A MULTIDISCIPLINARY, INTEGRATIVE APPROACH TO VALUING COASTAL ECOSYSTEM SERVICES FROM NATURAL INFRASTRUCTURE

2017 ADVISORY BOARD MEETING

Hatfield Marine Science Center – Newport, Oregon
Guin Library Seminar Room
April 14th, 2017 10 am to 4:30 pm

This research is supported by funding from NOAA's National Centers for Coastal Ocean Science/Center for Sponsored Coastal Ocean Science through a NOAA Cooperative Institutes Program award NA16OAR4320152 to the Cooperative Institute for Marine Resources Studies at Oregon State University.

WELCOME

- Welcome and thank you for you participation on our Advisory Board!
- 7 OSU faculty from 4 colleges working on an interdisciplinary research agenda
- Work is made possible by NOAA's National Centers for Coastal Ocean Science and Center for Sponsored Coastal Ocean Science, and OSU's Cooperative Institute for Marine Resources Studies (CIMRS).
- **Funding Title:** Assessing the Benefits of Natural (Green) Infrastructure for Shoreline Stabilization: Ecosystem Service Valuation for Decision-making in Coastal Communities

MEETING OBJECTIVES

- Bring together stakeholders, decision makers, and experts on issues of coastal infrastructure and resilience in the Pacific Northwest.
- Provide updates on project objectives and research progress.
- Provide a structured setting for comment and input from the board.
- Plan future engagement with research team and board members.

TODAY'S AGENDA

10:00 am Welcome, Introductions, and Project Update/Overview

Felix Martinez – Program Manager, NOAA NCCOS

Steven Dundas – Assistant Professor, OSU Applied Economics, COMES

10:45 am Coffee Break

11:00 am Discussion of Estuarine Restoration/Coho Salmon Survey Instrument

11:35 am Uses for Economic Survey Results

Dave Lewis – Professor, OSU Applied Economics

12 Noon Working Lunch

Coastal Dune Landscape survey update

David Kling – Assistant Professor, OSU Applied Economics

Tu Nguyen – Ph.D. Student, OSU Applied Economics

TODAY'S AGENDA

1:00 pm Linking Economic Valuation with Ecological Production

Sally Hacker – Professor, OSU Integrative Biology

Dave Lewis – Professor, OSU Applied Economics

Peter Ruggiero – Associate Professor, OSU CEOAS

David Kling – Assistant Professor, OSU Applied Economics

2:00 pm Coastal Protection Valuation Summary

Chris Parrish – Associate Professor, OSU Civil & Construction Engineering

Laura Barreiro Fernández – M.S. student, OSU Geomatics

Steven Dundas – Assistant Professor, OSU Applied Economics, COMES

Jason Beasley & Cassie Finer – Ph.D. Students, OSU Applied Economics

2:45 pm Coffee Break

TODAY'S AGENDA

3:00 pm Breakout Sessions by Research Pathway

4:00 pm Summary of Breakout Sessions

4:15 pm Open Discussion

4:30 pm Closing Remarks & Adjourn

A MULTIDISCIPLINARY, INTEGRATIVE APPROACH TO VALUING COASTAL ECOSYSTEM SERVICES FROM NATURAL INFRASTRUCTURE

2017 ADVISORY BOARD MEETING

Welcome & Introductions

Oregon State UNIVERSITY OSU

NCCOS

CIMRS

PROJECT OVERVIEW

- Advances the transdisciplinary science of ecosystem services
- Focus is on coastal natural infrastructure in Pacific Northwest: beaches, dunes, and estuaries.
- Aim to understand the nature and determinants of socially-optimal investment in natural infrastructure in coasts and estuaries from an economic perspective.

PROJECT OVERVIEW

Investment in natural infrastructure is drawing increasing interest.

- President Obama issues Memorandum (10/7/15)
  - "The goal … is to better integrate into Federal decision making due consideration of the full range of benefits and tradeoffs among ecosystem services associated with potential Federal actions, including benefits and costs that may not be recognized in private markets because of the public-good nature of some ecosystem services."
- Paris Agreement
  - Stated goal: "Enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change."

However, investment in natural infrastructure remains underemphasized and inadequately studied.

PROJECT OVERVIEW

- Optimizing provision of ecosystem services with natural infrastructure investments is a complex, transdisciplinary challenge with substantive implications for human well-being
- A cost-effective approach to natural infrastructure investment seeks out high-expected return projects over broad ecological and economic scales.

PROJECT OVERVIEW

- Little is known about the total economic value of natural infrastructure investments
- Two major methodological challenges:
  - Quantifying the benefit of an ecosystem service that lacks a market price
  - Understanding the "production function" relationship between an investment and expected service provision (plus expected ancillary effects on other service flows).

PROJECT OVERVIEW

- Our research addresses these two challenges by joining state-of-the-art non-market valuation methods with empirical ecological-economic and engineering-economic models of natural infrastructure investment.

WHY STUDY THE PACIFIC NORTHWEST?

- Great illustration of why a one-size fits all approach to coastal infrastructure investment may not be successful.
  - Under-studied ecosystem types, chronic (e.g., erosion, SLR) and acute (e.g., tsunami) risks, and ancillary opportunities (e.g., endangered species habitat restoration).
  - Less disturbed/developed/studied than the East/Gulf coasts

PRIMARY RESEARCH QUESTION

- How do we allocate coastal natural infrastructure investments that provide ecosystem services efficiently?

- In other words, how to we prudently budget for nature-based investments in coastal ecosystems?

RESEARCH STRUCTURE

Three Methodological Tracks

- **Track I**: Estimate willingness-to-pay (WTP) for protection services by analyzing coastal housing market data.
- **Track II:** Estimate WTP for ecosystem services that accrue as public goods benefits to a wide variety of coastal and non-coastal residents using choice experiment survey instruments
- **Track III:** Develop natural infrastructure investment models to maximize net present value of ecosystem services.

RESEARCH STRUCTURE

Four Applied Pathways

- Coastal Protection Pathway
- Estuary Restoration Pathway
- Coastal Dune Management Pathway
- Coastal Land Use Pathway

ECONOMICS OF ECOSYSTEM SERVICE VALUATION

Economists have developed an extensive theory and set of empirical tools to value price changes for private, marketed goods

- But….
  - The environment is a public good that is not bought and sold in traditional markets
  - And environmental policy questions are focused more on valuing quality changes (not price changes)

ECONOMICS OF ECOSYSTEM SERVICE VALUATION

- Non-market valuation: Collection of techniques to monetize the benefits associated with environmental goods/bads and ecosystem services
- Benefits from a **change in environmental quality** are equal to what people are willing to pay (**WTP)** for that change
- <u>Revealed versus Stated Preferences</u>
  - Revealed: use information revealed in real market transactions
  - Stated: use information generated from hypothetical/constructed markets

SOURCES OF ECONOMIC VALUE

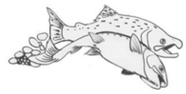
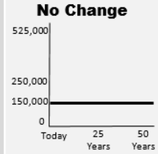
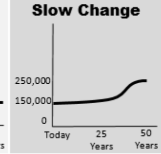
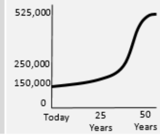
- **Use Value**: the utility of consuming a good
- **Option Value**: the value placed on individual WTP for maintaining a resource so they have the option to enjoy it in the future, although they may not currently use it.
- **Nonuse Value**: the value that people assign to economic goods even if they never have and never will use it.
  - Existence or Bequest

TRACK I: HEDONIC MODELING

- Revealed preference approach
- The hedonic price function for a house can be described as:
  - Housing price = F(structural characteristics, neighborhood characteristics, location characteristics)
- Each property characteristic has an implicit value and price.
- The hedonic method is a technique for sorting out these values and we can apply this to any differentiated product.

TRACK II: CHOICE EXPERIMENT

- Stated preference approach
- A choice experiment elicits individual values for selected attributes of a policy by directly asking them to state their **choice** over multiple hypothetical alternatives

	Results in 50 years		
	Status Quo	**Alternative A**	**Alternative B**
Population Status	**Threatened**	**Threatened**	**Recovered**
Population size (# of fish)	**150,000**	**250,000**	**525,000**
Population Over Time	**No Change** 	**Slow Change** 	**Slow Change** 
Recreational Fishing (# of fish that can be kept)	**Periodically Closed** **5 fish/year**	**Periodically Closed** **5 fish/year**	**Open Every Year** **10 fish/year**
Added cost to your household each year for 10 years	**$0**	**$50/year**	**$100/year**
Which alternative do you prefer? ***(Choose One)***	○1 **Status Quo**	○2 **Alternative A**	○3 **Alternative B**

TRACK III: COUPLED EMPIRICAL MODELS

- Our research is producing new data and models that will help identify which trade-offs may be best.
- Leverage natural science and economic models to predict the best *dynamic* investment strategy.

- Uses of ecosystem service valued:
  - Dynamic Investment decision => ***when*** is it efficient to invest?
  - Spatial Investment decision => ***where*** is it efficient to invest first? Second?

COASTAL PROTECTION PATHWAY

Research Questions

- How do coastal housing markets respond to different coastal landforms, different types of risk, and the ability to invest in protection?
- Does WTP differ for protective services based on the type of risk (i.e. chronic or acute) or the infrastructure used (i.e. rip-rap, dynamic revetment, or dunes)?

COASTAL PROTECTION PATHWAY

Potential Infrastructure Investments

- Grey: Rip-rap revetments, seawalls
- Natural (Green): Dune restoration/maintenance, dynamic revetments, managed retreat

COASTAL PROTECTION PATHWAY

Grey Infrastructure

COASTAL PROTECTION PATHWAY

Natural (Green) Infrastructure

COASTAL PROTECTION PATHWAY

Current projects

- How do Multiple Natural Hazards Affect the Value of Housing? Evidence from the Oregon Coast
- The Determinants of Coastal Armoring: Estimating influential determinants of parcel-level riprap installation
- Tools & Techniques for Long-term Monitoring of Shoreline Protective Structures

COASTAL PROTECTION PATHWAY

Planned projects

- Development of a survey instrument to understand public (not just waterfront property owners) values for coastline stabilization from different types of infrastructure investment
- Additional housing market analyses

ESTUARY RESTORATION PATHWAY

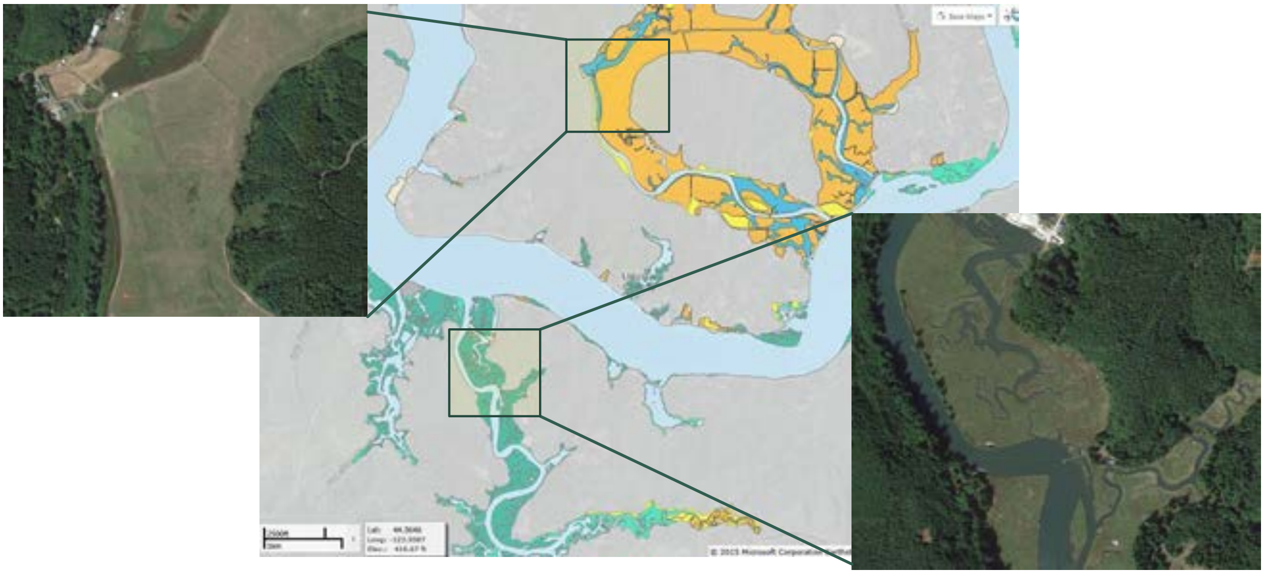
Research Questions

- How will coastal ecosystem services respond to **estuarine** restoration activities, and what are the values associated with restoration?
- Where should **estuarine** restoration activities be targeted to maximize benefits of such investments?

ESTUARY RESTORATION PATHWAY

Potential natural infrastructure investments

- Dike removal and salt marsh and river channel restoration – advocated by many, including NOAA's recovery plan for coastal coho salmon.
- Native eelgrass restoration, controlling invasive eelgrass, and controlling invasive species.
- Restoring native or non-native aquaculture oyster beds
- Restoring riparian buffers



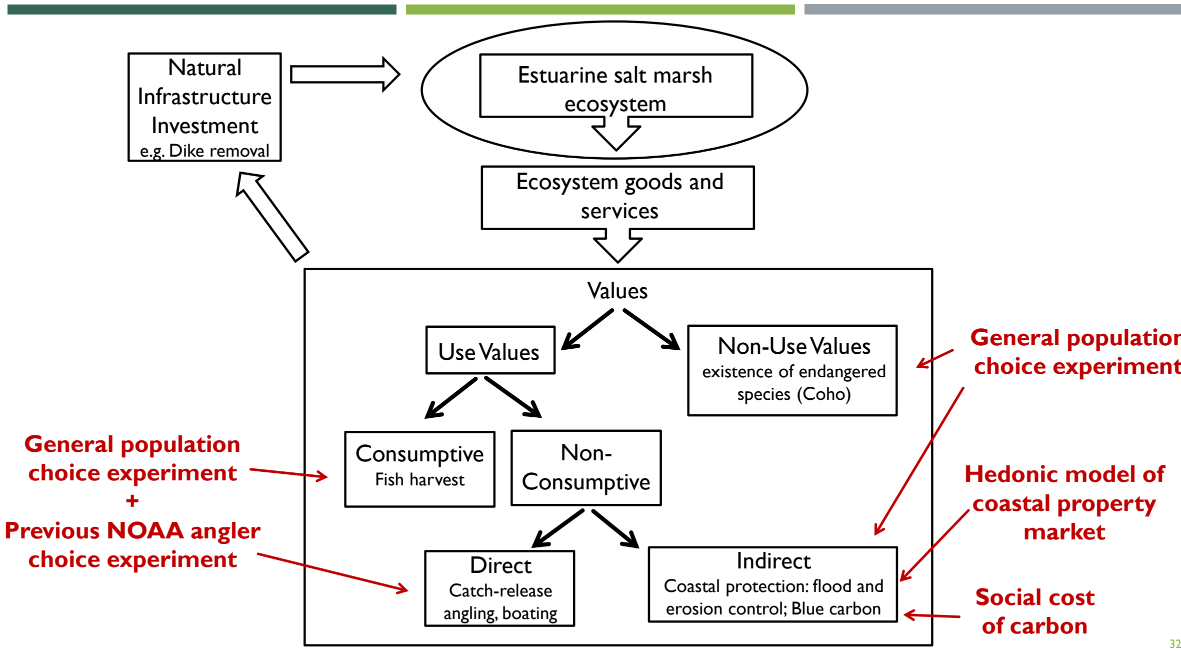


Figure adapted from NRC (2005) and Barbier et al. (2011)

ESTUARY RESTORATION PATHWAY

Current projects

- Restoring Oregon Coast Coho Salmon: What is your opinion? (survey)
- Dike Removal and Salt Marsh and River Channel Restoration for Fish Habitat: Estimating the Effects on Fish Production, Carbon Sequestration, Coastal Flooding, Water Quality, and Local Land Markets.
- Involves Estimating Ecological Production Functions from Natural Infrastructure Investment in Estuarine Restoration.

COASTAL DUNE MANAGEMENT PATHWAY

Research Questions

- What are the values associated with ecosystem services provided by sandy beach and dune systems?
- Where and how should optimal management of natural infrastructure occur in Pacific Northwest sandy beach and dune systems?

COASTAL DUNE MANAGEMENT PATHWAY

Sandy Beaches and Dunes: Ecosystem Services

- Provide unique **habitats** for native plants, shorebirds, amphibians, and mammals.
- Interface nature allows **buffering** from ocean waves, sea level rise, and terrestrial flooding.
- Natural **aquifers**: groundwater recharged and barrier to saltwater intrusion
- **Recreation**: consumptive (fishing) and nonconsumptive (ATV use)

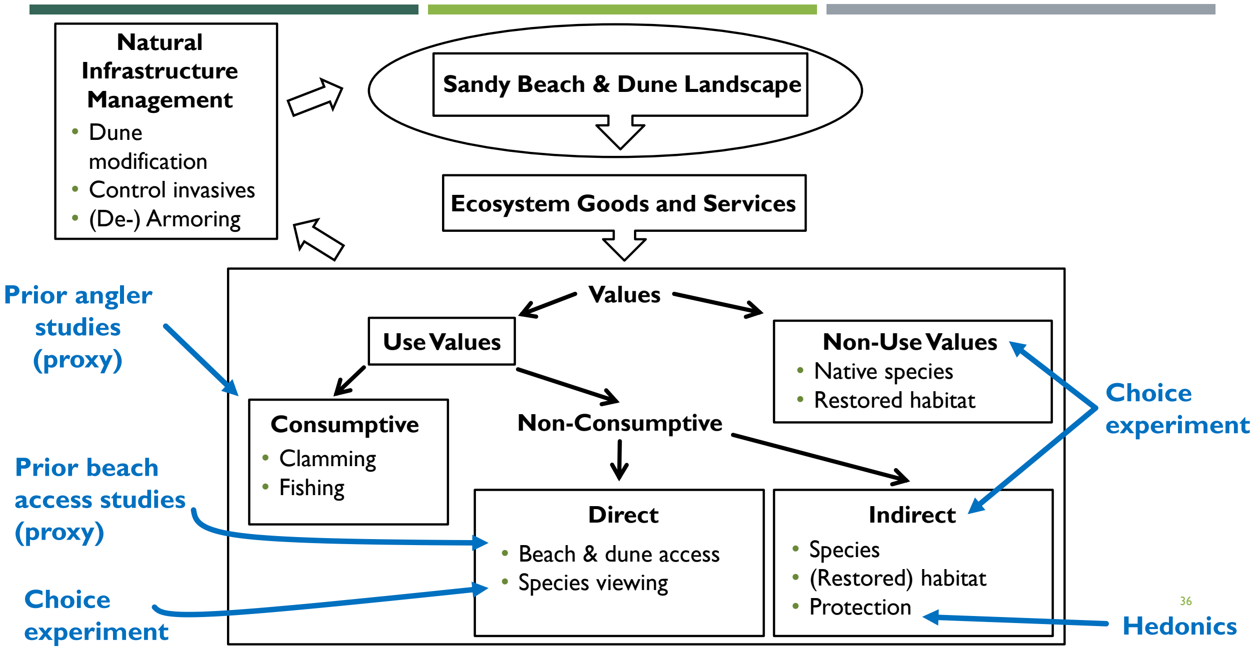


Figure adapted from NRC (2005) and Barbier et al. (2011)

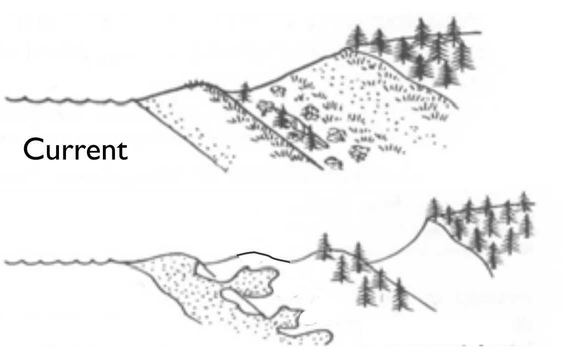
COASTAL DUNE MANAGEMENT PATHWAY

Potential Natural Infrastructure Management Strategies

- Dune modification
  - Removal or height reduction for restoration
  - Height increase and/or beach sand replenishment
- Non-native plant removal
- De-armoring

COASTAL DUNE MANAGEMENT PATHWAY

Infrastructure Management: *Trade-offs*



→Dune modification

→Non-native grass removal

↑ Open dunes

↑ Native species

↓ Stabilization

↓ Protection

↓ Other habitats

↑ Investment

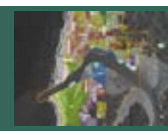
? Recreation

COASTAL DUNE MANAGEMENT PATHWAY

Current empirical projects

- Restoring Pacific Northwest Sandy Beach and Coastal Dune Landscapes: What is your opinion? (survey)
- Optimizing Coastal Dune Management
- Site Selection for Modification of Dune Landscapes in the Pacific Northwest

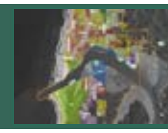
COASTAL LAND USE PATHWAY



Research questions

- How can natural infrastructure be optimally allocated within coastal communities, accounting for the value of life safety (via tsunami evacuation facilitation)?
- Given the current suite of risks, what land use policy decisions in the area of natural infrastructure can make coastal communities more resilient against those risks?

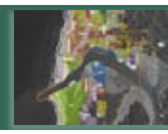
COASTAL LAND USE PATHWAY



Potential "Urban" Natural Infrastructure Investments

- Elevated Greenspace (park, playground, etc.)
- Greenways or trails

COASTAL LAND USE PATHWAY



Existing Models

- Tsunami inundation model
- Agent-based Model of Human Behavior Event Response
- Built infrastructure & transportation system model

In development

- Natural infrastructure placement

We plan to implement a wide range of tsunami, human behavior, and infrastructure conditions to evaluate alternatives to improve life safety.

2017 ADVISORY BOARD MEETING

Recovering Oregon Coast Coho Salmon: What is Your Opinion?

Oregon State University OSU NOAA NCCOS CIMRS

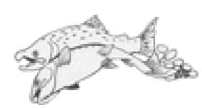
USES OF ECONOMIC SURVEY RESULTS

Dave Lewis
Professor
Applied Economics

Oregon State University OSU — NOAA — NCCOS — CIMRS

OBJECTIVES OF THE COHO SALMON CHOICE EXPERIMENT

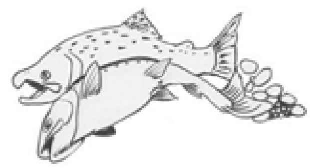
- Oregon Coast coho salmon are a primary beneficiary of investments in estuarine natural infrastructure.
- Estimate the public's demand for restoring Oregon Coast coho salmon.
- Survey to be sent to a random sample of the population from OR, WA, ID, and northern CA
  - Anglers and non-anglers will be in the pool
  - Estimated non-market values will include use values and non-use values
- Distinguish the public's willingness-to-pay for different attributes associated with restoring salmon (recovery, population, speed, recreation).



STEPS IN CONDUCTING A CHOICE EXPERIMENT

1. Characterize the decision problem
2. Identify and describe the attributes
3. Develop an experimental design
4. Develop the questionnaire
5. Collect data (send the survey)
6. Estimate model
7. Interpret results for policy analysis or decision support

- **Steps 1 – 4 are seen in the survey you just took**



From: Holmes and Adamowicz (2003)

HOW ARE THE RESPONSES USED?

Consider a highly simplified version

- Suppose someone picks Alternative A.
  - They are willing-to-pay at least $50 for an extra 175,000 fish beyond the baseline.
  - They are not willing-to-pay $25 for the next 50,000 fish beyond 325,000.
- Suppose someone picks Alternative B.
  - They are willing-to-pay at least $25 for an extra 50,000 fish beyond 325,000

	Status Quo	Alternative A	Alternative B
Abundance (# of fish)	150,000	325,000	375,000
Cost to your household	$0	$50	$75
Which alternative do you prefer?			

Observing many choices and many alternatives allows us to conduct this type of "all-else-equal" analysis for all attributes through statistical analysis of the data.

DESIGNING CHOICE EXPERIMENTS

A key feature is defining the change in environmental quality to value.

Key decision – Which attributes to value?

- ESA recovery, Population, Speed, & Recreation

Key decision – How many more fish could reasonably return with restoration?

- Baseline is 150,000 fish (average return since 1994).

  The federal government finds no evidence that habitat is improving.

- Highest number of returning fish is 525,000

  Derived from the State of Oregon's Coho Salmon Conservation Plan.

  Ocean-condition based goals from 101,000 fish (poor years) to 817,000 fish (good years)

  Applying the state's goals to the actual distribution of ocean conditions since 1994 gives ~525,000 fish.

DESIGNING CHOICE EXPERIMENTS

Another key feature is the experimental design (presenting attribute levels).

- With the possible attribute levels to the right, there are 810 possible combinations within an alternative.
- After ruling out implausible alternatives, there are over 25,000 combinations of two alternatives for each choice card.
- We use an "optimal" design strategy and subsequent model testing to pick 20 different surveys with 60 unique choice cards.

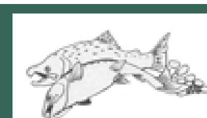
ESA Status	Population	Speed	Fishing	Cost
Threatened	150,000	Flat	Periodically closed (current)	$0
Recovered	250,000	Slow	Open every year	$10
	325,000	Fast	Open every year + 10/yr	$20
	375,000			$50
	525,000			$75
				$100
				$150
				$250
				$350

RECENT WTP ESTIMATES FOR THREATENED MARINE SPECIES

TABLE 2 | Recent disaggregate threatened, endangered, and rare marine species valuation studies[a].

Species	References	Valuation method	Mean/Median WTP range	Frequency of payment	Units[b]	Survey year	Good valued	Country
Upper Willamette River Chinook salmon	Wallmo and Lew, 2012	CE	$44.14	Annual	H	2009	Improved status	U.S.
Central California coast coho salmon	Wallmo and Lew, 2015	CE	$54.55–62.13	Annual	H	2010	Improved status	U.S.
Southern California steelhead	Wallmo and Lew, 2015	CE	$75.91–82.86	Annual	H	2010	Improved status	U.S.

USES OF WILLINGNESS-TO-PAY ESTIMATES



Evaluating the benefits and costs of natural infrastructure investment

The final recovery plan for Oregon Coast coho salmon recently released (December 2016) and includes many natural infrastructure investment proposals, such as:

- Dike removal in estuaries -> salt marsh restoration
- Tide gate modification in estuaries
- Riparian buffers along coastal rivers
- Increase habitat complexity

Recovery of coho salmon is a primary catalyst for natural infrastructure investment in Oregon estuaries

- Since we're valuing population changes, then we can value many potential scenarios that generate different population increases in coho salmon.
- Recovering species through natural infrastructure investment generates tradeoffs – monetizing costs and benefits allows tradeoffs to be compared in the same units.
- Non-market valuation estimates can be used in damage assessments.

VALUE OF NATURAL INFRASTRUCTURE INVESTMENT

$$\text{Unit price of capital} = \frac{\text{Ecosystem service flows} + \text{Capital gains}}{\text{Discount rate} - \text{Growth rate of capital stock (Net appreciation)}}$$

From Fenichel et al. (2015 PNAS)

Q: How does the value of an acre of restored salt marsh compare to the value of an acre of diked agricultural land?

2017 ADVISORY BOARD MEETING

Working Lunch

Oregon State University OSU NOAA NCCOS CIMRS

COASTAL DUNE MANAGEMENT SURVEY UPDATE

David Kling
Assistant Professor
Applied Economics

Tu Nguyen
Ph.D. Student
Applied Economics

PNW COASTAL DUNES

- ~45% of Oregon coast
- Largest dune sheet in North America occurs in Oregon (240 km long, 3 km wide)
- Sandy beach and coastal dune landscapes are natural infrastructure capital.
- This form of natural capital appears to provide several types of benefits to the public.

A LEGACY OF NATURAL INFRASTRUCTURE MANAGEMENT

- Prior to 1900: Oregon beaches and dunes were sparsely vegetated, with little grass and open shifting sand
- Non-native beach grasses were planted on the Oregon coast in the early 1900s to stabilize sand and create **foredunes**: hills of sand parallel to the shoreline.

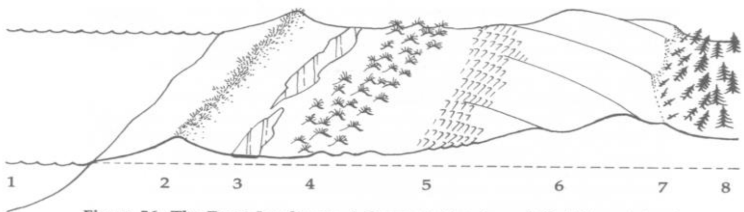
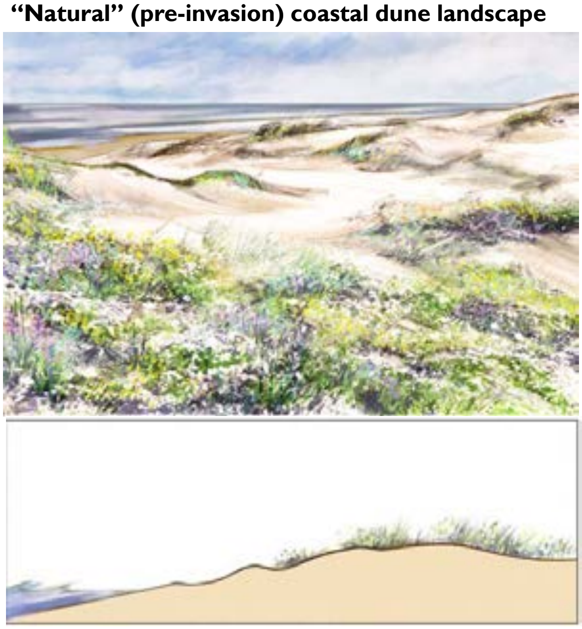
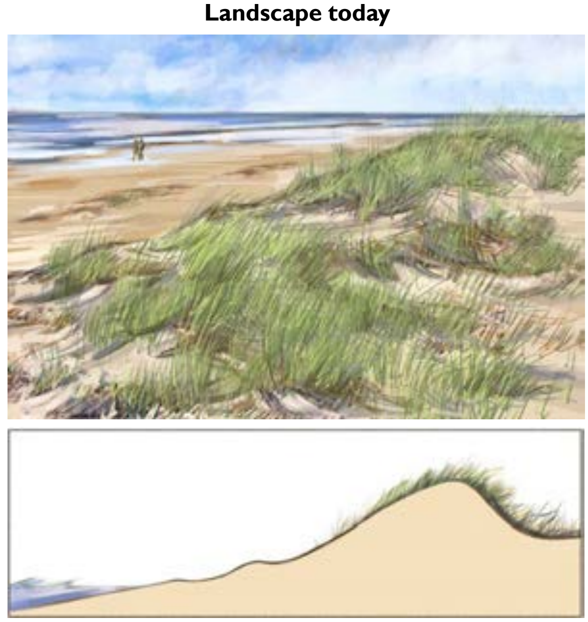


Figure 56. The Dune Landscape. 1 Ocean. 2 Foredune. 3 Deflation plain. 4 Beachgrass hummocks. 5 Transverse ridges. 6 Oblique dunes. 7 Retention ridge. 8 Forest. (Kellerman.)

"Natural" (pre-invasion) coastal dune landscape



Landscape today



HOW DO PEOPLE VALUE COASTAL DUNE LANDSCAPES?

Economic theory and evidence show that people may derive various benefits from a restored dune landscape

Specifically, people may enjoy:

- Scenery with more native plants and wildlife
- Recreational activities, which may be affected by restoration

HOW DOES THE PUBLIC VALUE DUNE LANDSCAPE RESTORATION?

- Research strategy: general population choice experiment survey
  - "Restoring Pacific Northwest Sandy Beach and Coastal Dune Landscapes: What is your opinion?"
- **Research questions** include:
  - Does the public value restored coastal dune landscapes?
  - How does this valuation tend to change as recreation opportunities in the restored landscape varied?

SURVEY DEVELOPMENT: BACKGROUND WORK

- Consultation with experts on species of concern in PNW coastal dune habitats.
  - o Substantial "in-house" expertise for this pathway.
- Methodological development:
  - Carefully-crafted background information and qualitative questions (majority of survey text).
  - Choice experiment design: what are we asking the public to value, and how will we measure public preferences?
- Contracted with a professional illustrator – *lucky break for this research*!

SURVEY DEVELOPMENT:
SPECIFYING A HYPOTHETICAL PROGRAM

- Restoration program:
  - o Multiple locations, spread out along the coast
  - o Away from densely populated areas to minimize loss of coastal protection
  - o Ongoing maintenance after restoration program is completed

SURVEY DEVELOPMENT: DESCRIBING LEVELS OF INVESTMENT

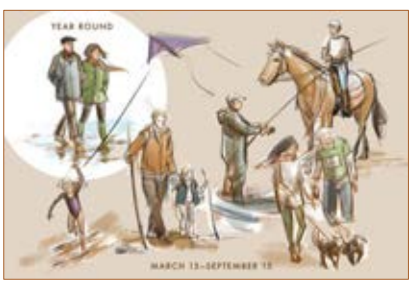
"Low" restoration

"Moderate" restoration

"Full" restoration

SURVEY DEVELOPMENT: RECREATION IN COASTAL DUNE LANDSCAPES

***Less recreation allowed**

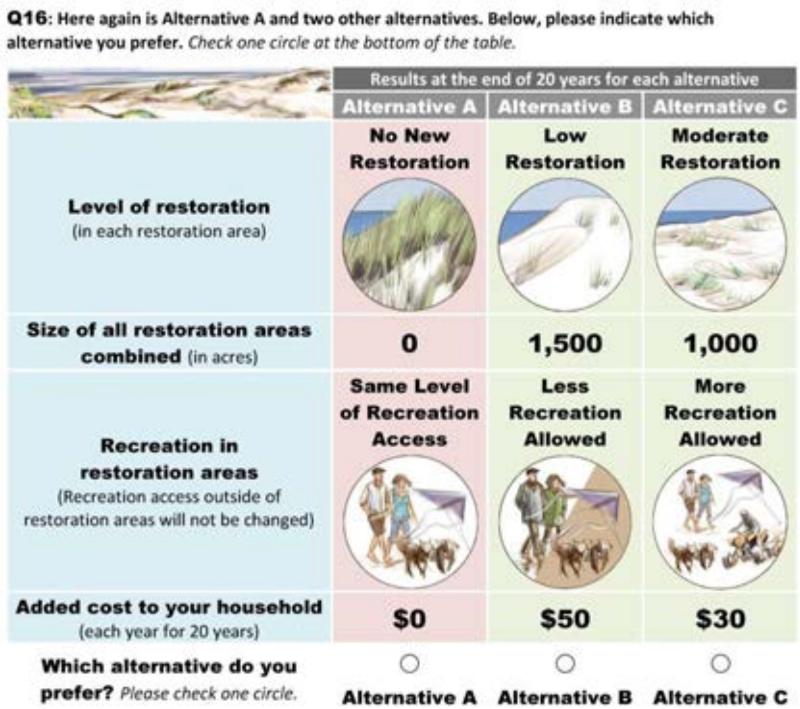


Status quo access

More recreation allowed

*These are only the preliminary sketches from our illustrator, Katheryn Roy

SURVEY DEVELOPMENT: CHOICE EXPERIMENTS



Q16: Here again is Alternative A and two other alternatives. Below, please indicate which alternative you prefer. *Check one circle at the bottom of the table.*

	Results at the end of 20 years for each alternative		
	Alternative A	Alternative B	Alternative C
Level of restoration (in each restoration area)	**No New Restoration**	**Low Restoration**	**Moderate Restoration**
Size of all restoration areas combined (in acres)	**0**	**1,500**	**1,000**
Recreation in restoration areas (Recreation access outside of restoration areas will not be changed)	**Same Level of Recreation Access**	**Less Recreation Allowed**	**More Recreation Allowed**
Added cost to your household (each year for 20 years)	**$0**	**$50**	**$30**
Which alternative do you prefer? *Please check one circle.*	○ **Alternative A**	○ **Alternative B**	○ **Alternative C**

SURVEY DEVELOPMENT: FOCUS GROUP TESTING

- Draft survey instrument focus group-tested in Fall 2016 (Sacramento) and Winter 2017 (Portland).
- Outcomes:
  - Awareness of PNW coastal dune landscapes tended to be low.
  - Salience of issues presented by survey appeared to be high among many participants.
  - Evidence of wide preference heterogeneity.
  - Draft instrument that included species of concern in choice experiment was too complicated for many participants.

NEXT STEPS

- Develop simpler survey that focuses on measuring preferences for coastal dune landscape restoration and recreation access.
  - This approach prioritizes natural infrastructure with less focus on values for species preservation.
- Optimize background information and qualitative questions for new focus groups. Then focus group test new instrument.
- Target deployment window: summer or early fall 2017.
- General population survey of OR & WA. Potential for ID & Northern CA

SOME EXPECTED RESULTS

- Responses to a large block of qualitative questions concerning public knowledge of and attitudes toward this system.
- Mean household willingness-to-pay for:
  - Naturalness of sandy beach and coastal dune landscapes
  - Scale of restoration projects
  - Recreation opportunities in restored areas
- To the best of our knowledge, this will be the first evidence on public values for coastal dune landscapes.

2017 ADVISORY BOARD MEETING

Linking Economic Valuation with Ecological Production Functions

ESTUARIES & SALMON

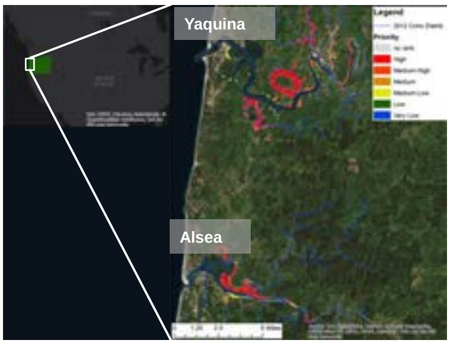
Sally Hacker
Professor
Integrative Biology

Dave Lewis
Professor
Applied Economics

Caitlin Magel
Ph.D. Student
Integrative Biology

INVESTING IN NATURAL INFRASTRUCTURE IN ESTUARIES

Consider investing in salt marsh restoration through dike removal.



OUTPUT FROM CHOICE SURVEY

- What we will know from choice survey: willingness-to-pay for specific changes in Coho salmon population size as a consequence of habitat restoration in estuarine watersheds in Oregon (e.g., what are you willing to pay for an increase of 175,000 fish?).

COHO SALMON PRODUCTION FUNCTION MODELS

- Next, we ask an ecological question: how do we translate investments in natural infrastructure (estuary habitat restoration) to numbers of returning salmon?
- In other words, how many adult coho salmon might we expect to be produced by estuarine habitat restoration?

COHO SALMON PRODUCTION FUNCTION MODELS

- "Expert-based" Approach
  - Nickelson (2012; report to TNC) used <u>published studies</u> and <u>historical abundance</u> to estimate the production function between estuarine habitat and coho salmon numbers.

Estimated 110-170 coho salmon per 100 acres of marsh wetland

COHO SALMON PRODUCTION FUNCTION MODELS

- "Expert-based" Approaches
  - Scheuerell (2006; *Can. J. Aquat. Sci.*) used the Shiraz model, a functional relationship approach, using literature and expert knowledge to estimate the production of Chinook from one stage to the next.
  - Has not been applied to coastal coho salmon recovery.

COHO SALMON PRODUCTION FUNCTION MODELS

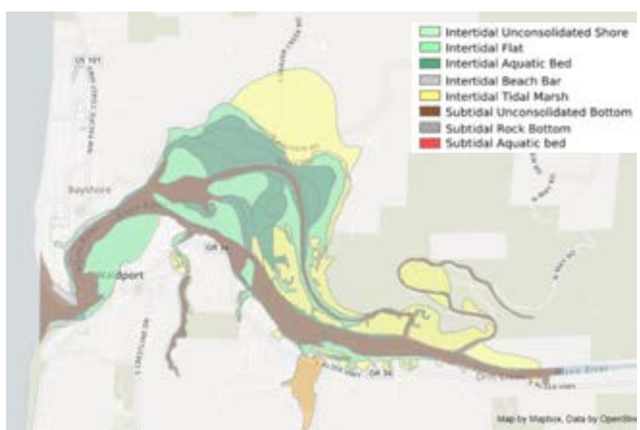
- "Data–driven" Approach
  - Scheuerell (2015; *Eco. & Evo.*) used a Bayesian statistical model to estimate the production of Chinook salmon under different hatchery supplementation programs for 22 different populations over 43 years of data.
  - Has not been applied to coastal coho salmon recovery.

BAYESIAN APPROACH TO LINK HABITAT TO SALMON

- We will use a Bayesian statistical model to estimate the production function for estuarine habitat and coho salmon abundance.
  - Main partner: Mark Scheuerell, Fish Ecology Division, Northwest Fisheries Science Center, NMFS, NOAA
- Requirement is a time series dataset for coho salmon multiple estuaries in Oregon:
  - Age structure and spawner abundance
  - Harvest rate
  - Ocean conditions (upwelling, climate variability)
  - Watershed conditions (river/stream characteristics)
  - Wetland marsh habitat in each estuary

BAYESIAN APPROACH TO LINK HABITAT TO SALMON

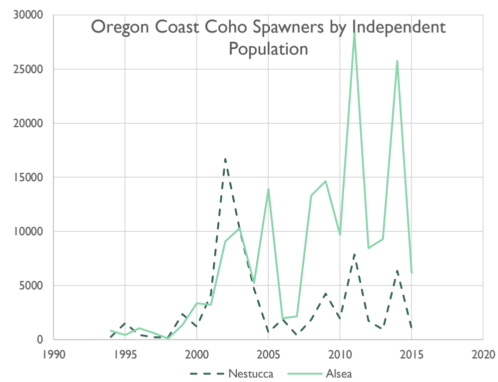
- Delineate estuarine habitat appropriate for coho salmon along the Oregon coast using publically available GIS products
  - Main partner: Laura Brophy, Greenpoint Consulting, Corvallis, OR.
  - Graduate student: Caitlin Magel, OSU
- Calculate estuary habitat for coho salmon: existing unrestored, restored, and priority for restoration.



BAYESIAN APPROACH TO LINK HABITAT TO SALMON

- Gather demographic data for coho salmon in multiple watersheds on the Oregon coast.
  - ODFW compiles these data.
  - 22 separate watersheds (independent populations).
- Calculate production using age class sizes: adult spawners, smolts, and juveniles.

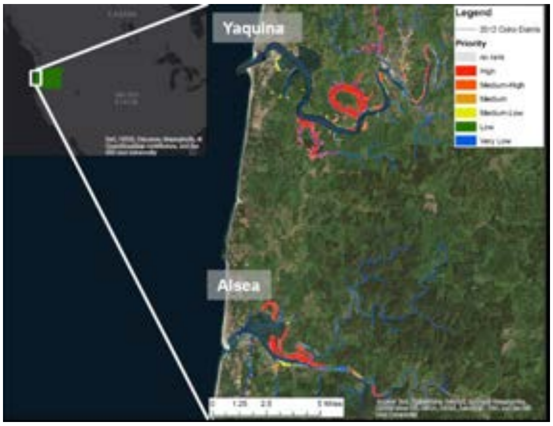
An example from two watersheds



BAYESIAN APPROACH TO LINK HABITAT TO SALMON

- Bayesian model will determine the variance explained by estuarine habitat area, ocean conditions, harvest, etc., on coho salmon production.
- Use production function of estuarine habitat to estimate the number of coho salmon produced under future estuarine habitat restoration efforts.

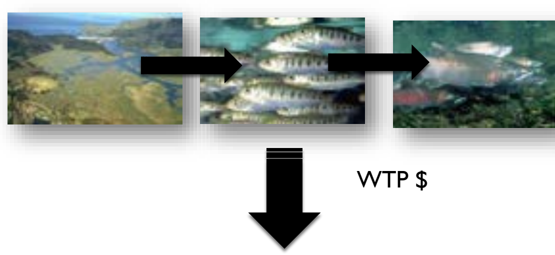
AN EXAMPLE RESTORATION SCENARIO



- An example restoration scenario would restore tidal flows and salt marshes (left), increasing habitat for coho salmon and thus production.
- Q: What are the economic benefits from this type of restoration in natural infrastructure?

AN EXAMPLE RESTORATION SCENARIO

- Bayesian Coho Model: Estimates how many additional coho return in each watershed under a restoration scenario.
  - This is a quantity. (e.g. 75,000 fish per restored watershed)
- Choice Experiment Model: Estimates the public's willingness-to-pay (WTP) for additional Coho salmon.
  - This is a price (e.g. WTP $50/year per household for 75,000 fish)
- Combining the Choice Experiment with the Bayesian Coho model:
  - Total economic benefits are the multiplication of the price the average public household is WTP for a given change in salmon by the number of households in the population.
  - For example, $50 x 4 million households (OR, WA) = $200 million/year.

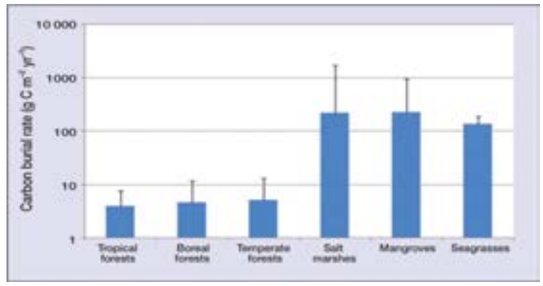


Total economic benefits of estuarine watershed restoration

We'll discuss the economic costs of restoration later.

OTHER ECOSYSTEM SERVICE PRODUCTION FUNCTIONS

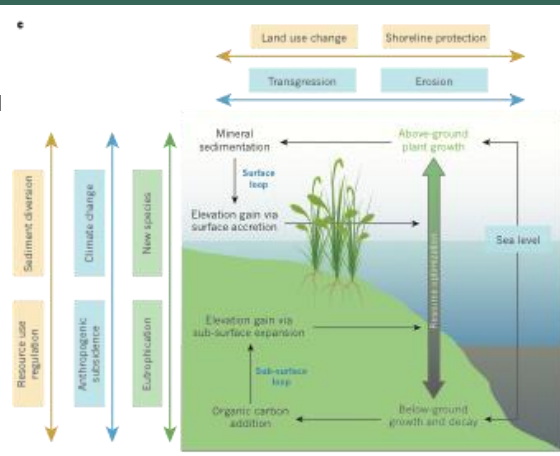
- Coastal blue carbon
  - Coastal salt marshes sequester very large amounts of carbon in sediments and other biomass.
  - Estuary restoration that increases salt marsh acreage and will sequester more carbon.
  - Q: How to model physical stock of blue carbon sequestration?
    - INVEST model from the Natural Capital Project.
    - Runs off spatial data (e.g., coastal habitat) and blue carbon estimates for PNW estuaries.
  - Q: How to measure price of carbon sequestration?
    - U.S. government's Social Cost of Carbon.
    - Easily available, unlike value of coho salmon.



- From Mcleod et al. (2011), *Frontiers in Ecology & Environment.*
- Mean long-term rates of C sequestration (g C m^{-2} yr^{-1}) in soils in terrestrial forests and sediments in vegetated coastal ecosystems. Note the logarithmic scale of the y axis.

OTHER ECOSYSTEM SERVICE PRODUCTION FUNCTIONS

- Coastal flood protection and sea level rise
  - Coastal salt marshes protect against flooding events and can mitigate sea level rise through sediment accretion.
  - Q: How to model the role of increased marsh area on coastal flood protection today and under SLR?
    - INVEST model from the Natural Capital Project.
    - Runs off spatial data (e.g., coastal habitat).
  - Q: How to estimate price of flood protection?
    - Prior studies have used the housing market.
    - Data is available (more later), but method is challenging.



From Kirwin Megonigal (2013), *Nature*

SANDY BEACHES & DUNES

David Kling
Assistant Professor
Applied Economics

Peter Ruggiero
Associate Professor
CEOAS

Sally Hacker
Professor
Integrative Biology

Oregon State University OSU · NOAA · NCCOS · CIMRS

MANAGING COASTAL DUNES AS NATURAL INFRASTRUCTURE CAPITAL

Once benefits and costs of PNW sandy beach and coastal dune landscapes are tabulated and quantified, a question arises:

- **How might the current inventory of coastal dunes be managed differently to generate greater benefits for the public?**

For example → Are there areas where coastal dunes can be:

- Built-up to increase protection to built infrastructure? *Or…*
- Restored to their original state

- If so, how might the cost of such an investment compare to potential benefits?

GENERAL FRAMEWORK FOR EVALUATING INVESTMENT

$$\underset{\text{from time } t \text{ to } T}{\textbf{maximize}} \begin{pmatrix} \text{discounted} \\ \text{sum} \\ \text{of} \ldots \end{pmatrix} \begin{bmatrix} \text{expected value of} \\ \textbf{goods} \text{ and } \textbf{services} \\ \text{at time } t \end{bmatrix}$$

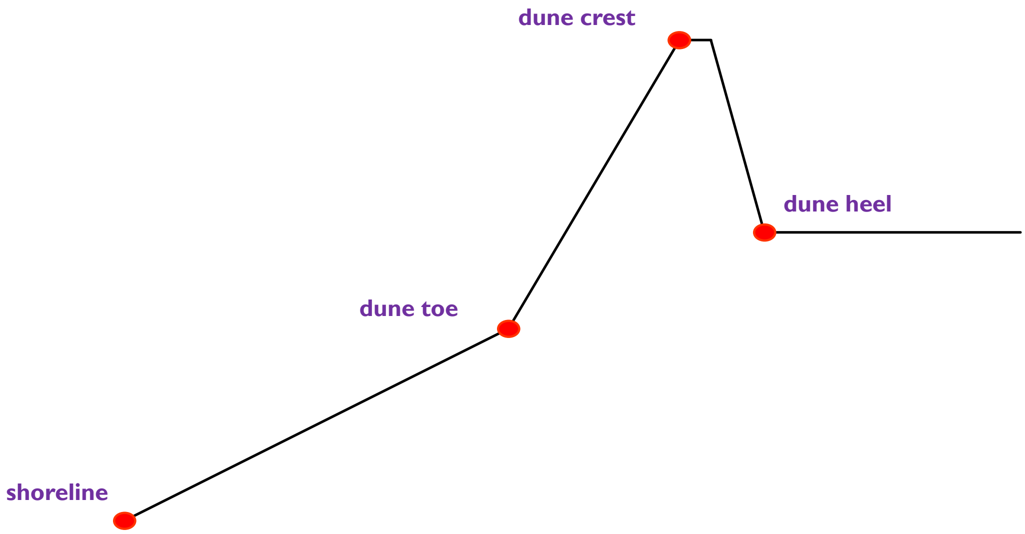
Subject to:

$$\begin{bmatrix} \textbf{goods} \text{ and } \textbf{services} \\ \text{at time } t+1 \end{bmatrix} = \begin{matrix} \text{Production} \\ \text{Funtion} \end{matrix} \left(\begin{bmatrix} \textbf{goods} \text{ and } \textbf{services} \\ \text{at time } t \end{bmatrix} \right)$$

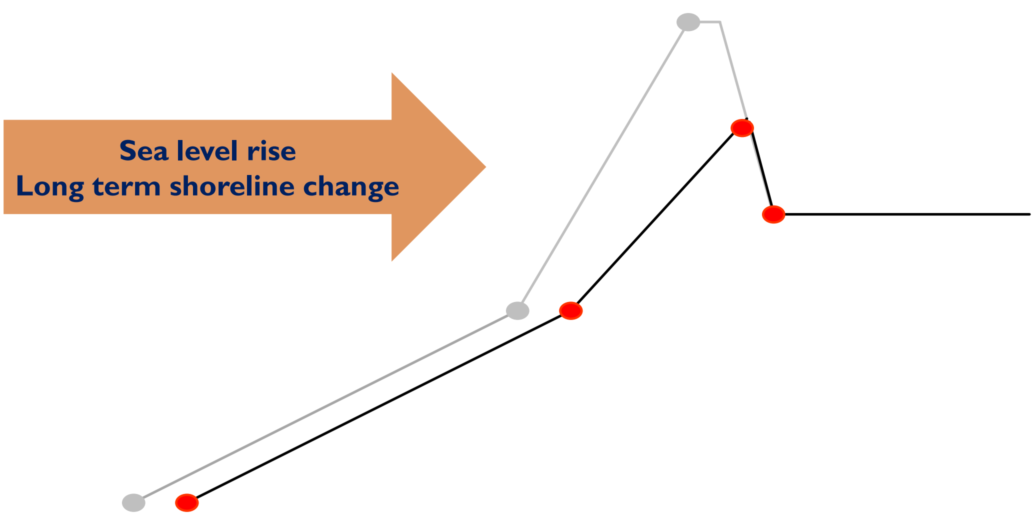
TOWARD A GENERAL FRAMEWORK: TWO MODELS

- **Original survey research**: generate information on how the public values coastal dune landscapes
- **Modeling strategy 1: stylized optimization**
  - Develop a stylized model simple enough to thoroughly explore using optimization.
  - Calibrate model using information from past research on PNW coastal dunes.
    - *But*! Aim to describe essential features of a coastal dune landscape while keeping the structure fairly general.
  - Aim for conclusions that are likely to be generalizable to sandy beach and coastal dune landscapes inside *and* outside the PNW.

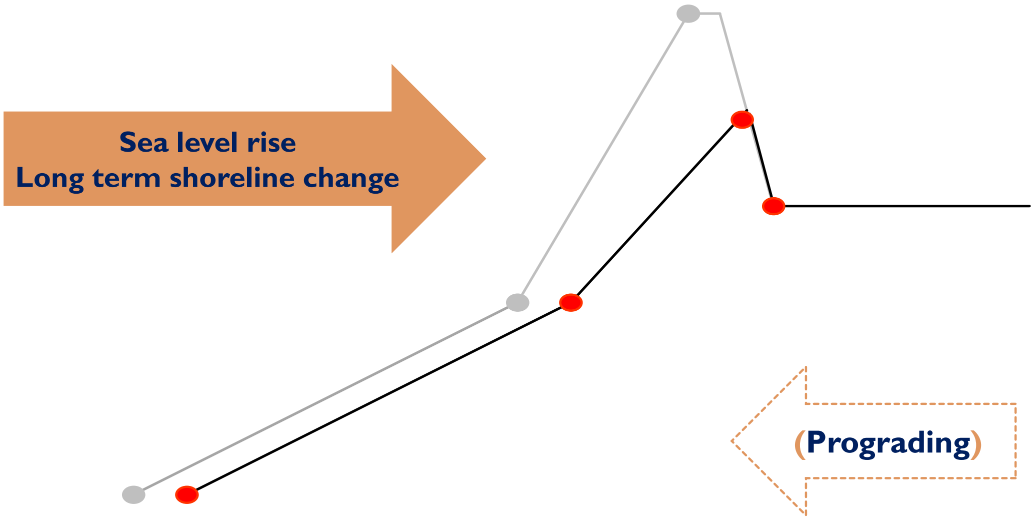
STRATEGY 1: STYLIZED OPTIMIZATION



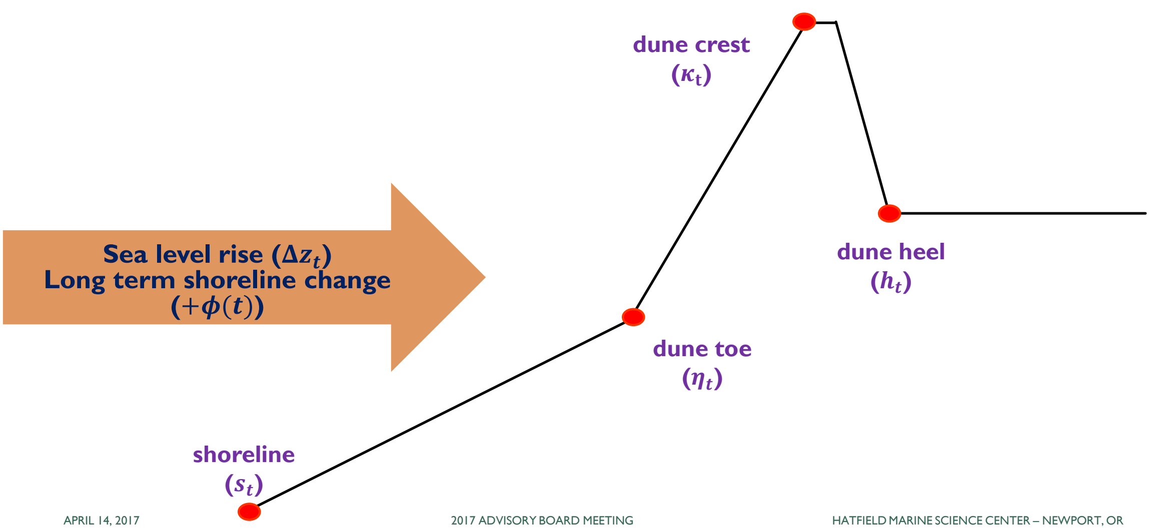
STRATEGY 1: STYLIZED OPTIMIZATION



STRATEGY 1: STYLIZED OPTIMIZATION



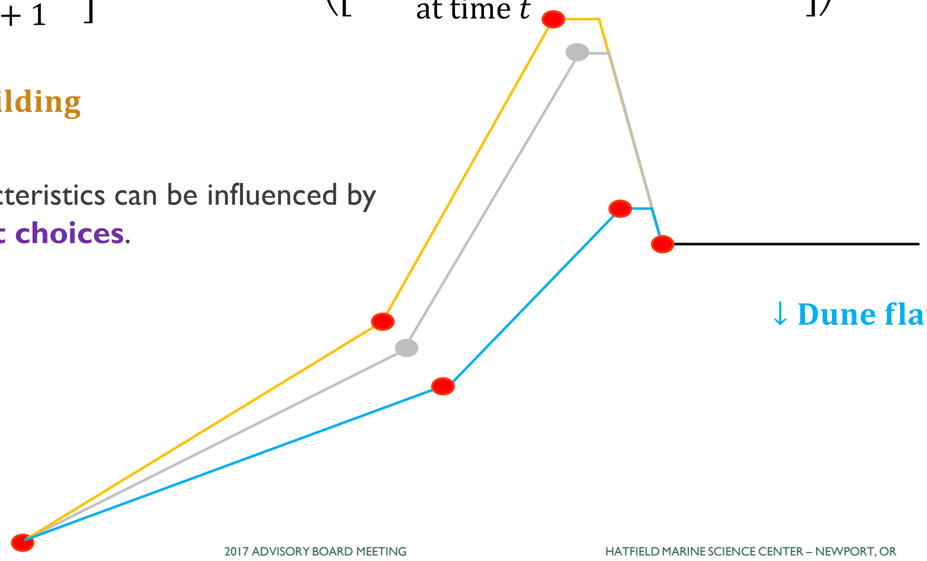
Metrics that represent (average) characteristics of coastal dune and sandy shore landscape become dynamic **state variables** that are tracked over time.



$$\begin{bmatrix}\text{dune/shoreline}\\\text{characteristics}\\\text{at time } t+1\end{bmatrix} = \begin{matrix}\text{Production}\\\text{Funtion}\end{matrix}\left(\begin{bmatrix}\text{dune/shoreline}\\\text{characteristics}\\\text{at time } t\end{bmatrix}, \begin{bmatrix}\text{Investment}\\\text{at time } t\end{bmatrix}\right)$$

↑ Dune building

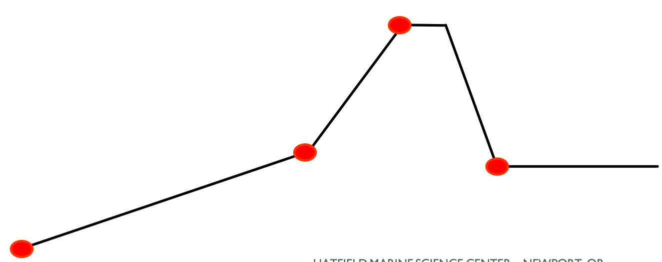
Dune characteristics can be influenced by **investment choices**.



↓ Dune flattening

Objective of optimization model:

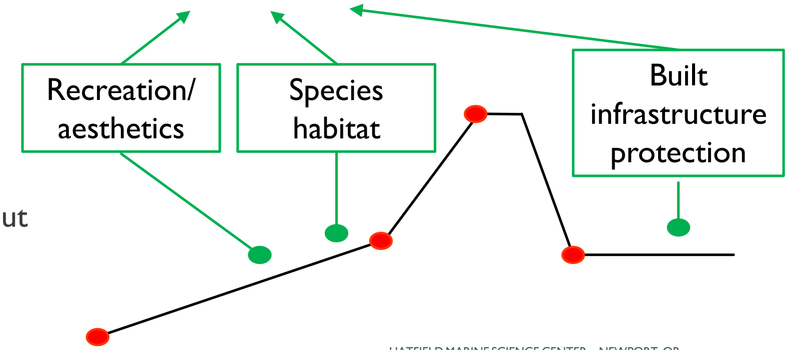
$$\begin{matrix}\text{maximize}\\\text{from time } t \text{ to } T\end{matrix}\left(\begin{matrix}\text{discounted}\\\text{sum}\\\text{of ...}\end{matrix}\begin{bmatrix}\begin{matrix}\text{Value of}\\\text{dune/shoreline}\\\text{characteristics}\\\text{at time } t\end{matrix} - \begin{matrix}\text{Cost of}\\\text{investment}\\\text{choices}\\\text{at time } t\end{matrix}\end{bmatrix}\right)$$



Objective of optimization model:

$$\text{maximize from time } t \text{ to } T \left(\begin{array}{c}\text{discounted}\\ \text{sum}\\ \text{of ...}\end{array} \left[\begin{array}{c}\text{Value of}\\ \textbf{dune/shoreline}\\ \textbf{characteristics}\\ \text{at time } t\end{array} - \begin{array}{c}\text{Cost of}\\ \textbf{investment}\\ \textbf{choices}\\ \text{at time } t\end{array} \right] \right)$$

- Different coastal dune landscape states generate different types of benefits.
- **Example**: tall foredunes provide more protection, but deprive some species of habitat.



RESEARCH QUESTIONS & NEXT STEPS

Stylized Optimization: Some research questions

- How is economically-optimal (i.e., cost-effective) sandy beach and coastal dune landscape management influenced by various benefit/cost profiles?
- How do managed beach-dune morphodynamics compare to the expected status-quo trend?
- How do different expected sea level rise/storm regime predictions influence optimal management?

RESEARCH QUESTIONS & NEXT STEPS

Stylized Optimization: Some research questions

- How is economically-optimal (i.e., cost-effective) sandy beach and coastal dune landscape management influenced by various benefit/cost profiles?
- How do managed beach-dune morphodynamics compare to the expected status-quo trend?
- How do different expected sea level rise/storm regime predictions influence optimal management?

Next steps:

- Develop model of beach-dune morphodynamics that can be tailored to the PNW coast.
- Calibrate model
- Use numerical optimization methods to characterize economically-optimal sandy beach and coastal dune landscape management for different benefit/cost profiles.
- Use results to inform empirically-focused "Strategy II" analysis…

STRATEGY II: EMPIRICAL EXPLORATION OF MANAGEMENT

Explore possible scenarios (i.e., where, how much, and for what) in which coastal dune landscapes in the Pacific Northwest are modified to maximize ecosystem services:

- Are there areas where dunes can be built-up to increase protection to built infrastructure?
- Can 'original' coastal dune landscapes be restored in some places?
- What would the associated costs and benefits be?

Approach will be constrained by a particular budget or a specified number of restored acres

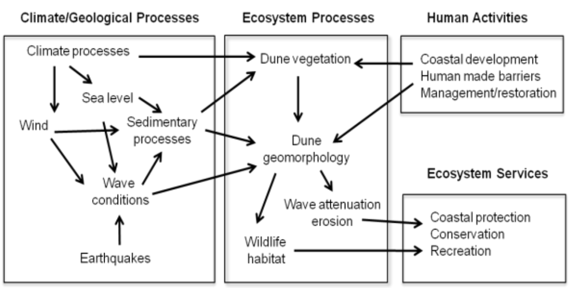
- Develop a beach dune landscape model that is as realistic as possible
- Model will be spatially explicit and data intensive
- Simulation-based analysis likely (optimization less likely) – explore efficient management strategies that maximize ecosystem services.

STRATEGY II: EMPIRICAL EXPLORATION

Coastal Dunes of the US Pacific Northwest

Nearly 45% of the Oregon and Washington coasts are dune backed (20% of California)

STRATEGY II: EMPIRICAL EXPLORATION



Objectives of our research to date:

1. Determine the effect of beach grasses on foredune shape;
2. Determine the implications of beach grass invaders to coastal flooding risk,
3. Determine the implications of beach grasses to conservation of native species.

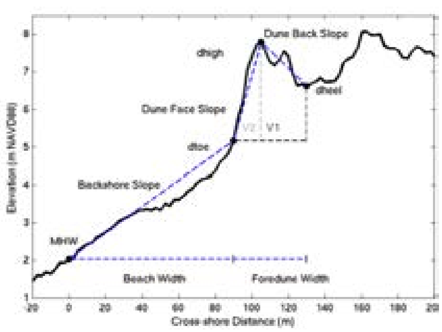
STRATEGY II: EMPIRICAL EXPLORATION

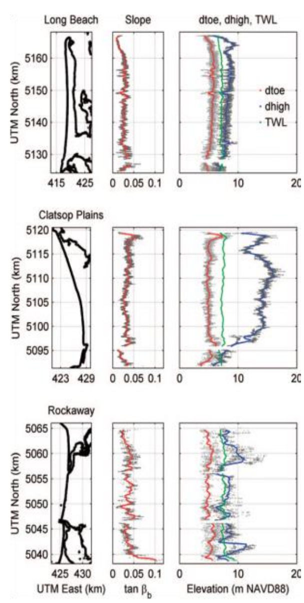
Available Data/Knowledge

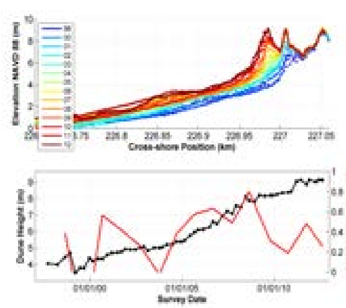
Hacker et al. 2012. *Oikos*
Zarnetske, et al. 2012. *Ecology*
Zarnetske et al. 2013. *J. of Ecology*
Seabloom et al. 2013. *GCB*
Ruggiero et al. 2013. *USGS OFR*
Zarnetske et al. 2015. *RSI*
Ruggiero et al., 2016, Marine Geology
Moore et al., 2016, Geology
Ruggiero et al., in press, Textbook Chapter
Biel et al., in press, Ecosphere
Carroll et al., in prep.

STRATEGY II: EMPIRICAL EXPLORATION

Beach and Dune Morphometrics

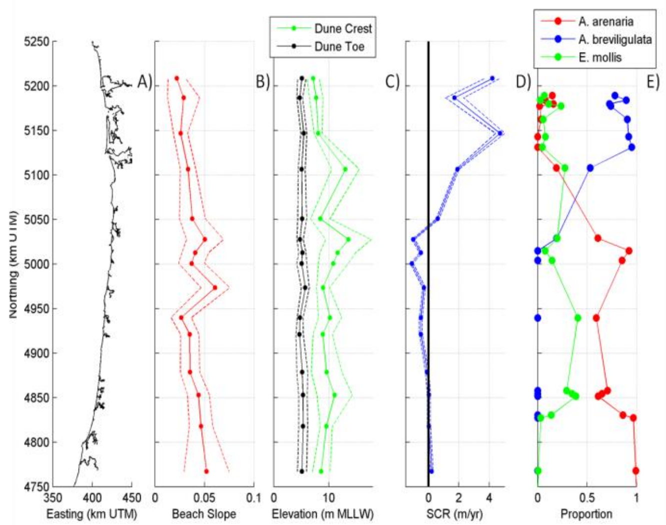






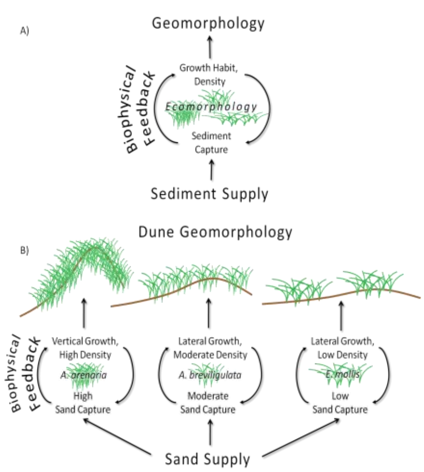
STRATEGY II: EMPIRICAL EXPLORATION

Beach and dune morphometrics; Spatial distribution of grasses

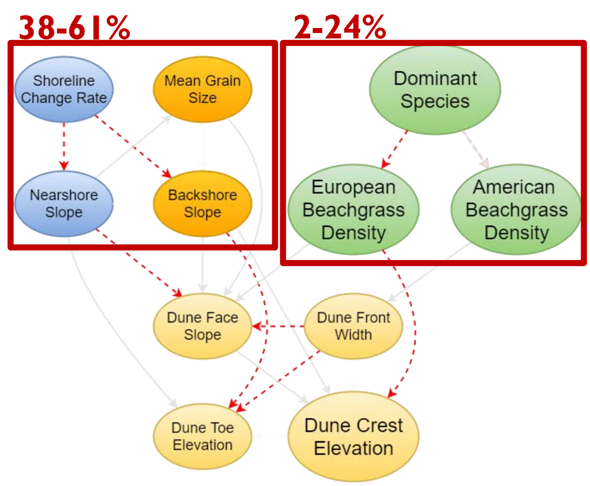


STRATEGY II: EMPIRICAL EXPLORATION

Species specific ecomorphodynamic feedbacks (Hacker et al. 2012, Zarnetske et al. 2012)

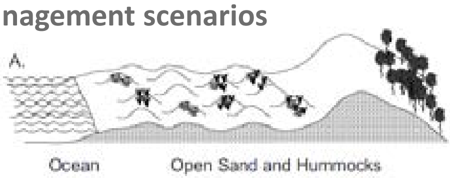


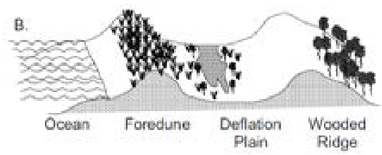
Bayesian Analyses of abiotic versus biotic control of dune morphometrics (Biel et al. In prep)



STRATEGY II: EMPIRICAL EXPLORATION

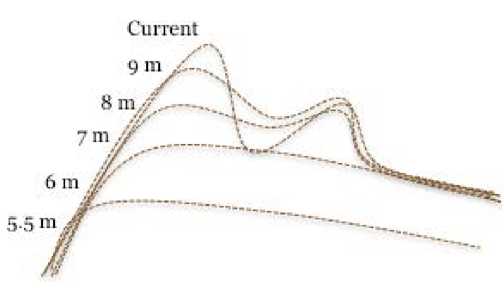
Develop management scenarios with a portfolio of dune shapes for different management scenarios

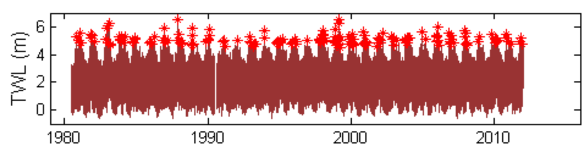


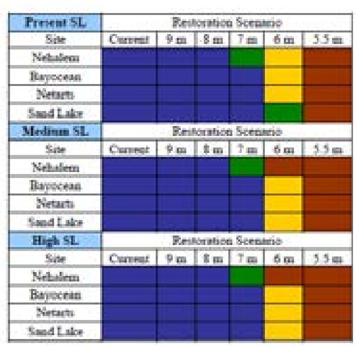


STRATEGY II: EMPIRICAL EXPLORATION

Different dune shape management scenarios can be modeled to understand how those dunes will be impacted by extreme waves and with sea level rise (e.g., Carroll et al. In preparation)







Overtopping days per year blue (< 1 day/year), green (≥ 1 day/year), yellow (≥ 5 days/ year), and red (≥ 10 days/ year)

RESEARCH QUESTIONS & NEXT STEPS

Empirical Exploration: Some Research Questions

- Can a spatially explicit beach and dune landscape model identify management scenarios that maximize the ecosystem services provided by coastal beaches and dunes to a diverse set of stakeholders?
- How do different expected sea level rise/storm regime predictions alter the timing and location of optimal investment in dune landscapes?
- Is the manner in which Goal 18 handles coastal protection an efficient land use strategy?

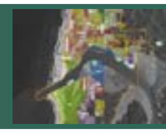
Next Steps

- Data exploration
- Incorporate knowledge of system function
- Define scenarios
- Quantify cost and benefits

URBAN NATURAL INFRASTRUCTURE & LIFE SAFETY

Steven Dundas
Assistant Professor
Applied Economics & COMES

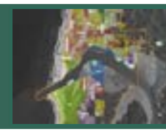
COASTAL LAND USE PATHWAY



Research questions

- How can natural infrastructure be optimally allocated within coastal communities, accounting for the value of life safety (via tsunami evacuation facilitation)?
  - What is the role of coastal pathways and other land use changes to increase life safety?
- Given the current suite of risks, what land use policy decisions in the area of natural infrastructure can make coastal communities more resilient against those risks?
  - What is the role of coastal dunes and vegetation in mitigating coastal risk?
  - How do these levels of risk compare with other natural and anthropogenic risks (e.g. comparison with other activities)?

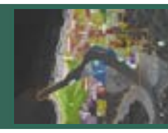
COASTAL LAND USE PATHWAY



Land use change to facilitate evacuation

- The ability of people to safely evacuate from a tsunami inundation zone depends in part on land use.
- The TEV of natural infrastructure in coastal communities includes the expected value of risk mitigation as well as the expected value of amenities.
- These methods rely on observed risk aversion behavior and its implicit valuation
  - Value of a statistical life
    - US DOT : $9.4 million
    - EPA: $8.7 million

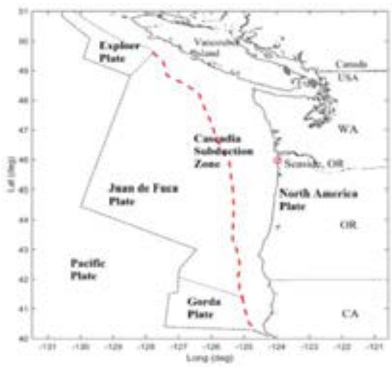
COASTAL LAND USE PATHWAY



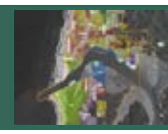
How does the natural infrastructure affect survivability for nearfield tsunami?

Cascadia Subduction Zone (CSZ)
Earthquake and Tsunami

- CSZ is relatively new hazard (since late 1980's)
- Probability of CSZ in the next 50 years (10% – 35%)
- Tsunami arrives to the coast in 20 minutes
- Tsunami height is approximately 5 to 10 m at the coast



COASTAL LAND USE PATHWAY



maximize from time t to T (discounted sum of … [Value of **park/trail characteristics** at time t − Cost of **construction/ maintainence** at time t])

Recreation/ aesthetics

Lives Saved (if inundation event occurs)

A MULTIDISCIPLINARY, INTEGRATIVE APPROACH TO VALUING ECOSYSTEM SERVICES FROM NATURAL INFRASTRUCTURE

2017 ADVISORY BOARD MEETING

Coastal Protection Data and Modeling Work

GEOSPATIAL DATA PROCESSING AND ANALYSIS

Chris Parrish
Associate Professor
Civil & Construction Engineering

Laura Barreiro Fernández
M.S. Student
Geomatics

GEOSPATIAL DATABASE GENERATION

Database with 173,000 parcels (5-mile strip parallel to the shoreline)

Main input data:

1. Taxlot layer
2. Digital Elevation Model (DEM)
3. Hazards (FEMA Flood Map Service Center/ DOGAMI inundation maps/ etc.)

Main attributes:

1. Taxlot data
2. Elevation
3. Tsunami, flooding and earthquake hazards
4. Geologic information
5. Ecological information

ADDING BUILDING ATTRIBUTES

Lidar data processing for detecting buildings

Study area: 5-mile strip area

Input data:

Lidar data collected by Oregon Department of Geology and Mineral Industries (DOGAMI) in 2009

Software:

LP360. Tool *Planar point filter*

Output:

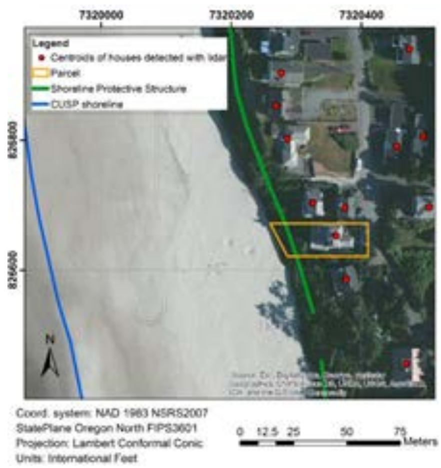
Close to 113,000 buildings detected

ANALYSIS

Database with 1,282 ocean front properties

<u>Main input data:</u>

1. Shoreline Protection Structure (SPS) data from Oregon Parks and Recreation Department (OPRD)
2. Lidar data collected by Oregon Department of Geology and Mineral Industries (DOGAMI) in 2009
3. Shoreline cartography (CUSP product from NOAA)
4. Oregon ShoreZone data (coastal habitat map)
5. Erosion data from National Assessment of Shoreline Change



AUTOMATIC MAPPING OF RIPRAP STRUCTURES FROM LIDAR

<u>What ?</u>

First attempt of designing an algorithm for detecting and mapping riprap. Final project of course *CE560 Coastal Remote Sensing*

<u>How?</u>

Supervised classification using eCognition Developer software and lidar-derived information layers

<u>Results</u>

- Good for monitoring physical characteristics of riprap (width, slope, length,…)
- Potential use for change detection between years with lidar data available
- Not tested yet in different study areas of lidar datasets

FUTURE WORK (SHORT TERM)

Databases

Database with Goal18 (oceanfront) parcels (9,444 properties)

Same attributes than delivered databases previously

New attributes

Field of view from each property (visible part of the ocean)

Tool: *Oceanfront Viewshed Analysis* (created by Rachel Albritton)

FUTURE WORK (LONG TERM)

New database

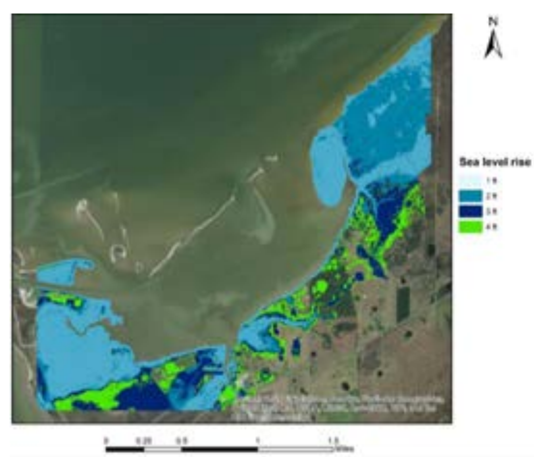
- Database for the 5-mile strip area

New attributes

- Inundation under different Sea Level Rise (SLR) scenarios

Master thesis

- Designing methodology for monitoring Shoreline Protective Structures located in Oregon Coast using Remote Sensing



TOOLS & TECHNIQUES FOR LONG-TERM MONITORING OF SPS
(COLLABORATION WITH OPRD)

- OPRD responsible for administering permit program for alterations to the Ocean Shore, as construction of shoreline protective structures (SPS), beach access ways, and so on.
- SPS cover more than 22 miles of the Oregon coast (greater than 95% of these structures are stretched over a 115 mile section of Oregon's north coast).
- Monitoring of existing SPS in the past has been undertaken with periodic site inspections
  - Time consuming
  - Big area to cover
  - Access difficulties
  - Changing conditions (buried SPS)

TOOLS & TECHNIQUES FOR LONG-TERM MONITORING OF SPS
(COLLABORATION WITH OPRD)

Our research studies whether Remote Sensing (RS) can be used to evaluate and monitor Shoreline Protective Structures. Different RS sensors will be tested as well as different data analysis.

The goal of the research is establishing a methodology for monitoring SPS in the long term and provide guidelines about accuracy and cost effectiveness.

This outcome would provide valuable data to OPRD as they evaluate strategies and policies for shore protection in a changing climate. Also, it will help to reduce field inspections and detect changes using RS data collected in different years.

HOW DO MULTIPLE HAZARDS AFFECT THE VALUE OF HOUSING?

EVIDENCE FROM THE OREGON COAST

Steven Dundas
Assistant Professor
Applied Economics & COMES

RESEARCH QUESTIONS

- How do coastal housing markets value the ability to invest in hazard protection at the parcel level?
- Do markets value the ability to protect against a *chronic* hazard differently if there is exposure to an additional *acute* hazard?

OVERVIEW

Hedonic model of Oregon oceanfront property transactions exploits clear variation in both a protection and a risk dimension.

- Ability to protect property from erosion is determined by a state planning goal
- Risk of tsunami inundation varies among oceanfront parcels

Preliminary results from post-matching regressions suggest that the value of the ability to protect from erosion is positive and significant

- But, that value diminishes with increasing potential exposure to tsunami inundation.

EROSION RISK SOLUTION: RIP-RAP REVETMENTS

EROSION RISK SOLUTION: RIP-RAP REVETMENTS

Bayocean, OR
Abandoned in 1960

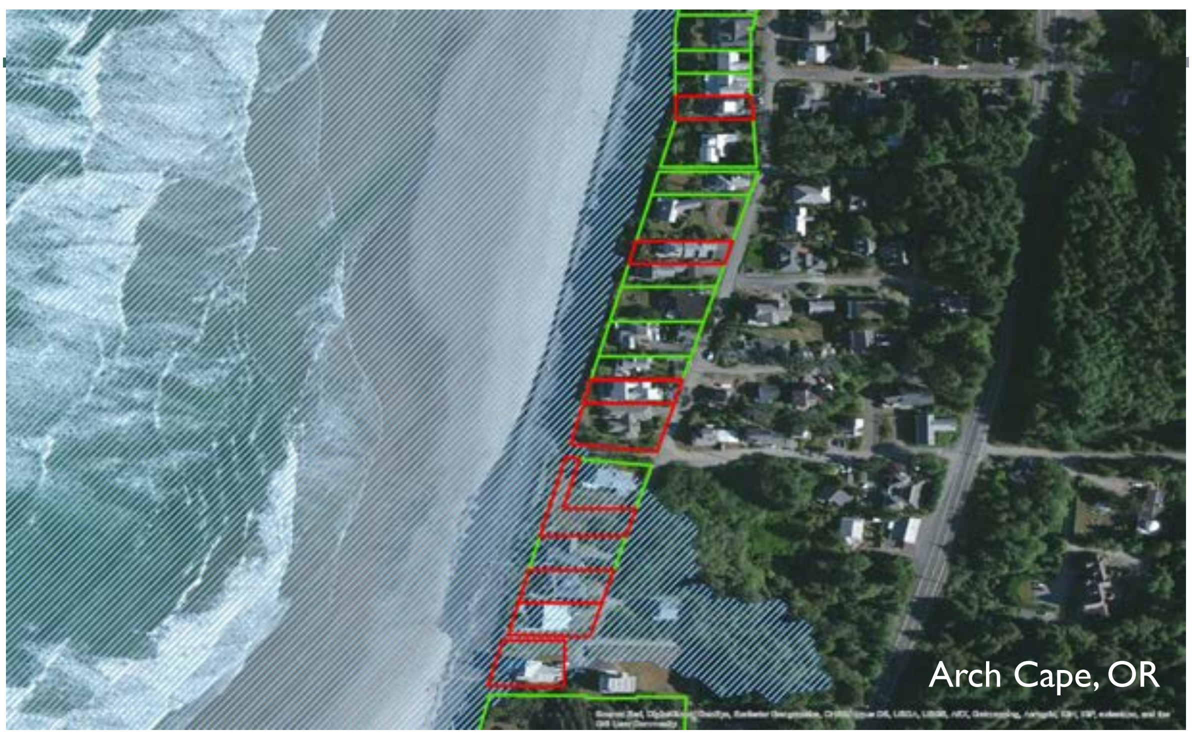
Rockaway Beach, OR
Soon to be abandoned home in 2016
if rip-rap permit continues to be denied

ACUTE RISK

"Acute" risk: Tsunami Inundation

- Cascadia subduction zone runs for 700 miles off the Pacific NW coast
- "Estimated chance in the next 50 years of a great subduction zone earthquake (~9.0) is between 10 and 20 %, assuming recurrence is on the order of 400 ± 200 years and last one was 300 years ago." (1995 State of Oregon report)
- Clear tsunami demarcation zones initially developed in 1995


Arch Cape, OR


Arch Cape, OR

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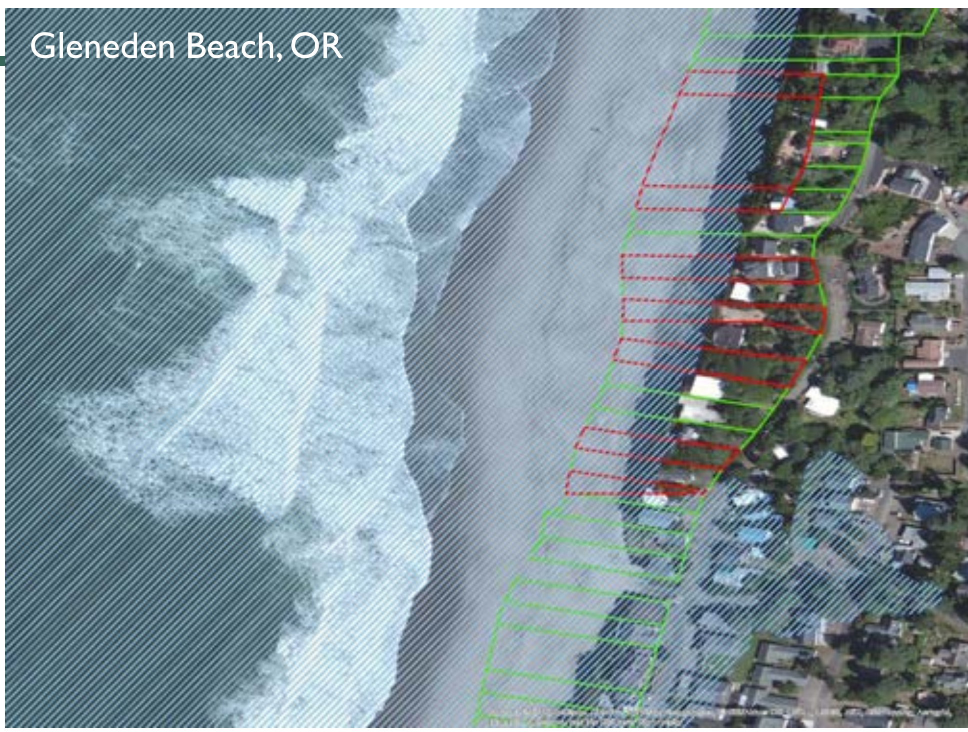

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DATA

- Universe of transactions in Oregon's seven coastal counties 2004 – 2015 (Deed records from CoreLogic)
- Tax parcel data from CoreLogic / State of Oregon
- Geospatial database used to quantify coastal land types, multiple dimensions of risk, and coastal amenities
- 1,506 observations of sales of oceanfront housing in Goal 18 eligibility zone from 2004 to 2015

DATA

- Goal 18 eligibility
- Tsunami Zones
  - High, Medium, Low, and No risk categories based on inundation modeling

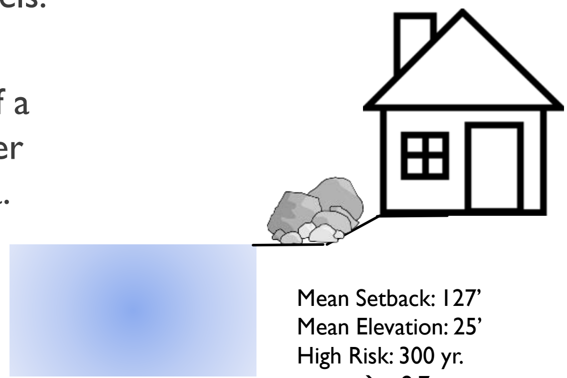
Parcel/risk characteristics:

Elevation, setback, distance to mean high water

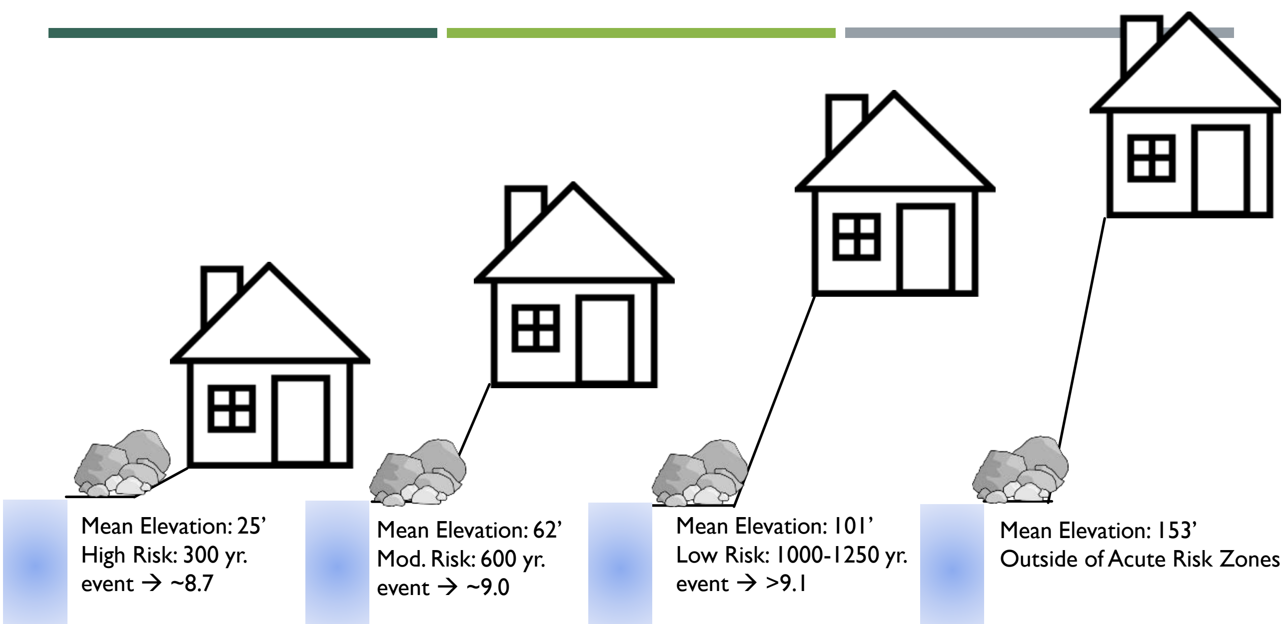
Indicators for 100-year flood plain, landslide area, state park proximity, bluff location

- Housing characteristics:
- Bedrooms, bathrooms, square footage, lot size, and indicators: exceptional views, garage, hot tub, air conditioning

- An interaction with Goal 18 eligibility and 'setback' is negative in all models.
- This indicates a dampening of the positive impact on G18 eligibility if a housing structure is setback further from the erosion/wave action area.



Mean Setback: 127'
Mean Elevation: 25'
High Risk: 300 yr. event → ~8.7



ON-GOING WORK

State planning Goal 18 results in variation in protection ability between **actual** neighboring parcels

Currently working on an actual neighbor matching estimation strategy to attempt to identify value of ability to protect from erosion hazards using Real Market Value to compare with results from transaction data.

Test the viability of this data type for valuation work outside of metro areas where transaction data may be thin.

THE DETERMINANTS OF COASTAL ARMORING:

ESTIMATING INFLUENTIAL DETERMINANTS OF PARCEL-LEVEL RIPRAP INSTALLATION

Jason Beasley
Ph.D. Student
Applied Economics

BEACHFRONT PROTECTIVE STRUCTURES

Research Question:

What are the influential determinants of a land owner's decision to install coastal armoring?

Eventually link these findings to models of shoreline change to more accurately predict future states.

BEACHFRONT PROTECTIVE STRUCTURES

DATA

- Annual RMV (Land & Structures)
- BPS Permit Data
  - Timing
  - Characteristics of proposed structure
- Geospatial Features
  - Short & Long Term Erosion Rates
  - Elevation
  - Distance to closest BPS
  - Distance from mean high-water shoreline
  - Shore Type

Photo Source: http://dankauffmanexcavating.com/wp-content/uploads/2013/06/erosion_control_rip_rap_1366x600.jpg

BEACHFRONT PROTECTIVE STRUCTURES

Early Preliminary Results

- Intuitive and significant results:
  - Further away from the shore, less likely to armor
  - Higher erosion rates, more likely to armor
  - Higher land values, more likely to armor

BEACHFRONT PROTECTIVE STRUCTURES

Next Steps:

- Continue to clean the linked data
- Move to more advanced models that overcome shortcomings of our basic model

DIKE REMOVAL AND SALTMARSH RESTORATION FOR FISH HABITAT

ESTIMATING THE EFFECTS ON COASTAL LAND MARKETS

Cassie Finer
NMFS/Sea Grant Fellow
Ph.D. student, Applied Economics

Oregon State University OSU · NOAA · NCCOS · CIMRS · Sea Grant

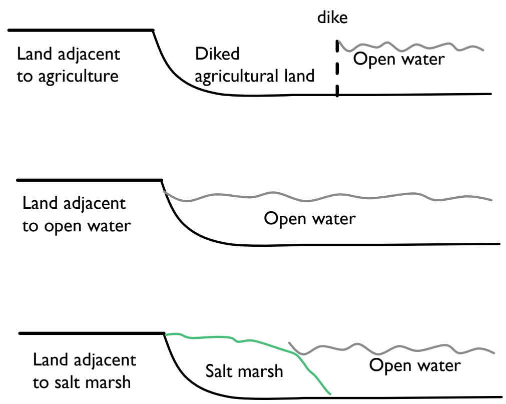
DIKE REMOVAL AND SALTMARSH RESTORATION

RESEARCH QUESTION

- How do dike removals for salmon habitat restoration affect adjacent land markets? Can better knowledge of land market impacts inform more efficient natural-infrastructure investment?
- Contribution
  - *Local* private costs/benefits of habitat restoration
  - Piece of larger optimal natural infrastructure investment model

DIKE REMOVAL AND SALTMARSH RESTORATION

Dike Removal & Land Markets



Current situation with dike

Short run without dike

Long run without dike

Economics of the land market will change over time

DIKE REMOVAL AND SALTMARSH RESTORATION

DATA

- Land parcel data
  - RMV/Deed rec
- Dike locations
- Estuary habitat quality and past/present location

DIKE REMOVAL AND SALTMARSH RESTORATION

NEXT STEPS

- Clean and match data
- Saltmarsh (restoration) production function
  - Time to restoration/level of protection
- Restoration policy analysis
  - Actual vs. Optimal

2017 ADVISORY BOARD MEETING

Breakout Sessions

2017 ADVISORY BOARD MEETING

Summary of Breakout Sessions

2017 ADVISORY BOARD MEETING

Concluding Remarks