Toward a Comparative Index of Seaport Climate-Vulnerability: Developing Indicators from Open-Data
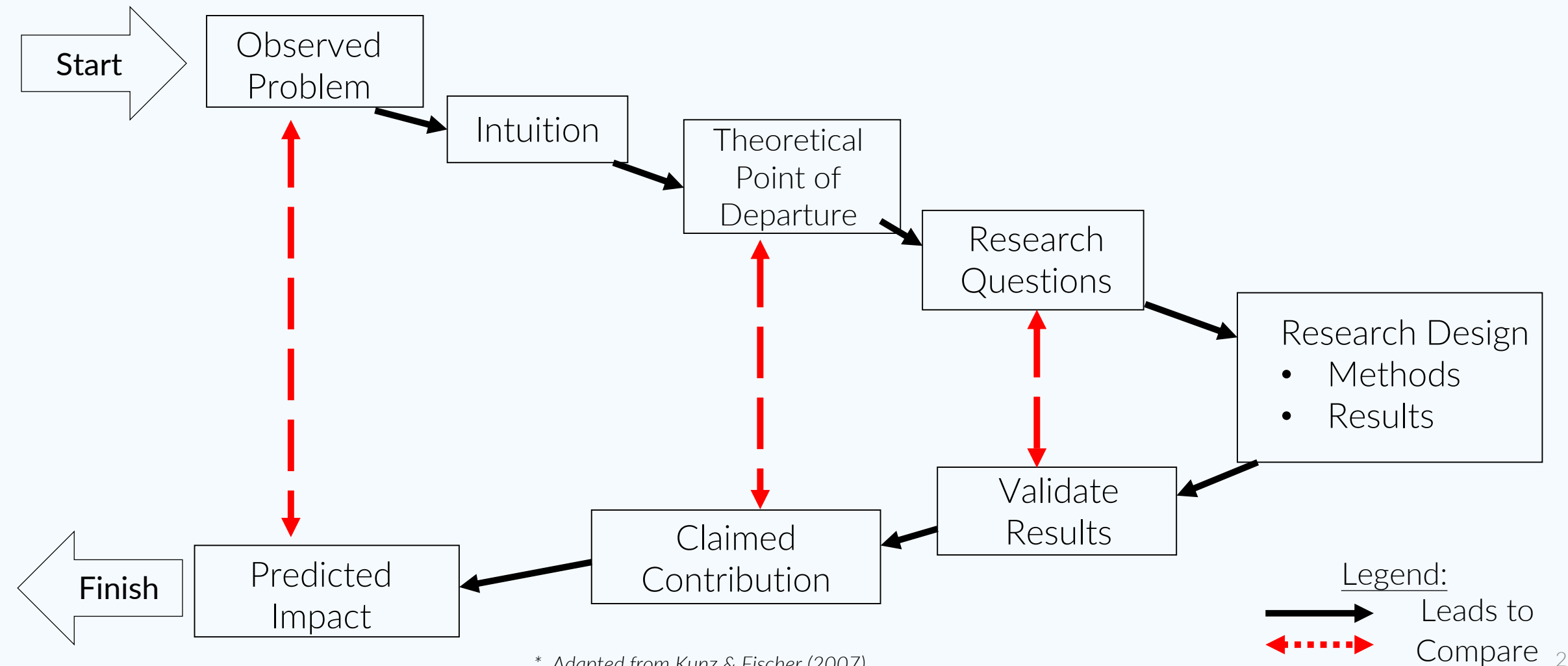
R. Duncan McIntosh
Austin Becker
Elizabeth Mclean
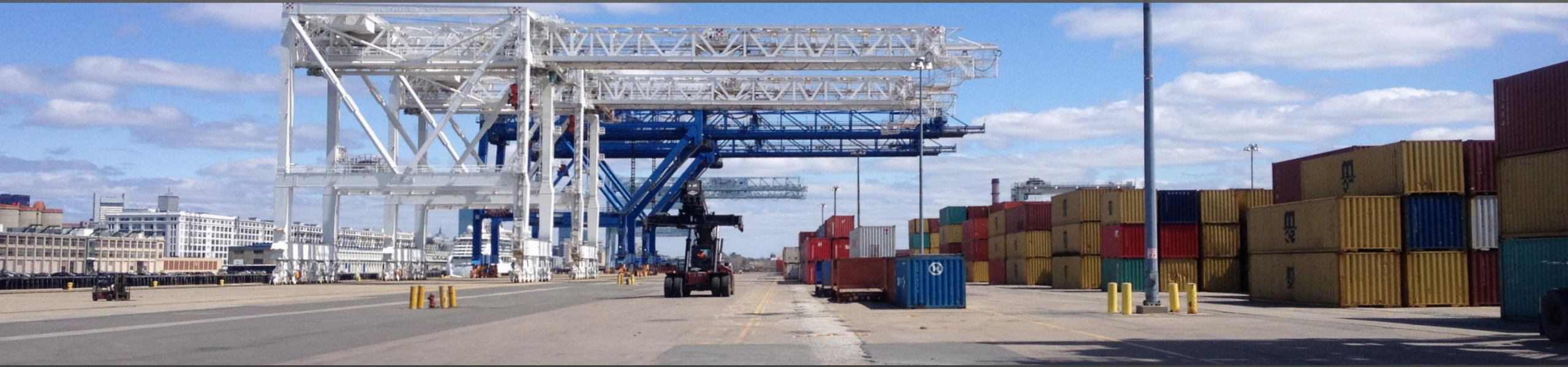
THE UNIVERSITY OF RHODE ISLAND
DEPARTMENT OF MARINE AFFAIRS

Research Horseshoe

Start → Observed Problem → Intuition → Theoretical Point of Departure → Research Questions → Research Design (• Methods • Results) → Validate Results → Claimed Contribution → Predicted Impact → Finish

Legend:
→ Leads to
⟷ Compare
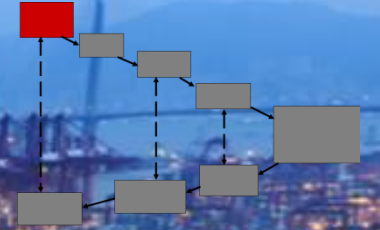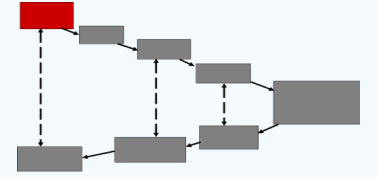
Adapted from Kunz & Fischer (2007)

Why Seaports?

- **Critical**: > 90% of global trade carried by sea (IMO 2012)

- **Constrained**: functionally restricted to water's edge

- **Exposed**: to impacts from today's weather extremes & tomorrow's projected climatic changes
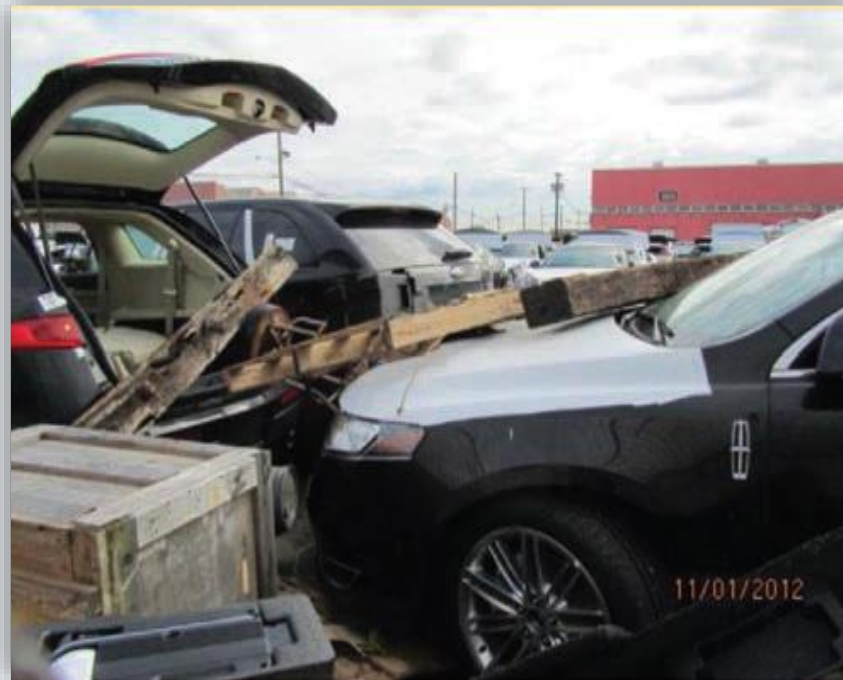
Photo: NYT 2016

3

Ports Are Being Damaged

Port of NY/NJ during and after Superstorm Sandy[1]

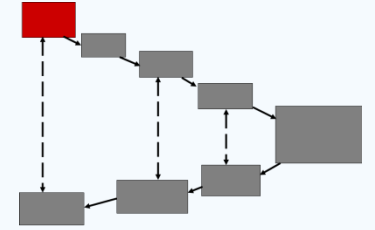1. Southworth, F., J. Hayes, S. McLeod, and A. Strauss-Wieder, 2014: *Making US Ports Resilient as Part of Extended Intermodal Supply Chains.*

Responsible Stakeholders Face Difficult Climate-Adaptation Decisions

Examples:

Single-Port Scale:

Which specific adaptation actions should my port take?

Multi-Port Scale:

Which ports in my jurisdiction are the most vulnerable and urgently in need of attention?

Vulnerability Assessments Provide Decision-Support
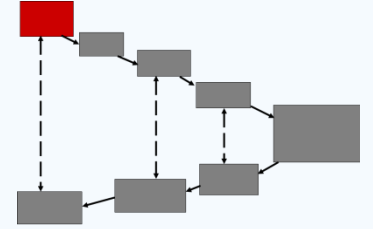
Vulnerability assessment = first step for risk-reduction & climate-adaptation[1]

Climate change vulnerability assessments (CCVA) can support climate-adaptation decisions by:

- bringing data into the conversation

- addressing the question; *Adapt to what?*

1. IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change (SREX)9781139177245.

CCVA for Seaports
Has Neglected the Multi-Port Scale
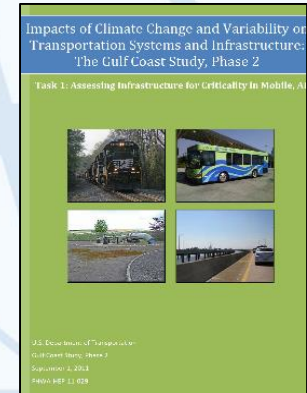
Most efforts to date have been at the **single-port scale**:

- **Self-assessment tools**: *Ports Resilience Index: A Port Management Self-Assessment*[1]

- **Case-studies**: *DOT Gulf Coast Study: Assessing Infrastructure for Criticality in Mobile, Alabama*[2]

    → Good at supporting single-port adaptation-decisions.

Problem: Difficult to compare *relative* vulnerability across ports

1 Morris, Lauren L., and Tracie Sempier. 2016. Ports Resilience Index: A Port Management Self-Assessment. U.S. Department of Commerce, Gulf of Mexico Alliance.
2 USDOT, 2014: Impacts of Climate Change and Variability on Transportation Systems and Infrastructure The Gulf Coast Study, Phase 2 Screening for Vulnerability Final Report, Task 3.1FHWA-HEP-14-033.
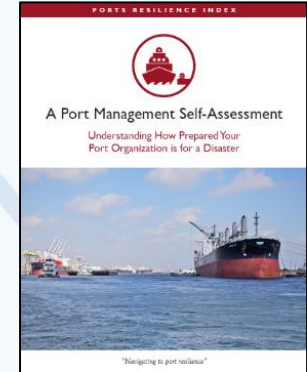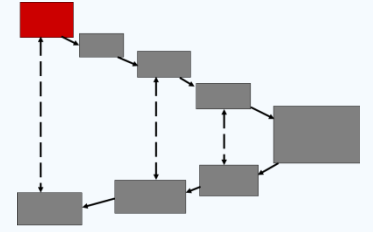
A Comparative Approach is Needed
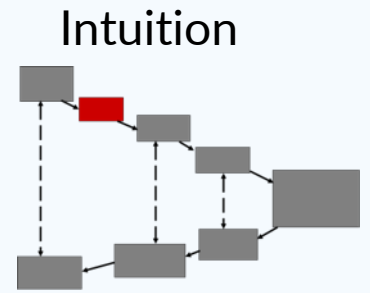
At the Multi-Port Scale:

- Insufficient resources to adapt all ports[1] ➔ Prioritization needed

- Prioritization involves comparing *relative* vulnerabilities across seaports

Intuition:

Development of a *comparative* CCVA approach for ports could fill the gap and support climate-adaptation decisions at the multi-port scale.

- **Comparative:** allows direct comparison of relative climate vulnerability among seaports

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1. Becker, A., N. T. Chase, M. Fischer, B. Schwegler, and K. Mosher, 2016: A method to estimate climate-critical construction materials applied to seaport protection. *Global Environ Chang,* **40, 125-136.**

Comparative Assessments in the Literature
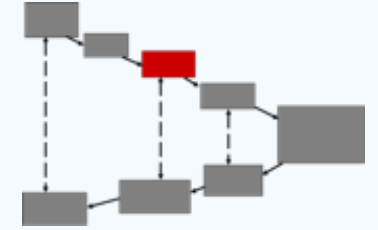
Comparative assessments of theoretical concepts (*vulnerability, resilience*) commonly based on indicators (Gallopin 1997, Hinkel 2011)

- **Indicators**: Measurable, observable quantities that serve as proxies for an aspect of a system that cannot itself be directly, adequately measured (Gallopin 1997, Hinkel 2011)

  - Can yield *composite-indices*, which synthesize multiple indicators into a single composite score, allowing for *direct comparisons* (Dedeke 2013)
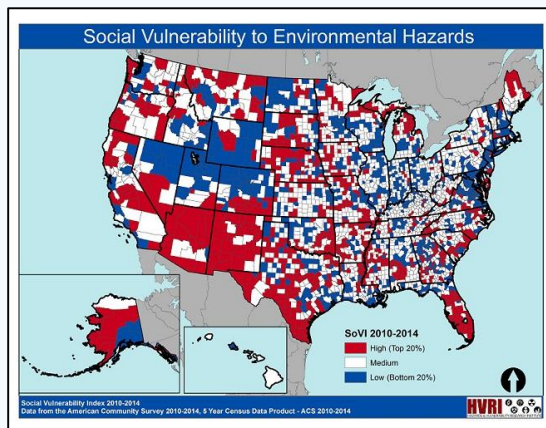
Social Vulnerability Index (SoVI)
(Cutter, Boruff and Shirley 2003)
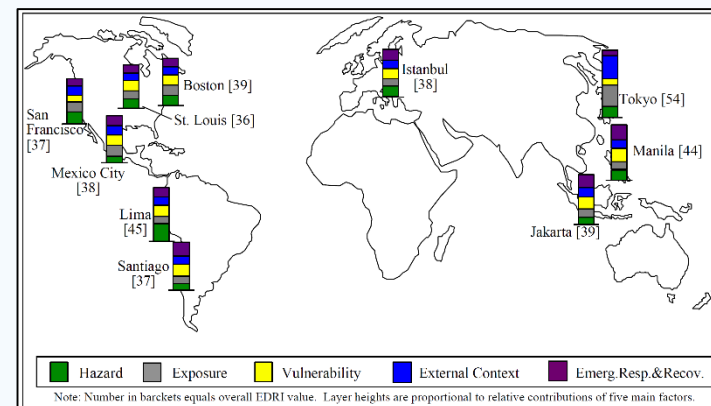
Earthquake Disaster Risk Index (EDRI)
(Davidson and Shah 1997)
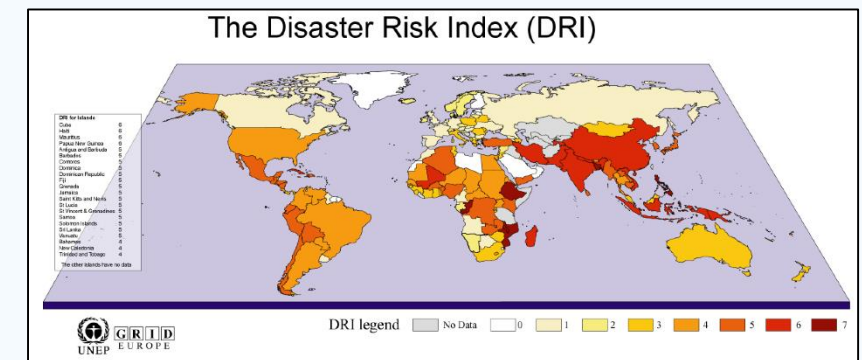
Disaster Risk Index
(Peduzzi et al. 2009)

9
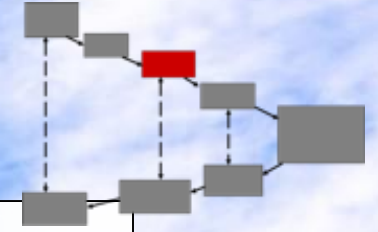
The Indicator-Based Assessment Process

Steps in the Process: (Hinkel 2011)

1. Define the response

2. Select indicators

3. Aggregate indicators into a 'score'

    *   This step may be omitted, but necessary to yield a comparative index

Strengths:

*   Can bring data into decision-making process

*   Results can be directly compared

Caveats:

*   Results lack high-resolution detail; appropriate for high-level overview only

*   Critical decision-support should always be supplemented with additional expertise
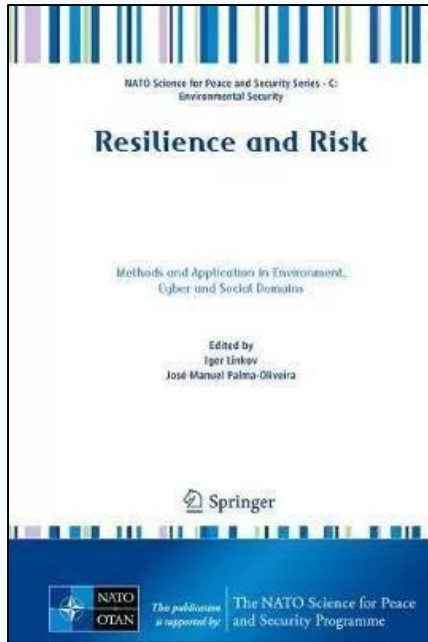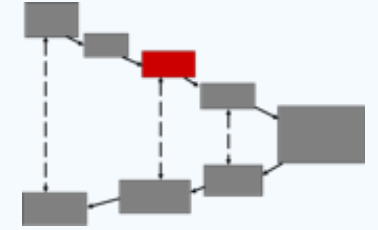
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Manuscript 1

Seaport Climate Vulnerability Assessment at the Multi-Port Scale: A Review of Approaches

R. Duncan McIntosh, PhDc* and Austin Becker, PhD
University of Rhode Island Dept. of Marine Affairs
Kingston, RI 02881

McIntosh, R. D., 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*, I. Linkov, and J. M. Palma-Oliveira, Eds., Springer Netherlands, *205-224.*

Summary of IBA Applied to Ports
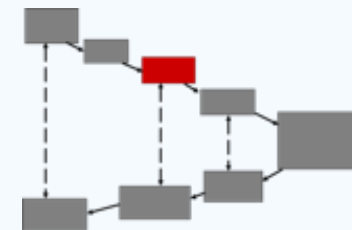
- Hsieh et al. only method to aggregate indicators into a 'score'
- Expert-elicitation is common approach to select indicators
- Opportunity exists to further develop indicator-based CCVA for port sector

Study	Response Indicated	Indicator Selection Method	Indicator Aggregation Method
PPRISM (ESPO)	Port Performance	• Literature Review • Expert Survey	Not aggregated
Nichols and Hanson et al.	Number of People & $ of Assets Below Flood Elevation	• Not true indicators	
Hsieh et al.	Port Interdependency	• Participatory discussion process with experts • Delphi Method	• Analytic Network Process • Weighted Sum Model
NOAA Port Tomorrow	Port Resilience	• Literature Search • Guiding-questions	Not aggregated

Theoretical Point of Departure
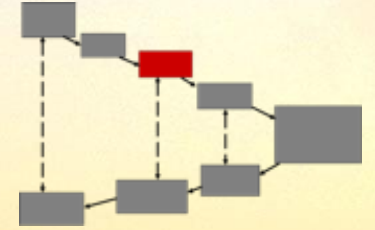
- Multi-port climate-adaptation decisions can be supported by comparative, indicator-based assessments and indices

- Most CCVA for ports to date has been limited to the *single-port* scale

- Most *multi-port* assessments stop short of comparative CCVA or focus on other concepts (e.g., performance)

  - No examples of a comparative index of climate-vulnerability for ports

Photo: Savannah Pilots

Research Questions

1. How sufficient is the current state of openly available data for and about the seaport sector to develop expert-supported climate-vulnerability indicators for ports?

    *   Objective: To investigate the suitability of openly available data to serve as indicators of seaport climate-vulnerability

2. How will a composite-index of port climate-vulnerability, based on expert-weighted open-data indicators, compare to experts' subjective port vulnerability rankings?

    *   Objective: To investigate the ability of an indicator-based composite index to measure relative port climate-vulnerability

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Photo: w-dog.net
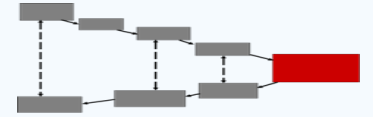
Research Design

Manuscript 2: RQ1

Manuscript 3: RQ2

Literature Review
- Start with definition of Vulnerability (IPCC)
- Sought indicators of *exposure, sensitivity, adaptive capacity* for ports
- 108 Candidate Indicators

Check Data Availability for Study Area Ports
- 48 Candidate Indicators
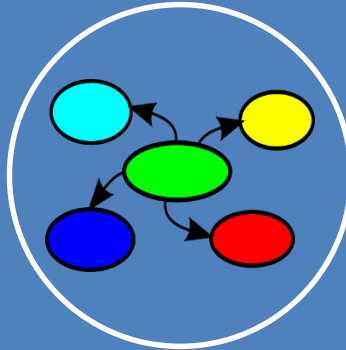
Mind Map Exercise
- 9 Federal experts from CMTS RIAT evaluated indicators for correlation
- 34 Candidate Indicators

Expert Evaluation Survey
- 64 Port-Experts rated indicators for correlation with *exposure, sensitivity* and *adaptive capacity*
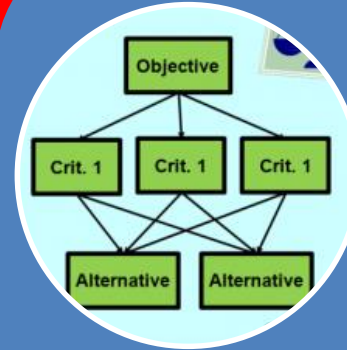
Analytic Hierarchy Process
- 37 Port-Experts generated indicator weights via pairwise comparisons

Aggregate Indicators into Prototype Composite-Index
- Using AHP-derived weights

North Atlantic Medium and High Use Ports

Searsport, ME
Portland, ME
Portsmouth, NH
Albany, NY
Boston, MA
Providence, RI
Fall River, MA
Bridgeport, CT
New Haven, CT
Port Jefferson, NY
Penn Manor, PA
Hempstead, NY
Philadelphia, PA
New York, NY and NJ
Chester, PA
Camden-Gloucester, NJ
Marcus Hook, PA
Paulsboro, NJ
Wilmington, DE
New Castle, DE
Baltimore, MD
Hopewell, VA
Virginia, VA, Port of

Medium Use: 1M - 10M Tons Annual Throughput
High Use: >10M Tons Annual Throughput

Data: USACE Principal Ports 2015

0 50 100 200 Miles

Study Area

Ports of the USACE North Atlantic Division with > 1M tons Annual Throughput

Manuscript 2:
Refining Candidate Indicators
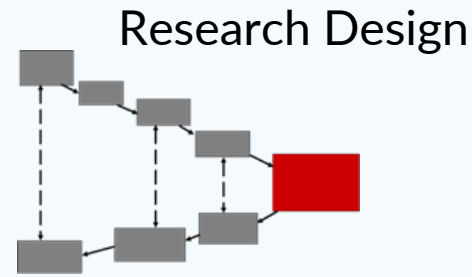
Literature Review

- Start with definition of Vulnerability (IPCC)
- Sought indicators of *exposure, sensitivity, adaptive capacity* for ports

108 Candidate Indicators

Check Data Availability for Study Area Ports

48 Candidate Indicators
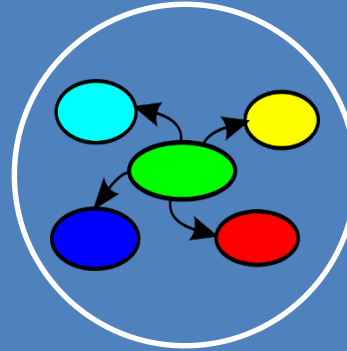
Mind Map Exercise

9 Federal experts from CMTS RIAT evaluated indicators for correlation

34 Candidate Indicators

1. Start with definition of climate-vulnerability
   - Identified 108 candidate indicators from literature

2. Eliminated those without a source of data for at least 16 of the 22 sample ports

3. Mind map exercise:

Candidate Indicator Mind Map

Resulted in a set of 34 Candidate Indicators

Manuscript 2:
Evaluation of 34 Candidate Indicators

Expert Evaluation Survey

- 64 Port-Experts rated indicators for correlation with *exposure, sensitivity* and *adaptive capacity*
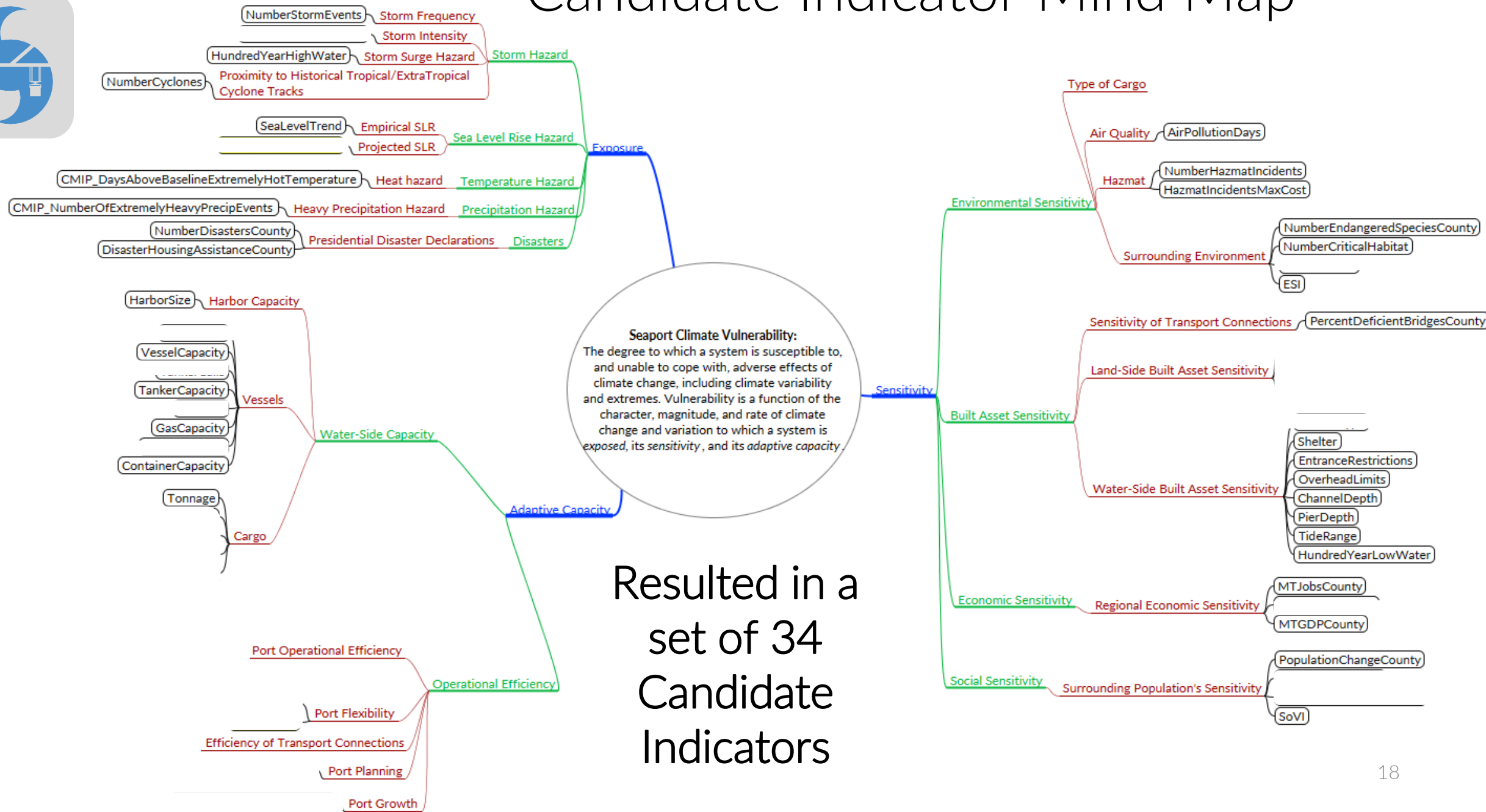
Experts in:

- seaport operations, planning, policy, data

- vulnerability of U.S. MTS to climate and extreme weather

Snowball sampling:

- 154 port-experts invited

  - 64 participated (42%)

Expert Self-Identification

Non-governmental Organization 2%
State Government 2%
Other 10%
Consultant 13%
Academic 21%
Practitioner 6%
Federal Government 46%

Manuscript 2:
Evaluation of 34 Candidate Indicators

Expert Evaluation Survey

- 64 Port-Experts rated indicators for correlation with *exposure, sensitivity* and *adaptive capacity*
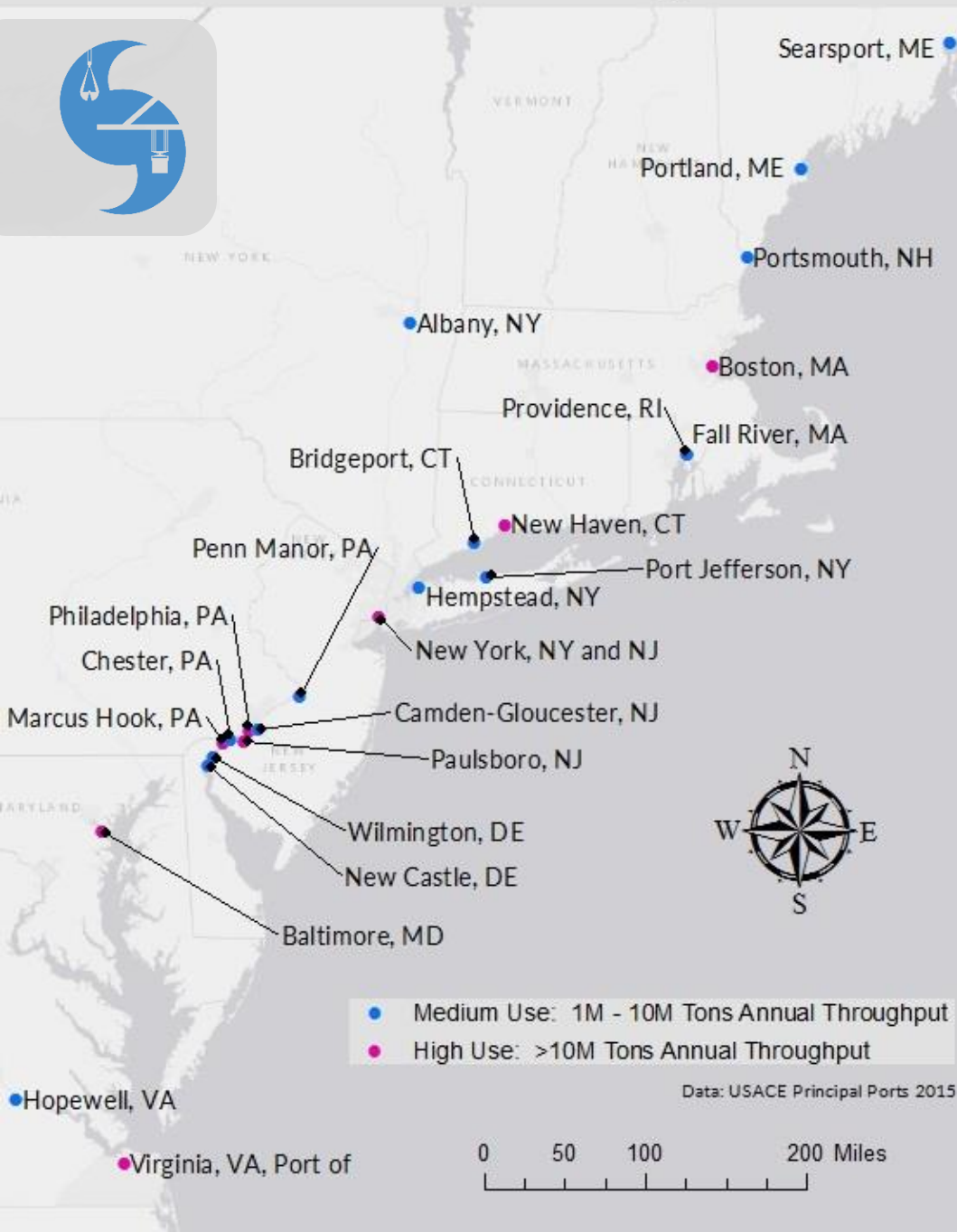
For each indicator:

- Determine whether it correlates with components of vulnerability

- Indicate the magnitude and direction of any correlation

	Decreases as **Sea Level Trend** increases	No Correlation	Increases as **Sea Level Trend** increases
	-100	0	100
Exposure			
Sensitivity			
Adaptive Capacity			

Manuscript 2: Results

34 Candidate indicators of seaport vulnerability to climate and extreme-weather:

Sorted by median expert-perceived magnitude of correlation with the three components of vulnerability

Port-Specific indicators in **bold**

Relatively low perceived correlation with adaptive capacity

Candidate Indicator:
- Population.Inside.Floodplain
- Sea.Level.Trend
- Hundred.Year.High.Water
- Number.of.Storm.Events
- Number.of.Critical.Habitat.Areas
- Average.Cost.of.Storm.Events
- Number.of.Cyclones
- Number.of.Disasters
- SoVI.Social.Vulnerability.Score
- Projected.Change.in.Number.of.Extremely.Heavy.Precipitation.Events
- Projected.Change.in.Days.Above.Baseline.Extremely.Hot.Temperature
- Population.Change
- **Tide.Range**
- **Shelter.Afforded**
- Percent.of.Bridges.Deficient
- **Entrance.Restrictions**
- **Harbor.Size**
- Environmental.Index..ESI.
- Hundred.Year.Low.Water
- **Containership.Capacity**
- **Marine.Transportation.GDP**
- **Vessel.Capacity**
- **Overhead.Limits**
- Number.of.Hazmat.Incidents
- **Marine.Transportation.Jobs**
- Number.of.Endangered.Species
- **Gas.Carrier.Capacity**
- **Tanker.Capacity**
- **Tonnage**
- Air.Pollution.Days
- Average.Cost.of.Hazmat.Incidents
- Disaster.Housing.Assistance
- **Channel.Depth**
- **Pier.Depth**

Legend:
- Adaptive Capacity
- Exposure
- Sensitivity

Median Expert-perceived Magnitude of Correlation (0 - 100)

Addressing Research Question 1:

1. How sufficient is the current state of openly available data for and about the seaport sector to develop expert-supported climate-vulnerability indicators for ports?

Key Findings:

- Open-data can be developed into expert-supported indicators of seaport climate *exposure* and *sensitivity*

- Relatively little expert-perceived correlation between open-data and a port's *adaptive capacity*

- Overall higher levels of expert-perceived correlation for *place-based* indicators than *port-specific* indicators

Manuscript 3
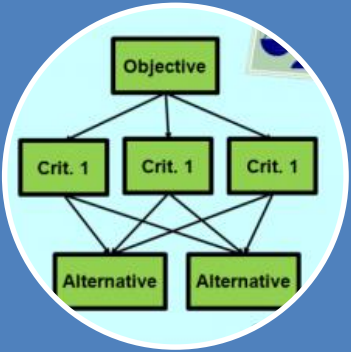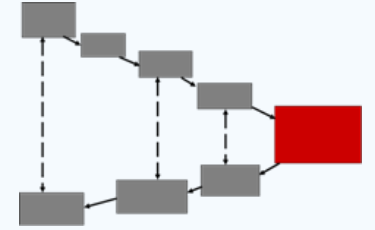
Analytic Hierarchy Process
- Experts generated indicator weights via pairwise comparisons

Aggregate indicators into composite-index
- Using AHP-derived weights and WSM

Objective:

To build and test a prototype composite-index of climate-vulnerability for a sample of ports

Design:

1. Applied AHP to generate weights for top-rated indicators from Manuscript 2

    • Lacking indicators of *adaptive capacity*

2. Aggregated indicators into prototype composite-index using weighted sum model

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Analytic Hierarchy Process (AHP)
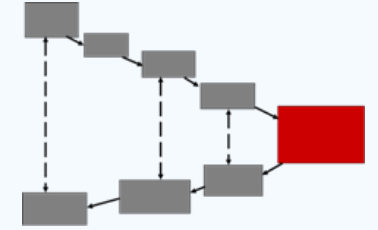
AHP: multi-criteria decision making process (Saaty 1977, Goepel 2013)

- Derives weights from pairwise-comparisons via an eigenvalue solution

For Port Climate-Vulnerability

- Experts compare 3 components
- Pairwise: Which is more important?

With respect to *Seaport Climate Exposure*, which criterion is more important?

For Exposure & Sensitivity

- Experts compare top 6 indicators
- Pairwise: Which is more important?

Sea Level Trend	18.0%	
Number of Disasters	20.0%	1
Number of Cyclones	14.3%	5
Number of Storm Events	19.6%	2
Hundred Year High Water	16.3%	4
...cted Change in Extreme Precip	11.8%	

AHP Generates Weights

- For each component of vulnerability
- For each indicator

AHP Design

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

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

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

(Goepel 2013)

AHP hierarchy showing equal weighting prior to pairwise comparisons

Adaptive Capacity	0.3333	
		Sea Level Trend	0.1667
		Number of Disasters	0.1667
		Number of Cyclones	0.1667
Exposure	0.3333	AHP
		Number of Storm Events	0.1667
		Hundred Year High Water	0.1667
		Projected Change in Extreme Precip	0.1667
Seaport Climate Vulnerability	AHP	
		Population Inside Floodplain	0.1667
		Average Cost of Storm Events	0.1667
		Number Critical Habitat Areas	0.1667
Sensitivity	0.3333	AHP
		SoVI Social Vulnerability Score	0.1667
		Population Change	0.1667
		Environmental Sensitivity Index ESI	0.1667

AHP Results

Component	Weight	Rank
Exposure	.394	1
Adaptive Capacity	.390	2
Sensitivity	.216	3

Indicator of Exposure	Weight	Rank
Number of Disasters	.200	1
Number of Storm Events	.196	2
Sea Level Trend	.180	3
Hundred Year High Water	.163	4
Number of Cyclones	.143	5
Projected Change in Extreme Precip	.118	6

Indicator of Sensitivity	Weight	Rank
Population Inside Floodplain	.229	1
SoVI Social Vulnerability Score	.213	2
Average Cost of Storm Events	.210	3
Environmental Sensitivity Index	.125	4
Population Change	.119	5
Number Critical Habitat Areas	.104	6
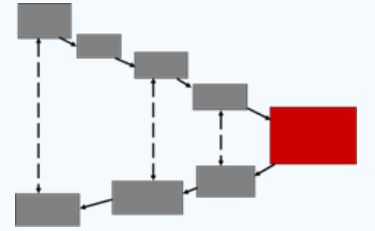
Constructing a Prototype Composite-Index

Aggregate indicators into composite-index

- Using AHP-derived weights and WSM

- Compiled indicator data for sample ports

- Standardized using z-scores: $z = \dfrac{X - \mu}{\sigma}$

  Distance from mean value

  Standard deviation

- Aggregated indicators via a weighted-sum model:

  Weight of indicator I_j

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

  Vulnerability score of port A_i

  Performance of port A_i in terms of indicator I_j

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Results

Aggregate indicators into composite-index
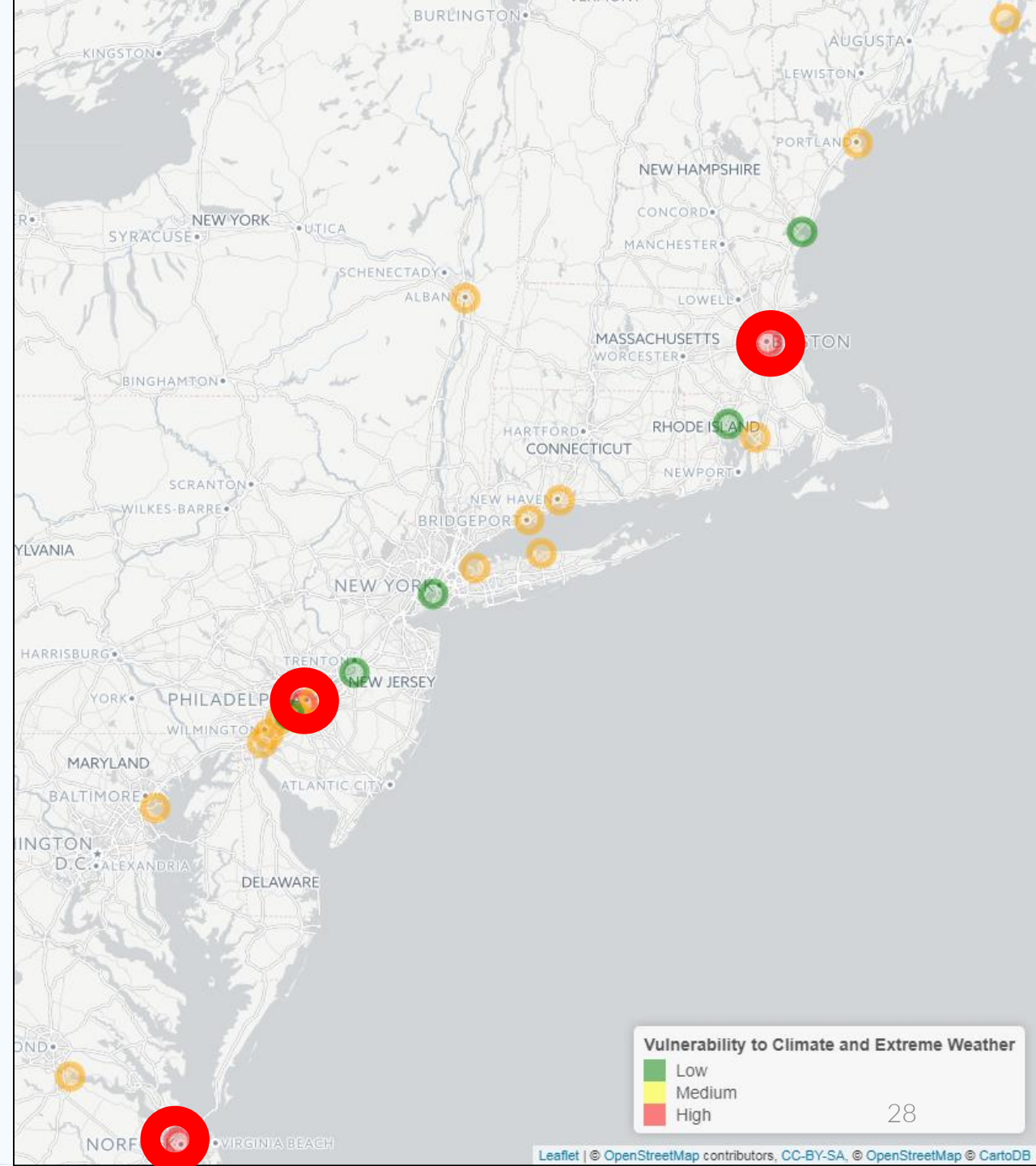
• Using AHP-derived weights and WSM

Potential hot-spots of vulnerability:

- Port of Boston

- Port of Philadelphia

- Port of Virginia

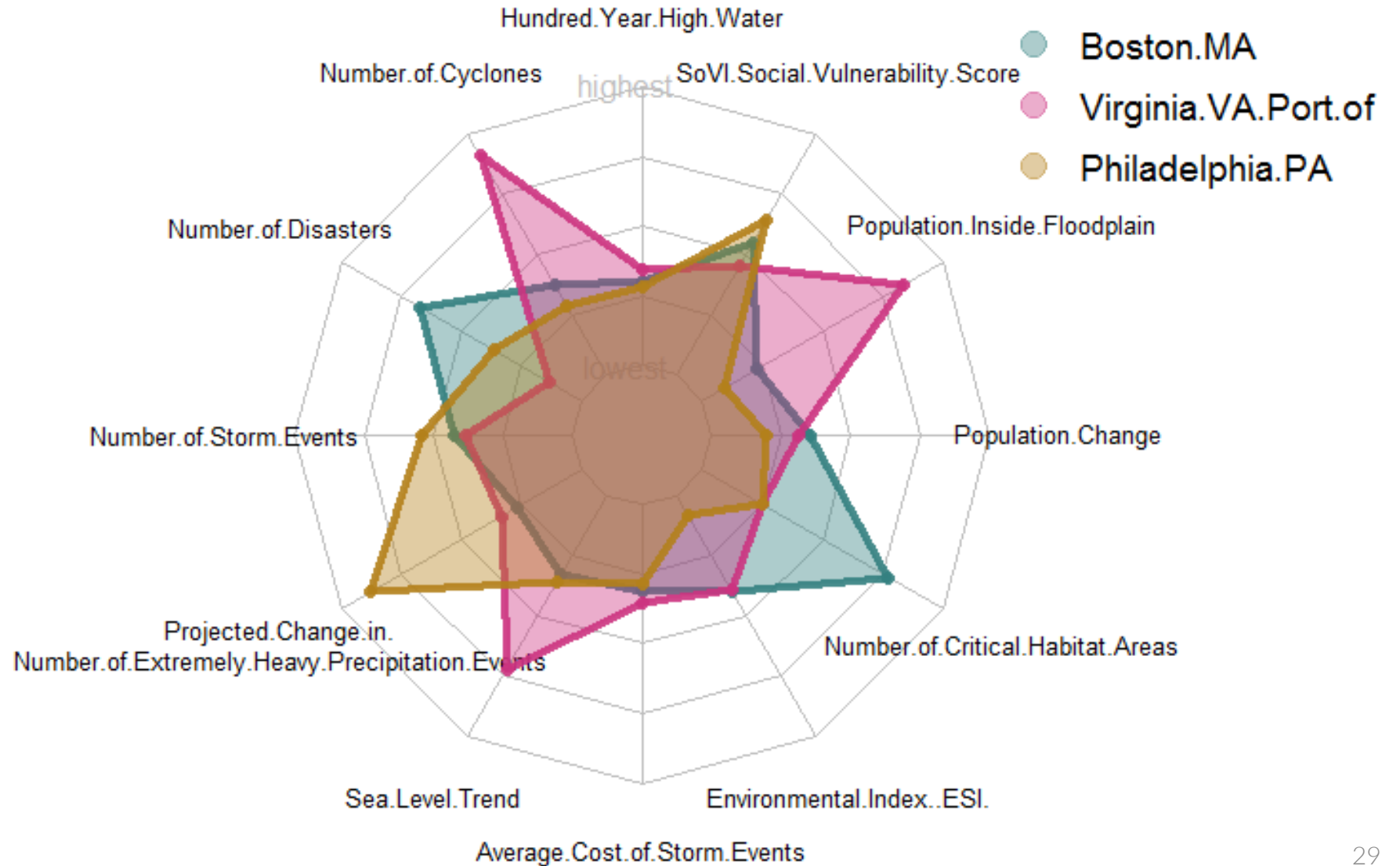Vulnerability to Climate and Extreme Weather
- Low
- Medium
- High

Leaflet | © OpenStreetMap contributors, CC-BY-SA, © OpenStreetMap © CartoDB

Boston vs Virginia vs Philadelphia

Visualize individual indicators

- Disaggregated sub structure

Validate Results

North Atlantic Medium and High Use Ports

Port-experts subjectively ranked:

• 10 **most vulnerable ports** and

• 10 **least vulnerable ports** out of the sample

Expert rankings were then compared to model rankings from the prototype composite-index

Searsport, ME
Portland, ME
Portsmouth, NH
Albany, NY
Boston, MA
Providence, RI
Fall River, MA
Bridgeport, CT
New Haven, CT
Penn Manor, PA
Port Jefferson, NY
Hempstead, NY
Philadelphia, PA
New York, NY and NJ
Chester, PA
Marcus Hook, PA
Camden-Gloucester, NJ
Paulsboro, NJ
Wilmington, DE
New Castle, DE
Baltimore, MD
Hopewell, VA
Virginia, VA, Port of

• Medium Use: 1M - 10M Tons Annual Throughput
• High Use: >10M Tons Annual Throughput

Data: USACE Principal Ports 2015

0   50   100   200 Miles

Photo: E. Mclean

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Addressing Research Question 2:

2. How will a composite-index of port climate-vulnerability, based on expert-weighted open-data indicators, compare to experts' subjective port vulnerability rankings?

Most Vulnerable Ports:

Model matched #1 and 3 out of top 4 most vulnerable ports

Port	Experts' Rank	Port	Model Rank
Virginia.VA.Port.of	1	Virginia.VA.Port.of	1
New.York.NY.and.NJ	2	Boston.MA	2
Boston.MA	3	Philadelphia.PA	3
New.Haven.CT	4	New.Haven.CT	4
Baltimore.MD	5	Port.Jefferson.NY	5
Providence.RI	6	Portland.ME	6
Portland.ME	7	Hopewell.VA	7
Portsmouth.NH	8	Fall.River.MA	8
Philadelphia.PA	9	Camden-Gloucester.NJ	9
Hempstead.NY	10	Baltimore.MD	10

Photo: E. Mclean

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Addressing Research Question 2:

2. How will a composite-index of port climate-vulnerability, based on expert-weighted open-data indicators, compare to experts' subjective port vulnerability rankings?

Least Vulnerable Ports:

Considerable discrepancies between model and experts' subjective rankings

Port	Experts' Rank
Albany.NY	1
Penn.Manor.PA	2
Philadelphia.PA	3
Camden-Gloucester.NJ	4
Hopewell.VA	5
Searsport.ME	6
Baltimore.MD	7
Paulsboro.NJ	8
Chester.PA	9
Portsmouth.NH	10

Port	Model Rank
Providence.RI	1
New.York.NY.and.NJ	2
Portsmouth.NH	3
Penn.Manor.PA	4
Chester.PA	5
Marcus.Hook.PA	6
Marcus.Hook.PA	7
Wilmington.DE	8
Albany.NY	9
Paulsboro.NJ	10

Photo: E. Mclean

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Claimed Contribution
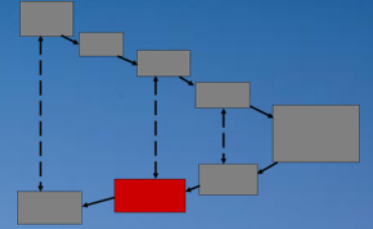
Theoretical Point of Departure: No examples of comparative CCVA for ports

- Developed a set of 34 expert-evaluated indicators of seaport climate-vulnerability from open-data.

- Quantified expert-preferences for weighting components of vulnerability

- Identified adaptive capacity as lacking representation in available data

- Contributed first attempt at indicator based composite-index for seaport climate-vulnerability
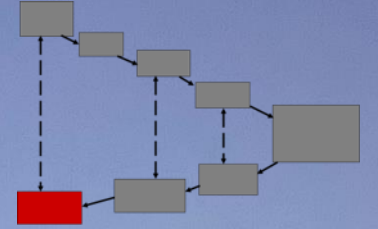
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Claimed Contribution

Limitations:

- Results sensitive to value-judgements:
  - How to delimit each port?
  - How to compile indicator data?
    - Max value or average value?
    - Highest county or average of counties?
- Reproducibility limited by expert subjectivity
- Composite-index lacked indicators of adaptive capacity

Predicted Impact

Observed Problem: Difficult to compare relative vulnerability across ports:

- Set of 34 expert-evaluated indicators can be monitored to assess relative vulnerabilities across ports

- Prototype composite-index allows rudimentary quantitative comparisons of exposure and sensitivity levels across ports

  - Able to capture relative outliers: main objective of composite-indices

  - Shows promise of indicator-based approach to compare port vulnerabilities

    - Points to areas for next steps:

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Predicted Impact

Recommendations:

- Focus effort on assessing adaptive capacity

  - Experts weight it high in importance

  - Yet, it lacks representation in data

- Investigate what types of bespoke data might be synthesized into new additional indicators

- Compliment this theoretical study with investigation of *empirical* impacts of climate/weather on seaports

Photo: E. Mclean

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Thank You

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