A parcel-scale quantitative sea level rise vulnerability analysis for Puget Sound, Washington State

Three Crabs Road near Sequim, WA in 2018. Photo by John Gussman

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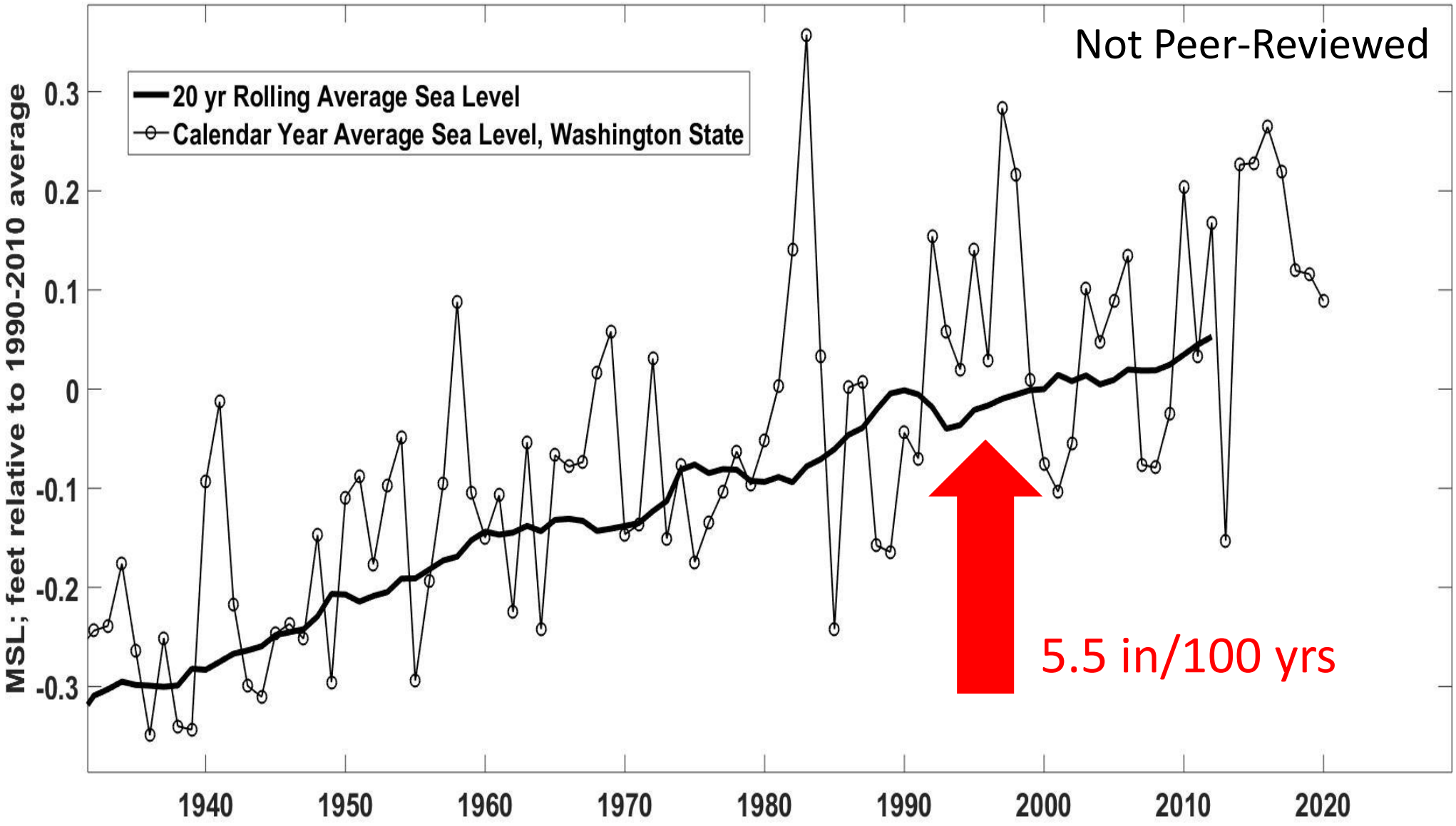
With
Jim Johannessen and Avery Maverick,
Coastal Geologic Services

Chloe Fleming and Seann Regan, NOAA
NCCOS

Sea Grant
Washington

We observe sea level rise in Washington

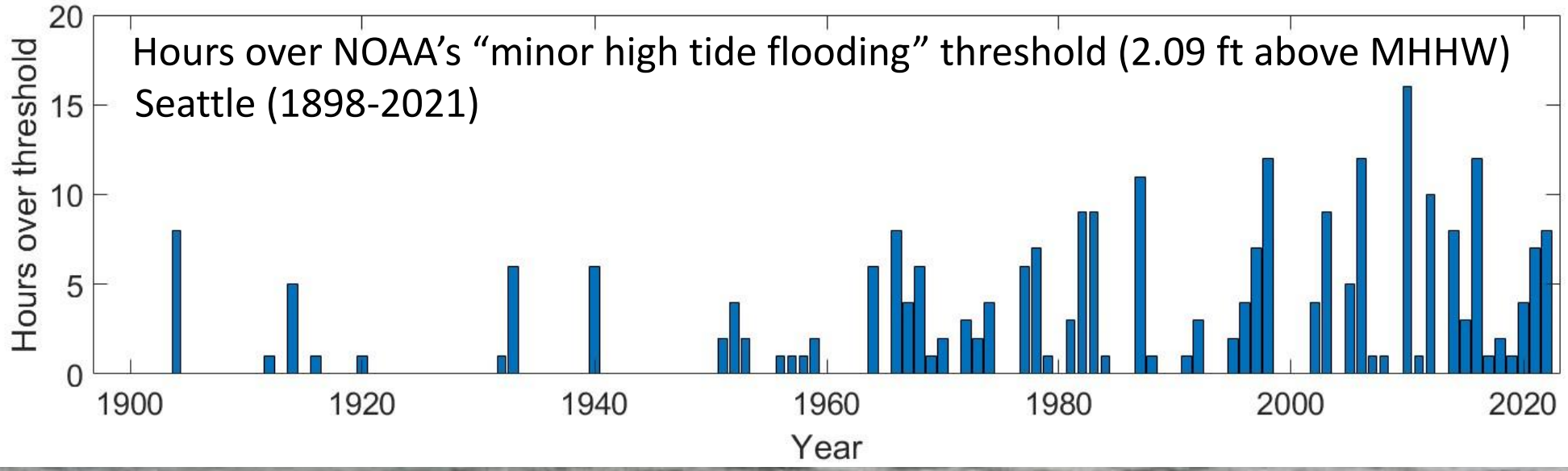


Data from NOAA (https://tidesandcurrents.noaa.gov/) and Newton et al., 2021

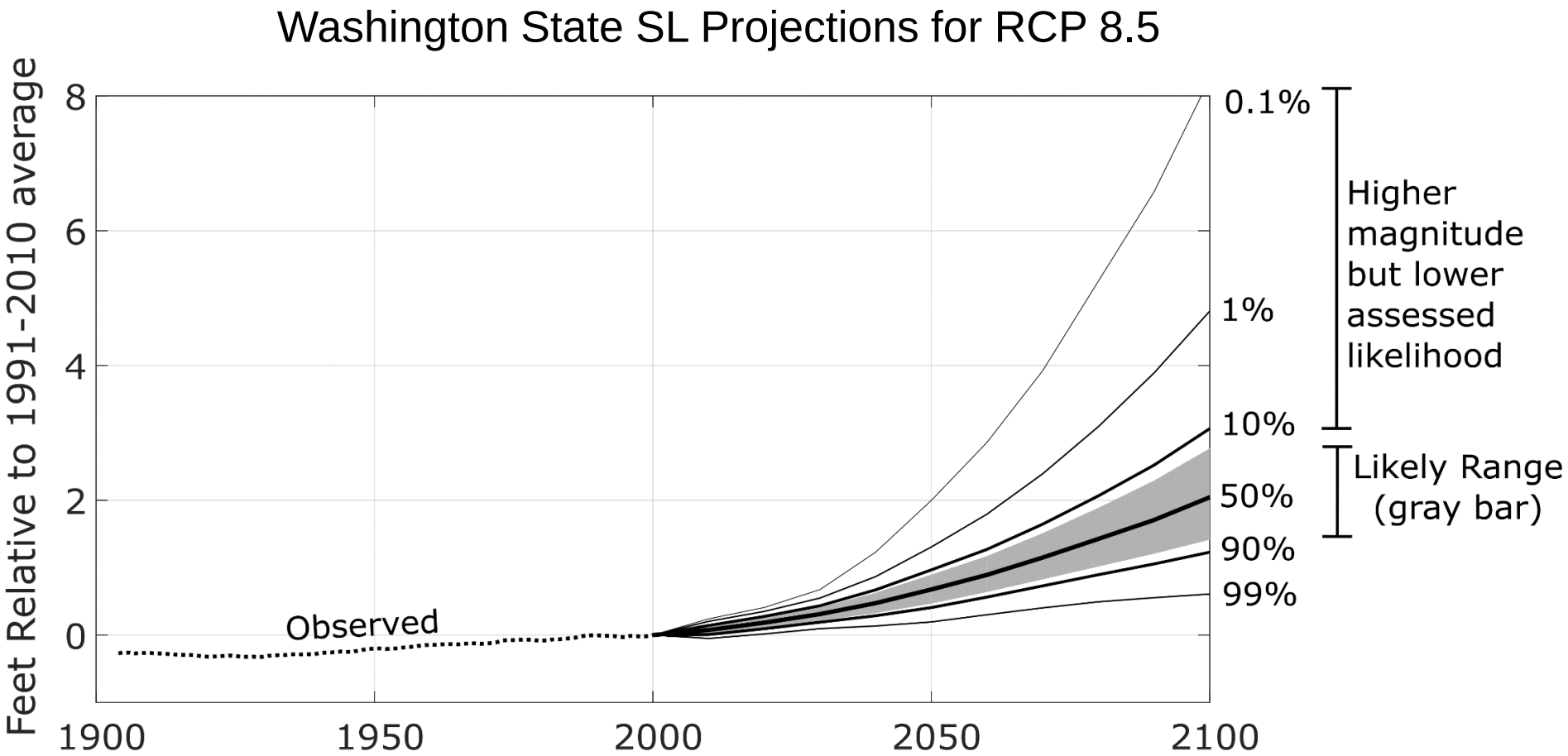
Gig Harbor, December 27, 2022

MyCoast/King Tides


Gig Harbor,
December 27, 2022
MyCoast/King Tides


Hours over NOAA's "minor high tide flooding" threshold (2.09 ft above MHHW)
Seattle (1898-2021)
Hours over threshold
0
5
10
15
20
1900
1920
1940
1960
1980
2000
2020
Year

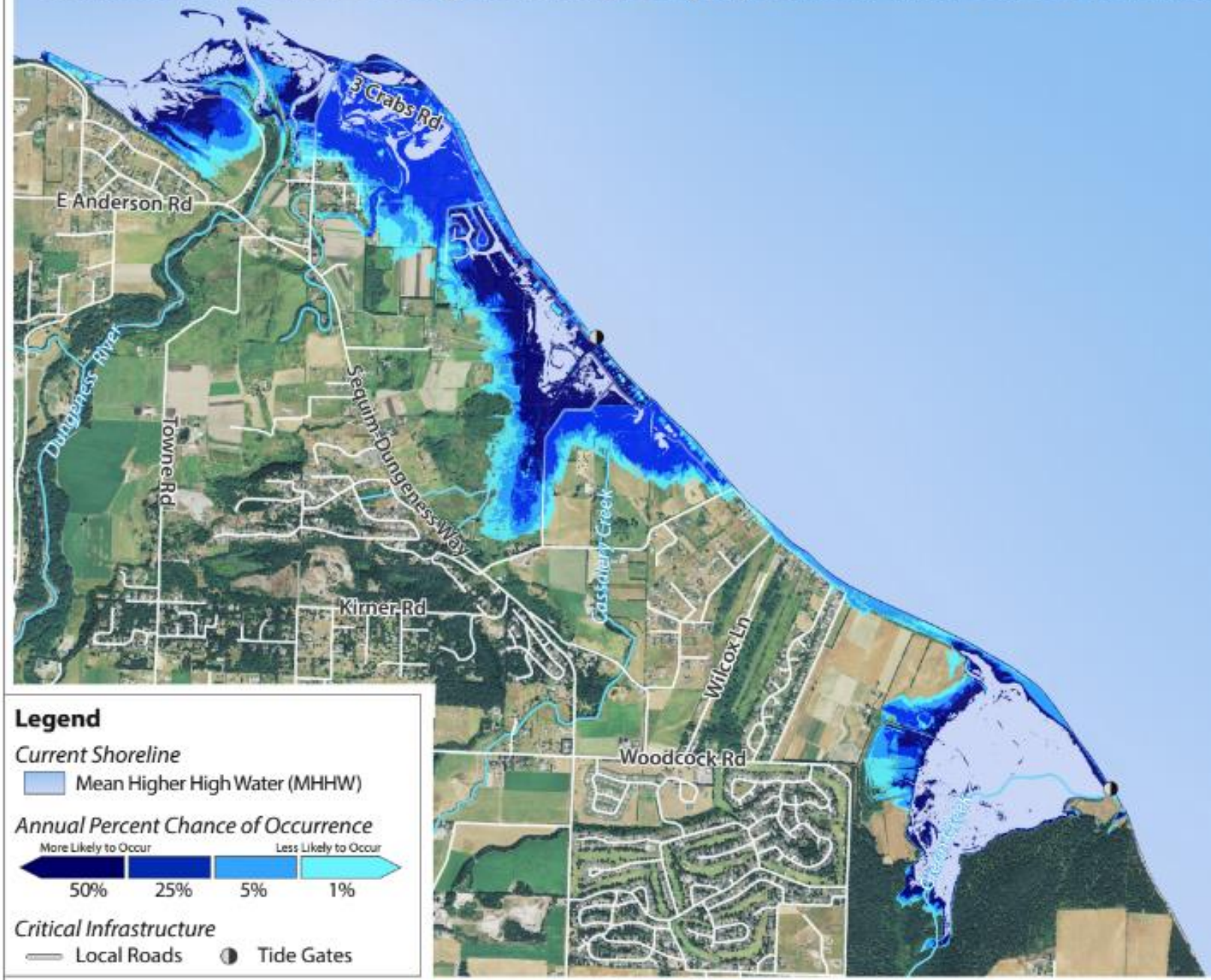
Sea level projections suggest a very high likelihood of acceleration



From Miller et al., 2018. Derived from Kopp et al, 2014

Sea Level Rise Inundation Area in 2100, DUNGENESS RIVER DELTA

Probabilistic Projections of Changes to Average Daily High Tide Inundation Due to Sea Level Rise



Legend

Current Shoreline

Mean Higher High Water (MHHW)

Annual Percent Chance of Occurrence

More Likely to Occur — Less Likely to Occur

50% 25% 5% 1%

Critical Infrastructure

Local Roads Tide Gates

Updated March 2017

Feet

0 2,000 4,000

“Traditional” vulnerability assessment approaches

SLR Vulnerability

Gets at if, when or to what degree a sea level related hazards will interact an asset.

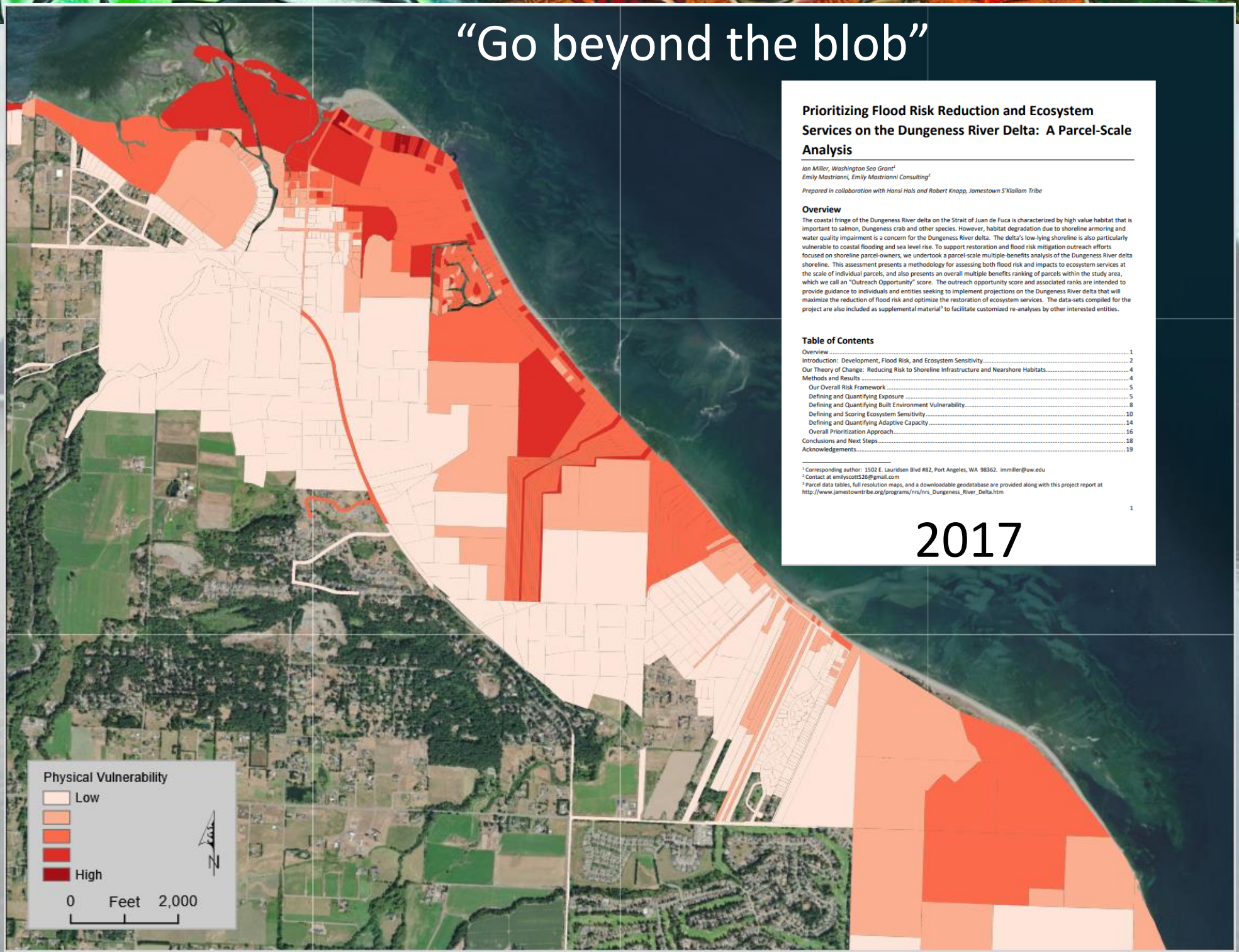
Gets at the consequences of the interaction with a hazard. What happens? How much damage occurs?

$$\text{Vulnerability} = \frac{\text{Exposure} + \text{Sensitivity}}{\text{Adaptive Capacity}}$$

Gets at any capacity or ability that a system may have to reduce either exposure or sensitivity

Modified from Brooks, 2003 and IPCC, 2012

“Go beyond the blob”



Prioritizing Flood Risk Reduction and Ecosystem Services on the Dungeness River Delta: A Parcel-Scale Analysis

Ian Miller, Washington Sea Grant[1]
Emily Mastrianni, Emily Mastrianni Consulting[2]

Prepared in collaboration with Hansi Hals and Robert Knapp, Jamestown S'Klallam Tribe

Overview

The coastal fringe of the Dungeness River delta on the Strait of Juan de Fuca is characterized by high value habitat that is important to salmon, Dungeness crab and other species. However, habitat degradation due to shoreline armoring and water quality impairment is a concern for the Dungeness River delta. The delta's low-lying shoreline is also particularly vulnerable to coastal flooding and sea level rise. To support restoration and flood risk mitigation outreach efforts focused on shoreline parcel-owners, we undertook a parcel-scale multiple-benefits analysis of the Dungeness River delta shoreline. This assessment presents a methodology for assessing both flood risk and impacts to ecosystem services at the scale of individual parcels, and also presents an overall multiple benefits ranking of parcels within the study area, which we call an "Outreach Opportunity" score. The outreach opportunity score and associated ranks are intended to provide guidance to individuals and entities seeking to implement projections on the Dungeness River delta that will maximize the reduction of flood risk and optimize the restoration of ecosystem services. The data-sets compiled for the project are also included as supplemental material[3] to facilitate customized re-analyses by other interested entities.

Table of Contents

[1] Corresponding author: 1502 E. Lauridsen Blvd #82, Port Angeles, WA 98362. immiller@uw.edu
[2] Contact at emilyscott526@gmail.com
[3] Parcel data tables, full resolution maps, and a downloadable geodatabase are provided along with this project report at http://www.jamestowntribe.org/programs/nrs/nrs_Dungeness_River_Delta.htm

2017

NTA 2018-0685: Prioritizing Sea Level Rise Exposure and Habitat Sensitivity Across Puget Sound

- Proposed to and funded through the Puget Sound NTA process (EPA NEP restoration funding, administered through WDFW)
- Parcel is the fundamental unit of analysis
- Performance Period: April 2020 – August 2022
- Advisory Group
  - Kevin Zerbe, Harriet Morgan, Bobbak Talebi, Travis Ball, Tish Conway-Cranos, TJ Moore, John Lovie, Nicole Faghin, David Trimbach

Puget Sound Parcel-scale Sea Level Rise Vulnerability Assessment

The Project

Between 2020 and 2022, a team from Washington Sea Grant and Coastal Geologic Services developed a quantitative sea level rise vulnerability approach for coastal parcels on Puget Sound. The goals of the project were to construct, calculate, and map a sea level rise vulnerability index that:

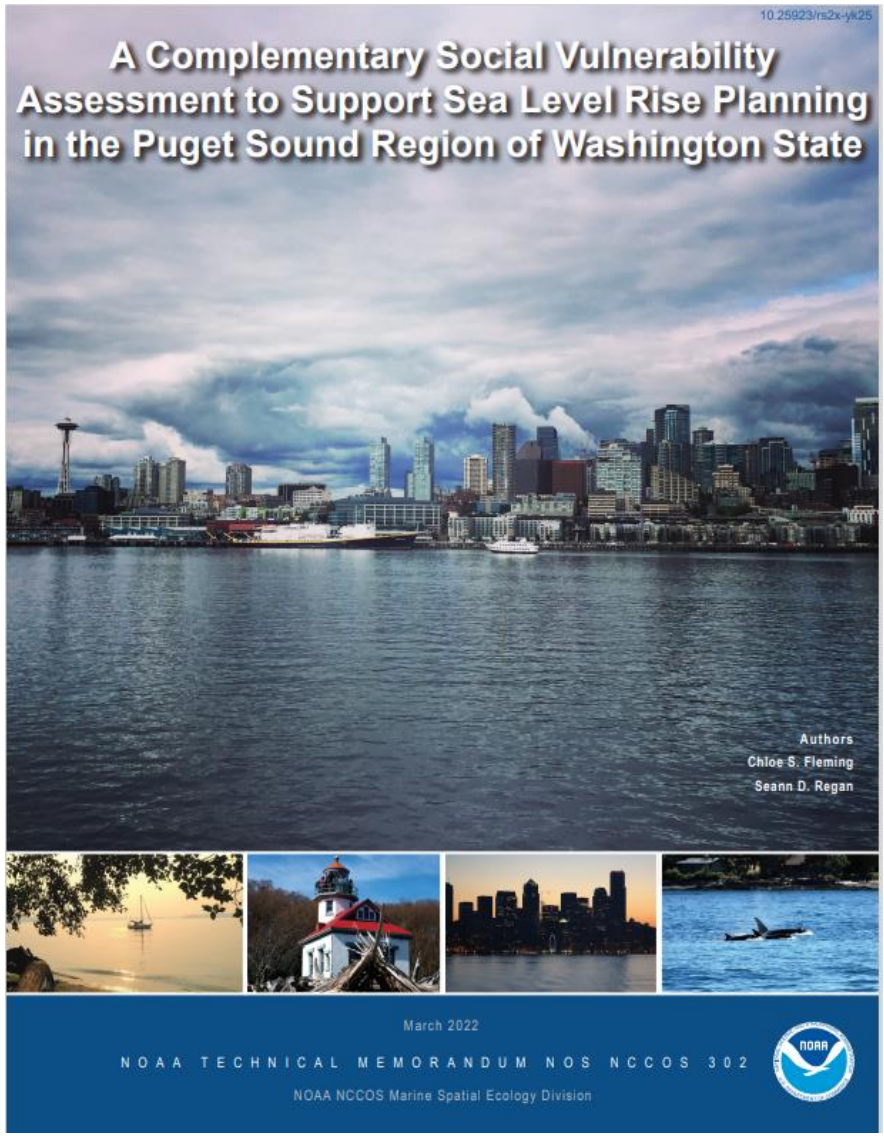
1. Accounts for potential impacts to both the built environment (homes, roads, and critical infrastructure) and the natural environment (coastal habitats);
2. Uses only publicly-available data;
3. Is based on exposure to both erosion and flooding;
4. Provides insights about differences in vulnerability between individual parcels in Puget Sound;
5. Enables new insights about the spatial distribution of vulnerability in Puget Sound, and helps to prioritize locations where vulnerability is highest.

While this project was viewed as a pilot, and the results preliminary in nature, after review by a project advisory group and a variety of engaged stakeholders, including three Local Integrating Organizations and one Marine Resource Committee, we are making the results available here. Based on their feedback, we conclude that this analysis offers a novel perspective on sea level rise vulnerability throughout Puget Sound. **However, limitations or errors in the data we used as inputs, and and assumptions incorporated into the approach should be carefully considered when interpreting those results.**

An accompanying Social Vulnerability Assessment was also completed for this work.

Sea level rise vulnerability results

https://wacoastalnetwork.com/puget-sound-parcel-scale-sea-level-rise-vulnerability-assessment/



https://repository.library.noaa.gov/view/noaa/37524

sustainability MDPI

Article

A Data-Driven Approach for Assessing Sea Level Rise Vulnerability Applied to Puget Sound, Washington State, USA

Ian Miller [1,*], Avery Maverick [2], Jim Johannessen [2], Chloe Fleming [3] and Seann Regan [3]

[1] Washington Sea Grant, Port Angeles, WA 98362, USA
[2] Coastal Geologic Services, Bellingham, WA 98225, USA
[3] CSS-Inc., under NOAA National Centers for Coastal Ocean Science Contract No. EA133C-1384, Fairfax, VA 22031, USA
* Correspondence: immiller@uw.edu

Abstract: Sea level rise (SLR) will exert pressures on assets with social value, including things such as infrastructure and habitats, in the coastal zone. Assessing and ranking the vulnerability of those assets can provide insights that support planning and projects that can reduce those vulnerabilities. In this study, we develop a quantitative, data-drive framework for calculating a sea level rise vulnerability score, using publicly available spatial data, for 111,239 parcels in Puget Sound, Washington State, USA. Notably, our approach incorporates an assessment of coastal erosion, as well as coastal flooding, in an evaluation of the exposure of each parcel, and impacts to habitats are quantified alongside impacts to existing infrastructure. The results suggest that sea level rise vulnerability in Puget Sound is widely distributed, but the overall distribution of scores is heavily skewed, suggesting that adaptation actions directed at a relatively small number of parcels could yield significant reductions in vulnerability. The results are also coupled with a concurrently developed social vulnerability index, which provides additional insight regarding those people and places that may be predisposed to adverse impacts from SLR-related hazards. We find that the proposed approach offers advantages in terms of advancing equitable SLR-related risk reduction, but also that the results should be carefully interpreted considering embedded assumptions and data limitations.

Keywords: sea level rise; vulnerability; climate; resilience; coastal management; coastal policy; GIS; spatial analysis

check for updates

Citation: Miller, I.; Maverick, A.; Johannessen, J.; Fleming, C.; Regan, S. A Data-Driven Approach for Assessing Sea Level Rise Vulnerability Applied to Puget Sound, Washington State, USA. *Sustainability* **2023**, *15*, 5401. https://doi.org/10.3390/su15065401

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1. Introduction

Sea level is rising at a globally averaged rate of approximately 1 foot/century (3 mm/yr), but with regional variations [1]. Regional sea level projections for Washington State [2], on the west coast of the United States (U.S.), suggest that accelerated rates of sea level rise are expected. Sea level rise exacerbates and worsens the impacts of existing coastal hazards, leading to increases in coastal flooding frequency and magnitude [3], accelerated coastal erosion [4], and saltwater intrusion into groundwater [5]. These hazards enhance risks to infrastructure, ecosystems, and cultural values, and ultimately can compromise community well-being [6]. The identification and prioritization of sea level rise vulnerabilities can help to direct attention or resources to places, people, or assets along the coast where impacts associated with sea level rise are likely to be greatest [7]. Approaches to reduce vulnerabilities can forestall future impacts and reduce overall adaptation costs, and integrating insights derived from the assessment of vulnerability into planning processes can help to build overall climate resilience in coastal areas [8].

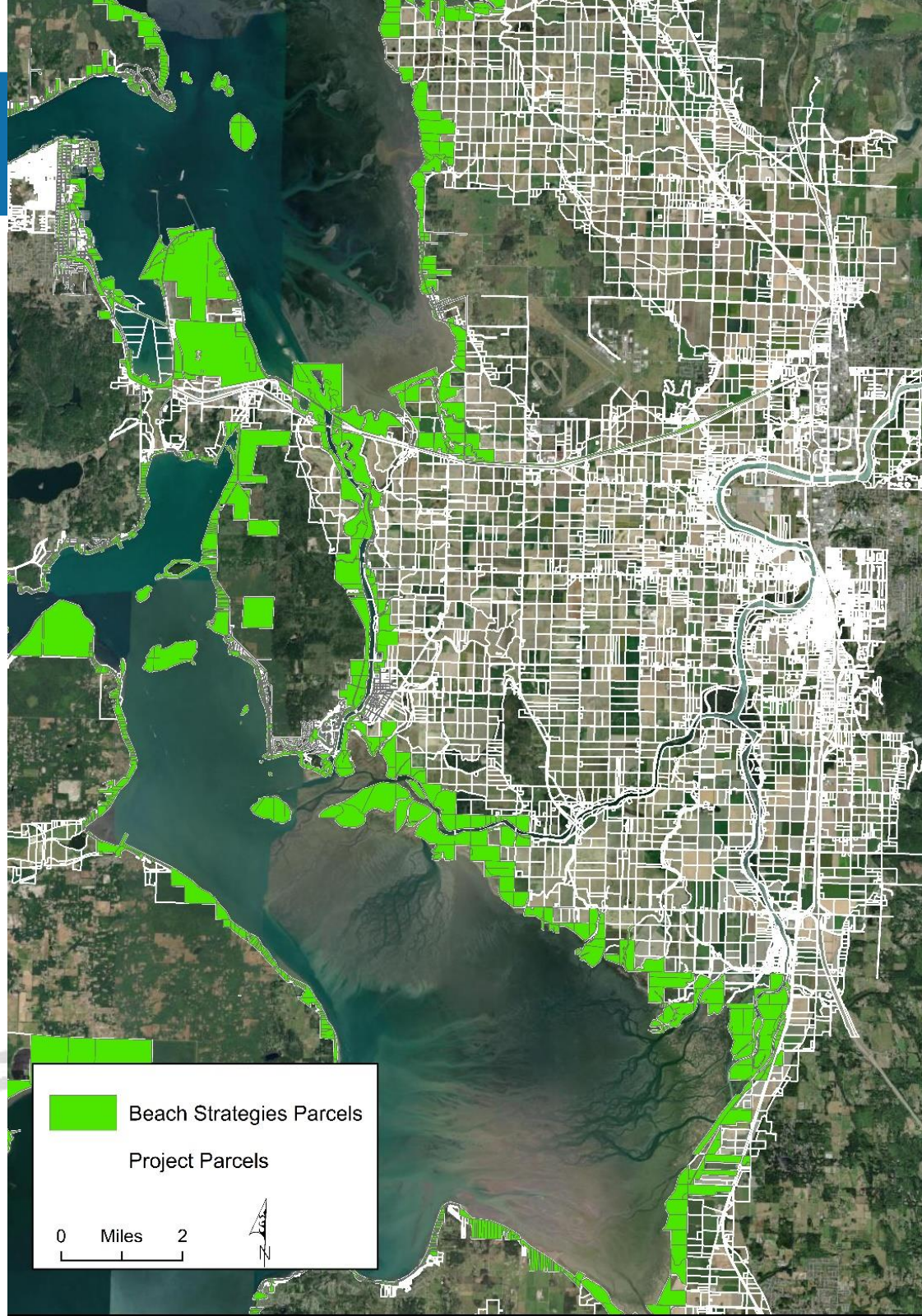
The concept of identifying, prioritizing, and addressing vulnerabilities is applied in many fields, including emergency management [9], food distribution markets [10], and cybersecurity defense [11], as a means for efficiently reducing risk. The concept has been advanced to support climate adaptation planning [12], in which vulnerability is conceptualized as a function of three components: (1) exposure, or the presence of people, assets, and

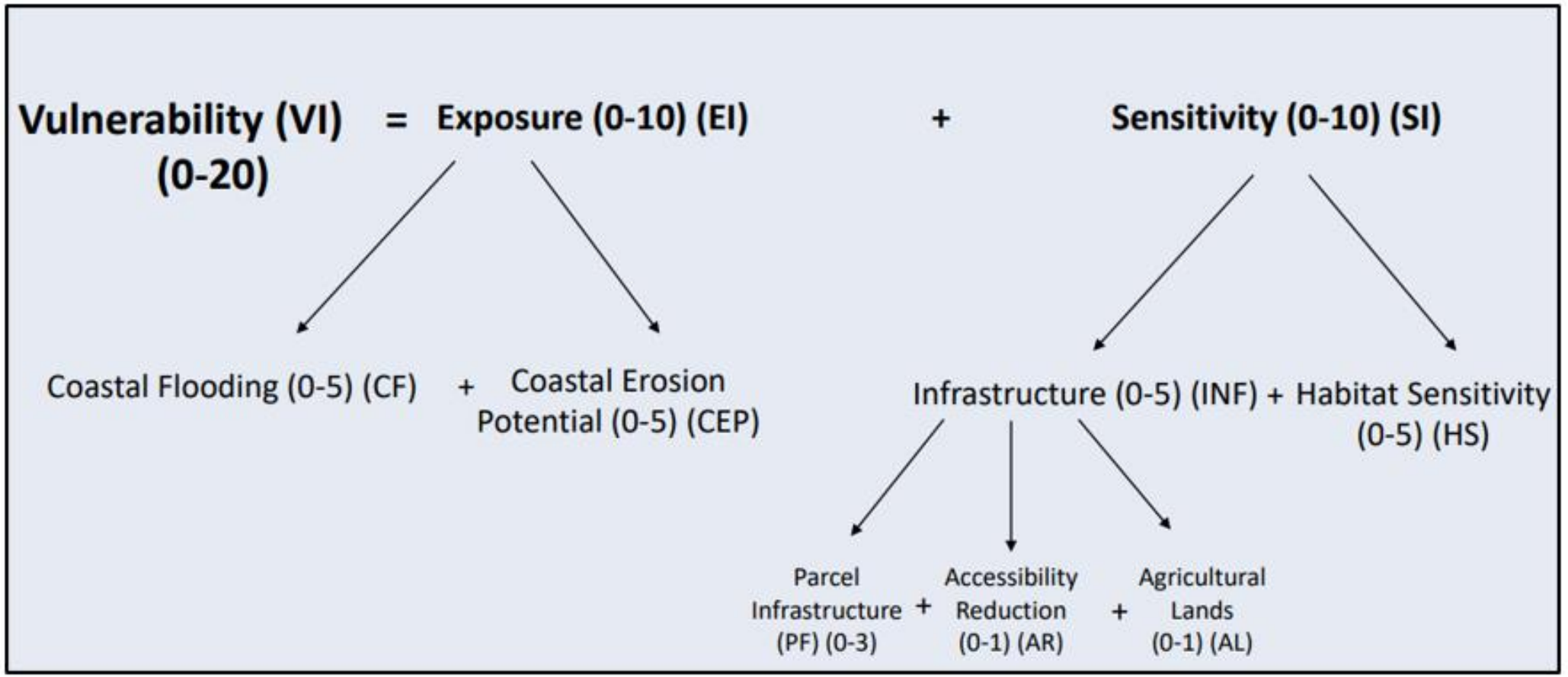
https://www.mdpi.com/2071-1050/15/6/5401

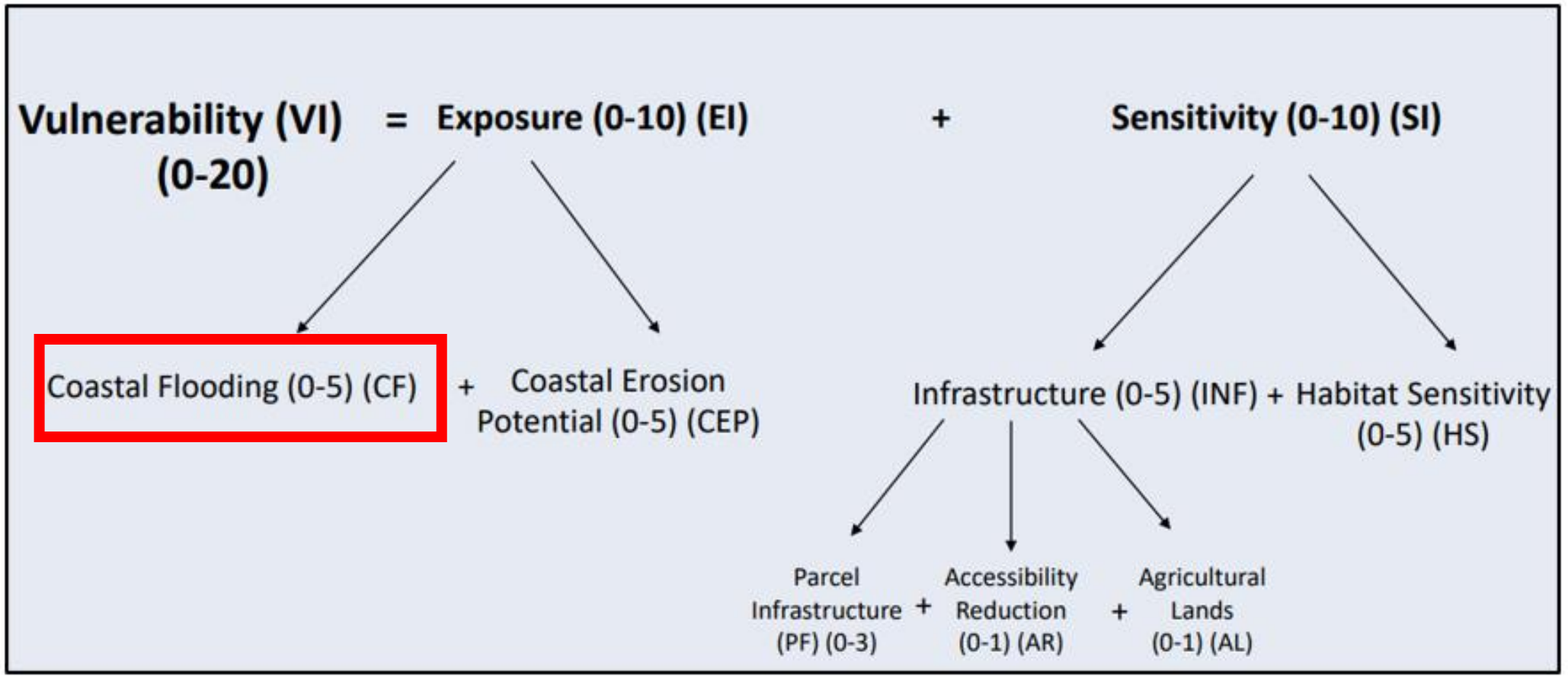
Project Background

Parcel Scale Analysis

- Beach Strategies (CGS, 2018) parcel layer (~50,000 parcels)
- Added parcels
  - 200 FT from ShoreZone shoreline
  - <30 FT elevation & hydro-connected
- Removed Lake Washington parcels past Ballard Locks
- **111,249** Total Parcels, and on each:
  - **Exposure**
    - To flooding and erosion
  - **Sensitivity**
    - For infrastructure and habitat
  - **Vulnerability**
    - The SUM of exposure and sensitivity

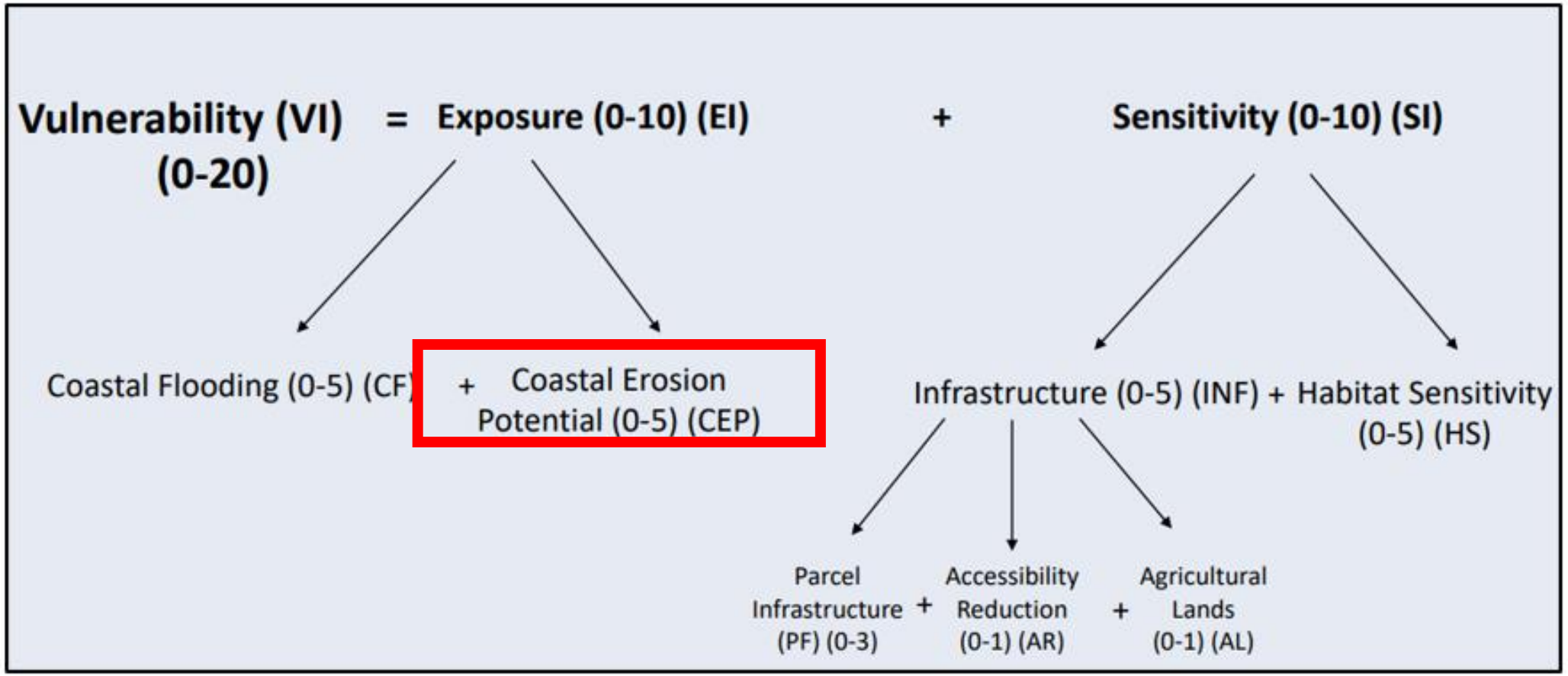



Vulnerability (VI) (0-20)
=
Exposure (0-10) (EI)
+
Sensitivity (0-10) (SI)
Coastal Flooding (0-5) (CF)
+
Coastal Erosion Potential (0-5) (CEP)
Infrastructure (0-5) (INF)
+
Habitat Sensitivity (0-5) (HS)
Parcel Infrastructure (PF) (0-3)
+
Accessibility Reduction (0-1) (AR)
+
Agricultural Lands (0-1) (AL)

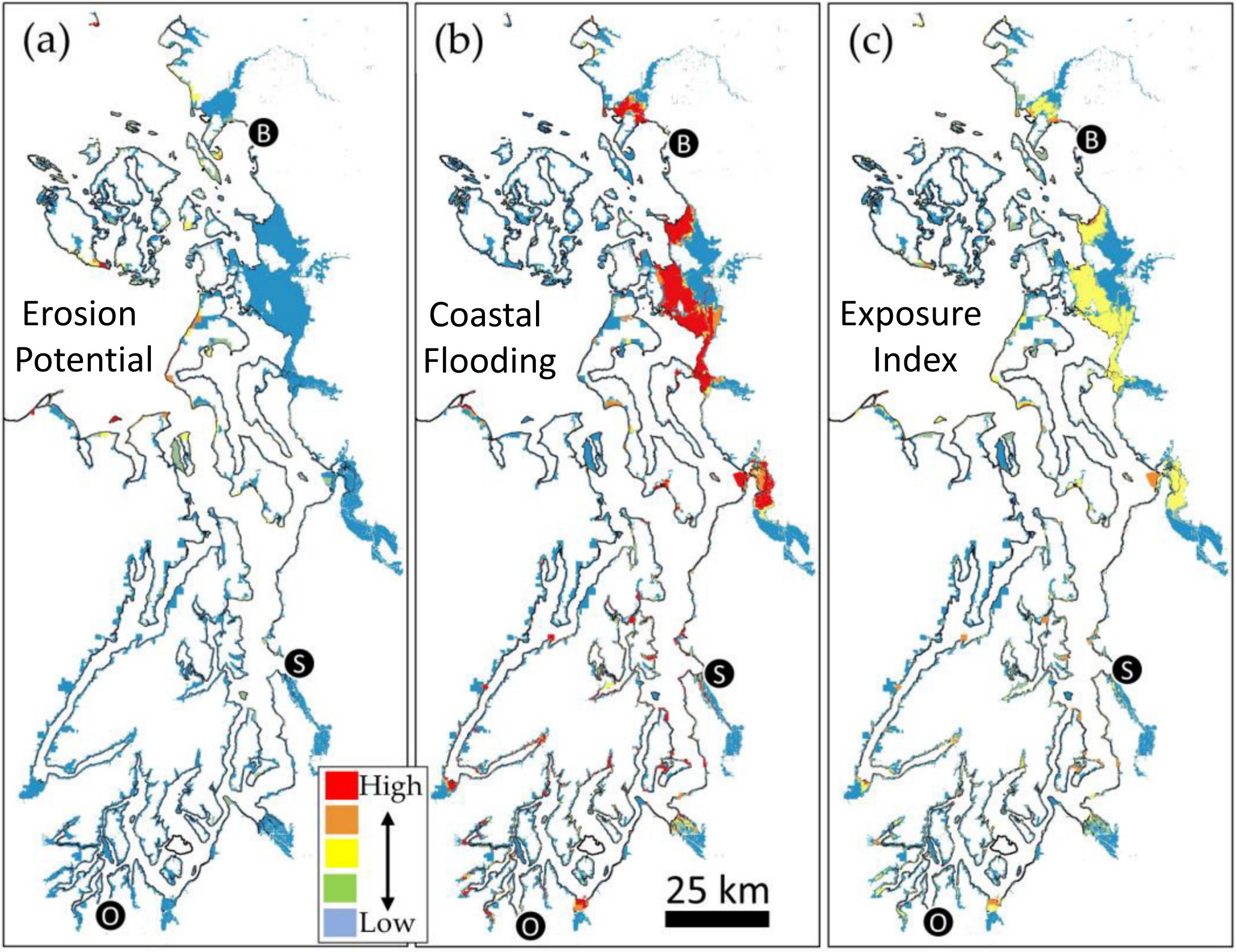


Scenario	% of Parcel Inundated
MHHW + extreme water level scenario (3.2 FT)	0-100
50% SLR 2050 + MHHW + extreme water level scenario	0-100
1% SLR 2050 + MHHW + extreme water level scenario	0-100
50% SLR 2100 + MHHW + extreme water level scenario	0-100
1% SLR 2100 + MHHW + extreme water level scenario	0-100
Exposure Score = sum (% parcel inundated for 5 scenarios)	

The sum of the percentage of each parcel inundated under each of five different sea level scenarios, drawn from Miller et al., 2018



An assessment of the relative likelihood of erosion on a parcel given modelled waves and shoretype/geology. NOT based on historic erosion rates, or physical erosion projections


(a)
(b)
(c)
Erosion Potential
Coastal Flooding
Exposure Index
B
S
O
High
Low
25 km

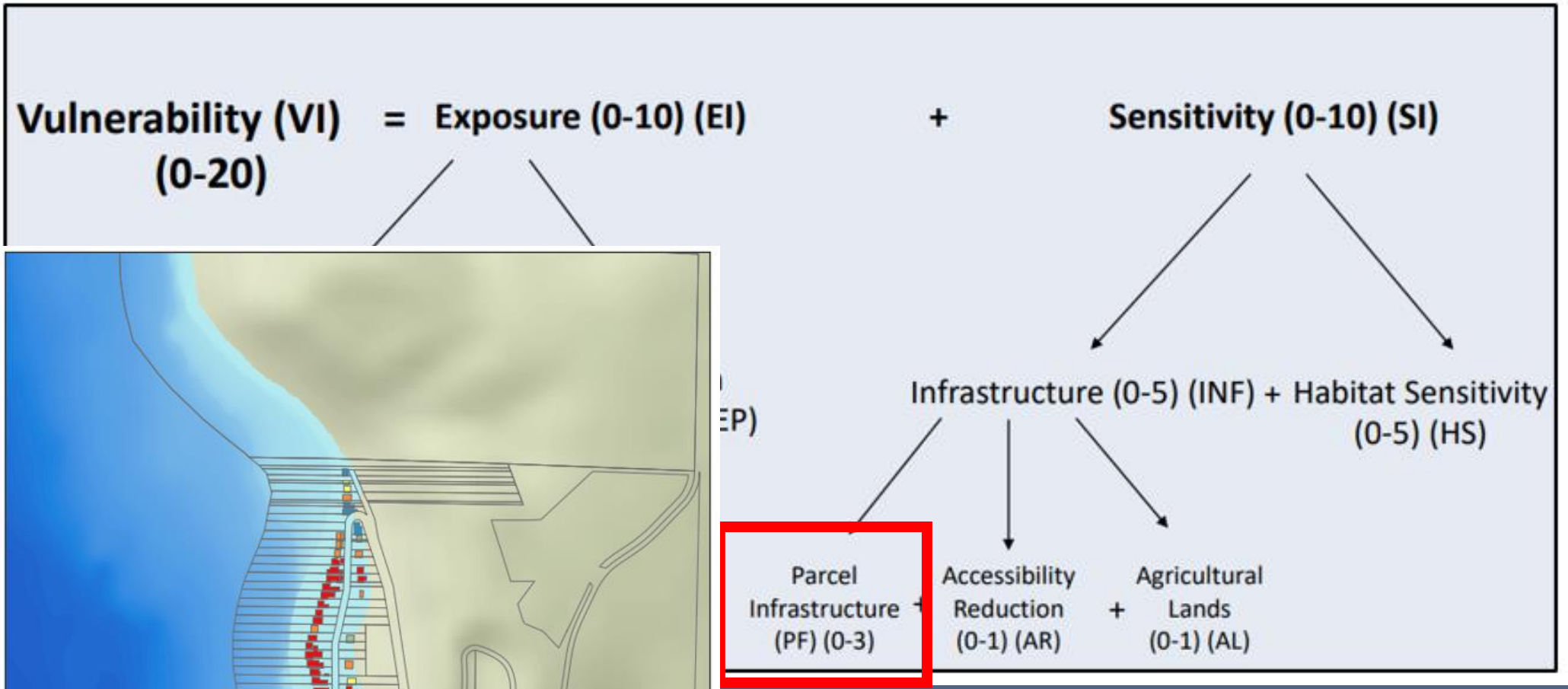
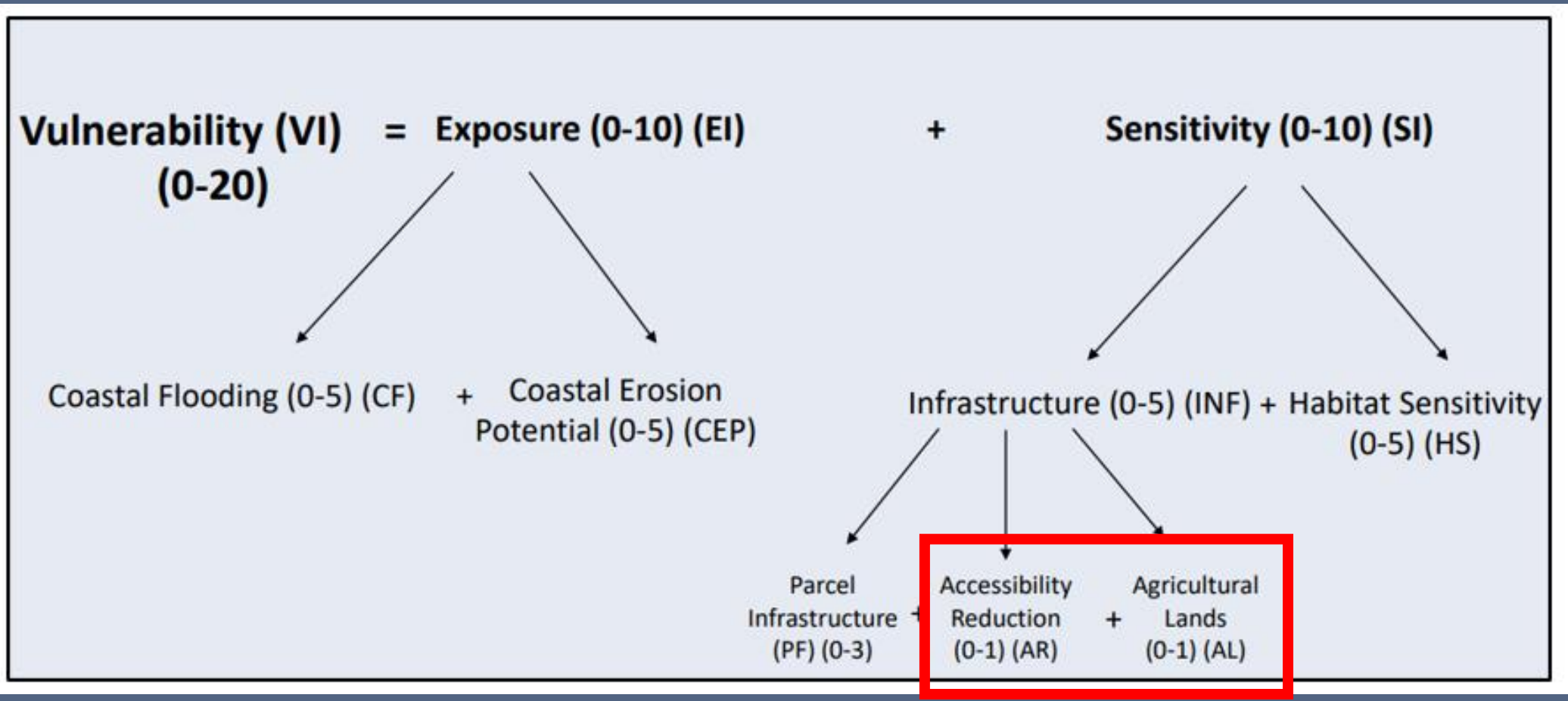
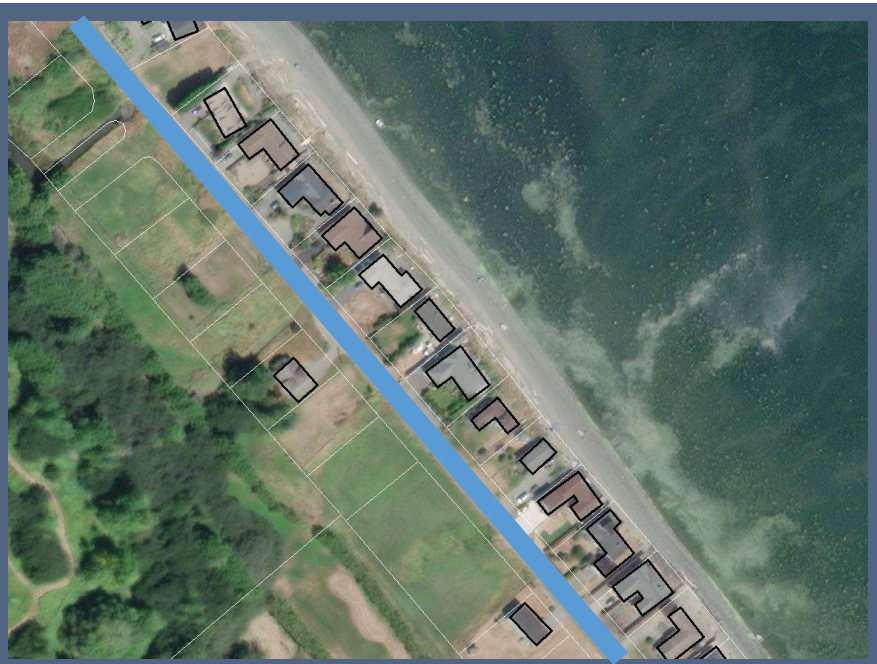


Figure 4. Parcel infrastructure score using alternative approach for the Tulare Beach area showing buildings and inundation for 2100 SLR scenario (RCP 8.5 1% exceedance probability).

The sum of the percentage of the building footprints on each parcel inundated under each of five different sea level scenarios, drawn from Miller et al., 2018





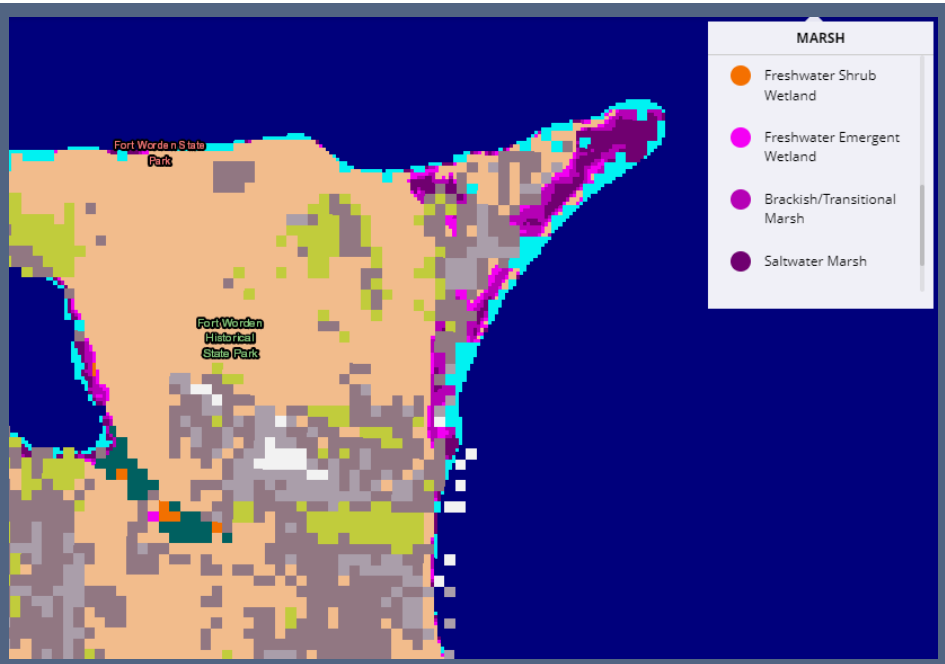
Small modifier for flooding of roads adjacent to a parcel and/or if the parcel is designated as having agricultural uses based on

Vulnerability (VI) (0-20) = **Exposure (0-10) (EI)** + **Sensitivity (0-10) (SI)**

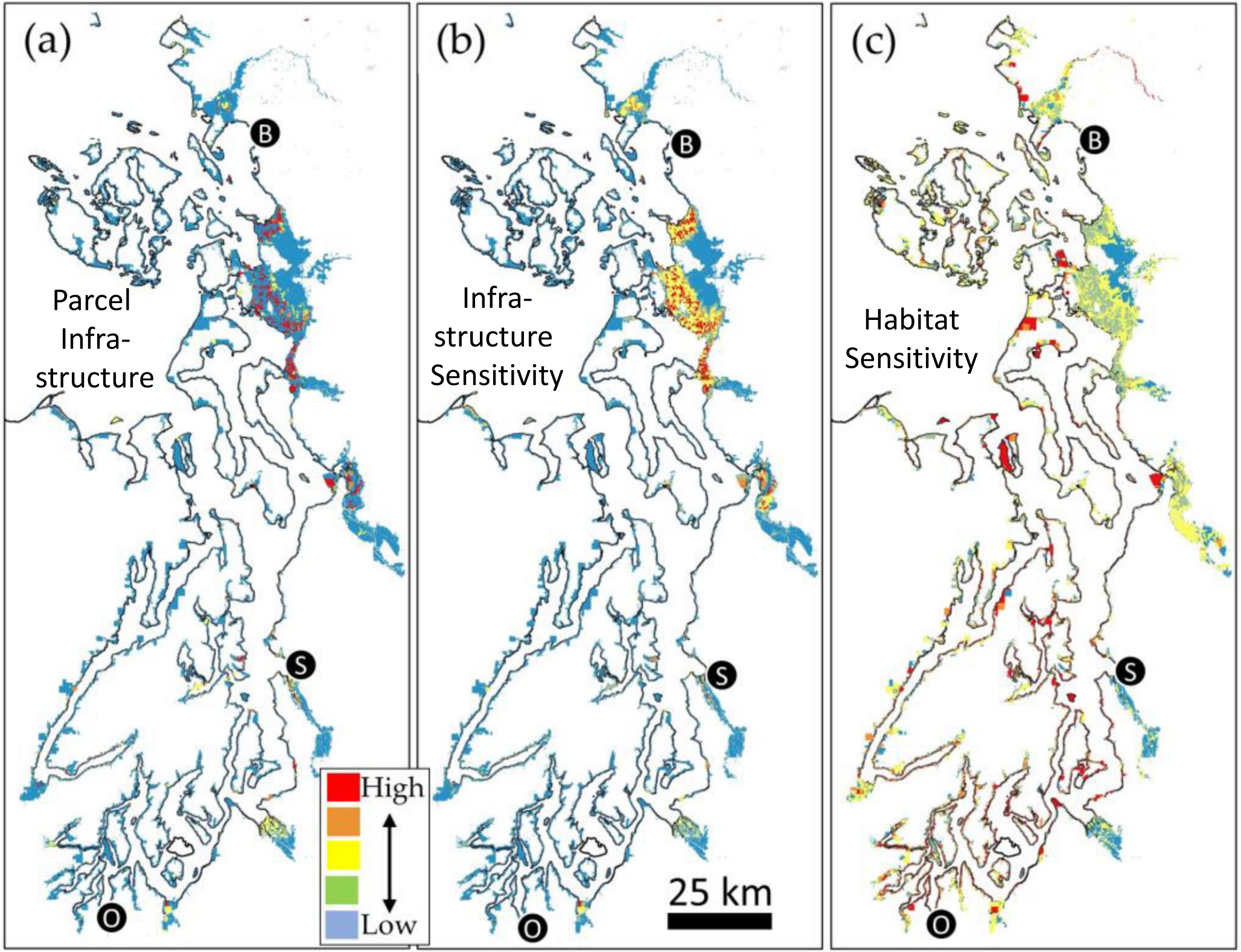
Exposure (0-10) (EI):
- Coastal Flooding (0-5) (CF) + Coastal Erosion Potential (0-5) (CEP)

Sensitivity (0-10) (SI):
- Infrastructure (0-5) (INF) + Habitat Sensitivity (0-5) (HS)

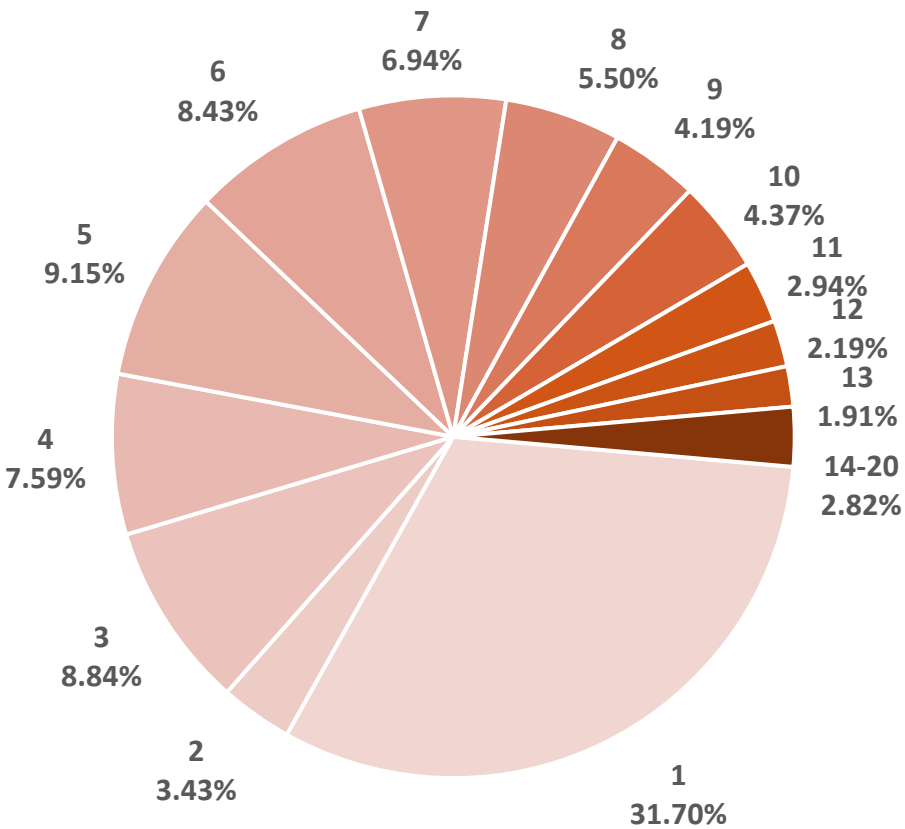
Infrastructure (0-5) (INF):
- Parcel Infrastructure (PF) (0-3) + Accessibility Reduction (0-1) (AR) + Agricultural Lands (0-1) (AL)

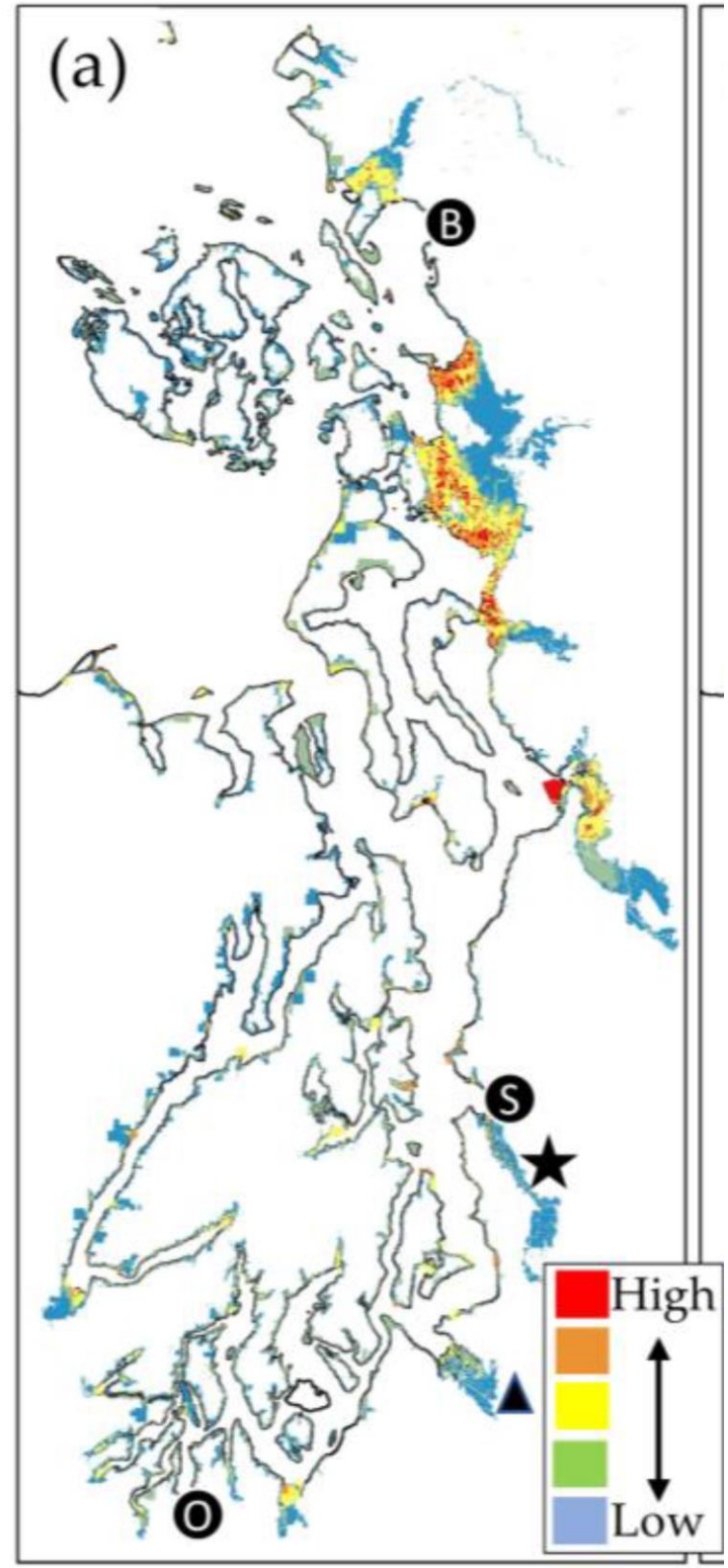


Used NOAA's marsh migration layer to assess the degree to which a parcel's coastal habitat area expanded or contracted across five sea level scenarios drawn from Miller et al. 2018

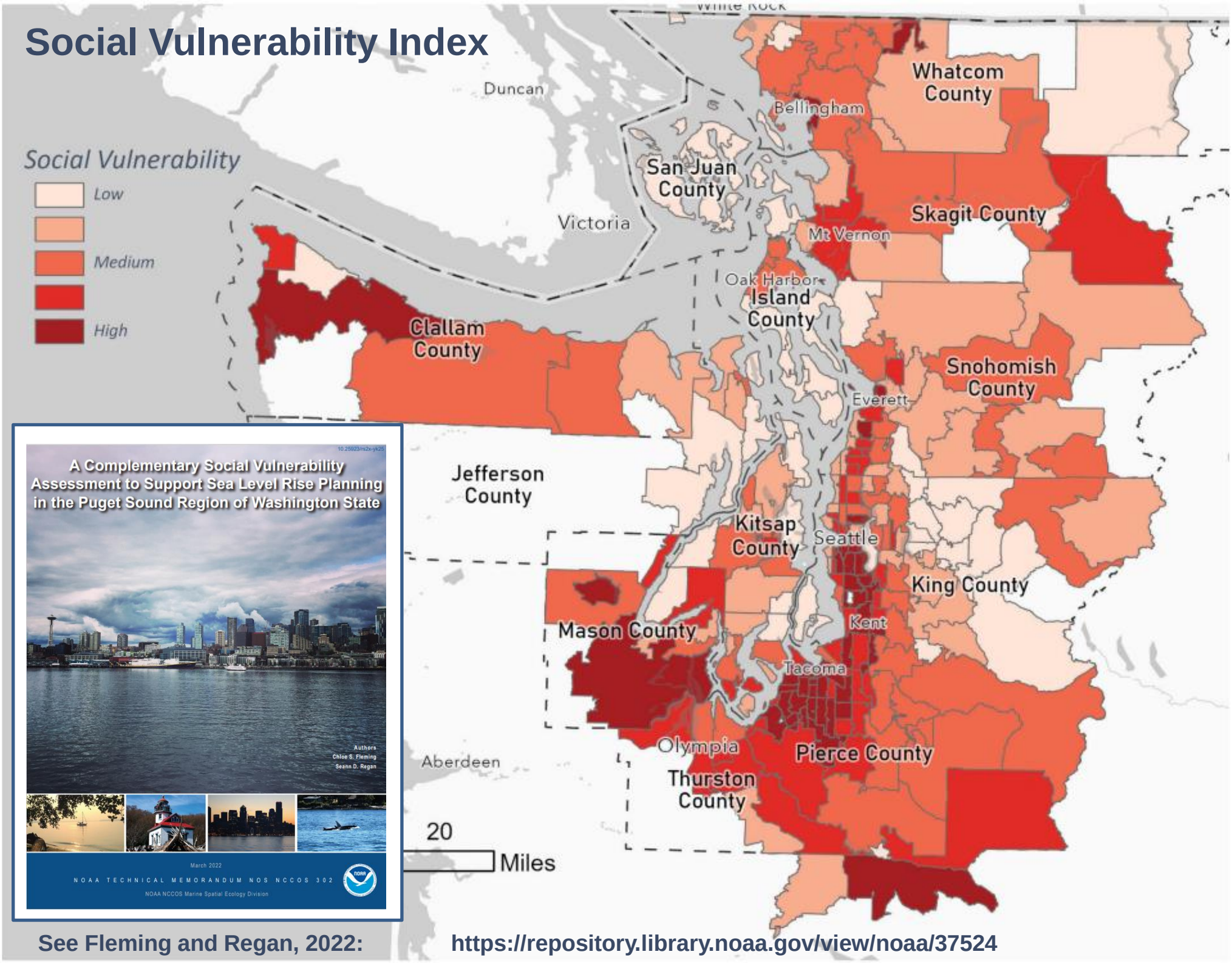

(a)
(b)
(c)
Parcel Infra-structure
Infra-structure Sensitivity
Habitat Sensitivity
B
S
O
High
Low
25 km

“Physical Vulnerability” = Exposure + Sensitivity

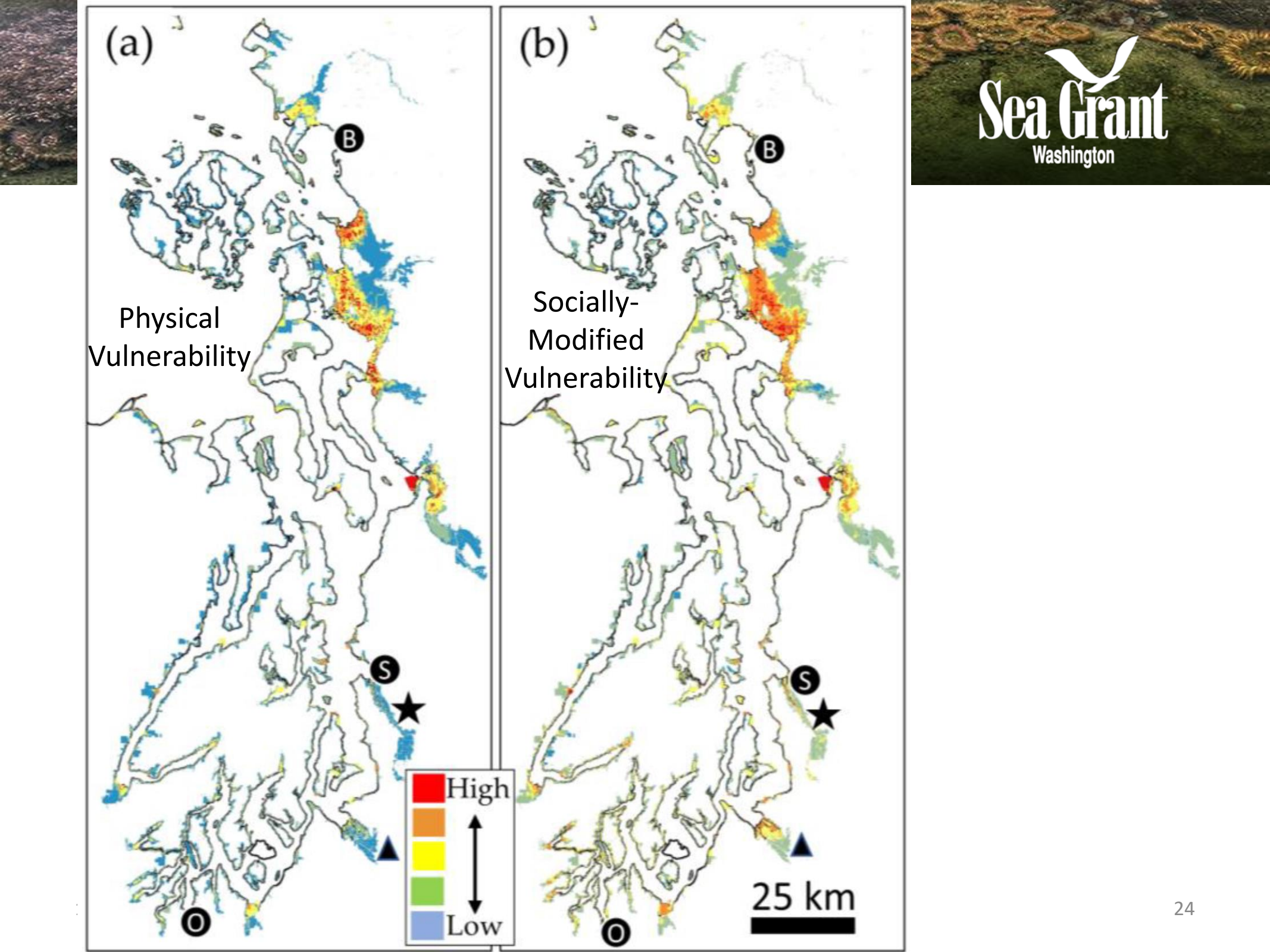


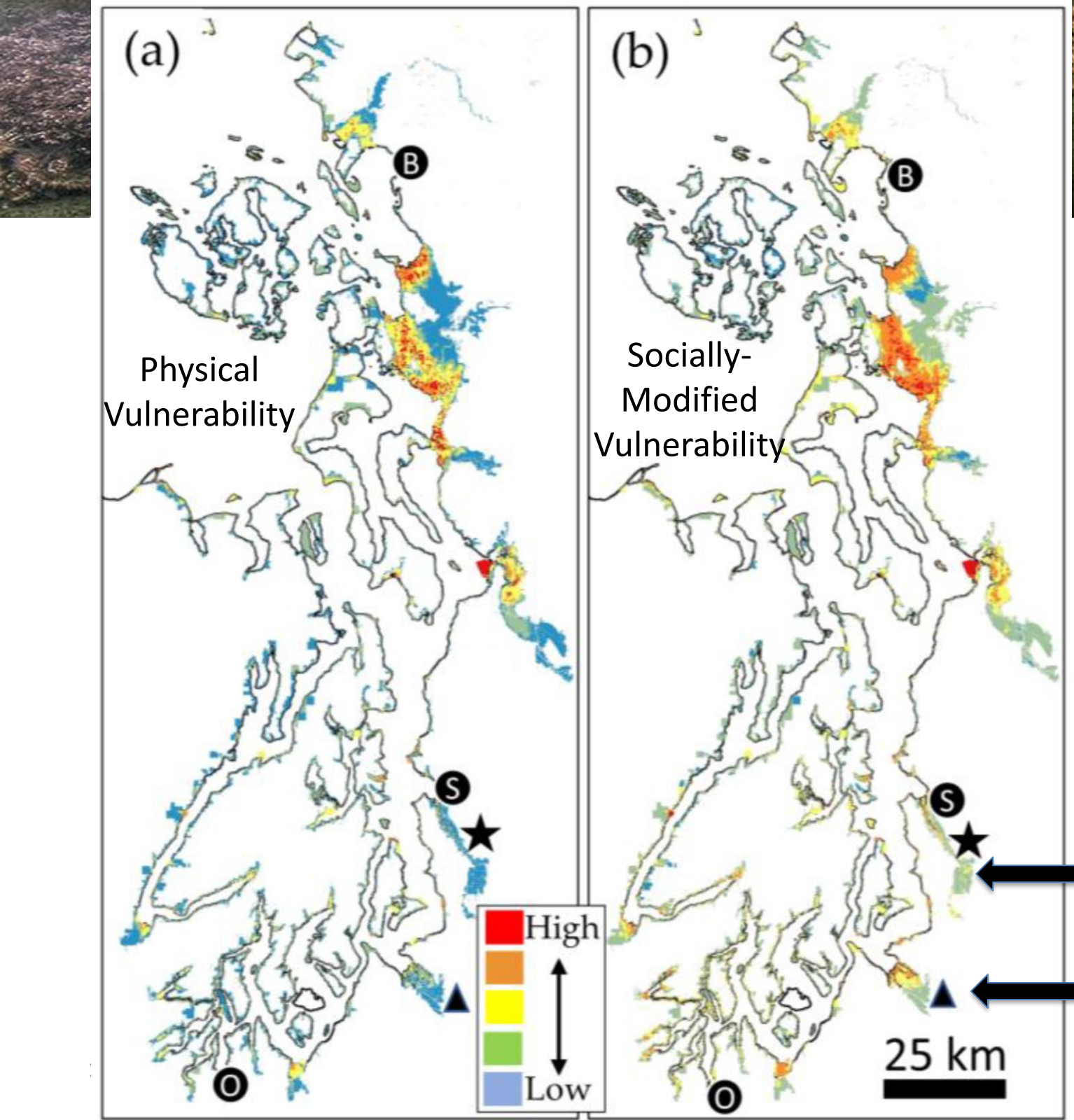


Social Vulnerability Index



See Fleming and Regan, 2022: https://repository.library.noaa.gov/view/noaa/37524

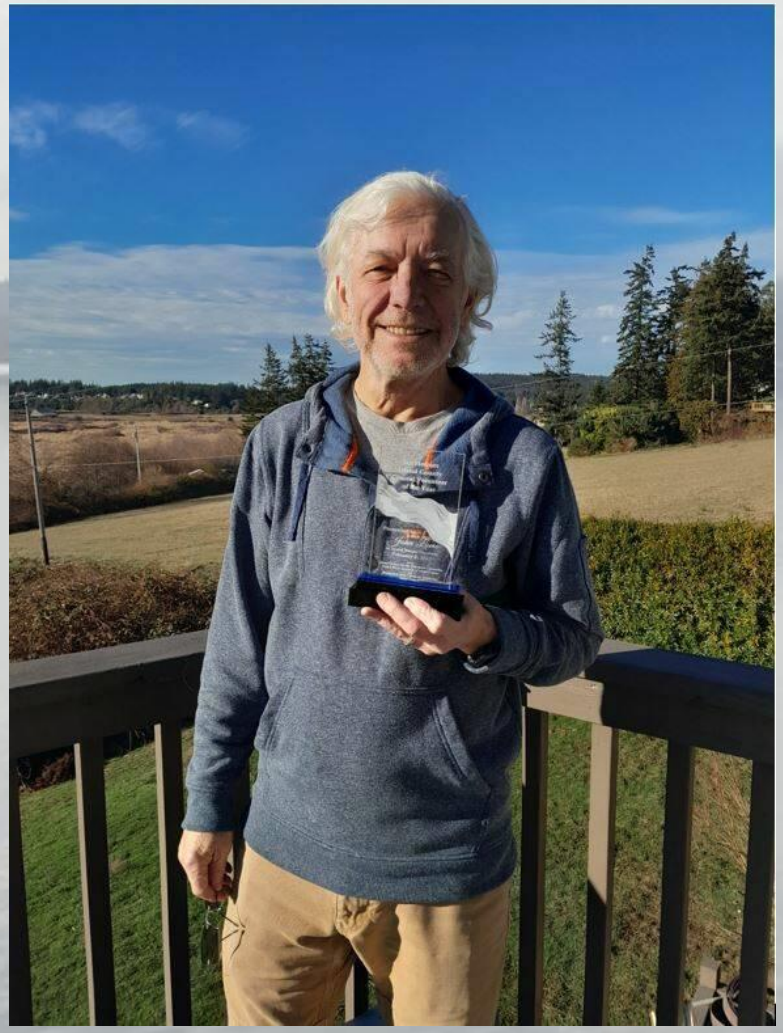

(a)
(b)
Physical Vulnerability
Socially-Modified Vulnerability
B
S
O
High
Low
25 km
Sea Grant
Washington



Sea Grant Washington

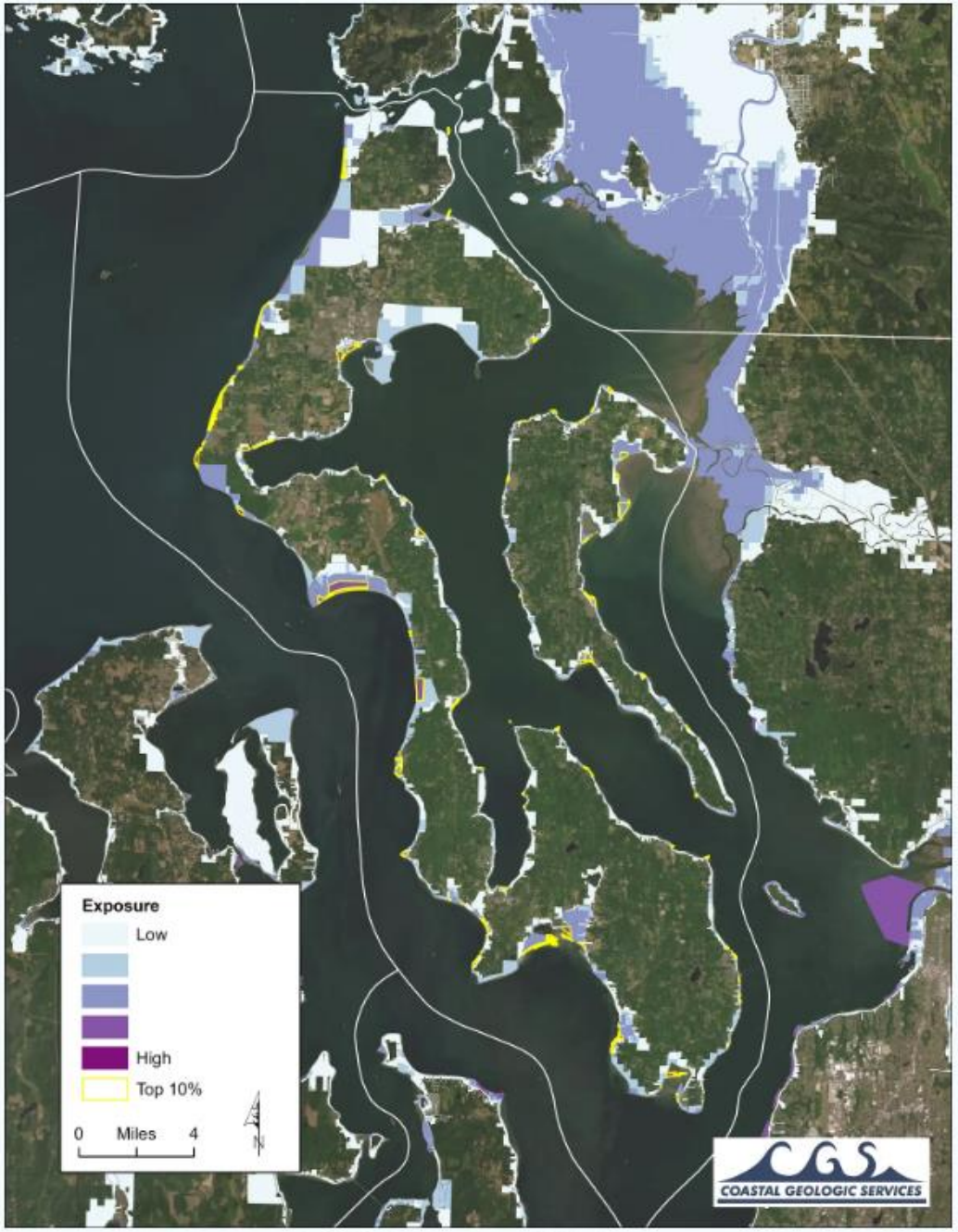
Amplifies assessed vulnerability in urban estuaries and other parts of Puget Sound

Validation



https://johnlovie.substack.com/p/an-imperfect-storm

Here is a map showing the level of exposure of parcels in Island County. The top ten percent of parcels with the highest exposure are highlighted in yellow. All the flooding in the recent storm occurred within those areas, and virtually all of them had some flooding.



Level of flood exposure of parcels in Island County

Limitations

- Erosion Potential is not as good as an erosion model
- The elevation data we use are good, but not perfect…especially for capturing levees and dikes
- Some parcels in Puget Sound include tidelands, and those parcels will have a bias to their coastal flooding index
- Large parcels theoretically should have a biased exposure score
- Buildings are different….but we treat them the same
- A large geodatabase isn't a great tool for supporting uses by coastal managers
- How do we "validate" something like a vulnerability score?

Launching a second phase….

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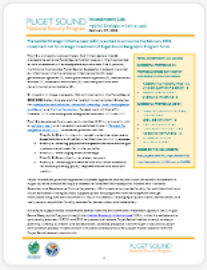

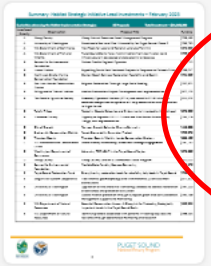

		This project will continue the KNRAMP, a collaborative project between Kitsap County, Suquamish Tribe, Port Gamble S'Klallam Tribe and Washington Environmental Council that has been supported by the NEP since 2019. The goal is to manage natural assets (such as forests, streams, and shorelines) using the same framework and asset management system the County and many other local jurisdictions use for built infrastructure (such as utilities and roadways). KNRAMP represents ecosystem services using quantitative "levels of service" (LOS) terminology common in public works approaches but not typically applied to natural systems. This phase will integrate natural system management with County asset management programs by refining existing and establishing desired LOS and identifying high level actions to close gaps between them. The project will improve the County's baseline stream inventory through water typing field surveys, habitat and fish data collection and map updates. The key outcomes are to change planning frameworks by integrating natural resource management, to guide habitat restoration and acquisition priorities, and to improve regulatory effectiveness for natural resource protection and recovery in Kitsap County.	
A	University of Washington	**Parcel-scale Sea Level Rise Vulnerability for Puget Sound: Phase 2** This project implements a second phase of Near-Term Action 2018-0685, funded between 2019-2022 under assistance agreement PC-01J22301 through the Washington Department of Fish and Wildlife, and titled, "Prioritizing Sea Level Rise Exposure and Habitat Sensitivity Across Puget Sound". In that project a quantitative sea level rise vulnerability framework was developed and applied to ~111,000 parcels in Puget Sound. The results were then shared and discussed with a variety of interested groups between January and June of 2022, and a set of next steps and improvements identified. The project proposed here would address those recommendations by (1) integrating new data to improve the framework and expand the spatial footprint of the analysis west to the mouth of the Strait of Juan de Fuca, (2) re-calculate exposure, sensitivity and vulnerability scores for the entire study area and (3) publish the results in an online interactive format as well as implement other communications actions to facilitate the use of the analysis in restoration, land use and hazard mitigation planning.	Puge
A	Washington Department of Commerce	**Map Tools for Local and Regional Land Use Planning** Commerce's Puget Sound Mapping Project standardized local zoning and planned land use maps across the region. The land use maps have been used by agencies and local governments to assess land use trends and compare proposed and actual development patterns but contain outdated information from 2012. Updating the maps would allow us to analyze trends over the past 10 years in where local governments are designating growth and protection of natural resources, and how these designations align with recovery priorities. After the initial update, we would conduct routine maintenance of the data as new information is received. In addition to updating the maps, we would develop a web application to display the completed maps alongside other resource agency maps that local planners should consider when making land use decisions. Allowing local governments to easily see the relationships between these layers and their proposed land use designations and development patterns would help them direct growth and conservation to the most appropriate areas. A simple web application that integrates key data sources could stand alone or be expanded in future phases to add functionality for land prioritization and scenario analysis.	Puge

Phase 2 will ….

- **Expand** the spatial reach of the analysis, using newly published elevation data

- **Improve** the analysis – possibilities include:
  - *Clip parcels to exclude intertidal portions*
  - *Delineate edges of bluffs and calculate setback distances to buildings/roads*
  - *Improve modelling of flooding over and around levees and dikes*
  - *Integrate building information or damage functions*

- **Validate** the results with an independent assessments of vulnerability

- **Communicate** the results with an online interactive format

Resources

- https://wacoastalnetwork.com/puget-sound-parcel-scale-sea-level-rise-vulnerability-assessment
  - Includes geodatabase and user guide
  - County maps
  - Technical Report
- https://www.mdpi.com/2201706
  - Examines results and assumptions
- https://repository.library.noaa.gov/view/noaa/37524
  - SVI for Puget Sound, results are for zip code areas

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement PC-01J22301 through the Washington Department of Fish and Wildlife.

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Sea Grant Washington