note that further work exploring the sensitivity of results to data compilation methods and developing a measure of adaptive capacity will be needed before such methods are robust enough for use in critical decision-making. Finally, the main caveat of these methods is that they will always be limited by the quality of the data that they incorporate.

6 Conclusion

This study finds that the development of weighted algorithms and composite indices, based on open data, for seaport relative vulnerability to climate and extreme weather can advance the goals of the MTS of the USACE by informing efforts and plans to prioritize and allocate limited resources to increase the climate-resilient seaports. This study also suggests that improvements in the standardized reporting and sharing of port data are necessary before such indicator-based assessment methods can inform decision-makers on the relative vulnerability and the level of resilience inherent to ports that can be used to evaluate port-related investment.

Through science and engineering, the USACE directs efforts to facilitate navigation in U.S. waterways and reduce risks to natural hazards that can impact the sustainability of social, economic, and environmental systems. Seaports are subject to extreme coastal weather and climate impacts, and they will be more vulnerable as these impact frequencies increase in the future. As port decision-makers wrestle with the incertitude of these projected impacts, this research effort attempted to broaden the base of the knowledge that serves to increase the USACE ability to prioritize resources in time by addressing identified gaps in the seaport vulnerability assessment process. This research presents a general method for developing and evaluating an expert-supported vulnerability indicators across a port region. This method can be applied to other fields of study beyond the seaport sector.

Attention must be given to the sufficiency of available open data to serve as vulnerability indicators for the seaport sector. Presently, the *exposure* and *sensitivity* — vulnerability components — can be represented by expert-supported indicators; however, this research was unable to identify available data sources that could yield expert-supported indicators of *adaptive capacity*.

Attention must be given to the sufficiency of available open data to serve as vulnerability indicators for the seaport sector. Presently, both exposure and sensitivity can be represented by expert-supported indicators; however, this research was unable to identify available data sources that could yield expert-supported indicators of adaptive capacity. Hence, an opportunity exists for further research and development of standardized, comparative CCVA methods for seaports and the MTS, with the objective of supporting Climate Impact, Adaptation, and Vulnerability decisions with information products that allow decision-makers to compare mechanisms and drivers of climate change across multiple ports.

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Appendix A: Terminology Definitions

Analytic Hierarchy Process (AHP) is a multi-objective, multi-criteria decision-making approach that uses a pairwise comparison procedure to arrive at a scale of preference among a set of alternatives (Saaty 2008b).

Indicators are measurable, observable quantities that serve as proxies for an aspect of a system that cannot itself be directly measured (Gallopin 1997; Hinkel 2011).

Mind map© is "an organized diagram that allows you to visually structure your ideas to help with analysis and recall. Concepts can be linked to and arranged around a central concept or subject using a non-linear graphical layout that allows the user to build an intuitive framework around a central concept" (Mindmap.com 2017).

Open-data source is information that is "released in a specific way to allow the public to access" (Chernoff 2017). These data are fully discoverable and usable by end users. Some valuable data are not accessible owing to the sensitive nature of the information.

Resilience is the capacity to prepare, resist, recover, and adapt to a disturbance, such as a major storm event (CARRI 2013; Rosati et al. 2015) and is a concept that in and of itself is not directly measurable.

Risk is the probability of an event to damage critical components of the infrastructure. Although potential outcomes are often uncertain (IPCC 2014a), these are often measured monetarily as it relates to the physical components of a facility/system, loss of function (interruptions), cost of repair and stabilizing conditions (debris removal, etc.).

Seaport here collectively refers to the collocated real property and infrastructure involved in the loading and unloading of cargo from maritime vessels. These are port, facilities, locks, etc. Lacking a universally accepted method for delimiting for port boundaries, and recognizing that some seaports span multiple counties, this study of port vulnerability considers a port as an inextricable part of its local socioeconomic and environmental systems.

Appendix B: Mind maps© from Expert Group

Figure B-1. *Mind map* of the components of vulnerability for seaports: Exposure.

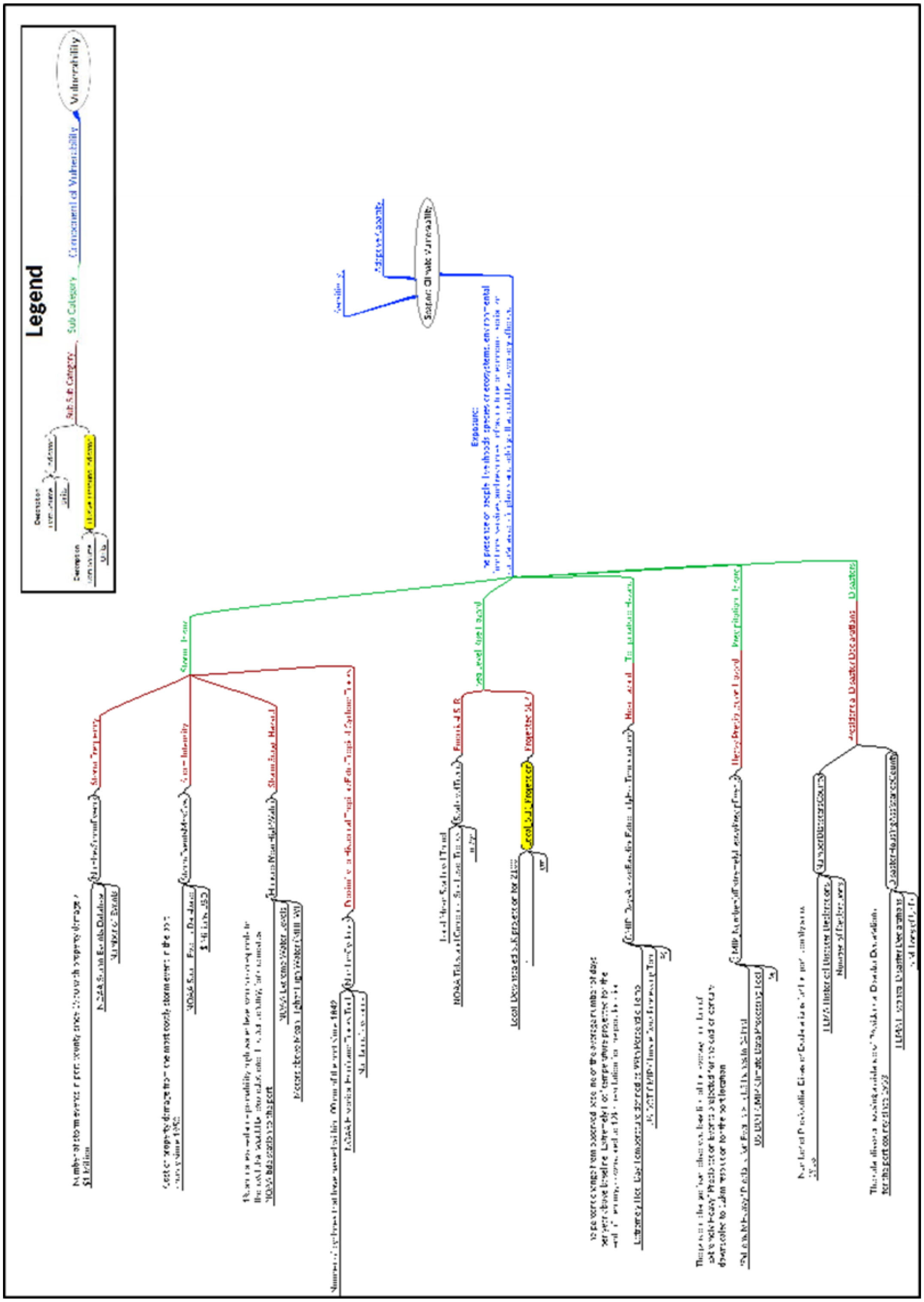


Figure B-2. *Mind map* of the components of vulnerability for seaports: Sensitivity.

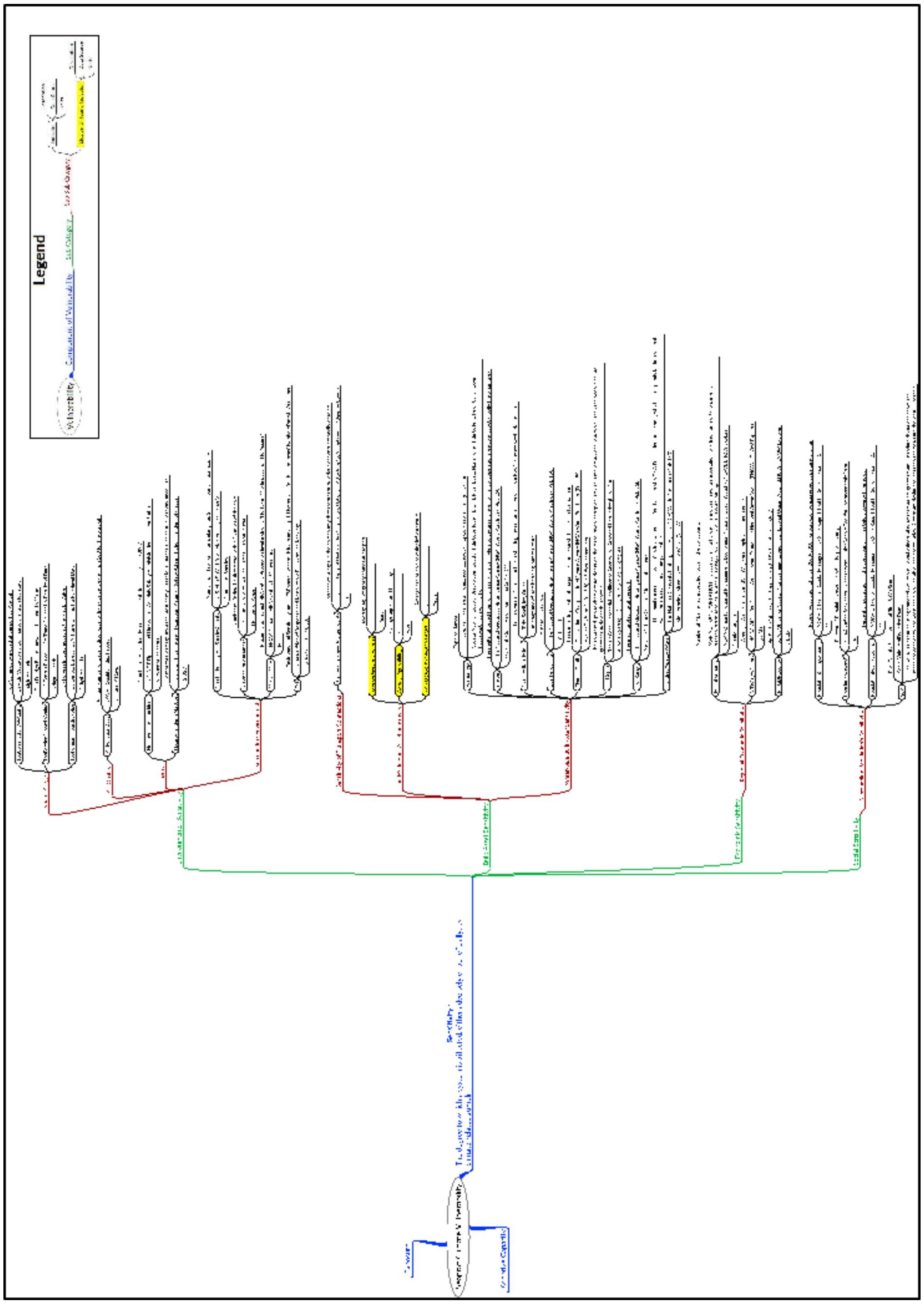
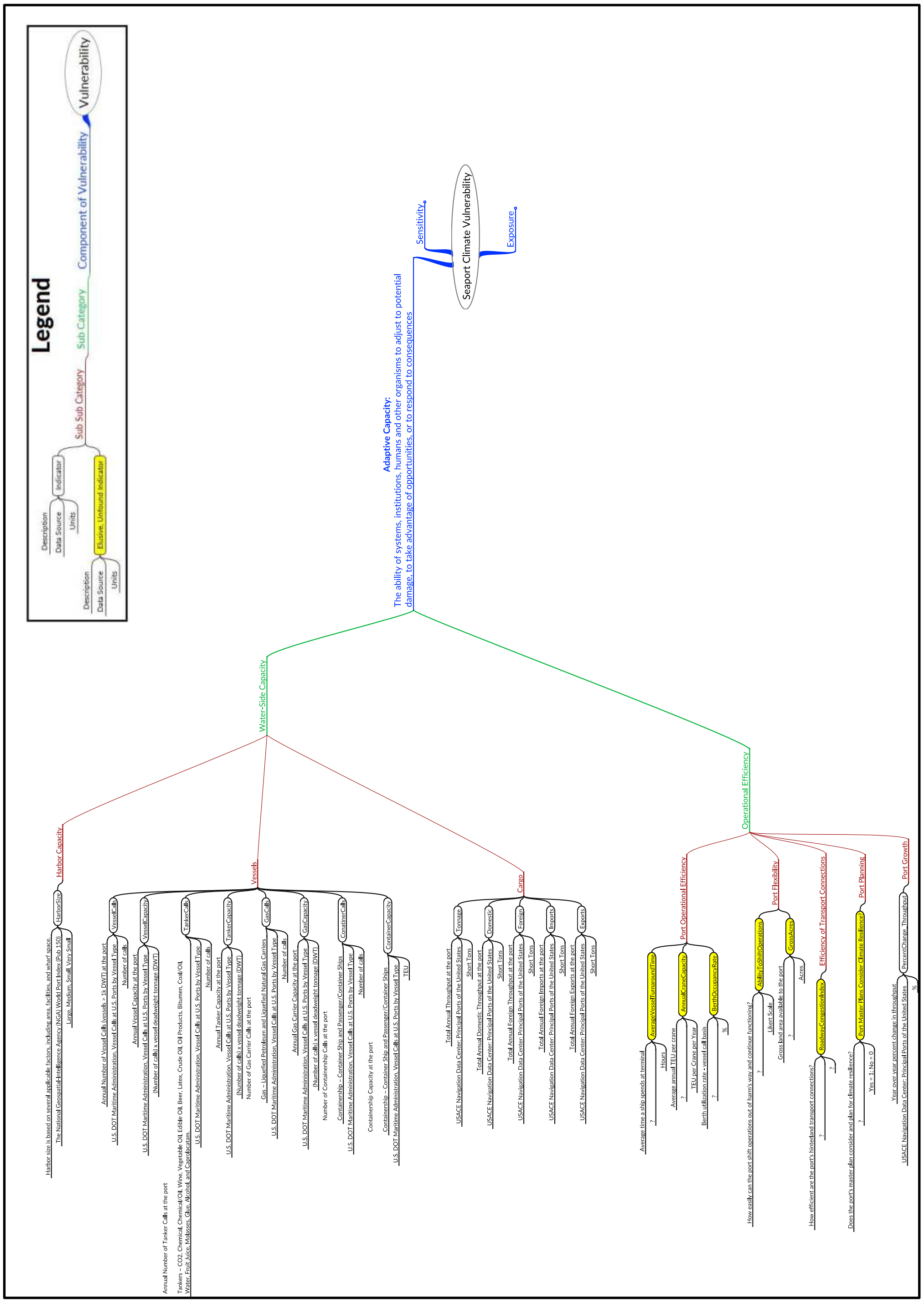


Figure B-3. *Mind map* of the components of extreme weather vulnerability for seaports: Adaptive Capacity.



Appendix C: Databases for Candidate Vulnerability Indicators

Table C-1. Twenty extreme weather vulnerability indicator database sources, time range for the data, 48 numbered candidate indicators and its corresponding unit of measurement. A full list of all the identified databases and indicators are presented in **URI – Digital Commons.**

Data Sources	Time Range	Candidate Indicators (#1-48)	Units
1. NOAA Storm Events Database	1950 - 2016	1.1 Number Storm Events (1)	Number of Events
	1950 - 2016	1.2 Storm Events Max Cost (2)	$ Millions USD
	1950 - 2016	1.3 Average Cost of Storm Event (3)	$ USD
2. NOAA Extreme Water Levels	1893 - Present	2.1 Hundred Year High Water (4)	Meters above mean higher high water (MHHW)
	1893 - Present	2.2 Hundred Year Low Water (5)	Meters below mean lower low water (MLLW)
3. NOAA Historical Hurricane Tracks Tool	1842 - Present	3.1 Number Cyclones (6)	Number of cyclones
4. NOAA Tides and Currents- Sea Level Trends	1854 - 2013	4.1 Sea Level Trend (7)	mm/yr
5. NOAA Office of Response and Restoration: ESI Shoreline Rankings	2001 - 2016	5.1 Environmental Sensitivity Index (ESI) (8)	ESI Rank (1.00 - 10.83)
6. NOAA Office for Coastal Management: Economics: National Ocean Watch – Economic National Ocean Watch: ENOW Explorer	2005 - 2013	6.1 MT Jobs County (9)	Number of jobs
	2005 – 2013	6.2 Marine Transportation Jobs (MT) Gross Domestic product (GDP) County (10)	$ USD

Data Sources	Time Range	Candidate Indicators (#1-48)	Units
	2005 - 2013	6.3 MT Wages County (11)	$ USD
7. NOAA Office for Coastal Management: Quick Report Tool for Socioeconomic Data	2000 - 2010	7.1 Population Change County (12)	%
8. NOAA Office for Coastal Management: County Snap shot		8.1 Population Inside Floodplain (13)	%
		8.2 Population Poverty County (14)	%
		8.3 Population Over 65 (15)	&
9. NOAA National Marine Protected Area (MPA) Center	2002-2005	9.1 Miles to MPA (16)	Miles
10. EPA Air Quality Index Report	1980 - 2016	10.1 Air Pollution Days (17)	Number of Days
11. FEMA Historical Disaster Declarations	1953 - Present	11.1 Number Disasters County (18)	Number of Declarations (Type)
		11.2 Disaster Housing Assistance County (19)	$ Millions of USD
12. US DOT Coupled Model Inter-comparison Project (CMIP) Climate Data Processing Tool	1953 - Present	12.1 Projected Change in Days Above Baseline Extremely Hot Temperature (20)	%
	1954 - Present	12.2 Number of Extremely Heavy Precipitation Events (21)	%

Data Sources	Time Range	Candidate Indicators (#1-48)	Units
13. U.S. DOT Pipeline and Hazardous Materials Safety Administration: Incident Statistics	2007 - 2012	13.1 Number Hazmat Incidents (22)	Number of Incidents
	2007 - 2012	13.2 Hazmat Incidents Max Cost (23)	$ USD
14. U.S. DOT Federal Highway Administration: National Bridge Inventory: Deficient Bridges by County	2006 - 2016	14.1 Percent Deficient Bridges County (24)	%
15. U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	Annual 2002 - 2017	15.1 Tanker Capacity (25)	(Number of calls) x vessel dead weight total (DWT) (metric tons)
	Annual 2002 - 2017	15.2 Tanker Calls (26)	Ship calls
	Annual 2002 - 2017	15.3 Container Capacity (27)	(Number of calls) x vessel dead weight total (DWT)
	Annual 2002 - 2017	15.4 Container Calls (28)	Ship calls
	Annual 2002 - 2017	15.5 Gas carrier Capacity (29)	(Number of calls) x vessel dead weight total (DWT)
	Annual 2002 - 2017	15.6 Gas Calls (30)	Ship calls
	Annual 2002 - 2017	15.7 Vessel Capacity (31)	(Number of calls) x vessel DWT
	Annual 2002 - 2017	15.8 Vessel Calls (32)	Ship Calls

Data Sources	Time Range	Candidate Indicators (#1-48)	Units
16. The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150)	2016	16.1 Shelter Afforded (33)	Excellent, Good, Fair, Poor, None (5,4,3,2,1)
	2016	16.2 Entrance Restrictions (34)	Tide, Swell, Ice, Other
	2016	16.3 Overhead Limits (35)	Y=1, N=0
	2016	16.4 Channel Depth (36)	A (over 76 ft) to Q (0 – 5 ft) in 5 ft increments
	2016	16.5 Pier Depth (37)	A (over 76 ft) to Q (0 – 5 ft) in 5 ft increments
	2016	16.6 Tide Range (38)	Feet
	2016	16.7 Harbor Size (39)	Large, Medium, Small, Very Small
	2016	16.8 Harbor Type (40)	Coastal natural, Coastal breakwater, Coastal tide gate, River basis, None, River, River tide gate, Lake or canal, Open roadstead, Typhoon harbor
17. USACE Navigation Data Center: Principal Ports of the United States	1996 – 2015	17.1 Tonnage (43)	Short Tons
	1996 – 2015	17.2 Domestic (44)	Tons
	1996 – 2015	17.3 Foreign (45)	Tons

Data Sources	Time Range	Candidate Indicators (#1-48)	Units
	1996 – 2015	17.4 Imports (46)	Tons
	1996 – 2015	17.5 Exports (47)	Tons
18. U.S. Fish and Wildlife Service, Endangered Species	Present Year	18.1 Number Endangered Species County (41)	Number of Species
19. U.S. Fish and Wildlife Service, Critical Habitat Portal	Present Year	19.1 Number Critical Habitat (42)	Number of Areas
20. Social Vulnerability Index Data	2006 – 2010	20.1 SoVI (48)	The SoVI is classified using standard deviations

Appendix D: Other Identified Datasets

Table D-1. List of datasets that contain potential candidate indicators for vulnerability, but the datasets did not contain information for at least 12 of the 22 ports in this pilot study. They are included here to note that they were considered for this study, but rejected for the pilot. The datasets are presented with their source, time range for which data are available, the candidate indicator(s), and the units in which these are recorded.

Data Sources	Time Range	Candidate Indicators	Units
NOAA Storm Events Database	1950 - 2016	Non-convective high winds	Knots
NOAA – Tides and Currents: Top Ten Highest Water Levels for long-term stations	2015 (annual, latest available)	Highest historical water level	Meters above MHHW
SurgeDAT	2012 (annual, latest available)	Max historical storm surge	Meters
National Hurricane Center	2014 (annual, latest available)	Tropical cyclone return period	Years
Global Sea Level Rise (SLR) Scenarios for the United States: National Climate Assessment	2012 (annual, latest available)	Local SLR Projections	mm / yr
Permanent Service for Mean Sea Level (PSMSL) Peltier GIA data sets	2012 (annual, latest available)	Annual uplift/subsidence rate	mm / yr
NOAA National Centers for Environmental Information NCDC	2014 (annual, latest available)	Average Annual Sea Surface Temp Anomaly	°F
NOAA National Estuaries Research Reserve System	2014 (annual, latest available)	Nearby Federally/State Managed Water	Acres
U.S. Fish and Wildlife Refugees	2014 (annual, latest available)	Nearby Wildlife Refugees	Acres
EPA Cleanups in My Community	2015 (annual, latest available)	EPA Brownfields near port	Number of sites

Data Sources	Time Range	Candidate Indicators	Units
FEMA National Flood Insurance Program Community Rating System: Communities and Their Classes	2015 (annual, latest available)	National Flood Insurance Program Community Rating System Score	Score number
Texas A&M University Texas Transportation Institute Urban Mobility Information, Congestion Data for Your City	2011 (annual, latest available)	Annual Truck Congestion Cost	Millions ($)
		Roadway Congestion Index	Unit-less
	2011 (annual, latest available)	Travel Time Index	Unit-less
North American Cruise Traffic	2013-2014	Cruise-Ship Calls	Ship calls
	2013-2014	Cruise-Ship Passengers	Passengers
Western Hemisphere Port TEU Container Volumes	1980-2013	Containerized Throughput	Twenty-foot equivalent units (TEU)
USA Trade Online: HS Port-level Data	2016 (annual, latest available)	Top Foreign Import by Value	6 digits Harmonized system commodity code (HS code)
		Top Foreign Import by Weight	6 digits HS code
		Top Foreign Export by Value	6 digits HS code
		Top Foreign Export by Weight	6 digits HS code
USACE Navigation Data Center: Principal Ports of the U.S.	2016 (latest)	Annual % change in throughput	%

Appendix E: List of Databases Used and Brief Descriptions

I. National Oceanic and Atmospheric Administration (NOAA)

1. NOAA Storm Events Database

Source: https://www.ncdc.noaa.gov/stormevents/

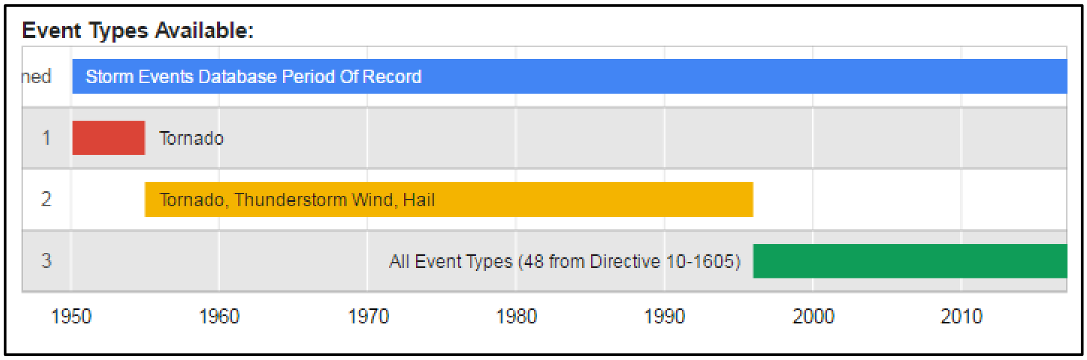
The Storm Events Database contains the records used to create the official NOAA storm data publication, documenting the following:

a. The occurrence of storms and other significant weather phenomena with sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce

b. Rare, unusual, weather phenomena that generate media attention, such as snow flurries in South Florida or the San Diego coastal area

c. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur about another event (Figure E-1).

Figure E-1. Examples of event types from NOAA storm event database.



The database currently contains data from January 1950 to February 2017, as entered by the NOAA National Weather Service. Due to changes in the data collection and processing procedures over time, there are unique periods of record available depending on the event type. The National Centers for Environmental Information has performed data reformatting and standardization of event types but has not changed any data values for locations, fatalities, injuries, damage, narratives, and any other event-specific information. Please refer to the database details page for further information.

Candidate indicators found in this database are the following:

1.1 Number of storm events (1)

1.2 Max. Cost of storm event (2)

1.3 Average Cost of Storm Event (3)

2. NOAA Extreme Water Levels

Source: https://tidesandcurrents.noaa.gov/est/northatlantic.html

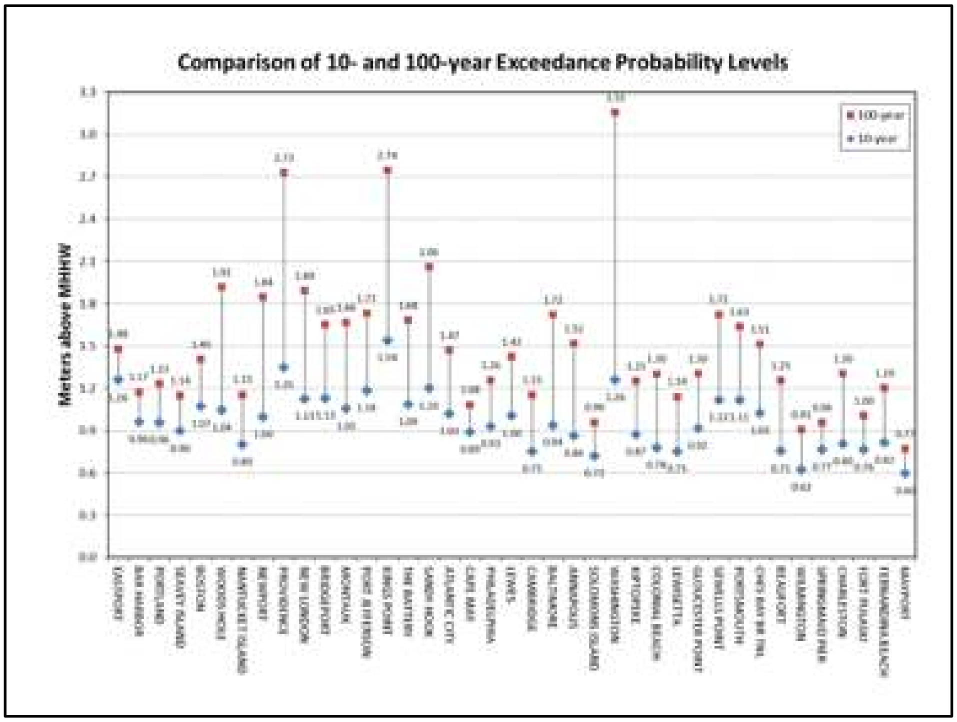
The extreme water levels product provides web-based access to exceedance probability statistics to approximately 110 NOAA Center for Operational Oceanographic Products and Services (CO-OPS) water level stations with at least 30 years of water level observations. Exceedance probability is the likelihood that water levels will exceed a given elevation based on a statistical analysis of historic observations. CO-OPS computes exceedance probability statistics to determine the extreme water levels that are likely to occur every year, every other year, every 10 years, and every 100 years (Figure E-2).

Extremely high or low water levels at coastal locations are an important public concern and a factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability, the likelihood that water levels will exceed a given elevation, is based on a statistical analysis of historic values.

Candidate indicators found in this database are the following:

2.1 Hundred Year High Water (4)
2.2 Hundred Year Low Water (5)

Figure E-2. Comparison of 10- and 100-year exceedance from NOAA database. Probability levels: meters above mean MHHW by locality.



3. NOAA Historical Tracks Tool

Source: https://coast.noaa.gov/hurricanes/

Storm track information is available from 1842 through the previous year's storms (e.g., 2016). This data service is for the tiled image of all tropical storms, it serves as an overlay within web maps. Although this imagery is available as a data service, most users will find the actual *Historical Hurricane Tracks* website to be more useful for finding and displaying storm information. Within that tool, users can search for a storm by name, time, or location. The actual storm track data are from the NOAA National Climatic Data Center's International Best Track Archive for Climate Stewardship data set and the NOAA National Weather Service Hurricane data set (HURDAT2).

Candidate indicator found in this database is the following:

3.1 Number of Cyclones (6)

4. NOAA Tides and Current

Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

The CO-OPS has measured sea level for over 150 years, with tide stations of the *national water level observation network* operating on all U.S. coasts. Changes in Mean Sea Level, either a sea level rise or sea level fall, are computed at 142 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements are averaged by month to remove the effect of higher frequency phenomena to compute an accurate linear sea level trend.

Candidate indicator found in this database is the following:

4.1 Sea Level Trend (7)

5. NOAA Office of Response and Restoration (OR&R)

Source: http://response.restoration.noaa.gov/maps-and-spatial-data/shoreline-rankings.html

The history of the OR&R began in 1976 with grounding of the tanker Argo Merchant near Nantucket shoals in Massachusetts. Lessons learned from that incident led to the development of oil and chemical spill emergency response, as it is known today. The OR&R is comprised of three divisions: (1) Emergency response, (2) Assessment and restoration, and (3) Marine debris. Collectively, the OR&R provides comprehensive solutions to environmental hazards caused by oil, chemicals, and marine debris.

Candidate indicator found in this database is the following:

5.1 Environmental *Sensitivity* Index (ESI) (8)

6. NOAA - Office for Coastal Management (OCM)

Source: https://coast.noaa.gov/digitalcoast/tools/enow.html

This online tool provides easy access to economic and demographic data for multiple coastal jurisdictions. After selecting the information, geography, and period of interest, users can download data. Information is derived from several key socioeconomic sources, including the U.S. Census

Bureau, Bureau of Economic Analysis, Bureau of Labor Statistics, and the FEMA Hazus database.

In 2010, 123.3 million people, or 39% of the nation's population lived in Coastal Shoreline Counties. Population growth in these counties occurred at a lower rate than the nation as a whole from 1970 to 2010. The population in Coastal Shoreline Counties increased by 34.8 million people, a 39% increase, while the nation's entire population increased by 52% over the same period.

Within the limited space of the nation's coast, population density far exceeds the nation as a whole, and this trend will continue into the future. This situation presents coastal managers with the challenge of protecting both coastal ecosystems from a growing population and protecting a growing population from coastal hazards.

The concentration of people impacts the integrity of coastal ecosystems, and at the same time, the lives and livelihoods of some of these residents and visitors can be at risk from natural processes at the coast – such as hurricanes, erosion, and sea level rise.

7. NOAA - Economics National Ocean Watch (ENOW)

Source: https://coast.noaa.gov/enowexplorer/#/employment/total/2013/44007

The ENOW provides time-series data on the ocean and Great Lakes economy, which includes six sectors dependent on the ocean and Great Lakes: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation.

The annual time-series contains data for over 400 coastal counties, 30 coastal states, 8 regions, and the nation, derived from the Bureau of Labor Statistics and the Bureau of Economic Analysis. It describes six economic sectors that depend on the oceans and Great Lakes and measures four economic indicators: (1) Establishments, (2) Employment, (3) Wages, and (4) Gross Domestic Product (GDP).

Candidate indicators found in this database are the following:

6.1 Marine Transportation Jobs County (9)

6.2 MT GDP County (10)

6.3 MT Wages County (11)

8. NOAA Office for Coastal Management9 (OCM): Quick Report Tool for Socioeconomic Data

Source: https://coast.noaa.gov/digitalcoast/tools/qrt.html

The quick reporting tool for socio-economics facilitates the following:

(a) Exploration of economic and demographic information for areas of interest

(b) Comparison of information for various geographies and time frames

(c) Downloading and share data.

Candidate indicator found in this database is the following:

7.1 Population Change County (12)

9. NOAA Coastal Management: County Snap Shot

Source: https://coast.noaa.gov/digitalcoast/training/population-report.html

This database presents two independent sections with basic demographic status and trends information for coastal shoreline counties and coastal watershed counties; in this way, the coastal management community can choose the appropriate statistics for their needs. The database also offers a simple comparison between the two groups of counties.

Candidate indicators found in this database are the following:

8.1 Population Inside Floodplain (13)
8.2 Population Poverty County (14)
8.3 Population Over 65 (15)

10. NOAA National Marine Protected Areas (MPA) Center

Source: https://marineprotectedareas.noaa.gov/aboutmpas/mpacenter

The National MPA Center was established in 2000 to strengthen and connect the nation's marine protected areas, as called for in Executive Order 13158. The MPA Center is a partnership between NOAA and the Department of the Interior to serve serving as a resource to all federal, state, territorial, and tribal programs responsible for the health of the nation's oceans. The National MPA Center goals are to accomplish the following:

Improve MPA design, stewardship, and effectiveness:

(a) Connect MPA programs and to advance public understanding
(b) Partnerships about MPA programs.

The NOAA MPA Inventory describes all MPAs in U.S. waters, where they are and what they do. This comprehensive geospatial database combines publicly available data with information from state and federal MPA programs. It can be used to view MPAs, explore status and trends of MPAs, create customized maps and analytical products, or add MPAs to data portals, online viewers, and other spatial data visualizations. Published annually, the MPA Inventory appears in various formats to meet a wide range of user needs.

Candidate indicator found in this database is the following:

9.1 Miles to MPA (16)

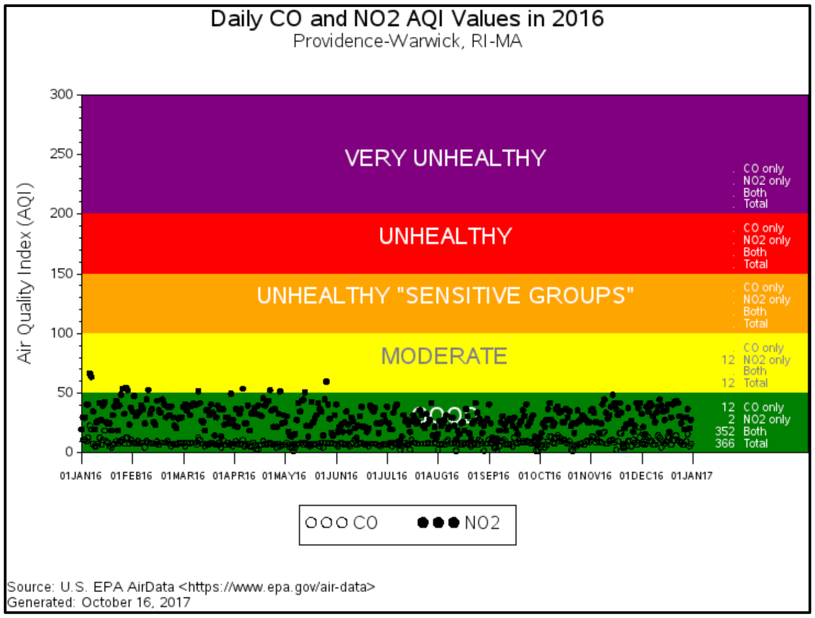
II. Environmental Protection Agency (EPA)

11. The Air Quality Index (AQI) database - For Air Pollution Days

Source: https://www.epa.gov/airdata

The Air Data Air Quality Index Summary Report displays an annual summary of AQI values for counties or Core Based Statistical Areas. AQI is an indicator of overall air quality presenting all the criteria air pollutants measured within a geographic area. AQI provides information on pollutant concentrations of ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide (Figure E-3).

Figure E-3. Daily CO and NO_2 AQI Values in 2016.



The AQI is based on pollutant concentration data measured by the *State* and *local air monitoring stations network* and by other special purpose monitors. For most pollutants in the index, the concentration is converted into index values between 0 and 500, *normalized* so that an index value of 100 represents the short-term, health-based standard for that pollutant as established by EPA (1999) are currently presented in the AIRNow.gov. The higher the index value, the greater the level of air pollution and health risk. An index value of 500 reflects a risk of imminent and substantial endangerment of public health. The level of the pollutant with the highest index value corresponds with the AQI level reported for that day.

Candidate indicator found in this database is the following:

11.1 Air Pollution Days (17)

III. Federal Emergency and Management Agency (FEMA)

For 38 years, the FEMA mission has been to lead America to prepare for, prevent, respond to, and recover from disasters with a vision of "A Nation Prepared." The origin of FEMA can be traced to the Congressional Act of 1803, considered the first piece of disaster legislation that provided assistance to a New Hampshire town following an extensive fire. On April 1, 1979, President Jimmy Carter signed the executive order that created the FEMA.

12. Historical Disaster Declarations

Source: https://www.fema.gov/data-visualization-disaster-declarations-states-and-counties

Major disaster declaration: The President can declare a major disaster for any natural event. These include any hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought, or, regardless of cause, fire, flood, or explosion that the President determines has caused damage of such severity that it is beyond the combined capabilities of state and local governments to respond. A major disaster declaration provides a wide range of federal assistance programs for individuals and public infrastructure, including funds for emergency and permanent work[1]. In cases were a port spans multiple counties, the port county with highest number of disasters is used.

Candidate indicators found in this database are the following:

11.1 Number Disasters County (18)
11.2 Disaster Housing Assistance County (19)

IV. U.S. Department of Transportation (USDOT)

13. U.S. DOT Climate Data Processing Tool (CMIP)

Source: https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/modules/index.cfm?moduleid=4#tools

The U.S. DOT CMIP climate data processing tool processes readily available downscaled climate data at the local level into relevant statistics for transportation planners. This tool works with data from the U.S. Bureau of Reclamation's downscaled CMIP3 and CMIP5 Climate and Hydrology Projections website, available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. This website houses climate model data from phase 3 (CMIP3) and phase 5 (CMIP5) of the World Climate Research Program's Coupled Model Inter-comparison Project (CMIP).

The CMIP Climate data processing tool, developed by the U.S. DOT, will

[1] FEMA Disaster declaration process: https://www.fema.gov/disaster-declaration-process.

process raw climate model outputs from the World Climate Research Program's CMIP3 and CMIP5 into relevant statistics for transportation planners. These statistics include changes in the frequency of very hot days and extreme precipitation events and other climate characteristics that may affect transportation infrastructure and services by the middle and end of the century.

Candidate indicators found in this database are the following:

12.1 Projected Change in Days above Baseline Extremely Hot Temperature (20)
12.2 Number of Extremely Heavy Precipitation Events (21)

14. U.S. DOT Pipeline and Hazardous Materials Safety and Administration (PHMSA): Incidents Statistics

Source: http://phmsa.dot.gov/hazmat/library/data-stats/incidents

The PHMSA agency develops and enforces regulation for the safe, reliable, and environmentally sound operation of the nation's 2.6-million-mile pipeline transportation system and the nearly 1 million daily shipments of hazardous materials by land, sea, and air. PHMSA comprises two safety offices, the Office of Pipeline Safety and the Office of Hazardous Materials Safety.

Hazardous material means a substance or material that the Secretary of Transportation has determined can pose an unreasonable risk to health, safety, and property when transported in commerce and has designated as hazardous under section 5103 of federal hazardous materials transportation law (49 U.S.C. 5103).

Each person in physical possession of a hazardous material at the time that any of the following incidents occurs during transportation (including loading, unloading, and temporary storage) must submit a hazardous materials incident report within 30 days of discovery of the incident.

Candidate indicators found in this database are the following:

13.1 Number Hazmat Incidents (22)
13.2 Hazmat Incidents Max Cost (23)

15. U.S. DOT Federal Highway Administration – National Bridge Inventory

Source: https://www.fhwa.dot.gov/bridge/nbi/no10/county.cfm

The National Bridge Inventory has information on bridges in the port county that are structurally deficient or functionally obsolete. These are presented in percentage. *Structurally deficient* means that the condition of the bridge includes a significant defect, which often means that speed or weight limits must be put on the bridge to ensure safety; a structural evaluation of 4 or lower qualifies a bridge as structurally deficient. The designation can also apply if the approaches flood regularly.

Functionally obsolete means that the design of a bridge is not suitable for its current use, such as lack of safety shoulders or the inability to handle current traffic volume, speed, size, or weight.

Candidate indicator found in this database is the following:

14.1 Percent Deficient Bridges County (24)

16. U.S. DOT Maritime Administration (MARAD)

Source: https://www.marad.dot.gov/resources/data-statistics/

This dataset contains a calculation of vessel calls and vessel capacity for privately owned, oceangoing merchant vessels of all flags of registries over 1,000 gross tons calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam, and Puerto Rico. Vessel capacity is defined as the number of vessel calls multiplied by the dead weight total (DWT) of the vessels. This gives a more insightful picture of port activity than number of calls alone, since some vessels are larger than others. Though the Maritime Administration (MARAD) strives to provide the most accurate information on vessel activity in the United States, these numbers may vary from statistics collected by port authorities and terminal operators. In addition, vessels calling on a port may not necessarily be engaged in onloading/offloading of cargoes.

MARAD database presents a list that contains over 110,000 privately owned, oceangoing merchant vessels registered with an International Maritime Organization number and isolate cargo-carrying vessels from all other types of vessels utilizing the “Statcode.” From this list, all passenger and passenger/roll on-roll off (ro-ro) cargo ships are eliminated. Then, this list of vessels is taken and compared against the Automatic Identification System (AIS) data generated for that vessel.

Vessel Types: MARAD uses six vessel categories in this report: (1) Containerships, (2) Tanker, (3) Dry Bulk, (4) General Cargo, (5) Roll On – Roll Off, and (6) Gas.

Calls are calculated by how many times a vessel arrived at a port, facility, or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo, and may include other activities related to vessel, port, or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessarily be engaged in onloading/offloading of cargoes.

Capacity is the sum of vessel calls weighted by vessel DWT. DWT is the total weight (metric tons) of cargo, fuel, fresh water, stores and crew, which a ship can carry when immersed to its load line. Capacities can be expressed in Twenty Foot Equivalent Units (TEU) for containerships and cubic meters for gas carriers.

Candidate indicators found in this database are the following:

15.1 Tanker Capacity (25)
15.2 Tanker Calls (26)
15.3 Container Capacity (27)
15.4 Container Calls (28)
15.5 Gas carrier Capacity (29)
15.6 Gas Calls (30)
15.7 Vessel Capacity (31)
15.8 Vessel Calls (32)

V. The National Geospatial-Intelligence Agency (NGA)

17. NGA - World Port Index (Pub 150)

Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

The World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by, major ports and terminals worldwide (approximately 3700 entries as of 2016) in a tabular format. Entries are organized geographically and in accordance with the diagrams of "port type" located in the front of the publication. Information on individual ports is submitted by port representatives and not collected through a regular systematic method. Thus, there may be discrepancies and errors in the data reported.

The World Port Index publication can be downloaded as an Adobe PDF document file, a Microsoft Access database, or an ESRI Arc shapefile. The specific World Port Index entries can be retrieved from the on-line database using the query form (Figure E-4).

Figure E-4. World Port Index entries query form.

Candidate indicators found in this database are the following:

16.1 Shelter Afforded (33)
16.2 Entrance Restrictions (34)
16.3 Overhead Limits (35)
16.4 Channel Depth (36)
16.5 Pier Depth (37)
16.6 Tide Range (38)
16.7 Harbor Size (39)
16.8 Harbor Type (40)

VI. U.S. Army Corps of Engineers (USACE)

18. Navigation Data Center – U.S. Waterways Database

Source: http://www.navigationdatacenter.us/data/datappor.htm

The Principal port file contains USACE port codes, geographic locations (longitude, latitude), names, and commodity tonnage summaries (total tons, domestic, foreign, imports and exports) for Principal USACE Ports.

The ports are politically defined by port limits or USACE projects, excluding non-USACE projects not authorized for publication. The determination for the published Principal Ports is based upon the total tonnage for the port for the particular year; therefore, the top-150 list can vary from year to year.

Candidate indicators found in this database are the following:

17.1 Tonnage (41)
17.2 Domestic (42)
17.3 Foreign (43)
17.4 Imports (44)
17.5 Exports (45)

VII. U.S. Fish and Wildlife Service (USFWS)

19. USFWS - Endangered Species

Source: https://www.fws.gov/endangered/

Threatened or endangered species found by United States are reported for each county. The Endangered Species Act of 1973, as amended, is federal legislation intended to provide a means to conserve the ecosystems upon which endangered and threatened species depend and provide programs for the conservation of those species, thus preventing extinction of plants and animals. The law is administered by the Interior Department Fish and Wildlife Service (FWS) and the Commerce Department NOAA Fisheries, depending on the species.

An endangered species is an animal or plant species in danger of extinction throughout all or a sizable portion of its habitat range.

A threatened species is an animal or plant species likely to become endangered within the foreseeable future throughout all or a significant portion of its habitat range.

Candidate indicator found in this database is the following:

18.1 Number Endangered Species County (46)

20. Number of Critical Habitat Areas

Source: http://ecos.fws.gov/ecp/report/table/critical-habitat.html

Critical habitat for threatened and endangered species: A specific geographic area(s) that contains features essential for the conservation of a threatened or endangered species and that may require special management and protection, which are formally designated by rule published in the Federal Register. For a port, this is measured in the number of Critical Habitat Areas within 50 miles of the port.

Candidate indicator found in this database is the following:

19.1 Number Critical Habitat (47)

VIII. University of South Carolina Hazards and Vulnerability Research Institute

21. The Social Vulnerability Index (SoVI®)

Source: http://artsandsciences.sc.edu/geog/hvri/sovi-data

County-level socioeconomic and demographic data were used to construct an index of social vulnerability to environmental hazards (SoVI) for the United States based on data collected from 2005 to 2009. This hazards-of-place model (Cutter 1996a) combines the biophysical vulnerability (physical characteristics of hazards and environment) and social vulnerability to determine an overall place vulnerability. Social vulnerability is represented as the social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards.

Most of the sources used by the *Hazards research lab*, which created the SoVI, are obtained from the 5-year American community survey estimates compiled by the U.S. Census Bureau.

After obtaining the relevant data, a principal component analysis (PCA)[1] is used to reduce the data into set of components. Slight adjustments are made to the components to ensure that the sign of the component loadings

[1] Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possible correlated variables into a set of values of linearly uncorrelated variables called principal components.

coincide with the individual population characteristic's influence on vulnerability. All components are added together to determine a numerical value that represents the social vulnerability for each county (Cutter et al. 2003)

Candidate indicator found in this database is the following:

20.1 SoVI (48)

Appendix F: Additional Candidate Indicators Suggested by Experts

Table F-1. Expert-suggested candidate indicators of seaport vulnerability to climate and extreme weather impacts.

Indicator	Units	Description	Data Source
SLR changes in Nuisance and Repetitive Flooding	Percent of tax base at risk	Decreasing RE values	NA
Distance to nearest alternative seaport	Nautical or statute miles	Based on cargo received at the primary seaport	Charts
Alternative transportation modes between seaports	Transportation modes for freight (Pipeline, rail, highway)	As paucity of alternative transportation modes increases, so does the criticality and therefore vulnerability of the primary port	USDOT
Robustness of transportation infrastructure	Number of back-up routes	Robustness of port area to a shock to operations	Mapping
Land use	Industrial/mixed use	Low value vs. high value infrastructure	NA
Surface Transportation Vulnerability	NA	Ports are dependent on surface access	Local, perhaps FHWA

Additionally, potential climate and extreme weather vulnerability indicators identified as desirable are presented; these were not included as no parent database was identified (Table F-2).

Table F-2. Climate and extreme weather candidate vulnerability indicators, and their units, for which there was no clear database.

Vulnerability Indicator Description	Units
One percent annual exceedance wind speed for port	Knots
Energy consumption at port	Watts
Water consumption at port	Gallons
Solid waste production at port	Tons
Average age of gantry cranes	Years
Average age of buildings	Years
Average age of berthing infrastructure	Years
Time since last dredged	Months
Port indirect regional employment	Number of jobs
Port direct employment	Number of jobs
Port market share	%
Port insurance actuarial rate	$
Vessel turnaround time	Hours
Wharf productivity	Twenty-foot equivalent unit (TEU) / Foot of berth
Port Container productivity	Moves / hour
Average container lifts per hour	TEU
Annual crane capacity	TEU
Annual TEU/crane	TEU

Average annual TEU / CY slot (turns)	TEU / CY slot
Average drayage wait times	Minutes
Berth occupancy rate (berth utilization - vessel call basis)	%
Total berth feet	Feet
Number of gantry cranes	Number of cranes
Gantry crane max height	Feet
Gantry crane max outreach	Feet
Gantry crane max tonnage capacity	Tons
Presence of direct rail connections	Yes / no
Do port master plans consider resilience?	Yes / no
Do state and local adaptations plans consider resilience?	Yes / no
Does the port have sustainability plan?	Yes / no
Ability to shift operations	Likert scale
Gross acres	Acres
Container yard (CY) acres	Acres
Container yard / gross ratio	%
Average CY slots / acre – density	Slots per acre
Yard area per berth	Area
Number of berths	Number of berths
Number of berths	Number of berths

Appendix G: Summary 48 Vulnerability Indicators

Note: This list presents 48 selected seaport vulnerability indicators to climate and extreme weather with their descriptions, units, data sources, and example values. This compilation represents an updated version of the 2017 data dictionary; to see the earlier version used for the Visual Analogue Scale survey, go to URI – Digital Commons.

Indicator 1 – Air Pollution Days

Description: Number of days with AQI value greater than 100 for the port city, averaged over the past 5 years. The AQI provides information on pollutant concentrations of ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The AQI is data measured by the state and local air monitoring stations network and by other special purpose monitors.

Units: Number of days per year

Example values: Philadelphia, PA: 32 days per year
Albany, NY: 4 days per year

Data source: Environmental Protection Agency
Source: https://www.epa.gov/outdoor-air-quality-data/air-quality-index-report

Indicator 2 – Average Cost of Hazmat Incidents

Description: Average cost per incident of total damage from the 10 most costly hazardous materials incidents in the port city since 2007. Total amount of damages: This figure includes the cost of the material lost, carrier damage, property damage, response costs, and remediation cleanup costs.

Units: $USD

Example values: Port of NY/NJ: $2,877,763 per incident
Baltimore, MD: $5,099,343 per incident

Data source: U.S. DOT Pipeline and Hazardous Materials Safety Administration – Incident Statistics
Source: http://phmsa.dot.gov/hazmat/library/data-stats/incidents

Indicator 3 – Average Cost of Storm Events

Description: Average cost of property damage from storm events in the port county since 1950 with property damage greater than $1 million.

Units: $ millions USD

Example values: Port of Boston, MA (Suffolk County): $5.92 million
Searsport, ME (Waldo County): $7.05 million

Data source: NOAA Storm Events
Source: https://www.ncdc.noaa.gov/stormevents/

Indicator 4 – Maximum Cost of Storm Events

Description: The maximum cost is the value in property damage from the costliest storm event in the port county since 1950. Estimates of the costs of a storm are clear signal of economic loss. Communities can use the cost estimates to leverage investments that are needed to reduce the maximum cost.

Units: $ millions USD

Example values: Port of NY/NJ: $5,000 million due to Coastal Flooding
Bridgeport, CT: $6 million due to Flash Floods

Data source: NOAA Storm Events
Source: https://www.ncdc.noaa.gov/stormevents/

Indicator 5 – Channel Depth

Description: The controlling depth of the principal or deepest channel at chart datum. The channel selected should lead up to the anchorage if within the harbor or to the wharf/pier. If the channel depth decreases from the anchorage to the wharf/pier and cargo can be worked at the anchorage, then the depth leading to the anchorage is taken.

Depth information is generalized into 5-foot (ft) units, with the equivalents in meters, for the main channel, the main anchorage, and the principal cargo pier and/or oil terminal. A depth of 31 ft (9.5 meters [m]) would use letter “K,” a depth of 36 ft (11.0 m) would use “J,” etc. The letter

"K" means a least depth of 31 ft (9.5 m) or greater, but not as great as 36 ft (11.0 m).

Large ports may have sub-ports (smaller) that have their own number and entry in the World Port Index. The controlling depth of the channel should refer to a smaller channel (if present) leading from the main channel into the sub-port facilities and anchorages.

Units: A (over 76 ft) to Q (0 – 5 ft) in 5 ft increments

Example values: Wilmington, DE: M (21 - 25 ft)
Norfolk, VA: H (41 - 45 ft)

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 6 – CMIP Days above Baseline Extremely Hot Temperature

Description: The percent change from observed baseline of the average number of days per year above baseline "Extremely hot" temperature projected for the end-of-century, downscaled to 12 kilometer (km) resolution for the port location. "Extremely hot" day temperature defined as 99th percentile temperature.

Units: Percentage

Example values: Providence, RI: 440% increase
Portland, ME: 220% increase

Data source: U.S. DOT CMIP Climate Data Processing Tool
Source:
https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/modules/index.cfm?moduleid=4#tools

Indicator 7 – CMIP Number of Extremely Heavy Precipitation Events

Description: The percent change from observed baseline of the average number of "Extremely Heavy" precipitation events projected for the end-of-century, downscaled to 12 km resolution for the port location. "Extremely Heavy" precipitation events can be equal or greater than 1.5 inches in 24 hours.

Units: Percentage

Example values: Providence, RI: 122% increase
Portland, ME: 77% increase

Data source: U.S. DOT CMIP Climate Data Processing Tool

Source: https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/modules/index.cfm?moduleid=4#tools

Indicator 8 – Containership Calls

Description: Annual containership calls at the port. Containership is equal to *container ship and passenger/container ships*. Calls are calculated by how many times a vessel arrived at a port, facility or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo, and may include other activities related to vessel, port, or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessarily be engaged in onloading/offloading of cargoes.

Units: Number of calls × vessel DWT

Example values: Hampton Roads, VA: 104,862,259,278 in 2015
Providence, RI: 0 in 2015

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 9 – Containership Capacity

Description: The Containership Capacity is expressed in Twenty-Foot Equivalent Units (TEU) for containerships.

Units: Number of calls × vessel DWT

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 10 – Disaster Housing Assistance

Description: The total disaster housing assistance of Presidential disaster declarations for the port county. FEMA disaster declarations summary is a dataset describing all federally declared disasters. This information begins with the first disaster declaration in 1953 and features all three disaster declaration types: major disaster, emergency, and fire management assistance.

Units: Number of millions of USD

Example values: Providence, RI (Providence County): $9.98 million
Portland, ME (Cumberland County): $0.0

Data source: FEMA – Historical Disaster Housing Assistance
Source: https://www.fema.gov/data-visualization-disaster-housing-assistance

Indicator 11 – Entrance Restrictions

Description: Number of entrance restrictions to the port.

Units: Tide, swell, ice, other, or none

Example values: Port of NY/NJ: 1 (Tide)
Boston, MA: 0 (None)

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 12 – Environmental Sensitivity Index (ESI)

Description: ESI shoreline sensitivity to an oil spill. Using the ranking for the most sensitive shoreline within the port. The ranking scale goes from 1 to 10.

A rank of 1 represents shorelines with the least susceptibility to damage by oiling. Examples include steep, exposed rocky cliffs and banks. The oil cannot penetrate the rock and will be washed off quickly by the waves and tides.

A rank of 10 represents shorelines most likely to be damaged by oiling. Examples include protected, vegetated wetlands, such as mangrove swamps and saltwater marshes. Oil in these areas will remain for an extended period, penetrate deeply into the substrate, and inflict damage to many kinds of plants and animals.

Units: ESI Rank (1.00 - 10.83; the higher the number, the more sensitive the shoreline is to an oil spill)

Example values: Philadelphia, PA: 1.25
Albany, NY: 9.25

Data source: NOAA Office of Response and Restoration
Source: http://response.restoration.noaa.gov/maps-and-spatial-data/shoreline-rankings.html

Indicator 13 – Gas Calls

Description: Number of gas carrier calls at the port. Gas – liquefied petroleum and liquefied natural gas carriers.

Units: Number of gas carrier calls × vessel DWT

Example values: Boston, MA: 284,802 in 2015
Port of NY/NJ: 6,424 in 2015

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 14 – Gas Capacity

Description: Gas Carrier Capacity at the port.

Units: Number of calls × vessel DWT

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 15 – Harbor Size

Description: The classification of harbor size is based on several applicable factors, including area, facilities, and wharf space. It is not based on area alone or on any other single factor.

Units: Large, medium, small, very small

Example values: Port of NY/NJ: Large
Port of Providence, RI: Medium

Data source: NGA
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 16 – Harbor Type

Description: The classification of harbor size is based on several applicable factors, including area, facilities, and wharf space. It is not based on area alone or on any other single factor.

Units: Coastal Natural, Coastal Breakwater, Coastal Tide Gate, River Natural, River Basis, None, River Tide Gate, Lake or Canal, Open Roadstead, Typhoon Harbor.

Example values: Port of NY/NJ: Coastal River
Boston, MA: Coastal Natural

Data source: NGA
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 17 – Hundred-Year High Water

Description: The hundred-year high water results from probabilistic calculations; it represents the 1% annual exceedance probability high water level that corresponds to the level that would be exceeded one time per century, for the nearest NOAA tide station to the port.

Units: Meters above Mean Higher High Water (MHHW)

Example values: Port of Boston, MA: 1.40 m above MHHW
Providence, RI: 2.73 m above MHHW

Data source: NOAA Extreme Water Levels
Source: https://tidesandcurrents.noaa.gov/est/northatlantic.html

Indicator 18 – Hundred Year Low Water

Description: It is explained by 1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century.

Extremely high or low water levels at coastal locations are a public concern and a factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability, the likelihood that water levels will exceed a given elevation, is based on a statistical analysis of historic values.

Units: Meters below Mean Lower Low Water (MLLW)

Example values: Fall River, MA: 0.77 m below MLLW
Penn Manor, PA: 1.72 m below MLLW

Data source: NOAA Extreme Water Levels
Source: https://tidesandcurrents.noaa.gov/est/northatlantic.html

Indicator 19 – Marine Transportation Gross Domestic Product (GDP) County

Description: Gross Domestic Product of marine transportation in the port county.

Marine Transportation: Includes deep-sea freight, marine passenger transportation, pipeline transportation, marine transportation services, search and navigation equipment, and warehousing.

Units: $ millions USD

Example values: Providence, RI (PVD County): $59.8 million in 2013
Searsport, ME (Waldo County): $4.5 million in 2013

Data source: NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW)
Source: https://coast.noaa.gov/dataregistry/search/dataset/C3722030-943C-4BEE-B063-06715F815891

Indicator 20 – Marine Transportation Jobs

Description: Number of marine transportation jobs in the port county

Units: Number of jobs

Example values: Providence, RI (Providence County): 979 jobs in 2013
Searsport, ME (Waldo County): 54 jobs in 2013

Data source: NOAA Office for Coastal Management, and ENOW
Source: https://coast.noaa.gov/enowexplorer/#/employment/total/2013/44007

Indicator 21 – Marine Transportation Wages per County

Description: Average Marine Transportation Wage per employee in port county.

Units: $ USD

Example values: Port of NY/NJ: $1,121,532,498 in 2012
Port Jefferson, NJ: $490,972 in 2012

Data source: NOAA Office for Coastal Management: ENOW
Source: https://coast.noaa.gov/enowexplorer/#/employment/total/2013/44007

Indicator 22 – Miles to Marine Protected Areas (MPA)

Description: Proximity to nearest Marine Protected Area with a protection level including: “No Take,” “No Impact,” or “No Access”.

Units: Miles

Example values: Baltimore, MD: 97 miles
Marcus Hook, NY: 8 miles

Data source: NOAA National MPA Center
Source: https://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/

Indicator 23 – Number of Critical Habitat Areas

Description: Number of critical habitat areas within 50 miles of the port. Critical habitat for threatened and endangered species: A specific geographic area(s) that contains features essential for the conservation of a threatened or endangered species and that may require special management and protection and that have been formally designated by rule published in the federal registry.

Units: Number of areas

Example values: New Castle, DE: 0 areas
Boston, MA: 22 areas

Data source: U.S. Fish and Wildlife Service
Source: http://ecos.fws.gov/ecp/report/table/critical-habitat.html

Indicator 24 – Number of Cyclones

Description: These data are the number of cyclones that have passed within 100 nm of the port since 1842. This data service is for the tiled image of all tropical storms and it is used as an overlay within web maps.

Units: Number of cyclones

Example values: Norfolk, VA: 116 cyclones
Albany, NY: 28 cyclones

Data source: NOAA Historical Tracks Tool
Source: https://coast.noaa.gov/hurricanes/

Indicator 25 – Number of Disasters

Description: The number of disasters refers to the counts of presidential disaster declarations for the port county since 1953. In cases were a port spans multiple county, the port county with highest number of disasters is used.

Units: Number of declarations

Example values:
Providence, RI (Providence County): 18 disaster declarations
Portland, ME (Cumberland County): 33 disaster declarations

Data source: FEMA Historical Disaster Declarations
Source: https://www.fema.gov/data-visualization-disaster-declarations-states-and-counties

Indicator 26 – Number of Endangered Species

Description: Number of threatened or endangered species found in port county, if the port spans multiple counties, use the port county with the highest number.

An endangered species is an animal or plant species in danger of extinction throughout all or a sizable portion of its habitat range. A threatened species is an animal or plant species likely to become endangered within the foreseeable future throughout all or a significant portion of its habitat range.

The Endangered Species Act of 1973, as amended is federal legislation, is intended to provide a means to conserve the ecosystems upon which endangered and threatened species depend, and provide programs for the conservation of those species, thus preventing extinction of plants and animals. The law is administered by the Interior Department FWS and Commerce Department's NOAA Fisheries, depending on the species.

Units: Number of species

Example values: Providence, RI (Providence County): 8 species
Portland, ME (Cumberland County): 11 species

Data source: U.S. Fish and Wildlife Service
Source: https://www.fws.gov/endangered/

Indicator 27 – Number of Hazmat Incidents

Description: Number of Hazardous Materials Incidents in port city since 2007.

Hazardous material means a substance or material that the Secretary of Transportation has determined being capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and has designated as hazardous under section 5103 of federal hazardous materials transportation law (49 U.S.C. 5103). The term includes hazardous substances, hazardous wastes, marine pollutants, elevated temperature materials, as well as materials designated as hazardous in the Hazardous materials table (see 49 CFR 172.101).

Hazardous materials in various forms can cause death, serious injury, long-lasting health effects, and damage to buildings, homes, and other property. Many products containing hazardous chemicals are used and stored in homes routinely. These products are also shipped daily on the nation's highways, railroads, waterways, and pipelines.

Units: Number of incidents

Example values: Philadelphia, PA: 1,981 incidents
Camden, NJ: 154 incidents

Data source: U.S. DOT Pipeline and Hazardous Material Safety Administration
Source: https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/IncrSearch.aspx

Indicator 28 – Number of Storm Events

Description: The number of storm events in a port county is storms from 1950 to 2016 that have a recorded property damage of more than 1 million U.S. dollars. Records on the number of storms are useful to identify areas that are most vulnerable, based on their historical past.

Units: Number of storms

Example values: Port of Boston, MA (Suffolk County): 11 Events
Searsport, ME (Waldo County): 4 Events

Data source: NOAA Storm Events Database
Source: https://www.ncdc.noaa.gov/stormevents/

Indicator 29 – Overhead Limits

Description: Indicates that bridge and overhead power cables exist.

Units: Y=1, N=0

Example values: Port of NY/NJ: 1 (Yes)
Norfolk, VA: 0 (No)

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 30 – Percentage of Bridges Deficient County

Description: Percentage of bridges in the port county that are structurally deficient or functionally obsolete.

Structurally deficient means that the condition of the bridge includes a significant defect, which often means that speed or weight limits must be put on the bridge to ensure safety; a structural evaluation of 4 or lower qualifies a bridge as structurally deficient. The designation can also apply if the approaches flood regularly. *Functionally obsolete* means that the design of a bridge is not suitable for its current use, such as lack of safety shoulders or the inability to handle current traffic volume, speed, size, or weight.

Units: Percentage

Example values: Philadelphia, PA (Philadelphia County): 22.50%
Baltimore, MD (Baltimore-City County): 3.46%

Data source: U.S. DOT Federal Highway Administration, National Bridge Inventory
Source: https://www.fhwa.dot.gov/bridge/nbi/no10/county.cfm

Indicator 31 – Pier Depth

Description: The greatest depth at chart datum alongside the respective wharf/pier. If there is more than one wharf/pier, then the one that has greatest usable depth:

Units: A (over 76 ft) to Q (0 – 5 ft) in 5 ft increments

Example values: Baltimore, MD: G (46 - 51 ft)
Paulsboro, NJ: K (31 - 35 ft)

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode

See indicator 5 – Channel depth

Indicator 32 – Population Change County

Description: Rate of population change for a port county, expressed as percent change for a period (2000-2010).

Units: Percentage

Example values:
Baltimore, MD (Baltimore-City County): -4.64% decrease
Gloucester, NJ (Gloucester County): +13.20% increase

Data source: NOAA Office for Coastal Management
Source: https://coast.noaa.gov/digitalcoast/tools/qrt.html

Indicator 33 – Population inside Floodplain

Description: Percentage of the port county population living inside the FEMA floodplain.

The more homes and people located in a floodplain, the greater the potential for harm from flooding. Impacts are likely to be even greater when additional risk factors (age, income, capabilities) are involved, since people at greatest flood risk may have difficulty evacuating or taking action to reduce potential damage.

Units: Percentage

Example values: Wilmington, DE (New Castle County): 8%
Norfolk, VA (Norfolk County): 18%

Data source: NOAA Office for Coastal Management
Source: http://www.census.gov/programs-surveys/acs/data/summary-file.2013.html

Indicator 34 – Population over 65 Years Old

Description: Percentage of population over age 65 in the port county. Present results are based on 2009-2013 American Community Survey 5-year file summary data.

The more homes and people located in a floodplain, the greater the potential for harm from flooding. Impacts are likely to be even greater when additional risk factors (age, income, capabilities) are involved, since people at greatest flood risk may have difficulty evacuating or taking action to reduce potential damage.

Units: Percentage

Example Values: Baltimore, MD (Baltimore-City County): 4% in 2010
Portsmouth, ME (Portsmouth County: 14% in 2010

Data source: NOAA Office for Coastal Management
Source: http://www.census.gov/programs-surveys/acs/data/summary-file.2013.html

Indicator 35 – Population Poverty County

Description: Percentage of population in the port county living below poverty thresholds. Also based on 2009-2013 American Community Survey 5-year file summary data.

Units: Percentage

Example Values: Hampton Roads, VA: 13% in 2010
Philadelphia, PA: 1% in 2010

Data source: NOAA Office for Coastal Management
Source: http://www.census.gov/programs-surveys/acs/data/summary-file.2013.html

Indicator 36 – Sea Level Trend

Description: Relative sea level trends reflect changes in local sea level over time and are typically the most critical sea level trend for many coastal applications, including coastal mapping, marine boundary delineation, coastal zone management, coastal engineering, sustainable habitat restoration design, and the general public enjoying their favorite beach.

Units: Millimeters per year (mm/yr)

Example Values: Norfolk, VA: 4.6 mm/yr
Portland, ME: 1.9 mm/yr

Data source: NOAA Tides and Current – Sea Level Trend
Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

Indicator 37 – Shelter Afforded

Description: The shelter afforded from wind, sea, and swell refers to the area where normal port operations are conducted, usually the wharf area. Shelter afforded the anchorage area is given for ports where lighters handle the cargo.

Units: Excellent (5), good (4), fair (3), poor (2), none (1)

Example Values: New Haven, CT: Good (4)
Boston, MA: Excellent (5)

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 38 – SoVI Social Vulnerability Score

Description: Port County Social Vulnerability (SoVI) Score

Units: The SoVI is classified using standard deviations. Social vulnerability scores that are greater than 2 standard deviations above the mean are considered the most socially vulnerable, and scores below 2 standard deviations less than the mean are the least vulnerable.

Example Values:
Philadelphia, PA (Philadelphia County): 3.418284 (High)
Norfolk, VA (Norfolk County): -0.207217 (Medium)

Data source: University of South Carolina Hazards and Vulnerability Research Institute
Source: http://artsandsciences.sc.edu/geog/hvri/sovi-data

Also available at CDC: https://svi.cdc.gov/

And connected to: https://toolkit.climate.gov/tool/social-vulnerability-index

Social Vulnerability

The hazards-of-place model (Cutter 1996a) combines the biophysical vulnerability (physical characteristics of hazards and environment) and social vulnerability to determine an overall place vulnerability. *Social* *vulnerability* is the social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards.

Indicator 39 – Tanker Calls

Description: Number of tanker calls at the port. Numbers are based on annual data from 2001 – 2015.

Units: Number of tanker calls × vessel DWT

Example values: Albany, NY: 21,437,035 in 2015
Fall River, MA: 0 in 2015

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 40 – Tanker Capacity

Description: Annual tanker capacity at the port. Tankers – CO2, chemical, chemical/oil, wine, vegetable oil, edible oil, beer, latex, crude oil, oil products, bitumen, coal/oil, water, fruit juice, molasses, glue, alcohol, and caprolacatam.

Units: Number of tanker calls × vessel DWT

Example values: Philadelphia, PA: 59,323,793 calls × DWT 2012
Albany, NY: 147,445 calls × DWT 2012

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 41 – Tide Range

Description: The mean tidal range at the port. The mean tide range in meters is normally given for all U.S. ports and ports under the U.S. jurisdiction; the mean rise is substituted if range data are not available. The distinction between range and rise can be disregarded without affecting the general utility of this publication.

Units: Feet

Example Values: Baltimore, MD: 1 ft
Paulsboro, NJ: 6 ft

Data source: The National Geospatial-Intelligence Agency (NGA)
Source:
http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

Indicator 42 – Tonnage (Cargo)

Description: The tonnage is measured by the total annual throughput at the port.

The Principal Port file contains USACE port codes, geographic locations (longitude, latitude), names, and commodity tonnage summaries (total tons, domestic, foreign, imports and exports) for principal USACE ports.

Units: Short tons

Example values: Port of NY/NJ: 126,690,317 tons in 2015
Providence, RI: 8,043,051 tons in 2015

Data source: USACE Navigation Data Center - Principal Ports of the United States
Source: http://www.navigationdatacenter.us/data/datappor.htm

Indicator 43 – Imports

Description: Foreign imports measured by total annual throughput at the port. Names, and commodity tonnage annual throughput (total tons, domestic, foreign exports for principal USACE ports.

Units: Short tons

Example values: Bridgeport, CT: 82,673 short tons in 2013
Philadelphia, PA: 36,280,824 short tons in 2013

Data source: USACE Navigation Data Center - Principal Ports of the United States
Source: http://www.navigationdatacenter.us/data/datappor.htm

Indicator 44 – Exports

Description: Foreign exports measured by total annual throughput at the port.

Units: Short tons

Example values: Boston, MA: 888,169 short tons in 2013
Hampton Roads, VA: 61,673,749 short tons in 2013

Data source: USACE Navigation Data Center - Principal Ports of the United States
Source: http://www.navigationdatacenter.us/data/datappor.htm

Indicator 45 – Domestic

Description: Summary of the domestic total annual throughput at the port.

Units: Short tons

Example values: Portland, ME: 930,185 short tons in 2013
Port of NY/NJ: 46, 716,414 short tons in 2013

Data source: USACE Navigation Data Center - Principal Ports of the United States
Source: http://www.navigationdatacenter.us/data/datappor.htm

Indicator 46 – Foreign

Description: Foreign throughput is the total annual throughput of each commodity at the port.

Units: Short tons

Example values: Wilmington, DE: 4,553,381 short tons in 2013
Norfolk, VA: 42,339,524 short tons in 2013

Data source: USACE Navigation Data Center - Principal Ports of the United States
Source: http://www.navigationdatacenter.us/data/datappor.htm

Indicator 47 – Vessel Calls

Description: Annual vessel calls at the port. Data are available from 2002-2016. Vessel call calculation contains calls for privately-owned, oceangoing merchant vessels of all flags of registries over 1,000 gross tons (GT) calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam and Puerto Rico.

Units: Number of calls

Example values: Albany, NY: 223,943,760 in 2015
Fall River, MA: 14,707,900 in 2015

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Indicator 48 – Vessel Capacity

Description: Annual vessel calls at the port times the vessel's DWT.

Units: Number of vessel calls × vessel DWT

Example values: Port of NY/NJ: 198,869,452 calls × DWT in 2012
Providence, RI: 6,488, 451 calls × DWT in 2012

Data source: U.S. DOT Maritime Administration
Source: https://www.marad.dot.gov/resources/data-statistics/

Appendix H: Climate and Extreme Weather Vulnerability Indicators Identified by Web and Literature Search

Table H-1. Initial list of 108 potential vulnerability indicators sorted by categories and subcategories. Coded on the right columns in function of the data availability to compare the 22 seaports in the study: (I) Sufficient Data: included in *Mind map*, (J) Selected via *Mind map*: included in VAS survey, and (K) Selected via VAS survey: included in Analytic hierarchy process (AHP) (see **URI - Digital Commons**).

Category	Sub-Category	Sub-Sub-Category	No.	Description	Indicator	Units	Data Source	Sufficient Data: Included in Mind Map	Selected via Mind Map: Included in VA S Survey	Selected via VA S Survey: Included in AHP
Exposure	Storm Hazard	Storm Frequency	1	Number of storm events in port county w/ property damage > $1M	NumberStormEvents	events	NOAA Storm Events Database	yes	yes	yes
		Storm Damage	2	Cost of property damage from the most costly storm event in the port county since 1950	MaxCostStormEvents	$	NOAA Storm Events Database	yes	no	no
		Wind Hazard	3	Non-convective high winds	NA	kts	NOAA Storm Events Database	no	no	no
			4	1% annual exceedance wind speed	NA	kts	NA	no	no	no
		Storm Surge Hazard	5	Max historical storm surge	NA	meters	SurgeDAT	no	no	no
			6	Highest historical water level	NA	m above MHHW	Top Ten Highest Water Levels for long-term stations	no	no	no
			7	1% annual exceedance probability high water level which corresponds to the level that would be exceeded one time per century, for the nearest NOAA tide station to the port	HundredYearHighWater	m above MHHW	NOAA Tides and Currents: Extreme Water Levels	yes	yes	yes
		Tropical Cyclone Frequency	8	Number of cyclones that have passed within 100 nm of the port since 1842	NumberCyclones	Number of cyclones	NOAA Historical Hurricane Tracks Tool	yes	yes	yes
			9	Tropical cyclone return period	NA	years	National Hurricane Center	no	no	no
	Sea Level Rise Hazard	Empirical SLR	10	Local Mean Sea Level Trend	SeaLevelTrend	mm / yr	NOAA Tides and Currents: Sea Level Trends	yes	yes	yes
		Projected SLR	11	Local SLR Projections	NA	mm / yr	Global Sea Level Rise Scenarios for the United States: National Climate Assesment	no	no	no
		Rate of vertical land motion due to Glacial Isostatic Adjustment (GIA)	12	annual uplift/subsidence rate	NA	mm / yr	Permanent Service for Mean Sea Level (PSMSL) Peltier GIA data sets	no	no	no
		Sea Temperature Anomaly	13	Average Annual Sea Surface Temp Anomaly	NA	°F	NOAA National Centers For Environmental Information NCDC	no	no	no
	Temperature Hazard	Projected Temperature	14	The percent change from observed baseline of the average number of days per year above baseline "Extremely Hot" temperature projected for the end-of-century, downscaled to 12km resolution for the port location	CMIP_DaysAboveBaselineExtremelyHotTemperature	%	US DOT CMIP Climate Data Processing Tool	yes	yes	no
	Precipitation Hazard	Projected Precipitation	15	The percent change from observed baseline of the average number of "Extremely Heavy" Precipitation Events projected for the end-of-century, downscaled to 12km resolution for the port location	CMIP_NumberOfExtremelyHeavyPrecipEvents	%	US DOT CMIP Climate Data Processing Tool	yes	yes	yes
	Disasters	Disaster Frequency	16	Number of Presidential Disaster Declarations for the port county since 1953	NumberDisastersCounty	Disaster Type	FEMA, Historical Disaster Declarations	yes	yes	yes
		Disaster Intensity	17	The total disaster housing assistance of Presidential Disaster Declarations for the port county since 1953	DisasterHousingAssistanceCounty	Declarations	FEMA, Historical Disaster Declarations	yes	yes	no
Sensitivity	Environmental Sensitivity	Surrounding Environment	18	Nearby Federally/State Managed Water	NA	Acres	NOAA National Estuarie Research Reserve System	no	no	no
			19	Number of Threatened or Endangered Species found in port county	NumberEndangeredSpeciesCounty	Species	U.S. Fish & Wildlife Service: Endangered Species	yes	yes	no
			20	Nearby Wildlife Refugees	NA	Acres	U.S. Fish and Wildlife Refugees	no	no	no
			21	Number of Critical Habitat Areas within 50 miles of the port	NumberCriticalHabitat	Areas	U.S. Fish & Wildlife Service: Critical Habitat Portal	yes	yes	yes
			22	Proximity to nearest MPA with a Protection level including "No Take," "No Impact," or "No Access"	MilesToMPA	Miles	NOAA National MPA Center	yes	no	no
			23	Environmental Sensitivity Index (ESI) shoreline sensitivity to an oil spill for the most sensitive shoreline within the port	ESI	ESI Rank (1.00 - 10.83)	NOAA Office of Response and Restoration: Shoreline Rankings	yes	yes	yes
		Air Quality	24	Number of Days with Air Quality Index value greater than 100 for the port city	AirPollutionDays	Days	EPA Air Quality Report	yes	yes	no
		Port Consumption	25	Energy Consumption	NA	Watts	NA	no	no	no
			26	Water Consumption	NA	Gallons	NA	no	no	no
			27	Solid Waste Production	NA	Tons	NA	no	no	no
		Hazmat	28	EPA Brownfields near port	NA	Number of sites	EPA Cleanups in My Community	no	no	no
			29	Number of Hazardous Materials Incidents in port city since 2007	NumberHazmatIncidents	Number of Incidents	U.S. DOT Pipeline and Hazardous Materials Safety Administration: Incident Statistics	yes	yes	no
			30	Average cost per incident of total damage from the 10 most costly Hazardous Materials Incidents in the port city since 2007	AvgCostHazmatIncidents	$	U.S. DOT Pipeline and Hazardous Materials Safety Administration: Incident Statistics	yes	yes	no

Category	Sub-Category	Sub-Sub-Category	No.	Description	Indicator	Units	Data Source	Sufficient Data: Included in Mind Map	Selected via Mind Map: Included in VA S Survey	Selected via VA S Survey: Included in AHP
Sensitivity	Built Asset Sensitivity	Land-Side Built Asset Sensitivity	31	Average age of gantry cranes	NA	years	NA	no	no	no
			32	Average age of buildings	NA	years	NA	no	no	no
			33	Average age of berthing infrastructure	NA	years	NA	no	no	no
			34	Average cost of property damage from storm events in the port county since 1950 with property damage > $1 Million	AvgCostStormEvents	$	NOAA Storm Events Database	yes	yes	yes
			35	Percent of bridges in the port county that are structurally deficient or functionally obsolete	PercentDeficientBridgesCounty	%	US DOT FHA National Bridge Inventory: Deficient Bridges by County	yes	yes	no
		Water-Side Built Asset Sensitivity	36	Shelter Afforded	Shelter	Excellent (5), Good (4), Fair (3), Poor (2), None (1)	World Port Index (Pub 150)	yes	yes	no
			37	Presence or absence of entrance restrictions	EntranceRestrictions	Tide, Swell, Ice, Other	World Port Index (Pub 150)	yes	yes	no
			38	Presence or absence of overhead limitations	OverheadLimits	Y/N	World Port Index (Pub 150)	yes	yes	no
			39	The controlling depth of the principal or deepest channel at chart datum	ChannelDepth	A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments	World Port Index (Pub 150)	yes	yes	no
			40	The greatest depth at chart datum alongside the respective wharf/pier. If there is more than one wharf/pier, then the one which has greatest usable depth is shown.	PierDepth	A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments	World Port Index (Pub 150)	yes	yes	no
			41	Mean tide range at the port	TideRange	feet	World Port Index (Pub 150)	yes	yes	no
			42	1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century	HundredYearLowWater	m below MLLW	NOAA Extreme Water Levels	yes	yes	no
			43	Type of Harbor	HarborType	Coastal Natural, Coastal Breakwater, Coastal Tide Gate, River Natural, River Basis, None, River Tide Gate, Lake or Canal, Open Roadstead, Typhoon Harbor	World Port Index (Pub 150)	yes	no	no
			44	Time since last dredged	NA	months	NA	no	no	no
	Economic Sensitivity	Regional Economic Sensitivity	45	Number of Marine Transportation Jobs in the port county	MTJobsCounty	number of jobs	NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW)	yes	yes	no
			46	Average Marine Transportation Wage per employee in port county	MTWagesCounty	$	NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW)	yes	no	no
			47	County Marine Transportation GDP	MTGDPCounty	$	NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW)	yes	yes	no
		Port Economic Sensitivity	48	Port Indirect Regional Employment	NA	number of jobs	NA	no	no	no
			49	Port Direct Employment	NA	number of jobs	NA	no	no	no
			50	Port Market Share	NA	%	NA	no	no	no
			51	Port Insurance Acutarial Rate	NA	$	NA	no	no	no
	Social Sensitivity	Surrounding Population's Sensitivity	52	Rate of population change (from 2000-2010) in the port county, expressed as a percent change	PopulationChangeCounty	%	NOAA Office for Coastal Management: Quick Report Tool for Socioeconomic Data	yes	yes	yes
			53	Percent of the port county population over age 65	PopulationOver65	%	NOAA Coastal County Snaphots	yes	no	no
			54	Percent of the port county population living below poverty thresholds	PopulationPovertyCounty	%	NOAA Coastal County Snaphots	yes	no	no
			55	Percent of the port county population living inside the FEMA Floodplain	PopulationInsideFloodplain	%	NOAA Coastal County Snaphots	yes	yes	yes
			56	Port County Social Vulnerability (SoVI) Score	SoVI	score number	SoVI® Social Vulnerability Index	yes	yes	yes
		Surrounding Structures / Asset Sensitivity	57	National Flood Insurance Program Community Rating System Score	NA	score number	FEMA National Flood Insurance Program Community Rating System: Communities and Their Classes	no	no	no

Category	Sub-Category	Sub-Sub-Category	No.	Description	Indicator	Units	Data Source	Sufficient Data: Included in Mind Map	Selected via Mind Map: Included in VAS Survey	Selected via VAS Survey: Included in AHP
Adaptive Capacity	Operational Efficiency	Port Opperational Efficiency	58	Vessel turnaround time	NA	hours	NA	no	no	no
			59	Wharf productivity	NA	TEU / Foot of Berth	NA	no	no	no
			60	Port Container Productivity	NA	moves / hour	NA	no	no	no
			61	average container lifts per hour	NA	TEU	NA	no	no	no
			62	annual Crane Capacity	NA	TEU	NA	no	no	no
			63	annual TEU/Crane	NA	TEU	NA	no	no	no
			64	Avg annual TEU / CY Slot (Turns)	NA	TEU / CY slot	NA	no	no	no
			65	average drayage wait times	NA	minutes	NA	no	no	no
			66	Berth occupancy rate (Berth Utilization - Vessel Call Basis)	NA	%	NA	no	no	no
		Efficiency of Transport Connections	67	annual Truck Congestion Cost	NA	$ millions	Texas A&M University Texas Transportation Institute Urban Mobility Information, Congestion Data for Your City	no	no	no
			68	Roadway Congestion Index	NA	unitless	Texas A&M University Texas Transportation Institute Urban Mobility Information, Congestion Data for Your City	no	no	no
			69	Travel Time Index	NA	unitless	Texas A&M University Texas Transportation Institute Urban Mobility Information, Congestion Data for Your City	no	no	no
	Water-Side Capacity	Vessels	70	Number of Annual Vessel Calls (vessels > 1k DWT) at the port	VesselCalls	ship calls	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	no	no
			71	Harbor Size	Harbor Size	Large, Medium, Small, Very-Small	World Port Index (Pub 150)	yes	yes	no
			72	Vessel Capacity (vessels > 10k DWT)	VesselCapacity	calls x DWT	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	yes	no
			73	Tanker Calls	TankerCalls	ship calls	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	no	no
			74	Tanker Capacity	TankerCapacity	calls x DWT	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	yes	no
			75	Gas Carrier Calls	GasCalls	ship calls	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	no	no
			76	Gas Carrier Capacity	GasCapacity	calls x DWT	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	yes	no
			77	Container Vessel Calls	ConatinerCalls	ship calls	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	no	no
			78	Container Vessel Capacity	ContainerCapacity	calls x DWT	U.S. DOT Maritime Administration, Vessel Calls at U.S. Ports by Vessel Type	yes	yes	no
			79	Cruise-Ship Calls	NA	ship calls	North American Cruise Traffic 2013-2014	no	no	no
			80	Cruise-Ship Passengers	NA	passengers	North American Cruise Traffic 2013-2015	no	no	no
		Cargo	81	Total Throughput	Tonnage	Tons	USACE Navigation Data Center (ports)	yes	yes	no
			82	Containerized Throughput	NA	TEU	Western Hemisphere Port TEU Container Volumes 1980-2013	no	no	no
			83	Domestic Throughput	Domestic	Tons	USACE Navigation Data Center: Principal Ports of the U.S.	yes	no	no
			84	Foreign Throughput	Foreign	Tons	USACE Navigation Data Center: Principal Ports of the U.S.	yes	no	no
			85	Foreign Imports	Imports	Tons	USACE Navigation Data Center: Principal Ports of the U.S.	yes	no	no
			86	Foreign Exports	Exports	Tons	USACE Navigation Data Center: Principal Ports of the U.S.	yes	no	no
			87	Top Foreign Import By Value	NA	6 digit HS code	USA Trade Online: HS Port-level Data	no	no	no
			88	Top Foreign Import By Weight	NA	6 digit HS code	USA Trade Online: HS Port-level Data	no	no	no
			89	Top Foreign Export By Value	NA	6 digit HS code	USA Trade Online: HS Port-level Data	no	no	no
			90	Top Foreign Export By Weight	NA	6 digit HS code	USA Trade Online: HS Port-level Data	no	no	no

Category	Sub-Category	Sub-Sub-Category	No.	Description	Indicator	Units	Data Source	Sufficient Data: Included in Mind Map	Selected via Mind Map: Included in VAS Survey	Selected via VAS Survey: Included in AHP
Adaptive Capacity	Land-Side Capacity	Flexibility	91	Ability to Shift Operations	NA	Likert scale	NA	no	no	no
			92	Gross Acres	NA	acres	NA	no	no	no
			93	Container Yard Acres	NA	acres	NA	no	no	no
			94	Container Yard / Gross Ratio	NA	%	NA	no	no	no
			95	Avg CY Slots / Acre - Density	NA	slots per acre	NA	no	no	no
			96	Yard area per berth	NA	area	NA	no	no	no
			97	Number of Berths	NA	Number of berths	NA	no	no	no
			98	Total Berth Feet	NA	feet	NA	no	no	no
			99	Number of Gantry Cranes	NA	Number of cranes	NA	no	no	no
			100	Gantry crane max height	NA	feet	NA	no	no	no
			101	Gantry crane max outreach	NA	feet	NA	no	no	no
			102	Gantry crane max tonnage capacity	NA	Tons	NA	no	no	no
			103	Presence of direct Rail Connections	NA	yes / no	NA	no	no	no
		Port Planning	104	Do port Master Plans consider resilience?	NA	yes / no	NA	no	no	no
			105	Do State and Local Adaptations Plans consider resilience?	NA	yes / no	NA	no	no	no
			106	Does the port have sustainability plan?	NA	yes / no	NA	no	no	no
		Port Growth	107	annual % change in throughput	NA	%	USACE Navigation Data Center: Principal Ports of the U.S.	no	no	no
			108	annual % change in Port Market Share	NA	%	NA	no	no	no

Appendix I: Visual Analogue Scale Selection Online Survey Instrument

Adapted from online version hosted via www.surveygizmo.com, internally tested December 2016 and January 2017, and open to invited experts from 25 January to 23 February 2017.

Indicating Seaport Vulnerabilities to Climate and Extreme Weather Impacts

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Informed Consent

Electronic Consent: Please select a choice below. Clicking on the "Agree" button indicates that

You have read the above information

You voluntarily agree to participate

*

( ) Agree - Enter Survey

( ) Disagree - Exit

Affiliation

Please select the category that best describes your professional affiliation:

(.) Consultant

( ) Academic

( ) (Port / Marine Transportation System) Practitioner

( ) Federal Government

( ) State Government

( ) Non-governmental Organization

( ) Other - Please Specify:

Instructions

Please consider whether this candidate indicator, (Measurable, observable quantity that serves as a proxy for an aspect of a system that cannot itself be directly, adequately measured [page("title")]), could be correlated (The condition of being interdependent; a mutual relation of two or more things such that a change in the value of one is associated with a change in the value or the expectation of the others) with one or more of the three components of climate vulnerability (The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its adaptive capacity):

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected

Example: a port on the U.S. East coast has a *higher exposure* to hurricanes than a port on the U.S. West Coast; independent of the ports' *sensitivity* to damage

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli

Example: a port with a storm surge barrier may be *less sensitive* to storm driven flooding impacts than a similar port without a storm surge barrier; independent of the ports' *exposure*

and/or the

Adaptive Capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences

Example: a port with a robust master plan that considers climate resilience and has a high degree of operational flexibility may have a *higher adaptive capacity* than a port with minimal planning and low redundancy; independent of the ports' *exposure* and *sensitivity* of a port, including the port's surrounding socioeconomic and environmental systems.

For each component of vulnerability: If you feel no correlation exists with [page ("title")], click the slider, leaving it in the center (0) position.

If you feel the component may be correlated with [page("title")], then drag each slider-To the Right if the correlation is Positive (i.e., an increase in one correlates to an increase in the other)

-To the Left if the correlation is Negative (i.e., an increase in one correlates to a decrease in the other)

-In the Center if you feel there is No Correlation to indicate your opinion of the magnitude and direction of the correlation Positive Correlation: An increase in one correlates to an increase in the other

Negative Correlation: an increase in one correlates to a *decrease* in the other

Study Area

Harbor Size

Shortname / Alias: Harbor Size

1)

Indicator	**Harbor Size**
Units	Large, Medium, Small, Very Small
Description	The classification of harbor size is based on several applicable factors, including: area, facilities, and wharf space. It is not based on area alone or on any other single factor.
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries).
Example Values	**Port of NY/NJ**: Large **Port of Providence, RI**: Medium

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Number of Storm Events

Shortname / Alias: Number of Storm Events

2)

Indicator	**Number of Storm Events**
Units	Number of Events

Description	Number of storm events in the port county since 1950 that resulted in property damage > $1 Million
Data Source	The NOAA Storm Events Database is an official publication of the National Oceanic and Atmospheric Administration (NOAA) which documents the occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce. National Centers for Environmental Information (NCEI) Storm Events Database contains the records used to create the official NOAA Storm Data publication, documenting: a. The occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce; b. Rare, unusual, weather phenomena that generate media attention, such as snow flurries in South Florida or the San Diego coastal area; and c. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event. NCEI receives Storm Data from the National Weather Service.
Example Values	**Port of Boston, MA** (Suffolk County): 11 Events **Searsport, ME** (Waldo County): 4 Events

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Average Cost of Storm Events

Shortname / Alias: Average Cost of Storm Events

3)

Indicator	**Average Cost of Storm Events**
Units	$ Millions USD
Description	Average cost of property damage from storm events in the port county since 1950 with property damage > $1 Million
Data Source	The NOAA Storm Events Database is an official publication of the National Oceanic and Atmospheric Administration (NOAA) which documents the occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce. National Centers for Environmental Information (NCEI) Storm Events Database contains the records used to create the official NOAA Storm Data publication, documenting: a. The occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce; b. Rare, unusual, weather phenomena that generate media attention, such as snow flurries in South Florida or the San Diego coastal area; and c. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event. NCEI receives Storm Data from the National Weather Service.
Example Values	**Port of Boston, MA** (Suffolk County): $5.92 Million **Searsport, ME** (Waldo County): $7.05 Million

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Hundred Year High Water

Shortname / Alias: Hundred Year High Water

4)

Indicator	**Hundred Year High Water**
Units	Meters above mean higher high water (MHHW)
Description	1% annual exceedance probability high water level which corresponds to the level that would be exceeded one time per century, for the nearest NOAA tide station to the port
Data Source	NOAA Extreme Water Levels Extremely high or low water levels at coastal locations are an important public concern and a factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability, the likelihood that water levels will exceed a given elevation, is based on a statistical analysis of historic values. The Extreme Water Levels product provides web-based access to Exceedance Probability Statistics at approximately 110 NOAA Center for Operational Oceanographic Products and Services (CO-OPS) water level stations with at least 30 years of water level observations.
Example Values	**Port of Boston, MA**: 1.40 meters above MHHW **Providence, RI**: 2.73 meters above MHHW

Exposure	-100	________________________[__]______________________________	100
Sensitivity	-100	________________________[__]______________________________	100
Adaptive Capacity	-100	________________________[__]______________________________	100

Comments (Please also explain any extreme views):

Hundred Year Low Water

Shortname / Alias: Hundred Year Low Water

5)

Indicator	**Hundred Year Low Water**
Units	Meters below Mean Lower Low Water (MLLW)
Description	1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century.
Data Source	NOAA Extreme Water Levels Extremely high or low water levels at coastal locations are an important public concern and a factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability, the likelihood that water levels will exceed a given elevation, is based on a statistical analysis of historic values. The Extreme Water Levels product provides web-based access to Exceedance Probability Statistics at approximately 110 NOAA Center for Operational Oceanographic Products and Services (CO-OPS) water level stations with at least 30 years of water level observations.
Example Values	**Fall River, MA**: 0.77 meters below MLLW **Penn Manor, PA**: 1.72 meters below MLLW

Exposure	-100	______________________	[__] ____________________________	100
Sensitivity	-100	______________________	[__] ____________________________	100
Adaptive Capacity	-100	______________________	[__] ____________________________	100

Comments (Please also explain any extreme views):

Number of Cyclones

Shortname / Alias: Number of Cyclones

6)

Indicator	**Number of Cyclones**
Units	Number of cyclones

Description	Number of cyclones that have passed within 100 (nm) of the port since 1842.
Data Source	NOAA Historical Hurricane Tracks Tool Storm track information is available from 1842 through the previous year's storms. The storm track data are from the NOAA National Climatic Data Center's International Best Track Archive for Climate Stewardship (IBTrACS) data set and the NOAA National Weather Service HURDAT2 data set.
Example Values	**Norfolk, VA**: 116 cyclones **Albany, NY**: 28 cyclones

Exposure	-100	____________________[__]________________________	100
Sensitivity	-100	____________________[__]________________________	100
Adaptive Capacity	-100	____________________[__]________________________	100

Comments (Please also explain any extreme views):

Sea Level Trend

Shortname / Alias: Sea Level Trend

7)

Indicator	**Sea Level Trend**
Units	millimeters per year (mm/yr)
Description	Local Mean Sea Level Trend
Data Source	NOAA Tides and Currents- Sea Level Trends The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 142 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency phenomena in order to compute an accurate linear sea level trend.

	Tide stations measure **Local Sea Level**, which refers to the height of the water as measured along the coast relative to a specific point on land. Water level measurements at tide stations are referenced to stable vertical points (or bench marks) on the land and a known relationship is established. However, **the measurements at any given tide station include both global sea level rise and vertical land motion**, such as subsidence, glacial rebound, or large-scale tectonic motion. Because the heights of both the land and the water are changing, the land-water interface can vary spatially and temporally and must be defined over time. Depending on the rates of vertical land motion relative to changes in sea level, observed local sea level trends may differ greatly from the average rate of global sea level rise, and vary widely from one location to the next. Relative Sea Level Trends reflect changes in local sea level over time and are typically the most critical sea level trend for many coastal applications, including coastal mapping, marine boundary delineation, coastal zone management, coastal engineering, sustainable habitat restoration design, and the general public enjoying their favorite beach. This website focuses on relative sea level trends, computed from monthly averages of hourly water levels observed at specific tide stations, called monthly mean sea level.
Example Values	**Norfolk, VA**: 4.6 mm/yr **Portland, ME**: 1.9 mm/yr

Exposure	-100	______________________[__]____________________________	100
Sensitivity	-100	______________________[__]____________________________	100
Adaptive Capacity	-100	______________________[__]____________________________	100

Comments (Please also explain any extreme views):

Number of Disasters

Shortname / Alias: Number of Disasters

8)

Indicator	**Number of Disasters**
Units	Number of Disaster Declarations
Description	Number of Presidential Disaster Declarations for the port county since 1953
Data Source	FEMA Historical Disaster Declarations FEMA Disaster Declarations Summary is a summarized dataset describing all federally declared disasters. This information begins with the first disaster declaration in 1953 and features all three disaster declaration types: major disaster, emergency and fire management assistance.
Example Values	**Providence, RI** (Providence County): 18 disaster declarations **Portland, ME** (Cumberland County): 33 disaster declarations

Exposure	-100	______________________[__]___________________________		100
Sensitivity	-100	______________________[__]___________________________		100
Adaptive Capacity	-100	______________________[__]___________________________		100

Comments (Please also explain any extreme views):

Disaster Housing Assistance

Shortname / Alias: Disaster Housing Assistance

9)

Indicator	**Disaster Housing Assistance**
Units	$ Millions of USD
Description	The total disaster housing assistance of Presidential Disaster Declarations in the port county since 1953
Data Source	FEMA Historical Disaster Declarations FEMA Disaster Declarations Summary is a summarized dataset describing all federally declared disasters. This information

	begins with the first disaster declaration in 1953 and features all three disaster declaration types: major disaster, emergency and fire management assistance. Disaster housing assistance funds are available through FEMA's Individual and Household Program.
Example Values	**Providence, RI** (Providence County): $9.98 Million **Portland, ME** (Cumberland County): $0.0

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Projected Change in Days Above Baseline Extremely Hot Temperature

Shortname / Alias: Projected Change in Days Above Baseline Extremely Hot Temperature

10)

Indicator	**Projected Change in Days Above Baseline Extremely Hot Temperature**
Units	%
Description	The **percent change** from observed baseline of the **average number of days per year above baseline "Extremely Hot" temperature** projected for the end-of-century, downscaled to 12km resolution for the port location. "**Extremely Hot**" Day Temperature defined as 99th Percentile Temp
Data Source	US DOT CMIP Climate Data Processing Tool The purpose of the U.S. DOT CMIP Climate Data Processing Tool is to process readily available downscaled climate data at the local level into relevant statistics for transportation planners.

	This tool works with data from the U.S. Bureau of Reclamation's Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (DCHP) website, available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. This website houses climate model data from phase 3 (CMIP3) and phase 5 (CMIP5) of the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP). The Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool, developed by the U.S. Department of Transportation, will process raw climate model outputs from the World Climate Research Programme's CMIP3 and CMIP5 into relevant statistics for transportation planners. These statistics include changes in the frequency of very hot days and extreme precipitation events and other climate characteristics that may affect transportation infrastructure and services by the middle and end of the century.
Example Values	**Providence, RI**: 440 % increase **Portland, ME**: 220 % increase

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Projected Change in Number of Extremely Heavy Precipitation Events

Shortname / Alias: Projected Change in Number of Extremely Heavy Precipitation Events

11)

Indicator	**Projected Change in Number of Extremely Heavy Precipitation Events**
Units	%

Description	The **percent change** from observed baseline of the **average number of "Extremely Heavy" Precipitation Events** projected for the end-of-century, downscaled to 12km resolution for the port location. **"Extremely Heavy" Precipitation Events** >= (1.5 inches in 24 hrs)
Data Source	US DOT CMIP Climate Data Processing Tool The purpose of the U.S. DOT CMIP Climate Data Processing Tool is to process readily available downscaled climate data at the local level into relevant statistics for transportation planners. This tool works with data from the U.S. Bureau of Reclamation's Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (DCHP) website, available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. This website houses climate model data from phase 3 (CMIP3) and phase 5 (CMIP5) of the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP). The Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool, developed by the U.S. Department of Transportation, will process raw climate model outputs from the World Climate Research Programme's CMIP3 and CMIP5 into relevant statistics for transportation planners. These statistics include changes in the frequency of very hot days and extreme precipitation events and other climate characteristics that may affect transportation infrastructure and services by the middle and end of the century.
Example Values	**Providence, RI**: 122 % increase **Portland, ME**: 77 % increase

Exposure	-100	________________________	[__]	______________________________	100
Sensitivity	-100	________________________	[__]	______________________________	100
Adaptive Capacity	-100	________________________	[__]	______________________________	100

Comments (Please also explain any extreme views):

Number of Endangered Species

Shortname / Alias: Number of Endangered Species

12)

Indicator	**Number of Endangered Species**
Units	Number of Species
Description	Number of Threatened or Endangered Species found in port county
Data Source	U.S. Fish & Wildlife Service, Endangered Species An endangered species is an animal or plant species in danger of extinction throughout all or a significant portion of its range. A threatened species is an animal or plant species likely to become endangered within the foreseeable future throughout all or a significant portion of its range.
Example Values	**Providence, RI** (Providence County): 8 species **Portland, ME** (Cumberland County): 11 species

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Number of Critical Habitat Areas

Shortname / Alias: Number of Critical Habitat Areas

13)

Indicator	**Number Critical Habitat Areas**
Units	Number of Areas

Description	Number of Critical Habitat Areas within 50 miles of the port
Data Source	U.S. Fish & Wildlife Service, Critical Habitat Portal Critical Habitat for Threatened & Endangered Species: A specific geographic area(s) that contains features essential for the conservation of a threatened or endangered species and that may require special management and protection and that have been formally designated by rule published in the Federal Register. Critical Habitat Online Mapper
Example Values	**New Castle, DE**: 0 areas **Boston, MA**: 22 areas

Exposure	-100 ____________________[__]________________________	100
Sensitivity	-100 ____________________[__]________________________	100
Adaptive Capacity	-100 ____________________[__]________________________	100

Comments (Please also explain any extreme views):

Environmental *Sensitivity* Index (ESI)

Shortname / Alias: Environmental *Sensitivity* Index (ESI)

14)

Indicator	**ESI**
Units	ESI Rank (1.00 - 10.83; the higher the number, the *more sensitive* the shoreline is to an oil spill)
Description	Environmental *Sensitivity* Index (ESI) shoreline *sensitivity* to an oil spill. Using the ranking for the most sensitive shoreline within the port
Data Source	NOAA Office of Response and Restoration: ESI Shoreline Rankings Environmental *Sensitivity* Index (ESI) maps use shoreline rankings to rate how sensitive an area of shoreline would be to an oil spill. The ranking scale goes from 1 to 10. A rank of 1 represents shorelines with the *least susceptibility to damage* by oiling. Examples include steep, exposed rocky cliffs

	and banks. The oil cannot penetrate into the rock and will be washed off quickly by the waves and tides. A rank of 10 represents shorelines *most likely to be damaged* by oiling. Examples include protected, vegetated wetlands, such as mangrove swamps and saltwater marshes. Oil in these areas will remain for a long period of time, penetrate deeply into the substrate, and inflict damage to many kinds of plants and animals.
Example Values	**Philadelphia, PA**: 1.25 **Albany, NY**: 9.25

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Air Pollution Days

Shortname / Alias: Air Pollution Days

15)

Indicator	**Air Pollution Days**
Units	Number of days per year
Description	Number of days per year with Air Quality Index value greater than 100 for the port city, averaged over the past five years
Data Source	EPA Air Quality Index Report The Air Quality Index (AQI) provides information on pollutant concentrations of ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The AQI is based on pollutant concentration data measured by the State and Local Air Monitoring Stations network and by other special purpose monitors. For most pollutants in the index, the concentration is converted into index values between 0 and 500, “normalized” so that an

	index value of 100 represents the short-term, health-based standard for that pollutant as established by EPA (U.S. EPA, 1999). **The higher the index value, the greater the level of air pollution and health risk**. An index value of 500 reflects a risk of imminent and substantial endangerment of public health. The level of the pollutant with the highest index value is reported as the AQI level for that day. **An AQI value greater than 100 means that at least one criteria pollutant has reached levels at which people in sensitive groups may experience health effects**.
Example Values	**Philadelphia, PA**: 32 days per year **Albany, NY**: 4 days per year

Comments (Please also explain any extreme views):

Number of Hazmat Incidents

Shortname / Alias: Number of Hazmat Incidents

16)

Indicator	**Number of Hazmat Incidents**
Units	Number of Incidents
Description	Number of Hazardous Materials Incidents in port city since 2007
Data Source	U.S. DOT Pipeline and Hazardous Materials Safety Administration: Incident Statistics Hazardous material means a substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and has designated as hazardous under section 5103 of Federal hazardous materials transportation law (49 U.S.C. 5103). Each person in physical possession of a hazardous material at the time that any of the following incidents occurs during transportation (including loading, unloading, and temporary storage) must submit a Hazardous Materials Incident Report on DOT Form F 5800.1 (01/2004) within 30 days of discovery of the incident:

	An unintentional release of a hazardous material or the discharge of any quantity of hazardous waste; A specification cargo tank with a capacity of 1,000 gallons or greater containing any hazardous material suffers structural damage to the lading retention system or damage that requires repair to a system intended to protect the lading retention system, even if there is no release of hazardous material; An undeclared hazardous material is discovered; or A fire, violent rupture, explosion or dangerous evolution of heat (***i.e.***, an amount of heat sufficient to be dangerous to packaging or personal safety to include charring of packaging, melting of packaging, scorching of packaging, or other evidence) occurs as a direct result of a battery or battery-powered device. Hazardous materials in various forms can cause death, serious injury, long-lasting health effects and damage to buildings, homes and other property. Many products containing hazardous chemicals are used and stored in homes routinely. These products are also shipped daily on the nation's highways, railroads, waterways and pipelines.
Example Values	**Philadelphia, PA**: 1,981 incidents **Camden, NJ**: 154 incidents

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Average Cost of Hazmat Incidents

Shortname / Alias: Average Cost of Hazmat Incidents

17)

Indicator	**Average Cost of Hazmat Incidents**

<table>
<tr><td>Units</td><td>$ USD</td></tr>
<tr><td>Description</td><td>Average cost per incident of total damage from the 10 most costly Hazardous Materials Incidents in the port city since 2007</td></tr>
<tr><td>Data Source</td><td>U.S. DOT Pipeline and Hazardous Materials Safety Administration: Incident Statistics

Total Amount of Damages. This figure includes the cost of the material lost, carrier damage, property damage, response costs, and remediation clean-up costs.

Hazardous material means a substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and has designated as hazardous under section 5103 of Federal hazardous materials transportation law (49 U.S.C. 5103).

Each person in physical possession of a hazardous material at the time that any of the following incidents occurs during transportation (including loading, unloading, and temporary storage) must submit a Hazardous Materials Incident Report on DOT Form F 5800.1 (01/2004) within 30 days of discovery of the incident:

An unintentional release of a hazardous material or the discharge of any quantity of hazardous waste;

A specification cargo tank with a capacity of 1,000 gallons or greater containing any hazardous material suffers structural damage to the lading retention system or damage that requires repair to a system intended to protect the lading retention system, even if there is no release of hazardous material;

An undeclared hazardous material is discovered; or

A fire, violent rupture, explosion or dangerous evolution of heat (i.e., an amount of heat sufficient to be dangerous to packaging or personal safety to include charring of packaging, melting of packaging, scorching of packaging, or other evidence) occurs as a direct result of a battery or battery-powered device.

Hazardous materials in various forms can cause death, serious injury, long-lasting health effects and damage to buildings, homes and other property. Many products containing hazardous chemicals are used and stored in homes routinely. These products are also shipped daily on the nation's highways, railroads, waterways and pipelines.</td></tr>
</table>

Example Values	**Port of NY/NJ**: $2,877,763 per incident **Baltimore, MD**: $5,099,343 per incident

Exposure	-100	______________________ [__] ___________________________	100
Sensitivity	-100	______________________ [__] ___________________________	100
Adaptive Capacity	-100	______________________ [__] ___________________________	100

Comments (Please also explain any extreme views):

Percent of Bridges Deficient

Shortname / Alias: Percent of Bridges Deficient

18)

Indicator	**Percent of Bridges that are Deficient**
Units	%
Description	Percent of bridges in the port county that are structurally deficient or functionally obsolete
Data Source	U.S. DOT Federal Highway Administration: National Bridge Inventory: Deficient Bridges by County "Structurally deficient" means that the condition of the bridge includes a significant defect, which often means that speed or weight limits must be put on the bridge to ensure safety; a structural evaluation of 4 or lower qualifies a bridge as "structurally deficient". The designation can also apply if the approaches flood regularly. "Functionally obsolete" means that the design of a bridge is not suitable for its current use, such as lack of safety shoulders or the inability to handle current traffic volume, speed, size, or weight.

Example Values	**Philadelphia, PA** (Philadelphia County): 22.50 % **Baltimore, MD** (Baltimore-City County): 3.46 %

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Shelter Afforded

Shortname / Alias: Shelter Afforded

19)

Indicator	**Shelter**
Units	Excellent (5), Good (4), Fair (3), Poor (2), None (1)
Description	Shelter afforded from wind, sea, and swell
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). The **shelter afforded** from wind, sea, and swell, refers to the area where normal port operations are conducted, usually the wharf area. Shelter afforded the anchorage area is given for ports where cargo is handled by lighters.
Example Values	**New Haven, CT**: Good (4) **Boston, MA**: Excellent (5)

Exposure	-100	______________________[__]___________________________	100

Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Entrance Restrictions

Shortname / Alias: Entrance Restrictions

20)

Indicator	**Number of Entrance Restrictions**
Units	Number of entrance restrictions (Tide, Swell, Ice, Other, or None)
Description	Entrance Restrictions are natural factors restricting the entrance of vessels, such as ice, heavy swell, etc.
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). **Entrance Restrictions** are natural factors restricting the entrance of vessels, such as ice, heavy swell, etc.
Example Values	**Port of NY/NJ**: 1 (Tide) **Boston, MA**: 0 (None)

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

---

20 Candidate Indicators Evaluated, Thank You!

21) You have evaluated 20 candidate indicators so far, thank you!

Though 14 additional candidate indicators remain to be evaluated, we understand your time is valuable.
If you prefer to skip ahead to the final section of this survey you may do so by selecting the appropriate choice below:

( ) Yes, I can evaluate the remaining 14 candidate indicators.

( ) No, I wish to skip ahead to the final section of this survey.

Overhead Limits

Shortname / Alias: Overhead Limits

22)

Indicator	**Overhead Limits**
Units	Yes=1, No=0
Description	Overhead Limitations: indicates that bridge and overhead power cables exist.
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). This entry is shown only to indicate that bridge and overhead power cables exist. It is advisable to refer to the chart for particulars.
Example Values	**Port of NY/NJ**: 1 (Yes) **Norfolk, VA:** 0 (No)

Exposure	-100	______________________	[__] ____________________________	100
Sensitivity	-100	______________________	[__] ____________________________	100
Adaptive Capacity	-100	______________________	[__] ____________________________	100

Comments (Please also explain any extreme views):

Channel Depth

Shortname / Alias: Channel Depth

23)

Indicator	**Channel Depth**
Units	A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments
Description	The controlling depth of the principal or deepest channel at chart datum
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). Depth information is generalized into 5-foot units, with the equivalents in meters, for the main channel, the main anchorage, and the principal cargo pier and/or oil terminal. Depths refer to chart datum. Depths are given in increments of 5 feet (1.5 meters) in order to lessen the number of changes when a small change in depth occurs. A depth of 31 feet (9.5 meters) would use letter "K," a depth of 36 feet (11.0 meters) would use "J," etc. The letter "K" means a least depth of 31 feet (9.5 meters) or greater, but not as great as 36 feet (11.0 meters). **CHANNEL (controlling)**—The controlling depth of the principal or deepest channel at chart datum is given. The channel selected should lead up to the anchorage if within the harbor or to the wharf/pier. If the channel depth decreases from the anchorage to the wharf/pier and cargo can be worked at the anchorage, then the depth leading to the anchorage is taken. Large ports may have sub-ports (smaller) which have their own number and entry in the World Port Index. The controlling depth

	of the channel should refer to a smaller channel (if present) leading from the main channel into the sub-port facilities and anchorages. Note.—The depth of small shoals is not a controlling depth unless it limits the passage of vessels. For example, if a channel is charted as having a depth of 39 feet (11.9 meters), but there are small shoals noted or charted with depths of 30 feet (9.1 meters), then the controlling depth is still 39 feet (11.9 meters) unless a ship with a draft of 39 feet (12 meters) cannot pass around the shoals and navigate the channel safely.
Example Values	**Wilmington, DE**: M (21 - 25 feet) **Norfolk, VA**: H (41 - 45 feet)

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Pier Depth

Shortname / Alias: Pier Depth

24)

Indicator	**Pier Depth**
Units	A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments
Description	The greatest depth at chart datum alongside the respective wharf/pier. If there is more than one wharf/pier, then the one which has greatest usable depth is shown.

Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). Depth information is generalized into 5-foot units, with the equivalents in meters, for the main channel, the main anchorage, and the principal cargo pier and/or oil terminal. Depths refer to chart datum. Depths are given in increments of 5 feet (1.5 meters) in order to lessen the number of changes when a small change in depth occurs. A depth of 31 feet (9.5 meters) would use letter "K," a depth of 36 feet (11.0 meters) would use "J," etc. The letter "K" means a least depth of 31 feet (9.5 meters) or greater, but not as great as 36 feet (11.0 meters). **CARGO PIER/WHARF**—The greatest depth at chart datum alongside the respective wharf/pier is given. If there is more than one wharf/pier, then the one which has greatest usable depth is shown. For example, if there are three cargo/container piers with depths of 23 feet (7.0 meters), 33 feet (10.1 meters), and 43 feet (13.1 meters), then Code H, representing the deepest depth of 43 feet (13.1 meters), would be entered into the World Port Index.
Example Values	**Baltimore, MD**: G (46 -51 feet) **Paulsboro, NJ**: K (31 - 35 feet)

Exposure	-100	________________________[__]______________________________	100
Sensitivity	-100	________________________[__]______________________________	100
Adaptive Capacity	-100	________________________[__]______________________________	100

Comments (Please also explain any extreme views):

Tide Range

Shortname / Alias: Tide Range

25)

Indicator	**Tide Range**
Units	Feet
Description	The mean tidal range at the port
Data Source	The National Geospatial-Intelligence Agency (NGA) World Port Index (Pub 150) contains the location and physical characteristics of, and the facilities and services offered by major ports and terminals world-wide (approximately 3700 entries). **TIDES** —The mean range in meters is normally given for all ports outside of United States (U.S.) jurisdiction, but the mean rise is substituted if range data are not available. The distinction between range and rise can be disregarded without affecting the general utility of this publication. Note —The mean range is given in feet for all US ports and ports under U.S. jurisdiction (Trust Territories, etc.).
Example Values	Baltimore, MD: 1 foot Paulsboro, NJ: 6 feet

Exposure	-100	____________[__]______________	100
Sensitivity	-100	____________[__]______________	100
Adaptive Capacity	-100	____________[__]______________	100

Comments (Please also explain any extreme views):

Marine Transportation Jobs

Shortname / Alias: Marine Transportation Jobs

26)

Indicator	**Marine Transportation Jobs**
Units	Number of jobs
Description	Number of Marine Transportation Jobs in the port county
Data Source	The NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW) ENOW Explorer contains annual time-series data for over 400 coastal counties, 30 coastal states, 8 regions, and the nation, derived from the Bureau of Labor Statistics and the Bureau of Economic Analysis. It describes six economic sectors that depend on the oceans and Great Lakes and measures four economic indicators: Establishments, Employment, Wages, and Gross Domestic Product (GDP). **Marine Transportation** includes deep sea freight, marine passenger transportation, pipeline transportation, marine transportation services, search and navigation equipment, and warehousing.
Example Values	**Providence, RI** (Providence County): 979 jobs in 2013 **Searsport, ME** (Waldo County): 54 jobs in 2013

Exposure	-100	______________________	[__] ___________________________	100
Sensitivity	-100	______________________	[__] ___________________________	100
Adaptive Capacity	-100	______________________	[__] ___________________________	100

Comments (Please also explain any extreme views):

Marine Transportation Gross Domestic Product (GDP)

Shortname / Alias: Marine Transportation GDP

27)

Indicator	**Marine Transportation GDP**
Units	$ Millions USD
Description	Gross Domestic Product of Marine Transportation in the port county
Data Source	The NOAA Office for Coastal Management: Economics: National Ocean Watch (ENOW) ENOW Explorer contains annual time-series data for over 400 coastal counties, 30 coastal states, 8 regions, and the nation, derived from the Bureau of Labor Statistics and the Bureau of Economic Analysis. It describes six economic sectors that depend on the oceans and Great Lakes and measures four economic indicators: Establishments, Employment, Wages, and Gross Domestic Product (GDP). **MARINE TRANSPORTATION** Includes deep sea freight, marine passenger transportation, pipeline transportation, marine transportation services, search and navigation equipment, and warehousing. **Gross Domestic Product (GDP)** represents the monetary value of all goods and services produced within a county's geographic borders over a specified period of time.
Example Values	**Providence, RI** (Providence County): $59.8 Million in 2013 **Searsport, ME** (Waldo County): $4.5 Million in 2013

Exposure	-100	______________________[__]___________________________	100

Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Population Change

Shortname / Alias: Population Change

28)

Indicator	**Population Change**
Units	%
Description	Rate of population change (from 2000-2010) in the port county, expressed as a percent change
Data Source	The NOAA Office for Coastal Management: Quick Report Tool for Socioeconomic Data provides easy access to economic and demographic data for multiple coastal jurisdictions. Information is derived from several key socioeconomic sources, including the U.S. Census Bureau, Bureau of Economic Analysis, Bureau of Labor Statistics, and Federal Emergency Management Agency's Hazus database. In 2010, 123.3 million people, or 39 percent of the nation's population lived in Coastal Shoreline Counties. Population growth in these counties occurred at a lower rate than the nation as a whole from 1970 to 2010. The population in Coastal Shoreline Counties increased by 34.8 million people, a 39 percent increase, while the nation's entire population increased by 52 percent over the same time period. Within the limited space of the nation's coast, population density far exceeds the nation as a whole, and this trend will continue into the future. This situation presents coastal managers with the challenge of protecting both coastal ecosystems from a growing population and protecting a growing population from coastal hazards. The concentration of people impacts the integrity of coastal ecosystems, and at the same time, the lives and livelihoods of some of these residents and visitors can be at risk from natural

	processes at the coast – such as hurricanes, erosion, and sea level rise.
Example Values	**Baltimore, MD** (Baltimore-City County): -4.64 % *decrease* **Gloucester, NJ** (Gloucester County): +13.20 % *increase*

Exposure	-100	____________________[__]________________________	100
Sensitivity	-100	____________________[__]________________________	100
Adaptive Capacity	-100	____________________[__]________________________	100

Comments (Please also explain any extreme views):

Population Inside Floodplain

Shortname / Alias: Population Inside Floodplain

29)

Indicator	**Population Inside Floodplain**
Units	%
Description	Percent of the port county population living inside the FEMA Floodplain
Data Source	NOAA Office for Coastal Management: Coastal County Snapshots; based on 2009-2013 American Community Survey 5-year Summary File data **People + Floodplains = Not Good** The more homes and people located in a floodplain, the greater the potential for harm from flooding. Impacts are likely to be even greater when additional risk factors (age, income, capabilities) are involved, since people at greatest flood risk may have difficulty evacuating or taking action to reduce potential damage. **Floodplain = 100 Year Flood Elevation = Base Flood Elevation (BFE):** The elevation shown on the Flood Insurance Rate Map (FIRM) that indicates the water surface elevation

	resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year.
Example Values	**Wilmington, DE** (New Castle County): 8 % **Norfolk, VA** (Norfolk County): 18 %

Exposure	-100	_____________________[__]__________________________	100
Sensitivity	-100	_____________________[__]__________________________	100
Adaptive Capacity	-100	_____________________[__]__________________________	100

Comments (Please also explain any extreme views):

SoVI® Social Vulnerability Score

Shortname / Alias: SoVI Social Vulnerability Score

30)

Indicator	**SoVI® Score**
Units	The SoVI® Social Vulnerability score is classified using standard deviations. Social vulnerability scores that are greater than 2 standard deviations above the mean are considered the most socially vulnerable, and scores below 2 standard deviations less than the mean are the least vulnerable.
Description	The SoVI® Social Vulnerability score of the port county
Data Source	University of South Carolina Hazards and Vulnerability Research Institute Social Vulnerability Index Data **Social Vulnerability** The hazards-of-place model (Cutter 1996a) combines the biophysical vulnerability (physical characteristics of hazards and environment) and social vulnerability to determine an overall place vulnerability. Social vulnerability is represented as the social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards. **The Social Vulnerability Index (SoVI®)**

	County-level socioeconomic and demographic data were used to construct an index of social vulnerability to environmental hazards, called the Social Vulnerability Index (SoVI®) for the United States **based on data collected from 2005 to 2009**. The majority of the sources used by the Hazards Research Lab are obtained from the five-year American Community Survey estimates compiled by the U.S. Census Bureau. After obtaining the relevant data, a principle components analysis is used to reduce the data into set of components. Slight adjustments are made to the components to ensure that the sign of the component loadings coincide with each individual population characteristic's influence on vulnerability. All components are added together to determine a numerical value that represents the social vulnerability for each county.
Example Values	**Philadelphia, PA** (Philadelphia County): 3.418284 (High) **Norfolk, VA** (Norfolk County): -0.207217 (Medium)

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Vessel Capacity

Shortname / Alias: Vessel Capacity

31)

Indicator	**Vessel Capacity**
Units	(Number of Vessel Calls) x (Vessel DWT)
Description	Annual vessel capacity at the port
Data Source	The U.S. DOT Maritime Administration: Vessel Calls in U.S. Ports, Selected Terminals and Lightering Areas is a report containing a calculation of vessel calls for privately-owned,

	oceangoing merchant vessels of all flags of registries over 1,000 gross tons (GT) calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam and Puerto Rico. Vessel Types: MARAD uses six vessel categories in this report: (1) Containerships, (2) Tanker, (3) Dry Bulk, (4) General Cargo, (5) Roll On – Roll Off (Ro-Ro), and (6) Gas. **Calls** are calculated by how many times a vessel arrived at a port, facility or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo and may also include other activities related to vessel, port or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessary be engaged in onloading/offloading of cargoes. **Capacity** is calculated as the sum of vessel calls weighted by vessel deadweight (DWT). DWT is defined as the total weight (metric tons) of cargo, fuel, fresh water, stores and crew which a ship can carry when immersed to its load line.
Example Values	**Albany, NY**: 223,943,760 in 2015 **Fall River, MA**: 14,707,900 in 2015

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Tanker Capacity

Shortname / Alias: Tanker Capacity

32)

Indicator	**Tanker Capacity**
Units	(Number of Tanker Calls) x (Vessel DWT)

Description	Annual tanker capacity at the port **Tankers** – CO2, Chemical, Chemical/Oil, Wine, Vegetable Oil, Edible Oil, Beer, Latex, Crude Oil, Oil Products, Bitumen, Coal/Oil, Water, Fruit Juice, Molasses, Glue, Alcohol, and Caprolacatam.
Data Source	The U.S. DOT Maritime Administration: Vessel Calls in U.S. Ports, Selected Terminals and Lightering Areas is a report containing a calculation of vessel calls for privately-owned, oceangoing merchant vessels of all flags of registries over 1,000 gross tons (GT) calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam and Puerto Rico. Vessel Types: MARAD uses six vessel categories in this report: (1) Containerships, (2) Tanker, (3) Dry Bulk, (4) General Cargo, (5) Roll On – Roll Off (Ro-Ro), and (6) Gas. **Calls** are calculated by how many times a vessel arrived at a port, facility or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo and may also include other activities related to vessel, port or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessary be engaged in onloading/offloading of cargoes. **Capacity** is calculated as the sum of vessel calls weighted by vessel deadweight (DWT). DWT is defined as the total weight (metric tons) of cargo, fuel, fresh water, stores and crew which a ship can carry when immersed to its load line.
Example Values	**Albany, NY**: 21,437,035 in 2015 **Fall River, MA**: 0 in 2015

Exposure -100 ______________________[__]___________________________ 100

Sensitivity -100 ______________________[__]___________________________ 100

Adaptive Capacity -100 ______________________[__]___________________________ 100

Comments (Please also explain any extreme views):

Gas Carrier Capacity

Shortname / Alias: Gas Carrier Capacity

33)

Indicator	**Gas Capacity**
Units	(Number of Gas Carrier Calls) x (Vessel DWT)
Description	Annual gas carrier capacity at the port **Gas** – Liquefied Petroleum and Liquefied Natural Gas Carriers
Data Source	The U.S. DOT Maritime Administration: Vessel Calls in U.S. Ports, Selected Terminals and Lightering Areas is a report containing a calculation of vessel calls for privately-owned, oceangoing merchant vessels of all flags of registries over 1,000 gross tons (GT) calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam and Puerto Rico. Vessel Types: MARAD uses six vessel categories in this report: (1) Containerships, (2) Tanker, (3) Dry Bulk, (4) General Cargo, (5) Roll On – Roll Off (Ro-Ro), and (6) Gas. **Calls** are calculated by how many times a vessel arrived at a port, facility or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo and may also include other activities related to vessel, port or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessary be engaged in onloading/offloading of cargoes. **Capacity** is calculated as the sum of vessel calls weighted by vessel deadweight (DWT). DWT is defined as the total weight (metric tons) of cargo, fuel, fresh water, stores and crew which a ship can carry when immersed to its load line.
Example Values	**Boston, MA**: 284,802 in 2015 **Port of NY/NJ**: 6,424 in 2015

Exposure	-100	____________________[__]_________________________	100
Sensitivity	-100	____________________[__]_________________________	100

Adaptive Capacity -100 ______________________[__]___________________________ 100	

Comments (Please also explain any extreme views):

Containership Capacity

Shortname / Alias: Containership Capacity

34)

Indicator	**Containership Capacity**
Units	(Number of Containership Calls) x (Vessel DWT)
Description	Annual containership capacity at the port **Containership** – Container Ship and Passenger/Container Ships
Data Source	The U.S. DOT Maritime Administration: Vessel Calls in U.S. Ports, Selected Terminals and Lightering Areas is a report containing a calculation of vessel calls for privately-owned, oceangoing merchant vessels of all flags of registries over 1,000 gross tons (GT) calling at ports and selected ports/terminals within the contiguous United States, Hawaii, Alaska, Guam and Puerto Rico. Vessel Types: MARAD uses six vessel categories in this report: (1) Containerships, (2) Tanker, (3) Dry Bulk, (4) General Cargo, (5) Roll On – Roll Off (Ro-Ro), and (6) Gas. **Calls** are calculated by how many times a vessel arrived at a port, facility or terminal. This number may include berth shifts, movement to and from an anchorage while awaiting cargo and may also include other activities related to vessel, port or terminal operations. Calls do not include vessels arriving at a designated anchorage area. In addition, vessels calling on a port may not necessary be engaged in onloading/offloading of cargoes. **Capacity** is calculated as the sum of vessel calls weighted by vessel deadweight (DWT). DWT is defined as the total weight (metric tons) of cargo, fuel, fresh water, stores and crew which a ship can carry when immersed to its load line.
Example Values	**Hampton Roads, VA**: 104,862,259,278 in 2015 **Providence, RI**: 0 in 2015

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Tonnage

Shortname / Alias: Tonnage

35)

Indicator	**Tonnage**
Units	Short Tons
Description	Total Annual Throughput at the port
Data Source	USACE Navigation Data Center: Principal Ports of the United States The Principal Port file contains USACE port codes, geographic locations (longitude, latitude), names, and commodity tonnage summaries (total tons, domestic, foreign, imports and exports) for Principal USACE Ports. The ports are politically defined by port limits or Corps projects, excluding non-Corps projects not authorized for publication. The determination for the published Principal Ports is based upon the total tonnage for the port for the particular year; therefore, the top 150 list can vary from year to year.
Example Values	**Port of NY/NJ**: 126,690,317 tons in 2015 **Providence, RI**: 8,043,051 tons in 2015

Exposure	-100	______________________[__]___________________________	100
Sensitivity	-100	______________________[__]___________________________	100
Adaptive Capacity	-100	______________________[__]___________________________	100

Comments (Please also explain any extreme views):

Most Vulnerable Ports

Shortname / Alias: Most Vulnerable Ports

Where are the highest levels of climate vulnerability? The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its *adaptive capacity* among the principal ports of the USACE United States Army Corps of Engineers North Atlantic Division?

Appendix J: Expert Elicitation Results; Indicator Evaluation

Figure J-1. Federal expert-perceived correlations with the components of vulnerability.

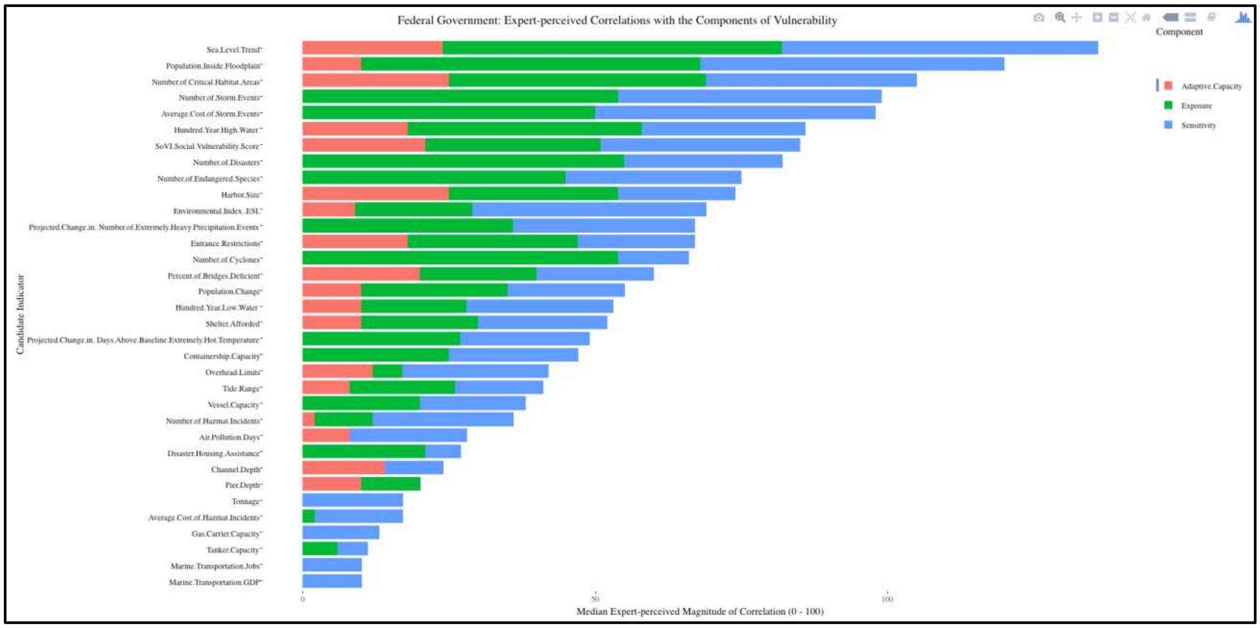


Figure J-2. Academics expert-perceived correlations with the components of vulnerability.

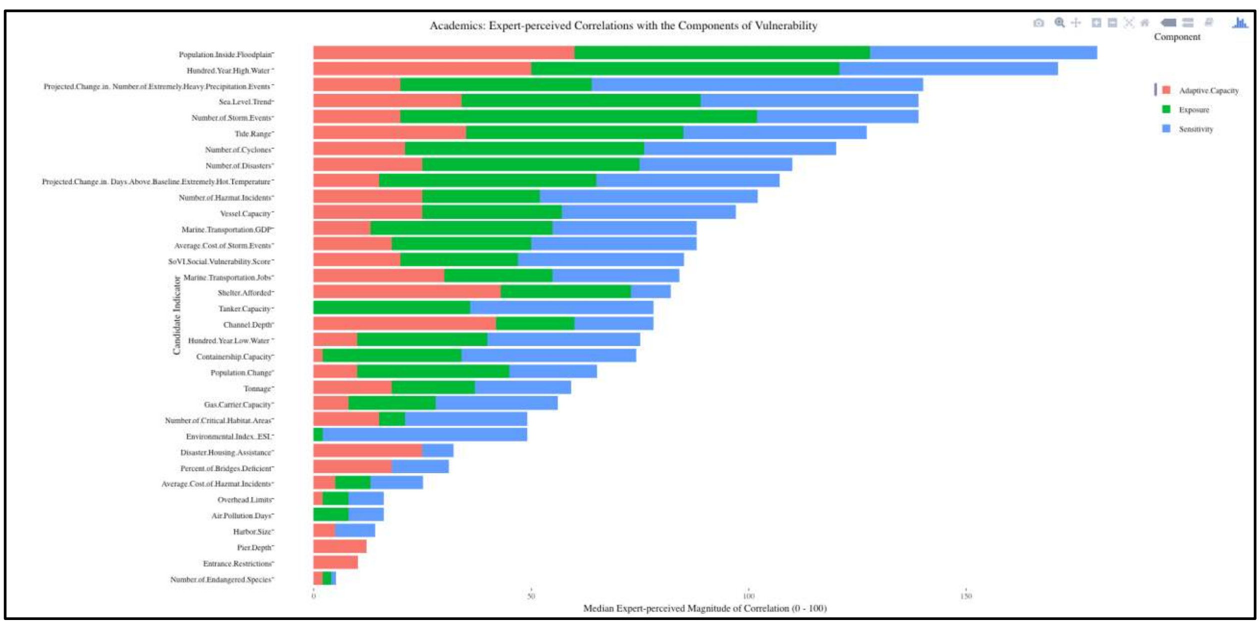


Figure J-3. Consultants expert-perceived correlations with the components of vulnerability.

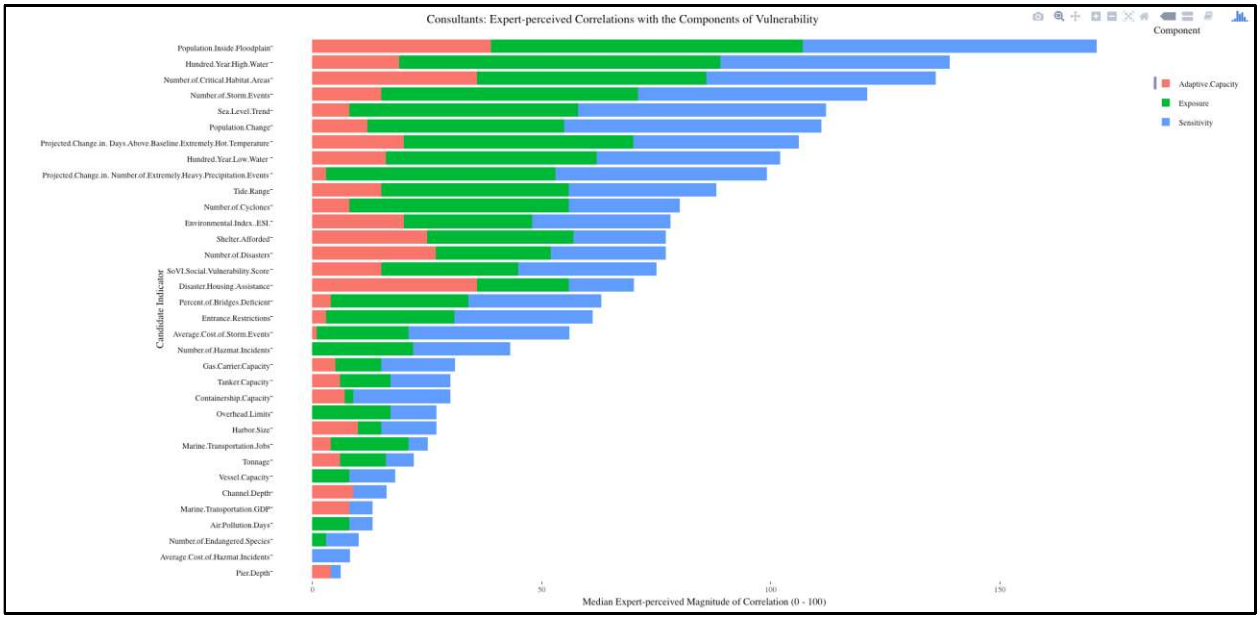


Figure J-4. Practitioners expert-perceived correlations with the components of vulnerability.

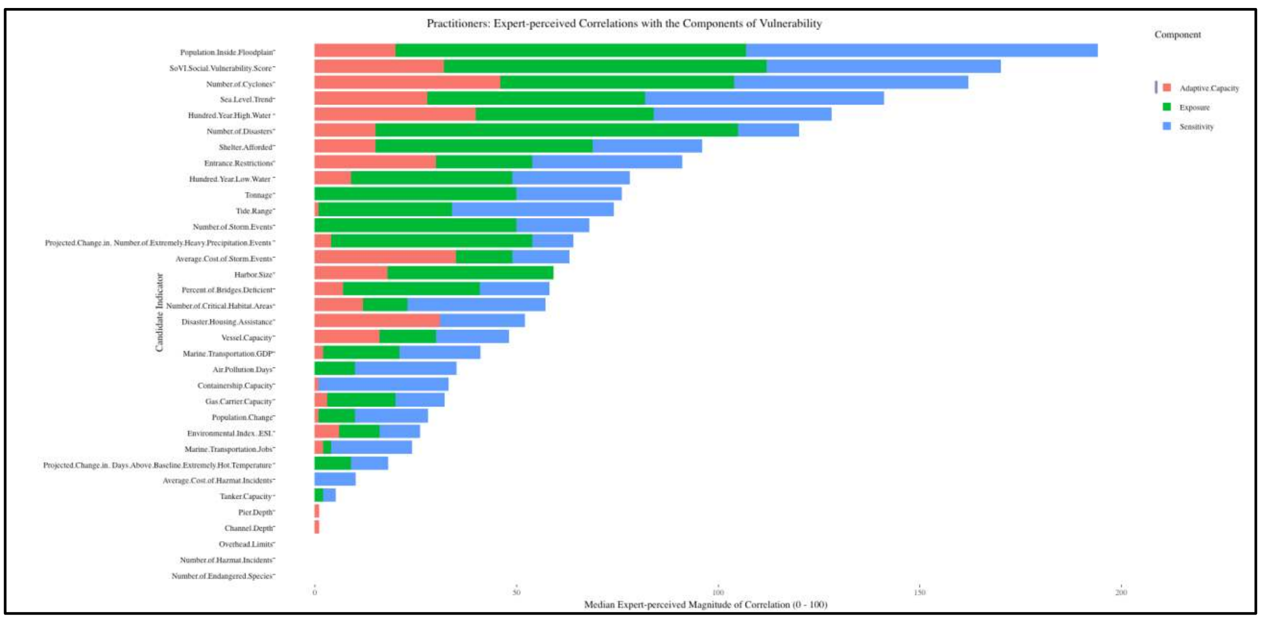
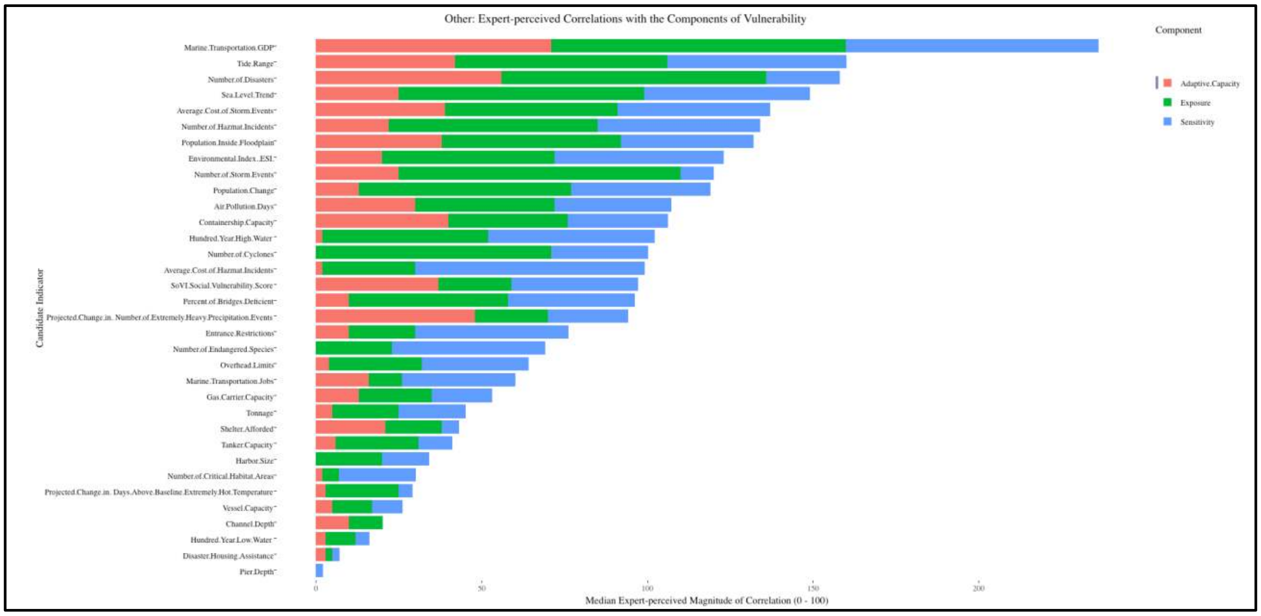
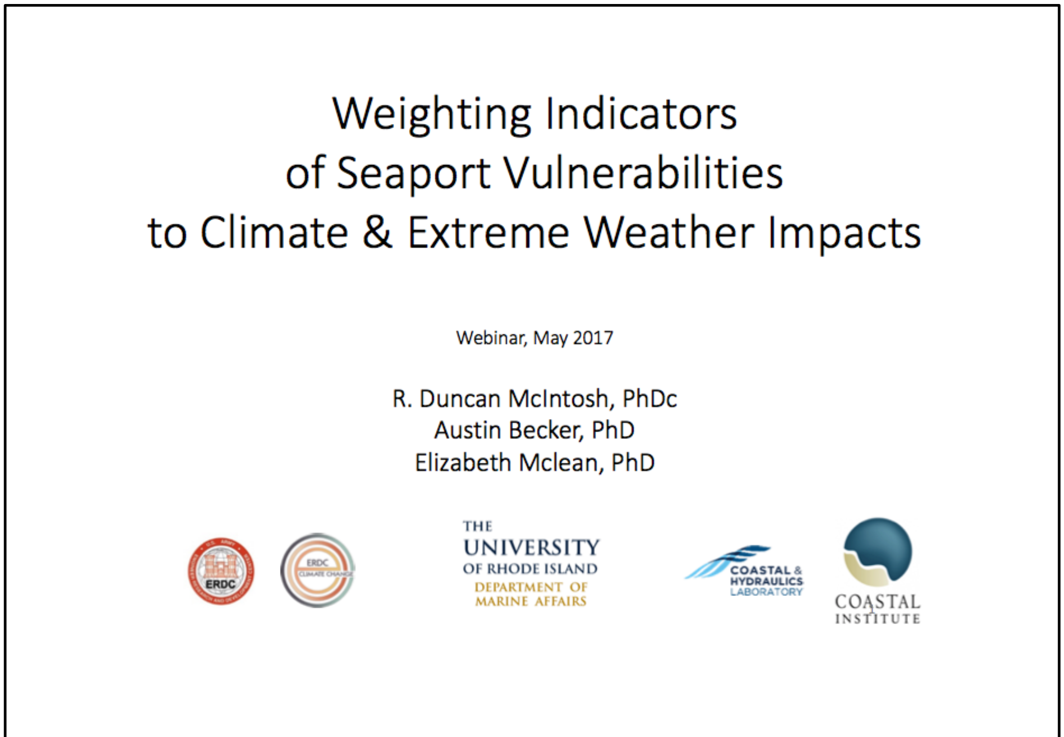
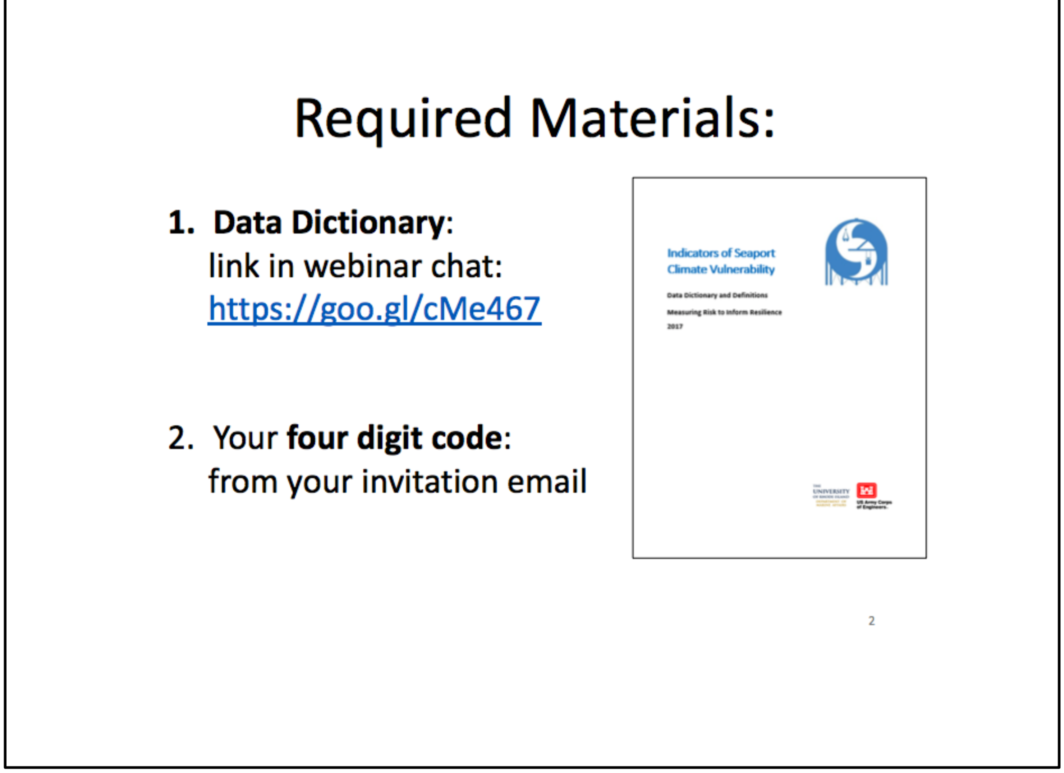


Figure J-5. Others expert-perceived correlations with the components of vulnerability.



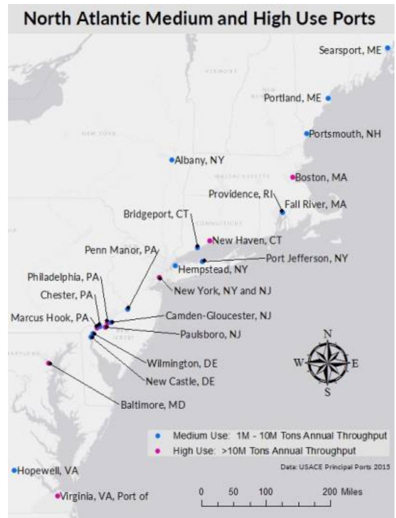
Appendix K: Webinar Slides for the Visual Analogue Scale (VAS) Selection





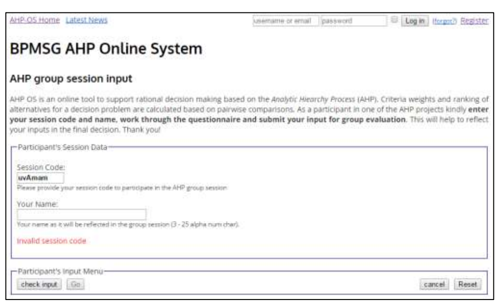
Study Area:

- Ports of the USACE North Atlantic Division (map)
- Vulnerabilities include ports' surrounding socioeconomic and environmental systems



Invitation Link:

Click the **invitation link** in the webinar chat


AHP-OS Home Latest News username or email password Log in (forgot?) Register

BPMSG AHP Online System

AHP group session input

AHP OS is an online tool to support rational decision making based on the *Analytic Hiearchy Process* (AHP). Criteria weights and ranking of alternatives for a decision problem are calculated based on pairwise comparisons. As a participant in one of the AHP projects kindly **enter your session code and name, work through the questionnaire and submit your input for group evaluation**. This will help to reflect your inputs in the final decision. Thank you!

Participant's Session Data

Session Code:
uvAmam
Please provide your session code to participate in the AHP group session

Your Name:
Your name as it will be reflected in the group session (3 - 25 alpha num char).

Invalid session code

Participant's Input Menu

check input Go cancel Reset

4

Logging In:

1. **Do not** "Log In" or "Register" (upper right)

2. Enter your **four digit code** in the box labeled "**Your Name**:"

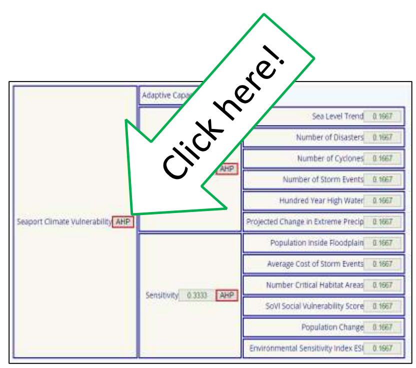
3. Click "**check input**" then click "**Go**"

5

Weighting the Components of Seaport Climate *Vulnerability*

1. Click the red **AHP** box next to "**Seaport Climate Vulnerability**"

- **Vulnerability**: The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is ***exposed***, its ***sensitivity***, and its ***adaptive capacity***.



Pairwise Comparisons:

With respect to *Seaport Climate* ***Vulnerability***, which criterion is more important, and how much more on a scale 1 to 9?

1. Refer to Data Dictionary (p. 5) for definitions
2. For each pair, indicate which is more important
3. Then, indicate how much more (1 – 9)
4. Click "**Check Consistency**," & adjust your responses if necessary
5. Click "**Submit_Priorities**"

7

Check Consistency:

The most *in*consistent responses are highlighted red, orange, yellow;

More consistent response choices highlighted in green.

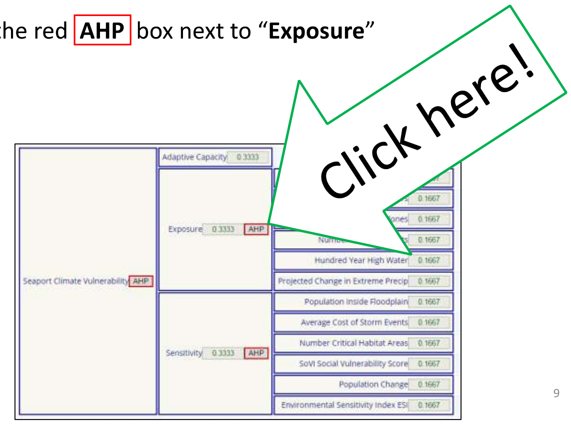
To improve consistency:

1. Slightly adjust highlighted judgments by plus or minus one or two points in the scale; then "**Check Consistency**" again
2. Repeat these adjustments as necessary (or until CR < 10%)

4

Weighting the Indicators of Seaport Climate *Exposure*

1. Click the red **AHP** box next to "**Exposure**"

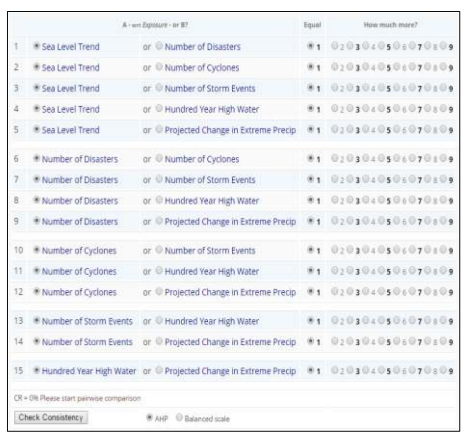


9

Pairwise Comparisons:

With respect to *Seaport Climate **Exposure***, which criterion is more important, and how much more on a scale 1 to 9?

1. Refer to Data Dictionary for descriptions of indicators
2. For each pair, indicate which is more important
3. Then, indicate how much more (1 – 9)
4. Click "**Check Consistency**," & adjust your responses if necessary
5. Click "**Submit_Priorities**"



Pairwise Comparisons:

With respect to *Seaport Climate* ***Exposure***, which criterion is more important, and how much more on a scale 1 to 9?

1. Refer to Data Dictionary for descriptions of indicators
2. For each pair, indicate which is more important
3. Then, indicate how much more (1 – 9)
4. Click "**Check Consistency**," & adjust your responses if necessary
5. Click "**Submit_Priorities**"

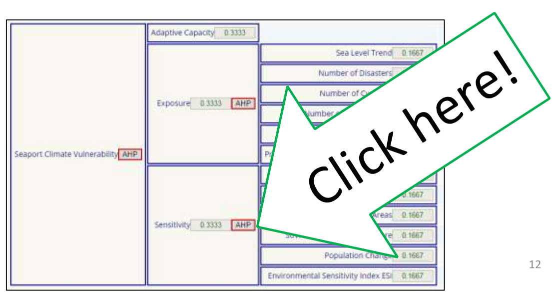
Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected

Exposure is a measure of the extent to which a port is located in the path of climate and extreme weather impacts, *regardless of whether the port is susceptible to damage or not*.

11

Weighting the Indicators of Seaport Climate *Sensitivity*

1. Click the red **AHP** box next to "**Sensitivity**"



12

Pairwise Comparisons:

With respect to *Seaport Climate* ***Sensitivity***, which criterion is more important, and how much more on a scale 1 to 9?

1. Refer to Data Dictionary for descriptions of indicators
2. For each pair, indicate which is more important
3. Then, indicate how much more (1 – 9)
4. Click "**Check Consistency**," & adjust your responses if necessary
5. Click "**Submit_Priorities**"

	A - wrt Sensitivity - or B?			Equal	How much more?
1	Population Inside Floodplain	or	Average Cost of Storm Events	1	2 3 4 5 6 7 8 9
2	Population Inside Floodplain	or	Number Critical Habitat Areas	1	2 3 4 5 6 7 8 9
3	Population Inside Floodplain	or	SoVI Social Vulnerability Score	1	2 3 4 5 6 7 8 9
4	Population Inside Floodplain	or	Population Change	1	2 3 4 5 6 7 8 9
5	Population Inside Floodplain	or	Environmental Sensitivity Index ESI	1	2 3 4 5 6 7 8 9
6	Average Cost of Storm Events	or	Number Critical Habitat Areas	1	2 3 4 5 6 7 8 9
7	Average Cost of Storm Events	or	SoVI Social Vulnerability Score	1	2 3 4 5 6 7 8 9
8	Average Cost of Storm Events	or	Population Change	1	2 3 4 5 6 7 8 9
9	Average Cost of Storm Events	or	Environmental Sensitivity Index ESI	1	2 3 4 5 6 7 8 9
10	Number Critical Habitat Areas	or	SoVI Social Vulnerability Score	1	2 3 4 5 6 7 8 9
11	Number Critical Habitat Areas	or	Population Change	1	2 3 4 5 6 7 8 9
12	Number Critical Habitat Areas	or	Environmental Sensitivity Index ESI	1	2 3 4 5 6 7 8 9
13	SoVI Social Vulnerability Score	or	Population Change	1	2 3 4 5 6 7 8 9
14	SoVI Social Vulnerability Score	or	Environmental Sensitivity Index ESI	1	2 3 4 5 6 7 8 9
15	Population Change	or	Environmental Sensitivity Index ESI	1	2 3 4 5 6 7 8 9

CR = 0% Please start pairwise comparison

Check Consistency — AHP / Balanced scale

Pairwise Comparisons:

With respect to *Seaport Climate* ***Sensitivity***, which criterion is more important, and how much more on a scale 1 to 9?

1. Refer to Data Dictionary for descriptions of indicators
2. For each pair, indicate which is more important
3. Then, indicate how much more (1 – 9)
4. Click "**Check Consistency**," & adjust your responses if necessary
5. Click "**Submit_Priorities**"

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate and extreme weather impacts

Example: a port with a storm surge barrier may be ***less sensitive*** to storm driven flooding impacts than a similar port without a storm surge barrier.

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Submit Answers:

1. Click "**Submit for group eval"**
2. [Optional] "**View group result"**
3. Click "**Done"**

Thank You!

You are helping make seaports more resilient!

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Definitions: (from Data Dictionary)

- **Vulnerability**: The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is *exposed*, its *sensitivity*, and its *adaptive capacity.*

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Definitions: (from Data Dictionary)

- **Exposure**: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected
- **Sensitivity**: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli
- **Adaptive Capacity**: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences

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How the Three Components of Climate Vulnerability Relate to Seaports:

Exposure is a measure of the extent to which a port is located in the path of climate and extreme weather impacts, regardless of whether the port is susceptible to damage or not.
Example**:** a port on the US East Coast has a ***higher exposure*** to hurricanes than a port on the US West Coast.
Sensitivity is a measure of the extent to which a port is affected negatively (or positively) by climate and extreme weather impacts.
Example**:** a port with a storm surge barrier may be ***less sensitive*** to storm driven flooding impacts than a similar port without a storm surge barrier.
Adaptive Capacity is a measure of a port's ability to adjust, take advantage of, or respond to climate and extreme weather impacts.
Example**:** a port with a robust master plan that considers climate resilience and has a high degree of operational flexibility may have a ***higher adaptive capacity*** than a port with minimal planning and low redundancy

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Appendix L: Radar Plots for the 22 Ports Studied

The composite-indices generated for the studied ports retain the ability to explore the disaggregated substructure behind the composite scores for each of the indicators. Users are able to ask "*Why* does a particular vulnerability indicator score 'high' or 'low' according to this index?"

Figure L-1. The disaggregated substructure of the composite-index vulnerability scores for the Port of Albany, NY. Indicators of *exposure* are on the left half of the plot, and indicators of *sensitivity* are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for the "Hundred Year High Water" scored higher than any other indicator, the second highest indicator being the "Environmental Index."

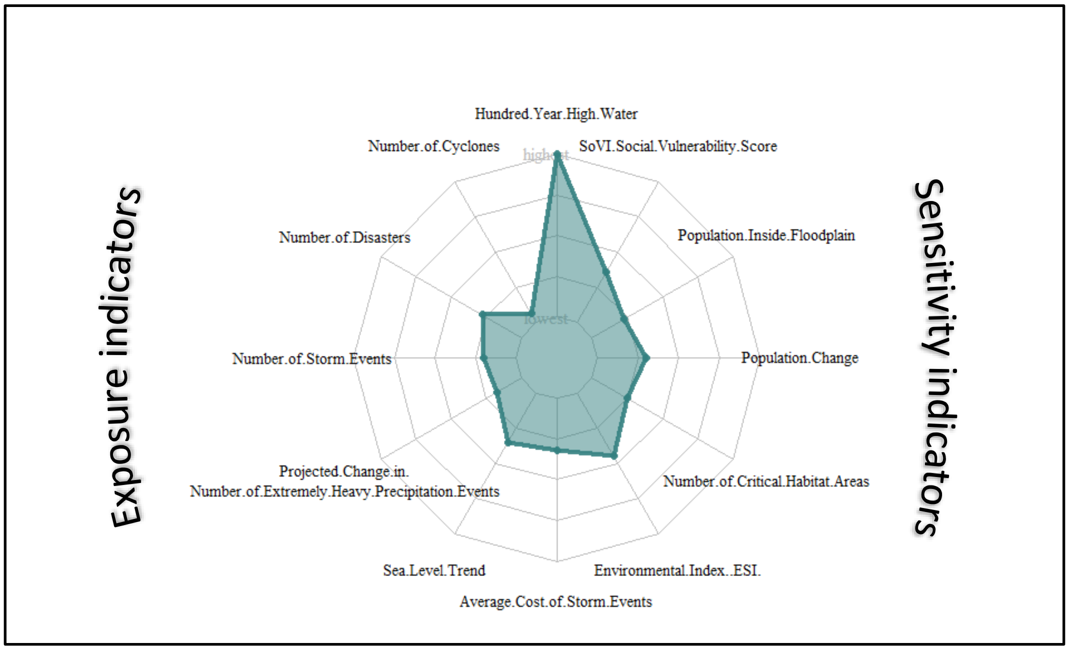


Figure L-2. The disaggregated substructure of the composite-index vulnerability scores for the Port of Baltimore, MD. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for the "Average Cost of Storm Events" and the "Social Vulnerability Score" scored higher than any other indicator.

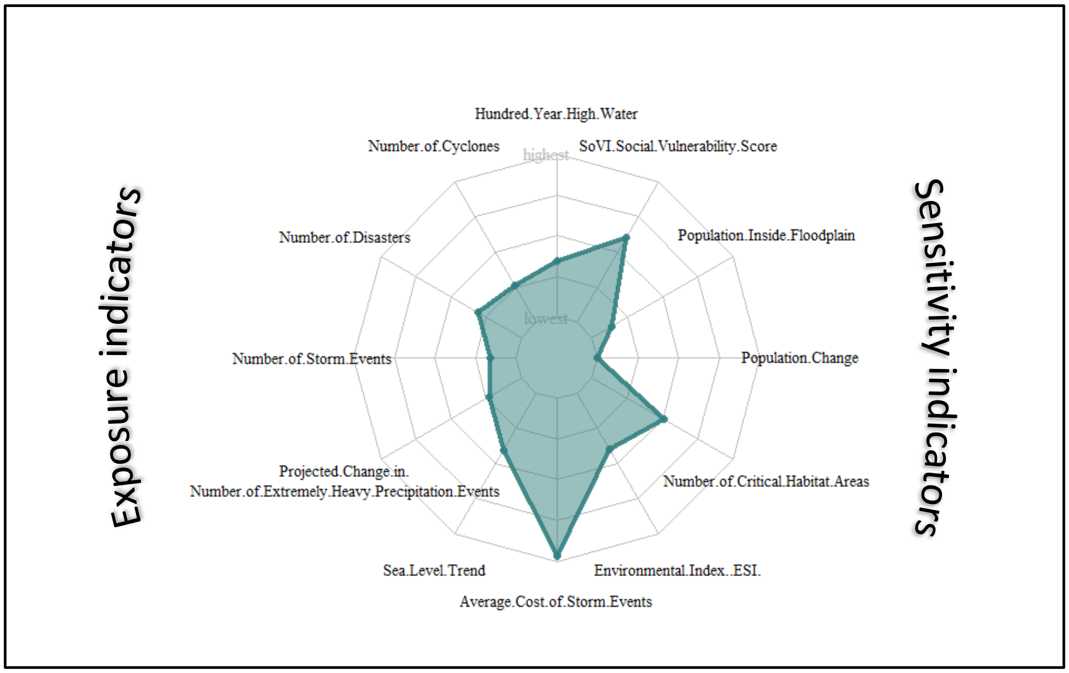


Figure L-3. The disaggregated substructure of the composite-index vulnerability scores for the Port of Boston, MA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Number of Cyclones" and "Population inside Floodplain" scored higher than the indicator for "Number of Disasters."

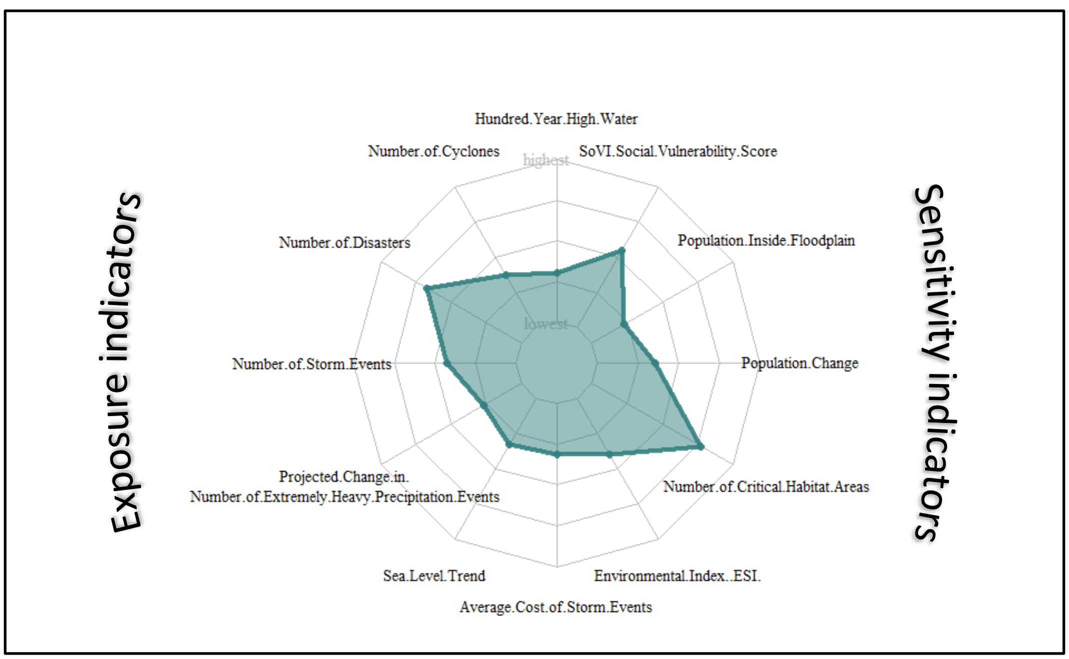


Figure L-4. The disaggregated substructure of the composite-index vulnerability scores for the Port of Bridgeport, CT. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals very small differences underlying the port's vulnerability. Indicators for "Population Inside Floodplain" scored higher than other indicators, followed by "Environmental Index," "Number of Storm Events" and "Number of Disasters."

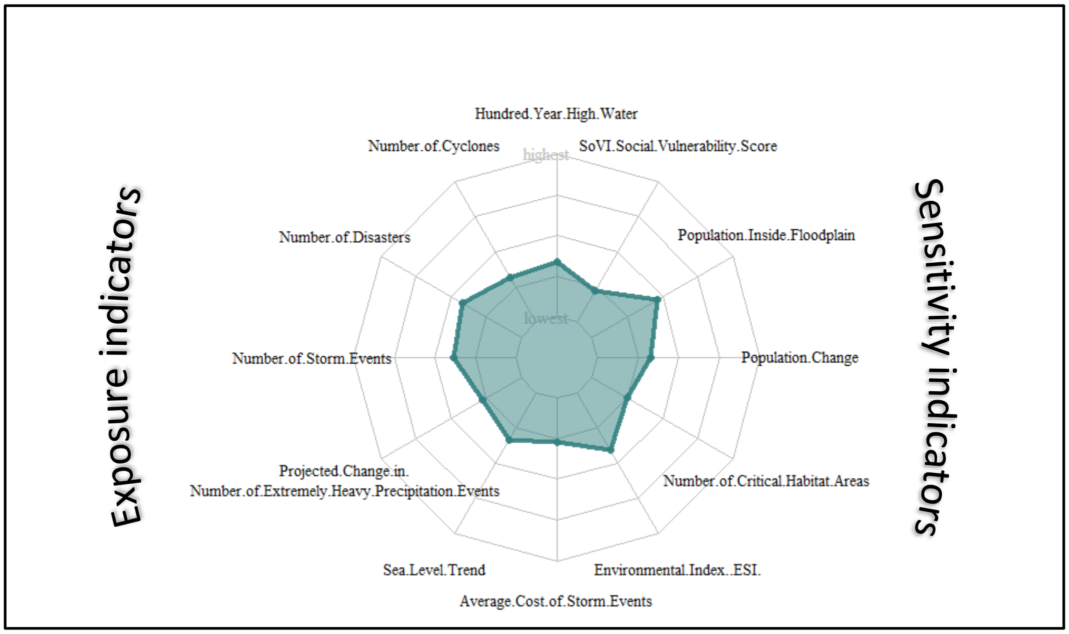


Figure L-5. The disaggregated substructure of the composite-index vulnerability scores for the Port of Camden-Gloucester, NJ. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population Change" and "Number of Storm Events" scored higher than the indicators for "Number of Cyclones" and "Hundred Year High Water."

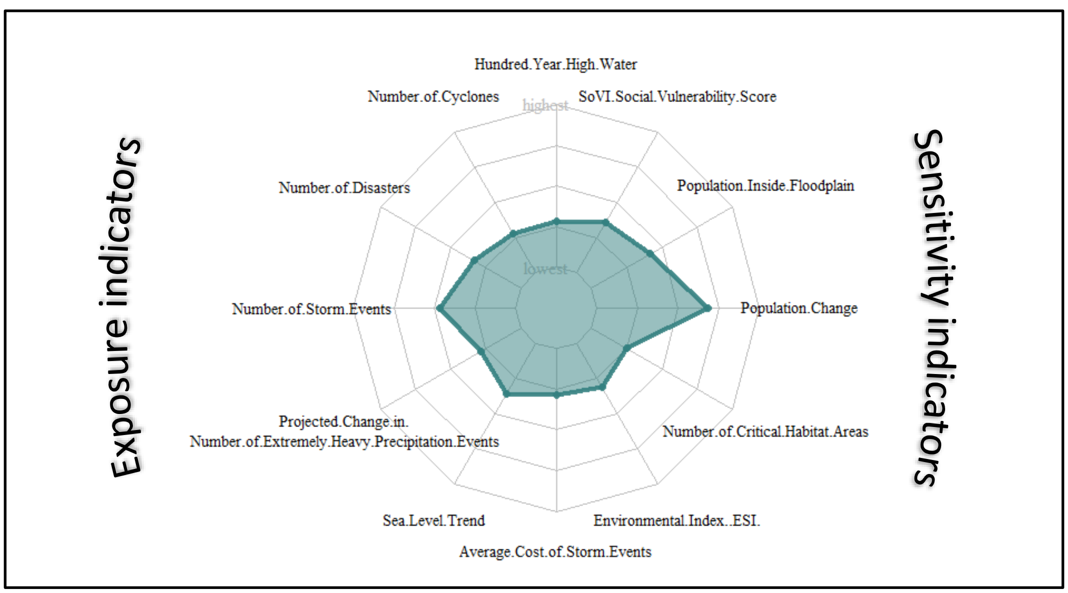


Figure L-6. The disaggregated substructure of the composite-index vulnerability scores for the Port of Chester, PA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Number of Storms" and "Sea Level Trend" scored higher than other indicators.

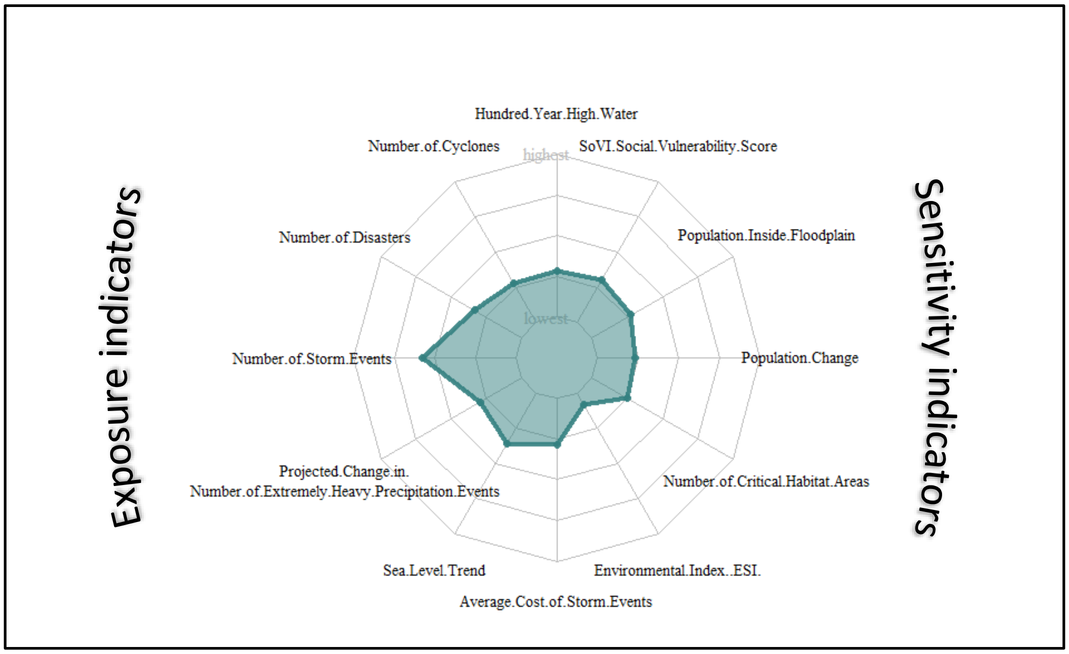


Figure L-7. The disaggregated substructure of the composite-index vulnerability scores for the Port of Fall River, MA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population Inside Flood Plain" and "Number of Critical Habitat Areas" scored higher than "Sea Level Trends."

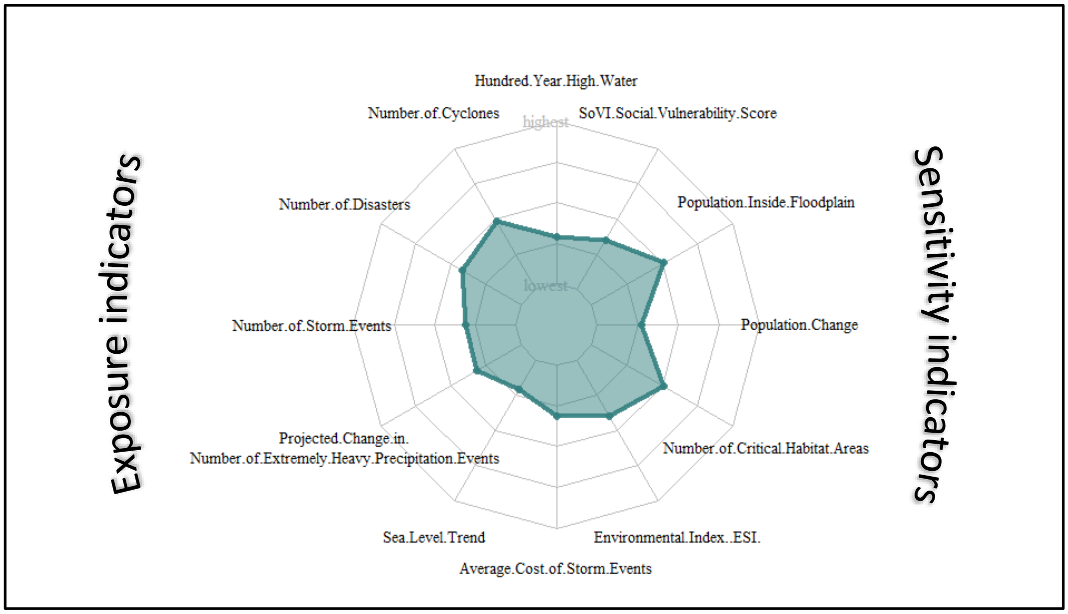


Figure L-8. The disaggregated substructure of the composite-index vulnerability scores for the Port of Hempstead, NY. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population inside Flood Plain," "Environmental Index - ESI" and "Hundred Year High Water" scored higher than the "Social Vulnerability Score."

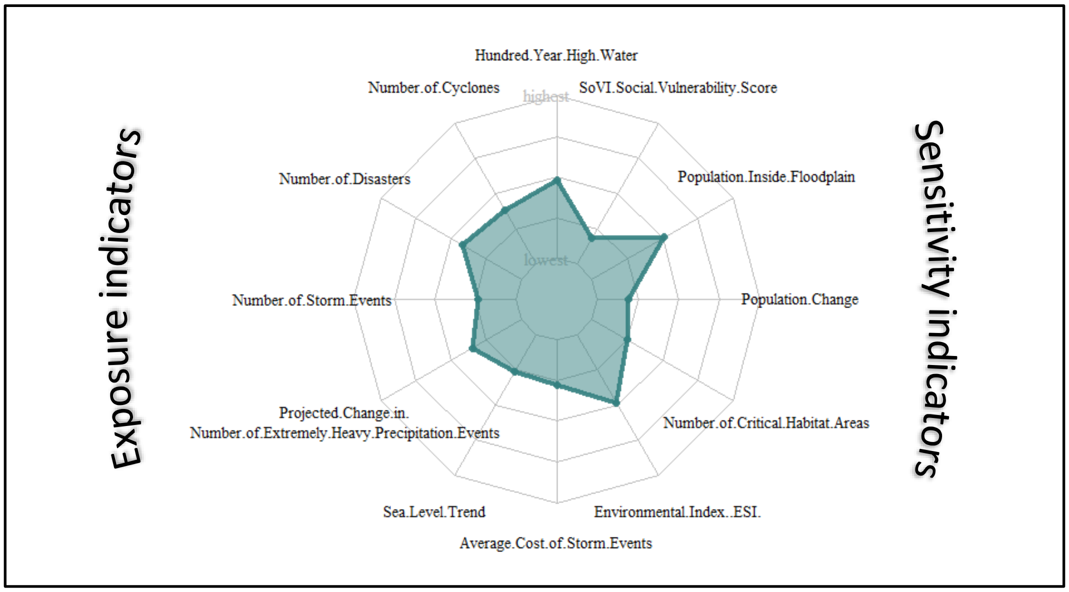


Figure L-9. The disaggregated substructure of the composite-index vulnerability scores for the Port of Hopewell, VA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Projected Change in Number of Extremely Heavy Precipitation Events" and "Sea Level Trend" scored higher than "Number of Storm Events" or "Number of Disasters."

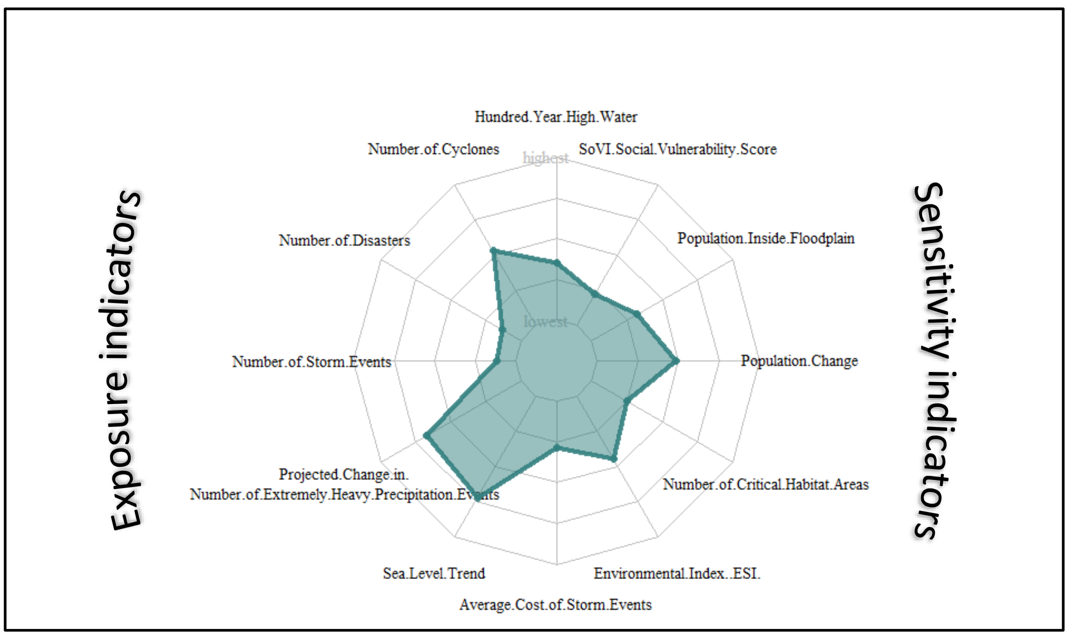


Figure L-10. The disaggregated substructure of the composite-index vulnerability scores for the Port of Marcus Hook, PA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Number of Storm Events" scored higher than most of other indicators and the "Environmental Index - ESI" scored the lowest.

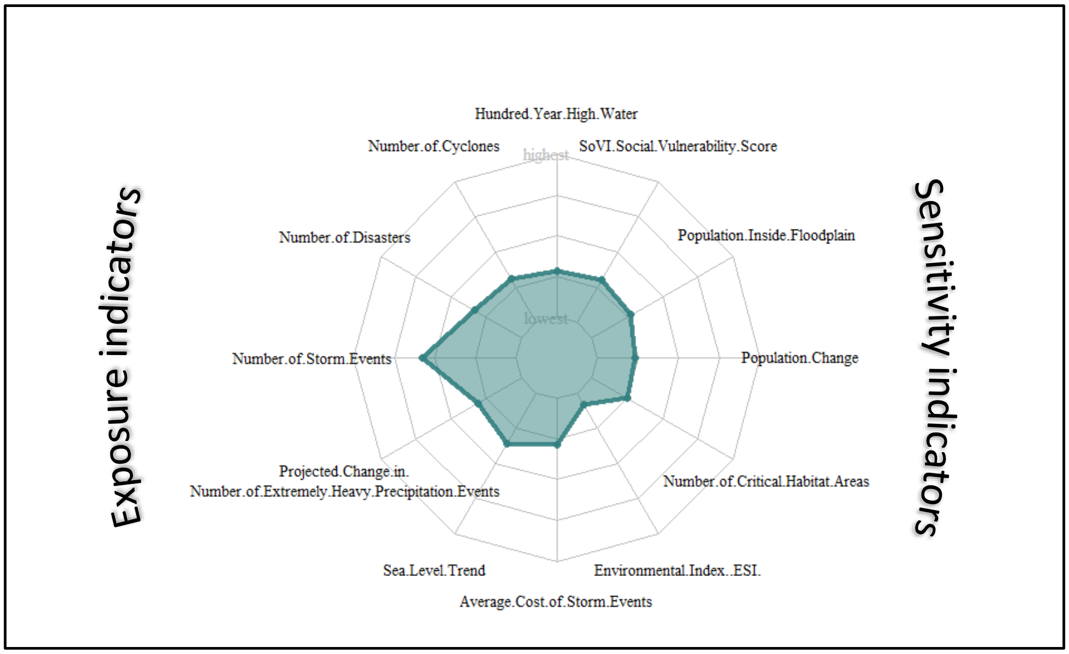


Figure L-11. The disaggregated substructure of the composite-index vulnerability scores for the Port of New Haven, CT. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Average Cost of Storm Events" scored higher than most of all the indicators, the second highest one being "Number of Disasters."

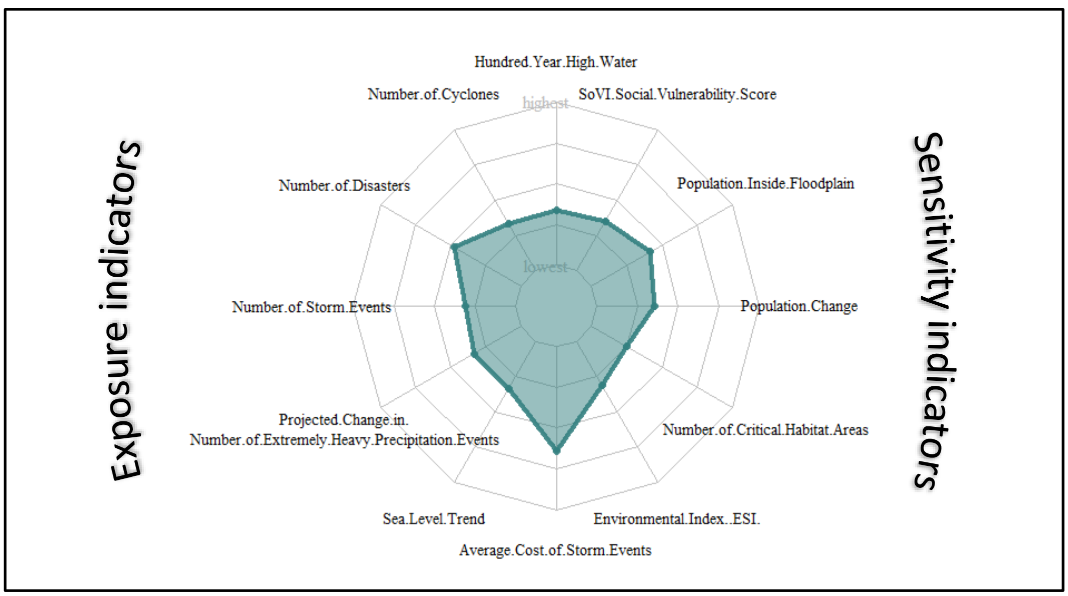


Figure L-12. The disaggregated substructure of the composite-index vulnerability scores for the Port of New York and New Jersey, NY and NJ. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicator for the "Social Vulnerability" scored higher than the indicator for "Number of Storm Events."

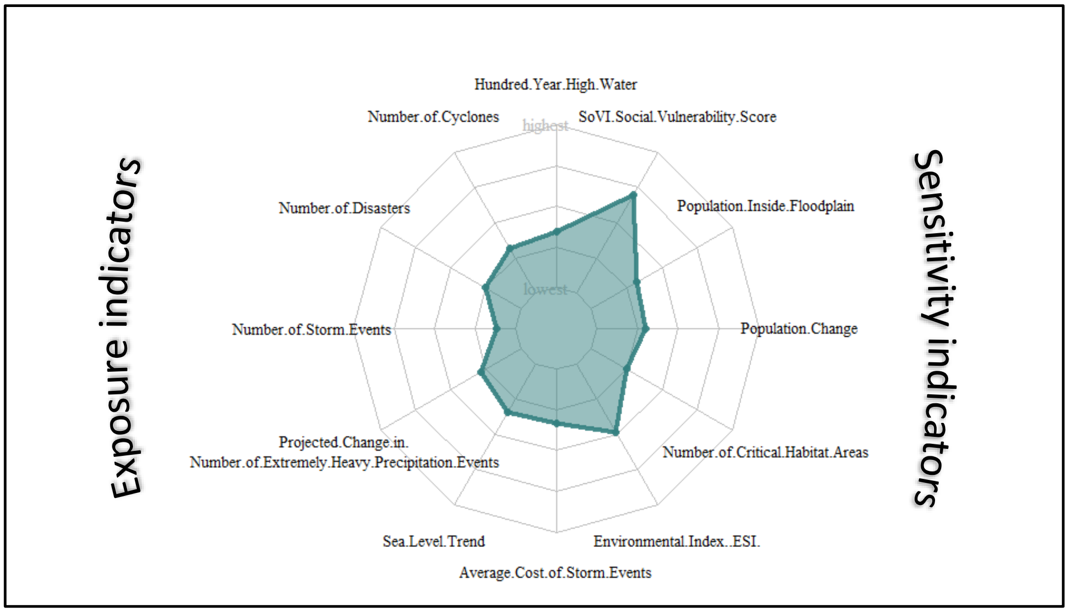


Figure L-13. The disaggregated substructure of the composite-index vulnerability scores for the Port of Paulsboro, PA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population Change" scored high, while the "Social Vulnerability Score", the "Number of Critical Habitat Areas" and the "Projected Change in Number of Extremely Heavy Precipitation Events" scored the lowest.

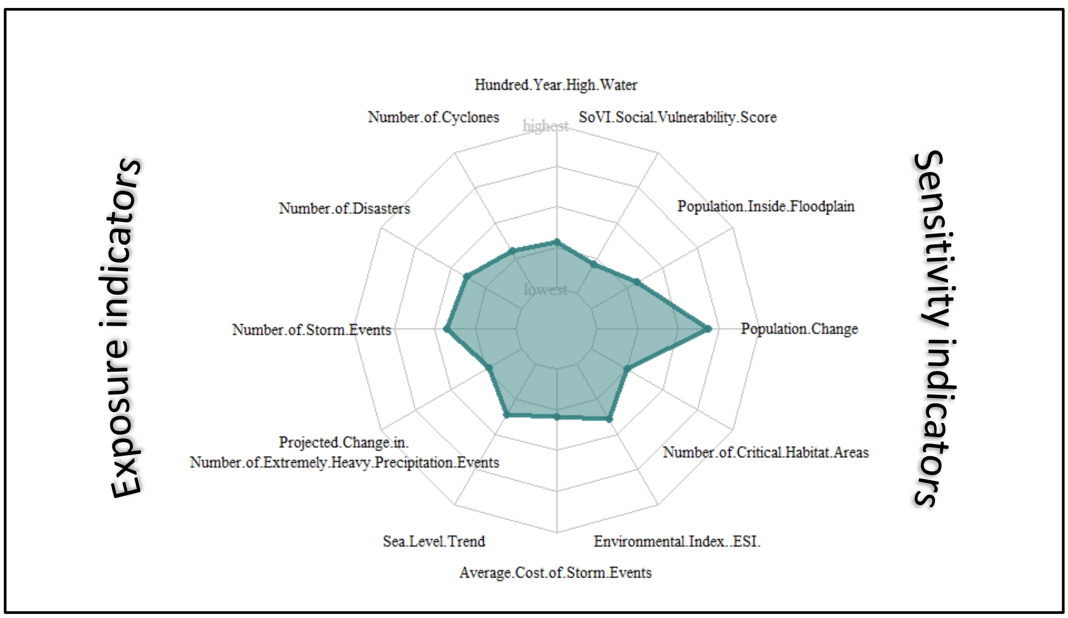


Figure L-14. The disaggregated substructure of the composite-index vulnerability scores for the Port of Penn Manor, PA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Most indicators scored low with the "Social Vulnerability Score" and the "Environmental Index – ESI" indicators scoring the lowest.

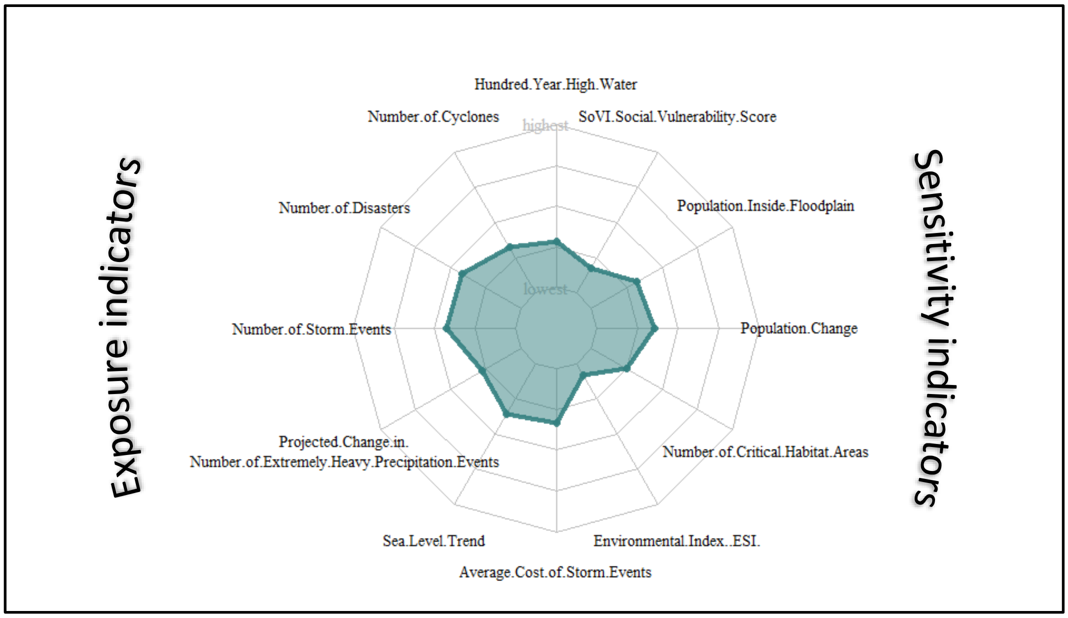


Figure L-15. The disaggregated substructure of the composite-index vulnerability scores for the Port of Philadelphia, PA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Projected Change in Number of Extremely Heavy Precipitation Events" and the "Social Vulnerability" scored higher than the indicators for "Environmental Index" and "Population Inside Floodplain."

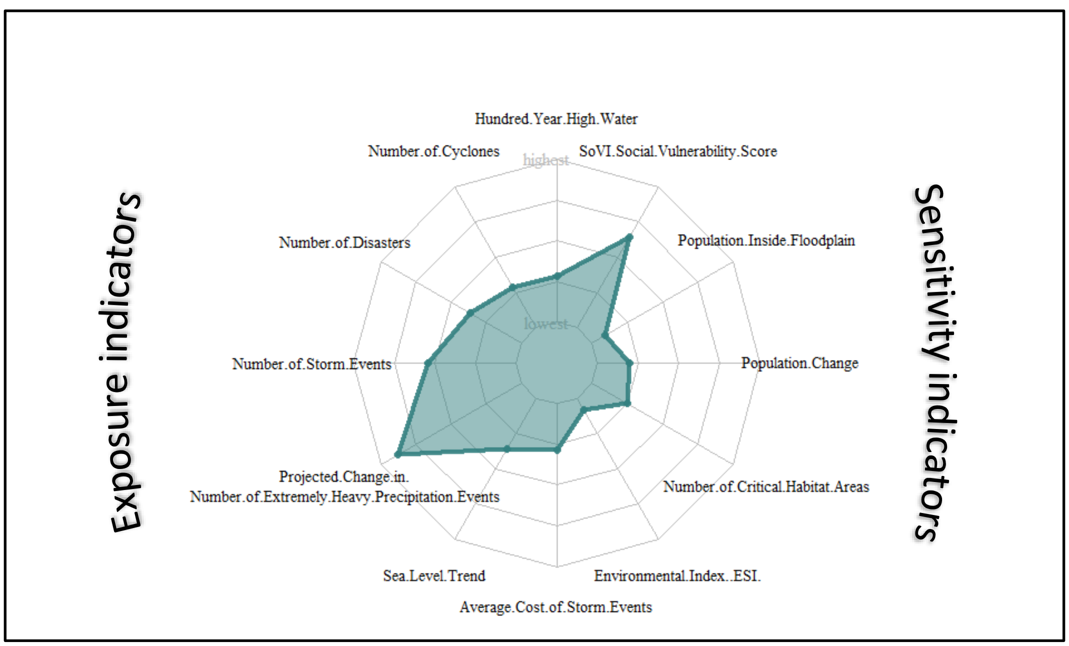


Figure L-16. The disaggregated substructure of the composite-index vulnerability scores for the Port of Portland, ME. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Number of Disasters" and "Projected Change in Number of Extremely Heavy Precipitation Events" scored higher than the indicator for "Sea Level Trend."

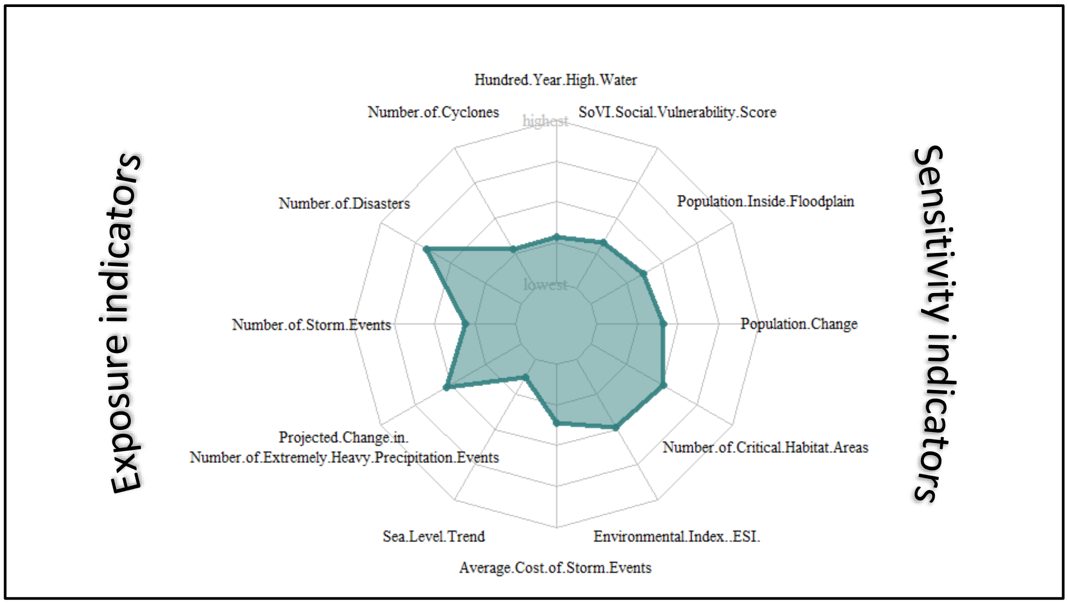


Figure L-17. The disaggregated substructure of the composite-index vulnerability scores for the port of Port Jefferson, NY. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. The indicator for "Number of Storm Events" scored higher that the indicators for "Social Vulnerability Score" and "Population inside Floodplain."

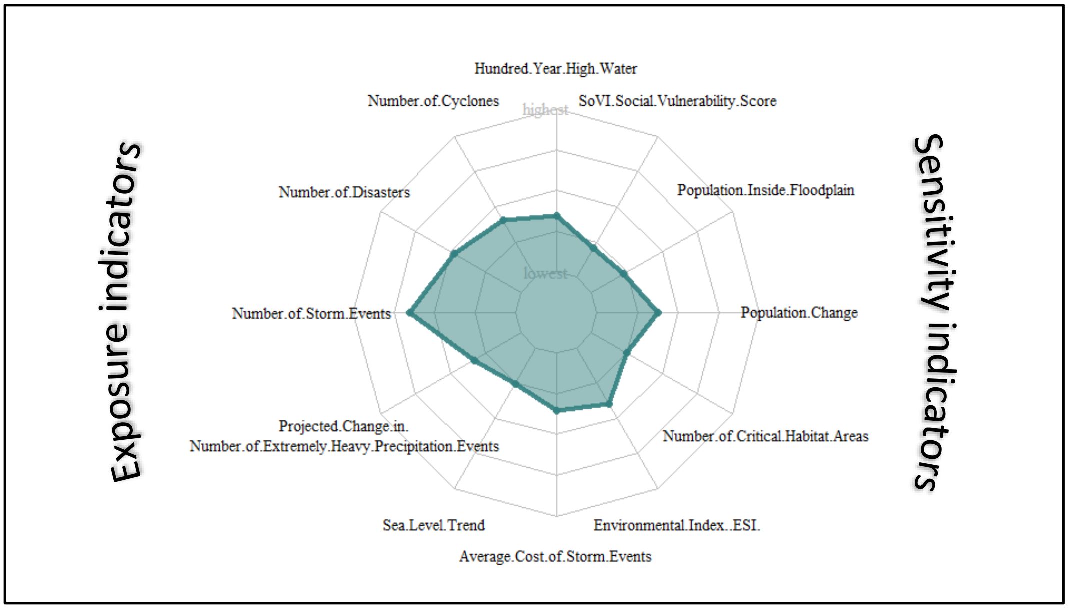


Figure L-18. The disaggregated substructure of the composite-index vulnerability scores for the Port of Portsmouth, NH. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population Inside Floodplain" and the "Environmental Index - ESI" scored higher than the indicators for "Sea level Trend" and the "Social Vulnerability Score."

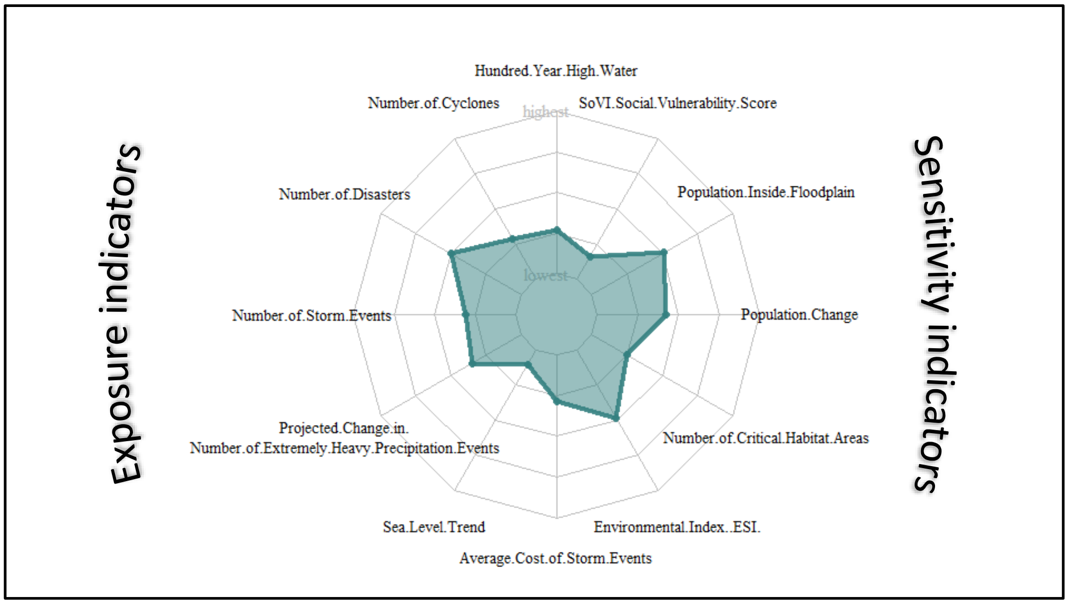


Figure L-19. The disaggregated substructure of the composite-index vulnerability scores for the Port of Providence Port, RI. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals only slight differences underlying the port's vulnerability. Indicator for "Number of Critical Habitat Areas" scored higher than the indicator for the "Number of Storm Events."

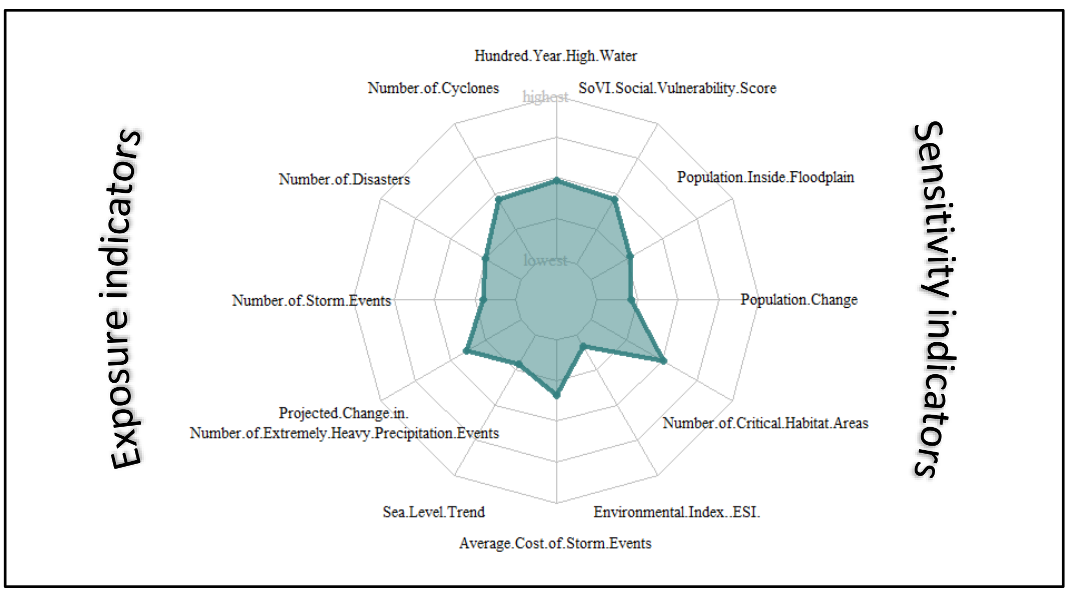


Figure L-20. The disaggregated substructure of the composite-index vulnerability scores for the Port of Searsport, ME. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Population Change," "Number of Critical Habitat Areas and the "Environmental Index – ESI" scored higher than the indicator for the "Number of Storm Events."

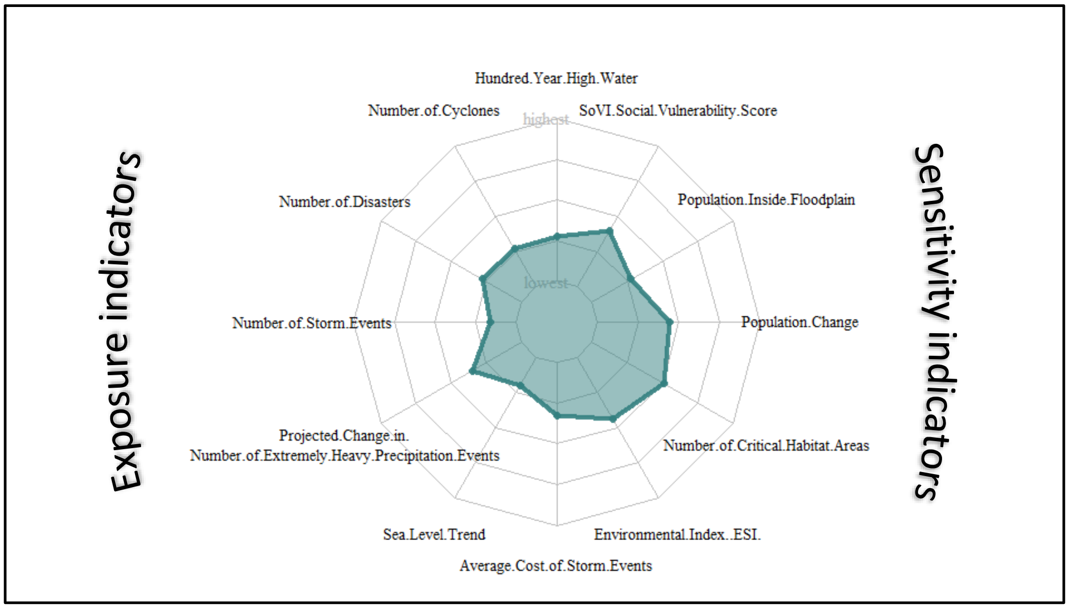


Figure L-21. The disaggregated substructure of the composite-index vulnerability scores for the Port of Virginia, VA. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals only slight differences underlying the port's vulnerability. Indicators for "Number of Cyclones" and "Population Inside Floodplain" scored higher than the indicators for the "Number of Disasters."

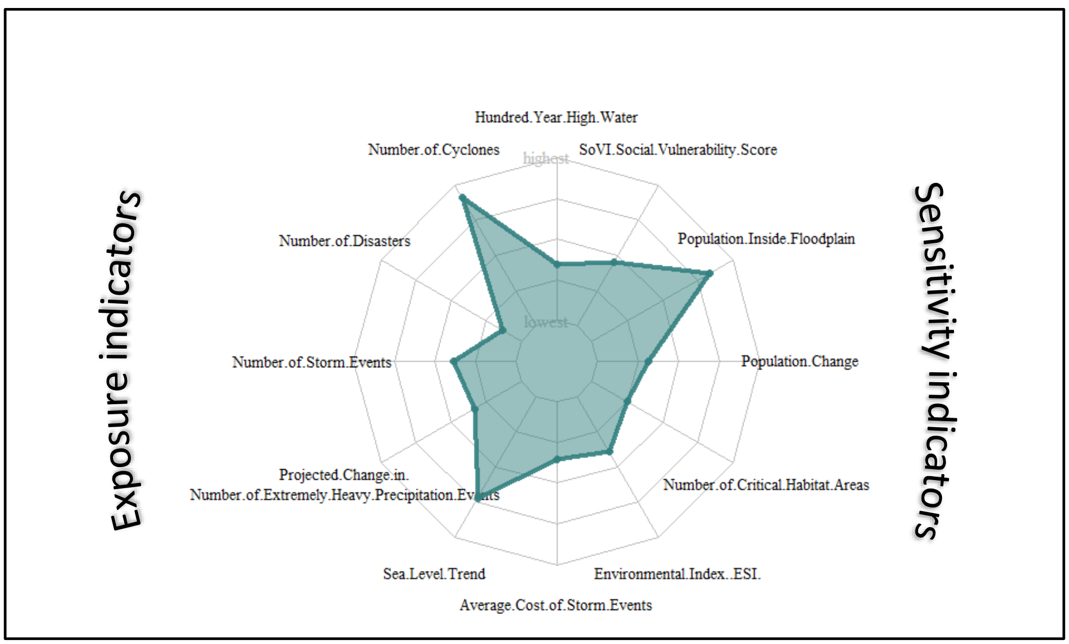
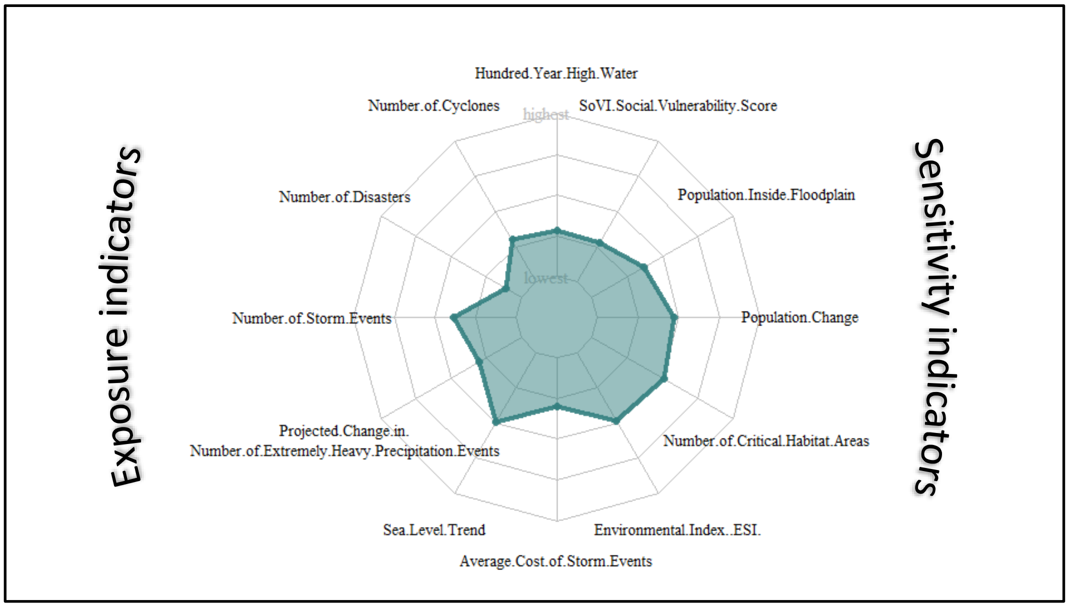


Figure L-22. The disaggregated substructure of the composite-index vulnerability scores for the Port of Wilmington, DE. Indicators of exposure are on the left half of the plot, and indicators of sensitivity are on the right half. Comparing individual indicators reveals differences underlying the port's vulnerability. Indicators for "Projected Change in Number of Extremely Heavy Precipitation Events" and "Number of Storm Events" scored higher than the indicator for the "Number of Disasters."



Appendix M: Abbreviations and Acronyms

AHP	Analytic Hierarchy Process
CENAD	Corps of Engineers North Atlantic Division
CCVA	Climate Change Vulnerability Assessment
ERDC	U.S. Army Engineer Research and Development Center
GIS	Geographic Information System
IBVA	Indicator-Based Vulnerability Assessment
IPCC	Intergovernmental Panel for Climate Change
KRNW	Knowledge Resource Nomination Worksheet
MTS	Marine Transportation System
RIAT	Resilience Integrated Action Team
URI	University of Rhode Island
USACE	United States Army Corps of Engineers (U.S. government)
VAS	Visual Analogue Scale
WSM	Weighted Sum Model

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	Square meters
feet	0.3048	Meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
gross tons (2,240pounds)	1.2023	Metric tons
Inches	0.0254	Meters
horsepower (550 foot-pounds force per second)	745.6999	watts
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	Meters
mils	0.0254	Millimeters
quarts (U.S. liquid)	9.463529 E-04	cubic meters
tons (long) per cubic yard	1,328.939	kilograms per cubic meter
tons (2,000 pounds, mass) or short tons	907.1847	Kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
tons (2,000 pounds, mass)	1.2023	Metric tons
yards	0.9144	meters

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14. ABSTRACT
This research identified vulnerability indicators from open-data sources that represent the three components of vulnerability, as outlined by the Intergovernmental Panel on Climate Change: exposure, sensitivity, and adaptive capacity. With input from experts knowledgeable in port operations, planning, policy, and data, researchers refined a set of high-level vulnerability indicators to answer the following key questions: (1) how sufficient is the current state of U.S. seaport sector data for developing expert-supported vulnerability indicators for a regional sample of ports and (2) how can indicators be used to measure the relative vulnerability (i.e., exposure, sensitivity, and adaptive capacity) of multiple ports? Using open-data sources, this study developed an Indicator-Based Vulnerability Assessment methodology that integrates multiple vulnerability indicators for ports in the North Atlantic region. The Analytic Hierarchy Process, a technique for organizing and analyzing complex decisions using pairwise comparisons, was used to develop a ranking that matched 3 of the top-4 most vulnerable ports that were subjectively identified by port experts. This demonstrates strong promise for this methodological approach to measure seaport vulnerability to climate and extreme weather events. Indices of seaport relative vulnerability to climate and extreme weather can advance goals for a resilient Marine Transportation System by informing efforts and plans to prioritize and allocate limited resources.

15. SUBJECT TERMS
Climatic changes—Risk assessment, Harbors, Inland navigation, Navigable waters, Navigation, Waterways

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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