The Tillamook County Coastal Futures Project

Exploring alternative scenarios for Tillamook County's coastline

Tillamook County Knowledge-to-Action Network

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Sea level rise (SLR), changing patterns of storminess, and increasing development have exposed coastal communities to coastal change and flood hazards. Several U.S. Pacific Northwest communities are at high risk from coastal hazards and local decision makers often lack tools for developing adaptive capacity to reduce vulnerability, particularly under climate change. Local community groups and land use planners in Oregon have begun to define responses to recent increases in the frequency and magnitude of coastal hazards (e.g., Neskowin Coastal Hazards Committee, 2013). Building on these and other efforts, a group of Oregon State University researchers and students, outreach specialists, and coastal community members in Tillamook County, Oregon (OR), are assessing climate change impacts and associated community and ecosystem vulnerability. Through sustained engagement with the Tillamook County Coastal Futures Knowledge to Action Network (TCCF KTAN), we co-developed a suite of alternative scenarios for exploring adaptation strategies for reducing vulnerability to coastal hazards based on a variety of drivers of change. These alternative scenarios were explored using *Envision*, a spatially explicit multi-agent modeling platform supporting scenario-based planning to examine interactions between the coupled human and natural coastal system. At its foundation is the identification of key stakeholder desires and outcomes for the future of the coastal shore (e.g., access to the beach, resilient infrastructure, etc.). These self-expressed outcomes are the orienting principle of this KTAN driven process. Probabilistic simulations of extreme total water levels, long-term coastal change, and storm-induced dune erosion along the shoreline allowed us to represent the variable impacts of SLR, wave climate, and the El Niño Southern Oscillation in a range of climate change scenarios through the end of the century. Additionally, we explored a range of alternative futures related to policy decisions and socioeconomic trends using input from KTAN participants. We quantified the impact of both policy scenarios and climate change scenarios on a range of participant defined metrics. In some scenarios, model results suggest severe reductions in beach accessibility (one metric highly valued by the TCCF KTAN) by the end of century, due to the cumulative placement of riprap backshore protection structures. Flooding and erosion to coastal buildings and infrastructure also increases on a variety of scales depending on the types of policies implemented. In general, human decisions introduced greater variability and uncertainty to the impacts to the landscape by coastal hazards than climate change uncertainty. In other words, the Tillamook County Coastal Futures Project has helped to determine the relative impact of policy and management decisions on the adaptive capacity of Tillamook County, OR under a range of future climate scenarios.

2. INTRODUCTION

Communities along the coast of Tillamook County, Oregon (OR) are faced with increasing flooding and erosion impacts of climate change. Impacts resulting from these types of events include physical (chronic to catastrophic coastal flooding and erosion), economic (i.e., increased costs to construct and maintain engineered backshore protection structures (BPS), beach nourishment, etc.), and social (i.e., beach closures, reduced scenic value, etc.) changes. Climatic extremes are projected to increase due to sea level rise (SLR), changes in storminess patterns, and possible variations in the magnitude and frequency of El Niño events (ENSO) (NRC, 2012; Allan & Komar, 2006; Ruggiero, et al., 2010; Cai, et al., 2014; Hemer, et al., 2013). To gain a better understanding of current and future conditions and possible management solutions, Tillamook County stakeholders were convened in the Tillamook County Coastal Futures (TCCF) project. This undertaking focused on co-producing information and assessing policy choices to increase coastal community climate adaptation. The project integrates natural, social, and environmental landscape data, stakeholder-developed land use and adaptation policy scenarios, and climate change projections within the multi-agent spatial framework *Envision* (Bolte, et al., 2007). This white paper was written to document the TCCF project's process and outcomes and to serve as a resource for Tillamook County and other communities grappling with coastal development and climate change issues.

3. BACKGROUND

The following sections introduce the geographic and climatological setting of Tillamook County as well as historical efforts and current land use planning to increase climate adaptation at the state, county, and local levels. The final section of this background material addresses recent coastal climate change adaptation efforts through the TCCF project and within *Envision*.

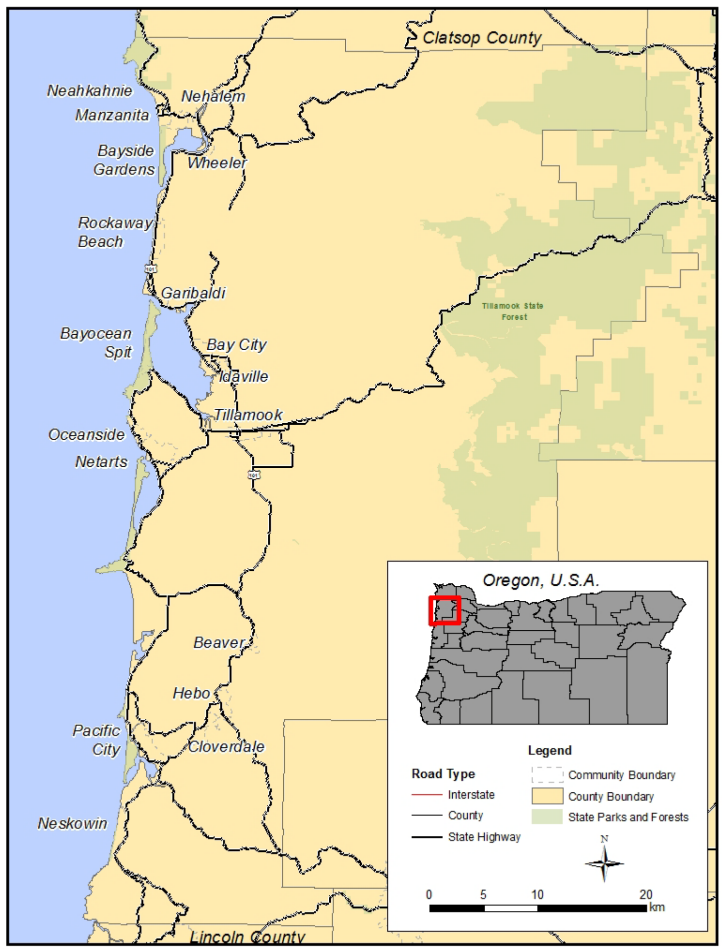


Figure 1: Map of Tillamook County, Oregon, showing the locations of coastal communites and roads.

3.1 Geographic and Climatological Setting

Encompassing ~75km of the northern Oregon shoreline, the Tillamook County coast is a popular location for full and part-time residents and visitors to enjoy the ecological, recreational, and aesthetic features of a Pacific Northwest (PNW) beach (Figure 1). The Tillamook County coast is comprised of four littoral cells, which are primarily comprised of sandy, dissipative, dune-backed beaches punctuated by rocky headlands (Ruggiero, et al., 2013). Communities along the coastline have historically experienced chronic winter coastal flooding and erosion when high water levels collide with or overtop foredunes or engineered backshore protection structures (BPS, i.e., riprap revetments). These extreme total water levels (TWLs) are typically the combined consequence of several factors including high winds driving large waves and storm surge during storm events, increases in sea level due to El Niño events, and astronomical tides.

Over the long-term record (1800s - 2002), Tillamook County experienced shoreline change rates that ranged from -0.5 to 0.3 meters per year (m/yr), while more recent (1960s - 2002) shoreline change rates ranged between -1.1 m/yr to 0.6 m/yr (Ruggiero, et al., 2013). During the last few decades, over 65% of the county's coastline has experienced erosion with approximately 40% of the shoreline eroding at rates exceeding 1 m/yr (Figure 2). Shoreline change rates are expected to continue varying in the future due to climate change factors including SLR, changes to storm wave heights, and possibly changes in the magnitude and frequency of El Niño events (NRC, 2012; Ruggiero, et al., 2013; Ruggiero, et al., 2010; Allan & Komar, 2006; Strauss, 2013). Tectonic activity in the PNW is another important factor in considering future coastal hazards because it creates alongshore variations in vertical land motions that impact relative SLR. When considering these localized tectonic changes, Tillamook County has experienced approximately 1 millimeter per year of relative SLR over the last several decades (Komar, et al., 2011). Accounting for local factors such as vertical land motion into the future, sea levels along

Oregon's coast are projected to rise between approximately 0.11m to 1.42m by the year 2100 (NRC, 2012). The PNW is also at risk of sudden, large scale, vertical land motions due to the Cascadia Subduction Zone offshore that are quite dramatic compared to the smaller chronic tectonic changes discussed above. However, the impacts of earthquake and tsunamis on coastal flooding and erosion were not in the scope of the TCCF project.

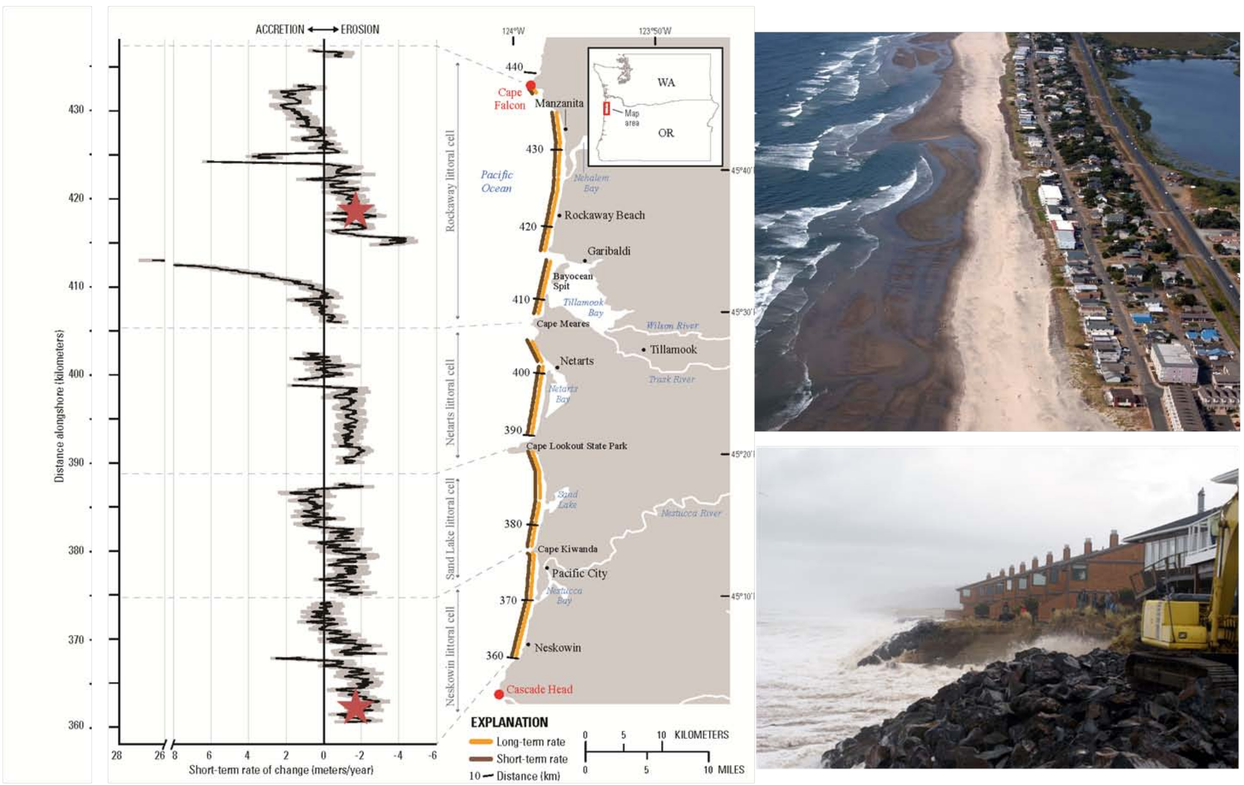


Figure 1: Shoreline change rates in Tillamook County, OR, computed between 1967 and 2002 (Ruggiero et al., 2013). The red stars represent the locations of the two photographs on the right (top- Rockaway Beach and bottom- Neskowin), communities that are experiencing relatively high shoreline erosion rates, are particularly exposed to coastal change and flood hazards, and are struggling with grey vs. green infrastructure responses to their coastal hazard problems (Neskowin, 2013).

The Oregon coast currently experiences severe winter storms, with approximately one event per year producing significant wave heights greater than 10m (Ruggiero, et al., 2010). As observed in historical data reviewed by Ruggiero et al. (2010), extreme wave heights generated by the largest storms increased between the late 1970s and mid-2000s at a greater rate (0.093m/yr) than the average winter wave heights (0.023m/yr). These increases in wave height had a more significant role in the increasing frequency of coastal flooding and erosion than SLR over the same time period (Ruggiero, et al., 2013).

Characterizing future coastal hazards in the region is further complicated by major El Niño events, which temporarily raise sea levels by as much as 30 centimeters (cm), change incident wave direction, increase coastal erosion and inundation (Barnard, et al., 2017; Kaminsky, et al., 1998; Komar, 1998). While it is generally agreed that El Niño events will remain an important driver of inter-annual climate variability globally (IPCC, 2013), there is little consensus on whether the frequency and intensity of these events may increase, decrease, or remain unchanged in the future (Vecchi & Wittenberg, 2010; Cane, 2004; Santoso, et al., 2013; Cai, et al., 2014).

3.2 Laws, Regulations, and Adaptation Efforts in Oregon

Historically, efforts to increase resilience to the impacts of coastal hazards and climate change in Tillamook County and elsewhere have been piece-meal, dependent on individual property-owners and emergency measures (Folke, 2006; Clarke, et al., 2013). Federal, state, and county agencies increasingly encourage strategic approaches to improve adaptation at a community-scale (Mason, et al., 2015; Flood & Schechtman, 2014). At the federal level, the Coastal Zone Management Act (CZMA) of 1972 delegates responsibility to coastal state and local governments for the “effective management, beneficial use, protection, and development of the coastal zone” (NOAA Office of Ocean & Coastal Resource Management, 2006). The 2006 reauthorization of CZMA encourages states to exercise their full authority over the lands and waters in the coastal zone, with Section 302 requiring coastal states to anticipate and plan for the occurrence of substantial SLR due to global warming (NOAA Office of Ocean & Coastal Resource Management, 2006).

At the state level, Oregon's common law ensures public ownership of the wet and dry beach up to the mean high water (MHW) line (typically seaward of the vegetation line), while public access is allowed up to the vegetation line. The public's rights under common law are further strengthened by the 1967 Oregon State Legislature Beach Bill (Or. Rev. Stat. § 390.605 et seq.) and the 1969 decision, State ex rel. Thornton vs. Hay (Wheatley, 2012). For example, common law accommodates incremental changes to public ownership and access by shifting MHW line levels, for example, which may result in a subsequent reduction in size of coastal properties unless movement of the beach is impeded by the existence of BPS (Neuman, 2012). However, significant changes to beaches during storm events pose a separate problem as property lines are permanently fixed to their pre-change locations. Thus, coastal property owners and the public alike are left with immersed land, as illustrated by the loss of properties due to sudden breaching along Bayocean Spit in the 1950s (Neuman, 2012).

Several state agencies, such as the Department of Land Conservation and Development (DLCD) and Oregon Parks and Recreation Department (OPRD) maintain the beach for public ownership and access. Statewide Planning Goals indicate preference for "non-structural solutions" (Goal 17) and limit properties eligible to construct engineered BPS to those that were platted and/or developed before January 1, 1977, with few exemptions and exceptions (Goal 18) (DLCD, 2010). OPRD manages the BPS permitting process under the premise that the public has a sovereign right to use the ocean shore. However, as sea levels continue to rise, the limitations of common law and existing state regulations will be under close scrutiny in locations where either public access is decreased due to the presence of BPS, or where infrastructure is threatened but ineligible for construction of BPS for protection.

3.2.1 Recent Coastal Adaptation Efforts

Recent attempts at statewide coastal adaptation including the 2009 Climate Ready Communities program, the 2010 Oregon Climate Change Framework, and the 2012 Natural Hazards Mitigation Plan, have acknowledged the need for local government participation in preparing effective adaptation plans (DLCD, 2009; State of Oregon, 2010; State of Oregon, 2012). However, resource-limited local governments are already struggling to manage day-to-day issues in addition to updating current county regulations and local land use ordinances that may be inadequate for dealing with changing climate conditions (Johnson & Schell, 2013).

The adaptation planning effort of the unincorporated community of Neskowin (~5km of coast) in southern Tillamook County is considered one of the best examples of success at the local level. Neskowin has experienced chronic coastal flooding and erosion since the mid-1990s, particularly during the strong El Niño winter of 1997-1998. The Neskowin Coastal Hazards Committee, with support from the Neskowin Citizen Advisory Committee, led efforts to fund and produce a community-wide coastal adaptation plan comprised of short- and long-term strategies to maintain the beach and preserve community infrastructure (Neskowin Coastal Hazards Committee, 2013). Strategies included the adoption of coastal hazard zones and construction requirements including siting in the "safest" location on a land parcel and at a minimum elevation. After several years of work, the plan was adopted by the county for use in Neskowin in October 2014.

4. TILLAMOOK COUNTY COASTAL FUTURES PROJECT

Momentum from the Neskowin effort and funding from NOAA led to the initiation of the Tillamook County Coastal Futures Project (TCCF) in 2012. The intent of the TCCF was to understand future risks and explore policy solutions by building a collaborative network of interested stakeholders. This effort built on similar efforts in Neskowin but is inclusive of coastal issues and interests from across Tillamook County. The network was modeled on a knowledge to action framework or 'network' (Cash et al. 2003, Stevenson et al. 2016) (KTAN) by convening participants from the state, county, and local agencies, non-governmental organizations (NGOs), and private citizens. Initial conversations with the local KTAN stakeholders served to identify, despite the chosen policy alternative, what end-result desired outcomes local people valued most concerning their coastal strip and beach. These are the essential values to be addressed in any preferred policy choice. The KTAN also included the project team which included researchers, students, and outreach specialists (Appendix Table 1).

The KTAN was interested in understanding how different policies, such as those eventually adopted in Neskowin, and climate change may impact the Tillamook County landscape in the future. To explore potential changes to the coast, the TCCF project utilized the multi-agent modeling framework, *Envision*, to develop and assess the impacts of alternative future climate and policy scenarios on coastal flooding and erosion projections. The framework allowed for the integration of diverse sets of data including current and future climatological, environmental, economic, and societal information from a range of sources (Figure 2).

5. MODELING ALTERNATIVE FUTURES WITH *ENVISION*

An understanding of future changes on the Tillamook County coast is only as robust as the information included within the alternative future scenarios. Therefore a variety of models, datasets and information including population growth and development, coastal flooding, coastal erosion, and adaptation policies were incorporated within *Envision* to project alternative futures on an assortment of geographical (community to county) and temporal (yearly from 2005 to 2099) scales. More information about *Envision* can be found here: http://*Envision*.bioe.orst.edu/Default.aspx. Impacts to the natural and built environment were modeled with 100m resolution in the alongshore and 10m in the cross-shore; scales fine enough to resolve impacts to individual homes and businesses yet coarse enough to support probabilistic approaches to simulation.

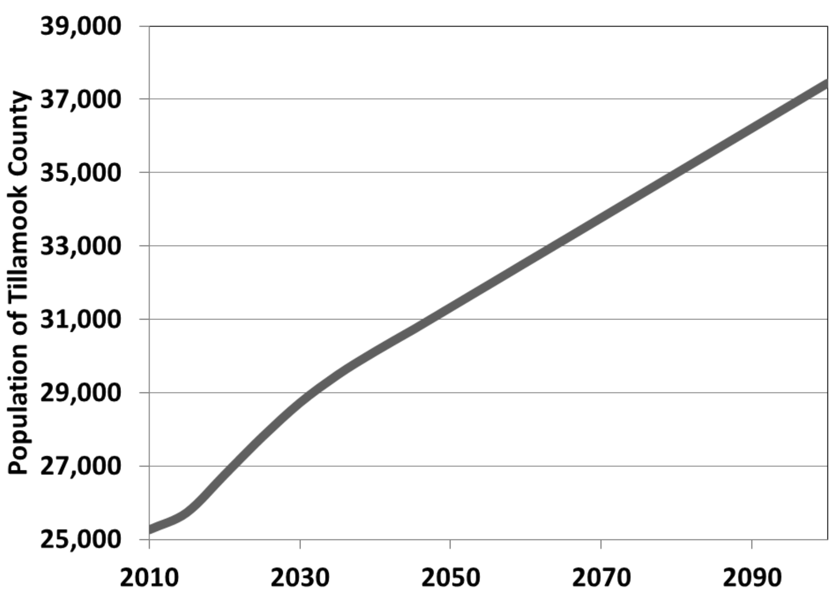


Figure 2: Estimate future population growth in Tillamook County from the year 2010 to 2100 (Oregon Office of Economic Analysis, 2013).

A single population growth rate was used throughout all policies scenarios and was obtained from the Oregon Office of Economic Analysis (Oregon Office of Economic Analysis, 2013) (Figure 3). This population growth was distributed across the Tillamook County landscape based on current zoning ordinances and the present-day distribution of population inside and outside of community growth boundaries in the county. Growth was further managed by individual policies within the policy scenarios (e.g., the Status Quo policy scenario reflects current development patterns).

Projections of coastal flooding and erosion were dependent on the elevation of the total water level (TWL), relative to elevations of important backshore features such as BPS/dune toe or crest (Figure 4). Multiple synthetic records of each TWL component, and their dependencies, were generated with the total water level full simulation model (TWL-FSM) of Serafin and Ruggiero (2014). The model produces various combinations of events, some of which may not have occurred yet in the observational record.

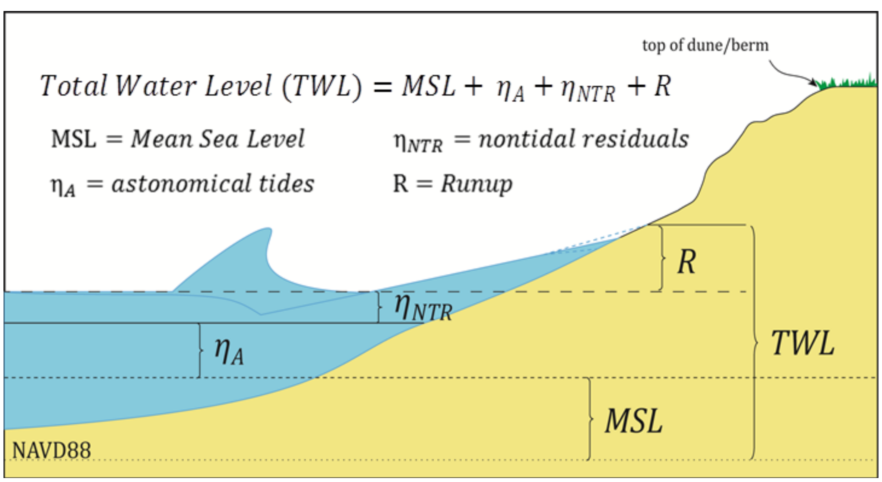


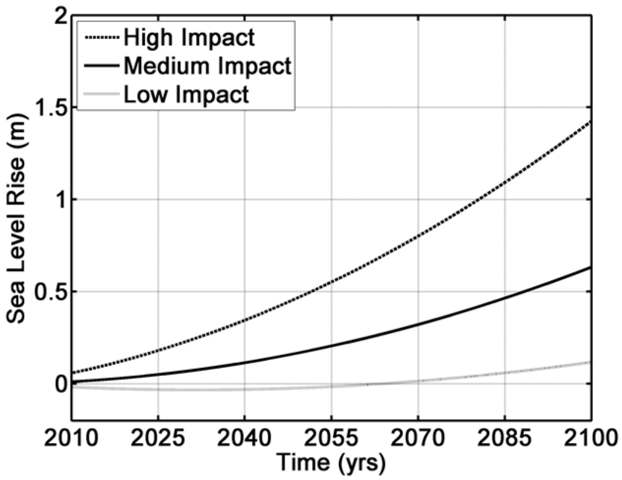
Figure 3: Components of Total Water Level.

The impacts of flooding and erosion were assessed at every alongshore model grid node (100m resolution), from the highest daily maximum TWL each year. Once the TWL reached a height that exceeded the backshore elevations, flooding occurred, with flooding extents computed using a simple bathtub model.

Estimates of beach and dune erosion were calculated several ways including event-based coastal erosion associated with the maximum annual storm event, the long-term (interannual- to decadal-scale) coastal change rate associated with sediment budget and climate factors not including SLR, and the long-term coastal change rate associated with SLR. While the coastal flooding and erosion models implemented were relatively simple, the approach was designed to be modular and more sophisticated models could be implemented if warranted.

6. CLIMATE CHANGE SCENARIOS

To appropriately model the range of possible future coastal conditions, three climate scenarios were created based on the National Research Council (NRC) SLR estimates for Oregon and Washington within suggested ranges of 0.11m to 1.42m by the end of the century (NRC, 2012) (Figure 5, left panel). Changes to the mean and maximum significant wave heights (SWH) were estimated using statistically and dynamically downscaled end of the century global climate model projections (Hemer, et al., 2013; Wang, et al., 2014). These shifts ranged from +/- 30cm by the end of the century (Figure 5, right panel). The frequencies of major El Niños varied between half and double the historic conditions. In total, 33 sub-climate simulations were run under every SLR scenario with randomly varying SWHs and frequency of El Niños within each, for a total of 99 climate conditions.



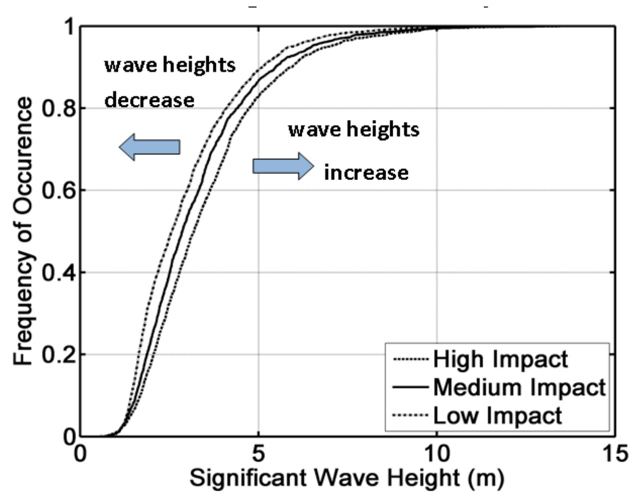


Figure 5: left panel) The three lines represent low, medium, and high estimates of SLR for the Oregon and Washington coast for 2010 to 2100 as estimated by the National Research Council (NRC, 2012). right panel) Wave height distributions by 2100. The solid line represents the present-day, downscaled from global climate model projections (Hemer, et al., 2013; Wang, et al., 2014). *The wave heights are allowed to shift +/- 30cm in either direction randomly within each sub-climate simulation.*

The co-developed policy scenarios and climate change scenarios (including sub-climate simulations) were integrated within *Envision* and projected over a span of 95 years to determine a range of participant identified metrics, such as beach accessibility and number of buildings impacted by hazards (Figure 6).

7. KTAN WORKSHOPS AND MEETINGS

To develop and explore possible coastal climate change adaptation policies, a total of six major workshops (Table 1) as well as several smaller KTAN meetings were hosted by OSU researchers between June 2013 and 2017.

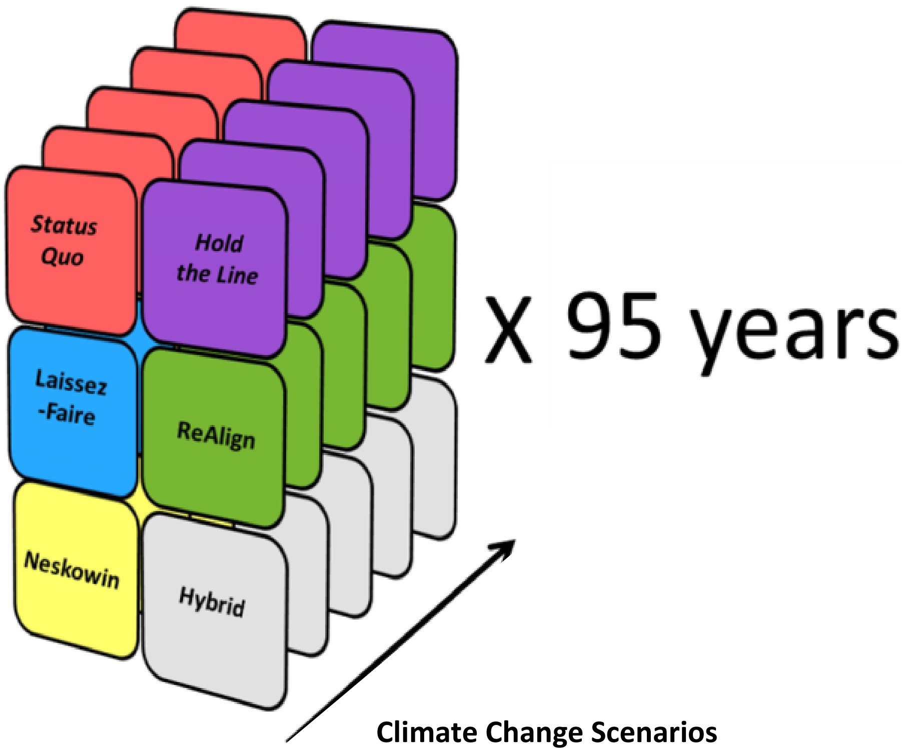


Figure 4: Co-developed policy scenarios integrated with climate change scenarios over 95 years.

Table 1: Date and purpose of six major TCCF KTAN workshops

Meeting Date	Purpose
June 2013	• Identify participant values, desired landscape outcomes, and community goals.
October 2013	• Develop potential policy adaptation scenarios.
June 2014	• Present initial results for discussion, consideration, and planning of future work.
December 2014	• Present results of five policy scenarios and incorporate participant suggestions and clarifications, and vet model assumptions. • Develop sixth policy scenario, Hybrid, through participant ranking process.
May 2015 **June 2015**	• Review of the process to date including how the climate and policy scenarios were created and resulting outcomes. • Summarize final results.

Initial KTAN meetings in June and October 2013 focused on identifying participant values, desired landscape outcomes, and community goals. In these workshops, participants also discussed potential adaptation land use, infrastructure (under retreat or defend scenarios), and economic development policies to reach these goals (Appendix Table 2).

The adaptation policies were grouped to create four policy scenario narratives (or policy scenarios): Status Quo (continuation of present day policies), Hold the Line (policies which resist environmental change in order to preserve both infrastructure and human activities), ReAlign (policies which change human activities to suit the changing environment), and Laissez-Faire (relaxation of current restrictive policies) (Appendix Table 3).

Through a series of smaller sub-group meetings in March and April 2014, and at the June 2014 KTAN meeting, the OSU team presented initial results for discussion, consideration, and planning of future work. Results were generated by *Envision* for each year (2005-2099) across almost 120 metrics, four policy scenarios, and three climate scenarios. The metrics, representing changes to the built and natural environments due to future development, extreme water levels, and the potential for flooding and erosion, and the implementation of adaptation policies, were quantified and tracked within *Envision.* Results were presented as “storylines” or groupings of metrics and questions about the impacts to a number of different coastal interests based on three conversational themes that occurred during the project workshops. These storylines included questions and metrics around 1) development patterns (Development), 2) risk to private property (Property risk) and 3) risks to public resources (Public good).

Two questions posed under the Development storyline include: "how do development patterns change over time?" and "how does the implementation of adaptation policies alter development?" For example, land use adaptation policies shift population and buildings outside of coastal hazard zones.

Questions around Property risk included "how will buildings be impacted by coastal flood and erosion hazards in the future?" and "when will homeowners need backshore protection structures (BPS) to protect their property?" In the case of the Rockaway Beach sub-littoral cell, the greatest need for additional BPS will occur between 2010 and 2040 (Figure 7). Questions around Public good, which addressed beach accessibility and public roads, included "how often is the beach accessible?" Beach accessibility is calculated as a percentage of the year which does not experience maximum daily TWLs which impact the base of the dune/BPS, and varying policy scenarios impact the rate of decrease in different ways (Figure 8). Other questions included, "how much money will it cost to keep the beach accessible?" and "how will roads be impacted by coastal hazards?"

Additional results related to these questions that were presented at the workshops can be found at http://*Envision*.bioe.orst.edu/StudyAreas/Tillamook/.

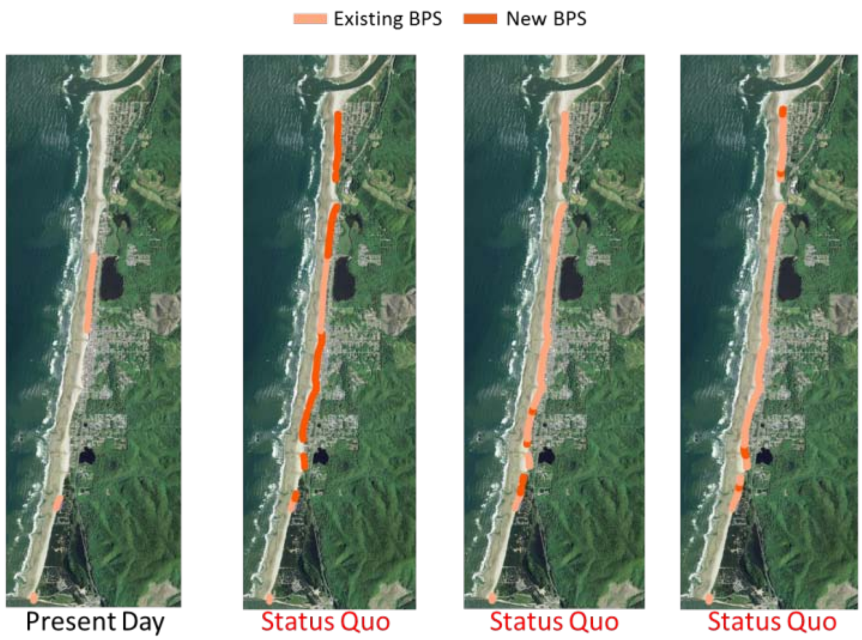


Figure 5: Locations of existing and new BPS construction over time under a medium impact cliamte scenario and Status Quo policy scenario in the Rockaway Beach Littoral Subcell.

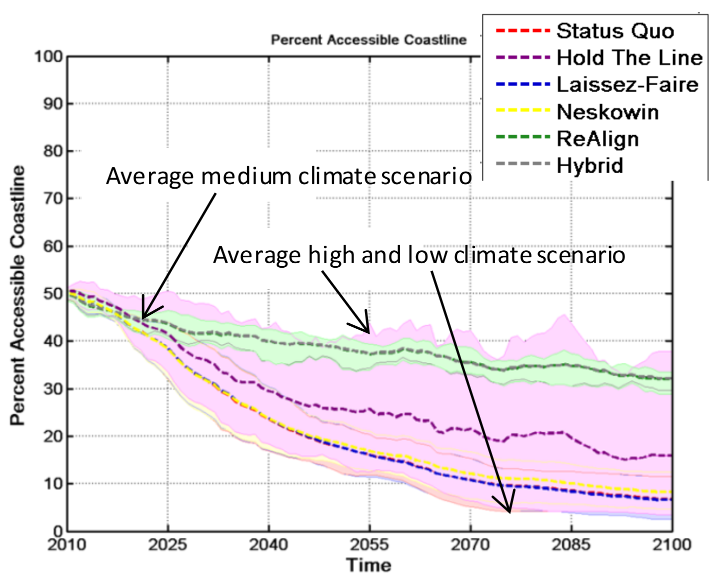
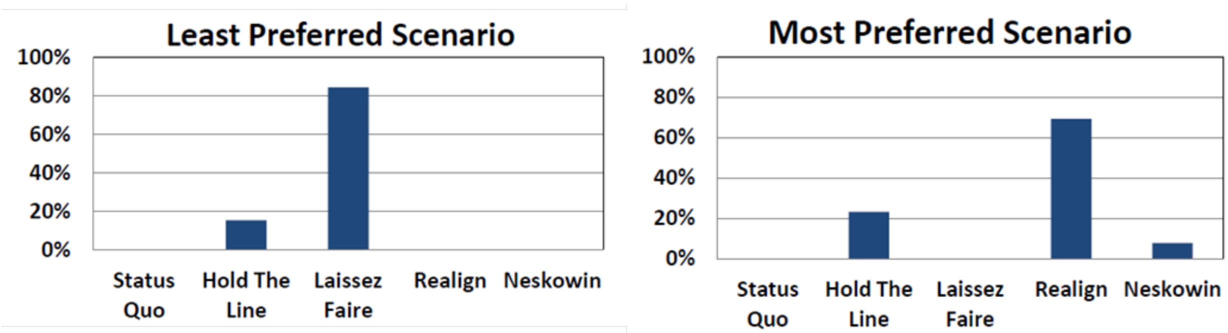


Figure 6:Rockaway Beach sub-littoral cell beach accessibility by policy scenario.

After the ratification of the Neskowin Coastal Adaptation Plan, KTAN members were interested in examining model results from its county-wide implementation. As a result, the set of Neskowin adaptation policies were added as a fifth policy scenario narrative modeled within *Envision* (Appendix B). Flooding and erosion outcomes under the five policy scenarios were presented to KTAN participants at the December 2014 workshop as well as in targeted sub-group meetings in order to incorporate suggestions and clarifications, and vet model assumptions. During this workshop, participants were asked to rank their most and least ideal policy scenarios and individual policies (Figures 9 and 10).



Figures 9 and 10: Least and most preferred scenario as rated by KTAN participants during the December 2014 workshop.

The highest ranked policy scenarios and underlying policies were combined and reviewed to form the Hybrid policy scenario (Appendix Table 3). In addition to ranking the most ideal policy scenarios, participants were asked to also identify metrics of most importance. The metrics included the length of roads impacted by flooding or erosion, the number of buildings impacted by flooding or erosion, the number of buildings destroyed by erosion as shorelines permanently shift landward, the total assessed value of the property impacted by flooding and erosion in 2012 dollars, and Beach Accessibility, in which higher percentages of beach accessibility correlate with greater beach walk-ability during all times of the year (see Figure 8 for example).

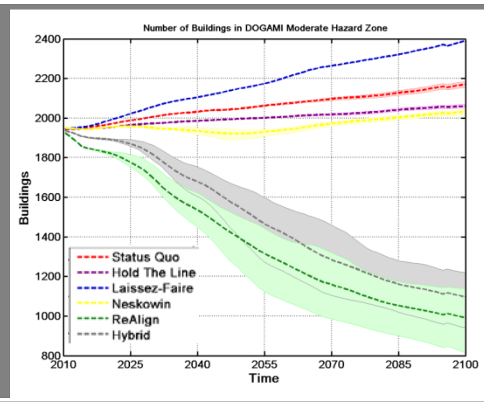
Final results were presented via two meetings, a May 2015 public meeting as well as a KTAN meeting held in June 2015. Each meeting contained a review of the process to date including how the climate and policy scenarios were created and resulting outcomes. Final results were summarized within the context of the aforementioned storylines (Table 2).

8. PROJECT RESULTS

We have presented our results as storylines: Development, Property Risk, and Public Good. See Table 2 below for a summary of the project results.

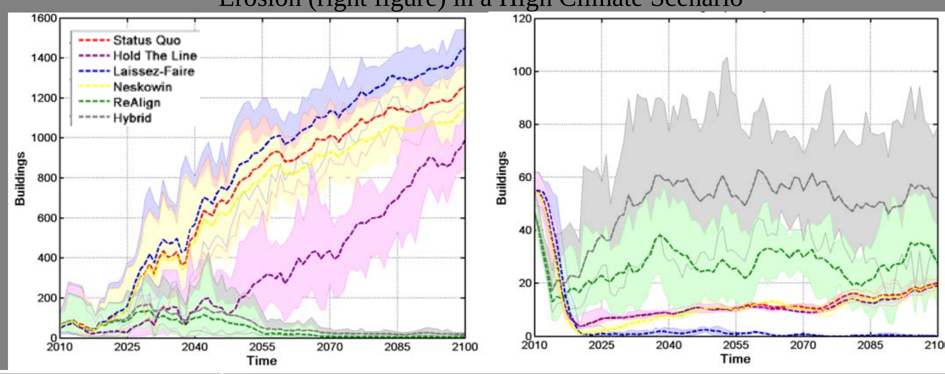
Table 2: General take home messages for each of the three storylines

<table>
<tr><th>Storyline</th><th>Question</th><th>Take Home Messages</th></tr>
<tr><td rowspan="3">Development</td><td>How do development patterns change over time?</td><td>By 2100, the total population of Tillamook County increases by approximately 12,000 people across all policy and climate scenarios. However, the underlying population density patterns differ by policy scenario.
Under all policy scenarios, much of Tillamook County is still sparsely populated by 2100.</td></tr>
<tr><td>How does the implementation of land use adaptation policies alter development?</td><td>Land use adaptation policies shift population and buildings outside of hazard zones.
In the medium and high impact climate scenarios, a greater population and number of buildings is relocated outside of the hazard zone than in a low climate impact scenario.</td></tr>
<tr><td colspan="2">For example: Number of Buildings in Tillamook County Located Within the DOGAMI Moderate Hazard Zone in a Medium Climate Scenario</td></tr>
</table>



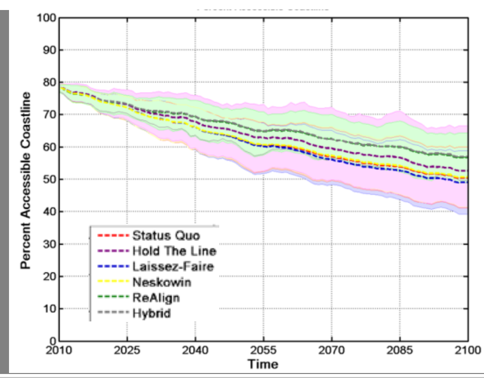
Property Risk	How will property be impacted by coastal flooding and erosion hazards?	• Policies that move people and buildings away from coastal hazards are most successful in protecting property from flooding impacts whereas policies that permit the construction of BPS protect property from erosion impacts.

For example: Number of Buildings Impacted in Tillamook County by Flooding (left figure) and Erosion (right figure) in a High Climate Scenario



Property Risk	When will homeowners need BPS to protect their property?	• To protect property from erosion, the majority of beachfront property owners would need to armor their properties prior to 2040.
	How do the costs of protecting property change over time?	• Cost associated with protecting the assessed value of coastal property increases overtime in all of the policy scenarios.
Public Good	What extent of the beach is accessible?	• By 2100, the combination of climate impacts and hardening of the shoreline significantly reduces beach accessibility (walk-ability). • Beach accessibility decreases under all policy scenarios by 2100, but less so in the Hold the Line, ReAlign, and Hybrid policy scenarios.

For example: County-Wide Beach Accessibility by Policy Scenario

		
	What are the relative costs of keeping the beach accessible?	• By 2100, the cost of converting beachfront property into easements is more than the cost of nourishing beaches across the county under all climate impact scenarios.
	How will roads be impacted by coastal hazards?	• Policies that add BPS significantly reduce the length of road impacted by erosion, but increase the length of road exposed to flooding.

9. SUMMARY AND CONTINUING EFFORTS

Growing coastal communities around the world, including those in Tillamook County, Oregon, are increasingly faced with the impacts of climate change. The combination of sea level rise, changes to wave heights, and possible variations to the frequency and magnitude of El Niño events have the potential to increase the effects of flooding and erosion on both the natural and built environments. Local, county, and state governments continue to struggle with managing a dynamic and changing environment where there is considerable uncertainty about its future hazards and the ability of their land use tools to address them.

Interested groups from Tillamook County and other parts of Oregon known as the Tillamook County Coastal Futures Knowledge to Action Network, have worked to address this uncertainty within their coastal system through an alternative futures process based on substantial stakeholder engagement and the modeling framework *Envision*. *Envision* allowed for the integration of the physical drivers (spatially explicit natural, social, and environmental landscape conditions and projections of evolving coastal hazards) and the human drivers (co-developed coastal community adaptation policy scenarios) of the coastal system to create alternative future scenarios.

Overall, the adaptation policies co-developed by the TCCF KTAN participants encompassed a range of local to internationally successful measures, such as coastal retreat of development and population centers, the construction of engineered backshore protection structures, and beach nourishment to protect infrastructure. Quantitatively modeling these qualitative policies required participant conversations and decisions about specific assumptions and triggers in order to suitably represent human decision-making. For example, future assessed property values were estimated using a simplistic hedonic price model based on available tax lot and census information.

Policy scenarios produced varying results across the climate scenarios, participant-identified metrics, and over time. The decision to implement one set of policies versus an alternative set of policies in Tillamook County, Oregon will be dependent on more than the factors discussed here, but this process has jump-started important conversations, bridged connections between researchers and decision makers, and provided a platform for considering the impacts of human decisions on an uncertain future. Both decision-makers and the public will need to consider questions like: What kinds of flooding and erosion impacts are they most concerned about? What kinds of social and economic impacts can be expected from the implementation of these policy scenarios? What level of risk are they comfortable with? What is the most cost-effective way to allocate current and future technical and financial resources?

In addition to determining which policy scenarios will result in lower coastal and flooding impacts, coastal stakeholders in government and otherwise will have to tackle regulatory and subjective barriers to climate change adaptation policy creation and implementation. County and state level governance can look to the success of the Neskowin community's efforts, especially the leadership and agency coordination that facilitated policy creation and, of critical importance, implementation.

Significant community engagement and the *Envision* model provide a powerful framework to compare possible future coastal flooding and erosion hazards along the Tillamook County coast across multiple scenarios. The resulting dialogue between interested stakeholders, decision-makers, and the research community will continue to inform decision-making in coastal communities within Tillamook County and elsewhere.

Ongoing work has focused on incorporating the ecosystem services provided by coastal beaches and dunes into the climate change adaptation planning in coastal Tillamook County and elsewhere in the Pacific Northwest (e.g., the Grays Harbor County Coastal Futures Project - http://explorer.bee.oregonstate.edu/Topic/GraysHarbor/ProjectOverview.aspx). A suite of models have been developed aimed at enabling researchers and decision makers the ability to evaluate the effects of climate on beach/dune biophysical dynamics and the associated coastal protection, recreation, and habitat services provided by these landscapes. Specific efforts include: (1) developing integrated models that couple beach grass dynamics and sediment supply to explore the effects on beach and foredune structure; (2) assessing the consequences of climate change to critical ecosystem services including coastal protection, conservation, and recreation; and (3) continued integration of these models into processes in which KTANs can co-explore the interactive dynamics and feedbacks of the coupled natural and human system in a spatially explicit, scenario-driven, policy centric framework.

10. ACKNOWLEDGEMENTS

Thanks to the members of the Tillamook County Coastal Futures Knowledge-to-Action-Network for their continued hard work and dedication to coastal climate change adaptation planning. The work described here was funded by the National Oceanic and Atmospheric Administration's (NOAA) Coastal and Ocean Climate Applications (COCA) program under NOAA grants NA12OAR4310109 and NA12OAR4310195 and NOAA's Regional Integrated Sciences and Assessments Program (RISA), under NOAA grant NA10OAR4310218.

Works Cited

Allan, J. C. & Hart, R., 2008. *Oregon beach and shoreline mapping and analysis program - 2007-2008 beach monitoring report*, Portland, Oregon: Oregon Department of Land Conservation and Development.

Allan, J. C. & Komar, P. D., 2006. Climate controls on U.S. West Coast erosion processes. *Journal of Coastal Research,* Volume 22, pp. 511-529.

Barnard, P. L. et al., 2011. The impact of the 2009-10 El Nino Modoki on U.S. West Coast beaches. *Geophysical Research Letters,* 38(13), pp. 1-7.

Barnard, P.L. et al., 2017. Historically significant oceanographic forcing and coastal response due to the 2015-2016 El Niño. *Nature Communications*, 8, 14365.

Bolte, J. P., Hulse, D. W., Gregory, S. V. & Smith, C., 2007. Modeling biocomplexity - actors, landscapes and alternative futures. *Environmental Modelling & Software,* 22(5), pp. 570-579.

Cai, W. et al., 2014. Increasing frequency of extreme El Nino events due to greenhouse warming. *Nature Climate Change,* pp. 111-116.

Cane, M. A., 2004. The evolution of El Nino, past and future. *Earth and Planetary Science Letters*, Volume 164, pp. 1-10.

Carroll, L. 2016. Evaluating coastal protection services associated with restoration management of an endangered shorebird in Oregon, U.S.A. Master's Thesis, Oregon State University.

Clarke, B. et al., 2013. Enhancing the knowledge-governance interface: coasts, climate and collaboration. *Ocean & Coastal Management*, Volume 86, pp. 88-99.

DLCD, 2009. *Climate Ready Communities,* s.l.: s.n.

DLCD, 2010. *Oregon's Statewide Planning Goals & Guidelines,* Salem, Oregon: Oregon Department of Land Conservation and Development.

Flood, S. & Schechtman, J., 2014. The rise of resilience: Evolution of a new concept in coastal planning in Ireland and the US. *Ocean & Coastal Management,* Volume 102, pp. 19-31.

Folke, C., 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change,* pp. 253-267.

Hemer, M. A. et al., 2013. Projected changes in wave climate from a multi-model ensemble. *Nature Climate Change,* pp. 471-476.

Hugo, G., 2011. Future demographic change and its interactions with migration and climate change. *Global Environmental Change,* 21(Supplement 1), pp. S21-S33.

IPCC, 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Johnson, C. B. & Schell, S. R., 2013. Adapting to Climate Change on the Oregon Coast: Lines in the Sand and Rolling Easements. *Journal of Environmental Law and Litigation,* Volume 28, pp. 447-514.

Kaminsky, G., Ruggiero, P. & Gelfenbaum, G., 1998. Monitoring coastal change in southwest Washington and northwest Oregon during the 1997/1998 El Nino. *Shore and Beach,* 66(3), pp. 42-51.

Komar, P., 1998. The 1997-1998 El Nino and erosion of the Oregon coast. *Shore and Beach,* 66(3), pp. 33-41.

Komar, P., Allan, J. & Ruggiero, P., 2011. Sealevel variations along the U.S. Pacific Northwest coast - Tectonic and climate controls. *Journal of Coastal Research,* 27(5), pp. 808-823.

Lipiec, E. 2015. Assessing Coastal Community Adaptation Scenarios in the Face of Climate Change: A Tillamook County, Oregon Example. Master's Thesis, Oregon State University.

Mason, C. M., Lim-Camacho, L., Scheepers, K. & Parr, J. M., 2015. Testing the water: Understanding stakeholder readiness for strategic coastal and marine management. *Ocean & Coastal Management,* Volume 104, pp. 45-56.

Mills, A. 2015. Exploring the Impacts of Climate and Management on Coastal Community Vulnerability through Alternative Future Scenarios. Master's Thesis, Oregon State University.

Moss, R. H. et al., 2013. Hell and High Water: Practice-Relevant Adaptation Science. *Science,* pp. 696-698.

Neskowin Coastal Hazards Committee, 2013. *Adapting to Coastal Erosion Hazards: A Plan for the Community of Neskowin,* s.l.: s.n.

Neuman, J., 2012. Accretion, Reliction, and Avulsion - Oregon Common Law. In: *Adapting to Climate Change on the Oregon Coast Part Two: Scientific and Policy Considerations.* s.l.:Oregon Shores.

Neumann, B., Vafeidis, A. T., Zimmermann, J. & Nicholls, R. J., 2015. Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. *PLoS ONE*, 10(3).

NOAA Office of Ocean & Coastal Resource Management, 2006. *Coastal Zone Management Act of 1972, as amended though Pub. L. No. 109-58, the Energy Policy Act of 2005,* s.l.: s.n.

NRC, 2012. *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future,* s.l.: Committee on Seal Rise in California, Oregon, and Washington: Board of Earth Sciences and Resources; Ocean Studies Board; Division on Earth and Life Studies.

Oregon Office of Economic Analysis, 2013. *Long Term County Population Forecast,* s.l.: s.n.

Ruggiero, P., Komar, P. D. & Allan, J. C., 2010. Increasing wave heights and extreme-value projections: the wave climate of the U.S. Pacific Northwest. *Coastal Engineering,* 57(5), pp. 539-552.

Ruggiero, P. et al., 2010. Impacts of climate change on Oregon's coasts and estuaries. In: K. D. Dello & P. W. Mote, eds. *Oregon Climate Change Reserach Institute Oregon Climate Assessment Report.* Corvallis, OR: College of Oceanic and Atmospheric Sciences, p. Chapter 6.

Ruggiero, P. et al., 2013. *National Assessment of Shoreline Change: Historical Shoreline Change Along the Pacific Northwest Coast,* s.l.: United States Geological Survey.

Santoso, A. et al., 2013. Late-twentieth-century emergence of the El Nino propogation asymmetry and future projections. *Nature,* pp. 126-130.

Serafin, K. A. & Ruggiero, P., 2014. Simulating extreme total water levels using a time-dependent, extreme value approach. *Journal of Geophysical Research: Oceans,* Volume 119.

Smalls, C. & Nicholls, R. J., 2013. A global analysis of human settlement in coastal zones. *Journal of Coastal Research,* Volume 19, pp. 584-599.

State of Oregon, 2010. *Oregon Climate Change Adaptation Framework,* s.l.: OCCRI.

State of Oregon, 2012. *Natural Hazards Mitigation Plan: Coastal Erosion Chapter.* [Online] Available at: http://csc.uoregon.edu/opdr/sites/csc.uoregon.edu.opdr/files/docs/ORNHMP/OR-SNHMP_coastal-erosion_chapter.pdf
[Accessed 28 February 2014].

Strauss, B. H., 2013. Rapid Accumulation of committed sea-level rise from global warming. *Proceedings of the National Academy of Sciences,* 110(34).

Vecchi, G. A. & Wittenberg, A. T., 2010. El Nino and our future climate: where do we stand?. *WIREs Climate Change*, 1(2).

Wang, X. L., Feng, Y. & Swail, V., 2014. Changes in global ocean wave heights using multi-model CMIP5 simulations. *Geophysical Research Letters.*

Wheatley, A., 2012. The Public Trust Doctrine in Oregon. In: *Adapting to Climate Change on the Oregon Coast Part Two: Scientific and Policy Considerations.* s.l.:Oregon Shores.

Appendices

Table 1: Organizations and affiliations involved with the Tillamook County Coastal Futures knowledge to action network.

Organization/Affiliation	Geographical Extent
Oregon Coastal Management Program	State
Oregon Department of Environmental Quality	State
Oregon Department of Forestry	State
Oregon Department of Fish and Wildlife	State
Oregon Department of Geology and Mineral Industries	State
Oregon Department of Land Conservation and Development	State
Oregon Department of Transportation	State
Oregon House of Representatives	State
Oregon Parks and Recreation Department	State
Oregon Sea Grant	State
Economic Development Council of Tillamook County	County
Tillamook County Board of Commissioners	County
Tillamook County Community Development	County
Tillamook County Emergency Management	County
Tillamook County Futures Council	County
Tillamook County Planning Commission	County
Tillamook County Public Works	County
City Mayor/Unincorporated Area Manager	Garibaldi, Nehalem
Citizen Advisory Committee	Neskowin, Pacific City
Property owner	Neskowin, Pacific City, Rockaway Beach
Surfrider Foundation	Non-governmental
Oregon State University	Academia
PNW Climate Impacts Research Consortium	Academia

Table 2: Oregon State University Team Members

Individual	Affiliation
Peter Ruggiero	College of Earth, Ocean, and Atmospheric Sciences (CEOAS)
John Bolte	Biological and Ecological Engineering (BEE)
Patrick Corcoran	Oregon Sea Grant
John Stevenson	Climate Impacts Research Consortium
Denise Lach	School of Public Policy
Alexis Mills	Biological and Ecological Engineering (BEE)
Eva Lipiec	(CEOAS)
Katy Serafin	(CEOAS)
Chad Zanocco	School of Public Policy

Table 3: October 2013 Results

LAND USE

Drivers	Endpoints	Policies
Rates of erosion	Detailed level of facts to help drive decisions	Better design BPS (both hard and soft options) to reduce erosion
Historical Records	% reduction in flooded structures per year	Managed retreat – not rebuilding in hazard zones when development is lost; If rebuilding, rebuild to new policies (i.e. greater setbacks); better design to move structures
Public opinion/values/level of understanding	Identified zones of risks (maps)	Details about hazards associated when buying in the area
Political will	% reduction in permitted beachfront protective structures and their repair	Details about hazards associated with a property being attached during sale/resale
	Comparing houses (prices) bought before and after updated FEMA flood maps	If inside geological hazard zone, requirements to carry-out more technical analysis
	Full beach access along entire Oregon coast at high tide 90% of the time	No more development/parcel creation in hazard zones; liability waivers to protect the city/county/state
		Conversion of land to redevelop development in hazard zones, elsewhere
		Safest site requirements to build in safest area of parcel

INFRASTRUCTURE - RETREAT

Drivers	Endpoints	Policies
Tsunami escape routes	Determine the range of costs for defending (define ways to capture range of costs)	Community defined policies (logical policies for different areas)
Hydrologic flow conditions and impacts of flooding at high tides	Location specific information of impacts	Dedicate funding (years in advance) to move critical infrastructure to non-hazardous areas
State vs Local Implementation	Prioritization of hazard areas for retreat	Prioritize infrastructure investments on critical lifelines
Address Seasonal/part time residents		State guidance for areas of inaction or impasse
		Consider the Neskowin Adaptation Plan
		Evaluating effectiveness (and costs) of protection standards over time
		Promote alternative transportation techniques using hydrogen/natural gas/pedal power

INFRASTRUCTURE - RETREAT

Drivers	Endpoints	Policies
Solutions impact adjacent properties via erosion and flooding	Eliminate Goal 18 (rip rap all) and limit state liability	Develop policy for realtors to understand geologic hazards
	Develop Tillamook County stormwater management plan	Develop policy including property disclosure from hazards , i.e. "Buyer Beware"
	Responsible development including emergency response, evacuation, stormwater management, coastal erosion	Adequate funding for operations and maintenance/public infrastructure (i.e. wastewater facility)
		Have two ingress/egress paths for communities with more than 30 homes
		Support other sustainable solutions to hardening besides riprap (groins, beach nourishments, break waters, etc)
		Policy to require neighbors to work together, "good neighbor policy"
		Develop policy which takes into account sand budget and natural erosion into project analysis
		Implement projects to reduce risk to communities (long and short term planning)
		Support green infrastructure

ECONOMIC DEVELOPMENT

Drivers	Endpoints	Policies
Entrepreneurial including agriculture, fishing, forestry, tourism, light manufacturing, and new technology	Increase destination spending (to $400 million by end of decade)	Capitalize on older retirees and their money/skills
Retirement population income	Resilience following catastrophe	Quality care county-wide
$180 million in destination spending	Increase in high tech jobs	Modify foredune policy for sand management
Decreasing Funds	Sufficient funds for investments in capital formation	Enhance access/tourism
	All communities can enact emergency ordinances (including non-incorporated ones)	Impact of moving waste water treatment plant
	Broader source of resources (in addition to transient room tax)	Airport in Pacific City
	Greater income equality	Change how jetties and channels are maintained (and moving that sand into beach nourishment)
		Change usage of transient room tax (30/70)
		Promote high tech i.e. fiber optics
		Potential seasonal sales tax on coast
		Support redundancy
		Provide ENSO based insurance for coastal flooding damages
		Work with FEMA for better rates for coastal insurance

		Support bond measures for additional funding

Table 4: Policy scenario narratives

Policy Scenario Narrative	Policy
Status Quo (SQ)	• Determine urban/community growth boundaries (U/CGB) in accordance with present-day policy. • Maintain current backshore protection structures (BPS) and allow more BPS to be built on State Goal 18 eligible lots.
Hold the Line (HTL)	• Maintain current backshore protection structures (BPS) and allow more BPS to be built on State Goal 18 eligible lots. • Add beach nourishment for locations where beach access in front of BPS has been lost (e.g., due to beach width reduction or frequent flooding). • Construct new buildings or developments only on lots with State Goal 18 BPS eligibility. • Construct new buildings above the Federal Emergency Management Agency's (FEMA) Base Flood Elevation (BFE) plus an additional 3ft and in the safest site of each respective lot. • Require property laws to disclose information about coastal hazards at the point of sale
ReAlign (RA)	• Determine C/UGB in accordance with the present-day policy but with development restrictions within hazard zones. • Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones. • Prohibit construction of BPS on additional properties, regardless of Goal 18 eligibility, but maintain previously constructed BPS. • Construct new buildings above the FEMA BFE plus an additional 3ft and in the safest site of each respective lot. • Remove buildings impacted by a coastal hazard (flooding or erosion) three times in the past five years from the shoreline and establish conservation, open space, or recreation uses within the coastal hazard zones, via buyouts, conservation easements, covenants, the creation of defeasible estates/future interests (when properties change owners), cluster development requirements, or transfer of development rights.

	• Inventory lots located outside of the DOGAMI active, high, and moderate coastal hazard zones and re-zone to permit future higher density development (i.e. low density residential areas become medium density residential lots) within the U/CGB. • Require property laws to disclose information about coastal hazards at the point of sale.
Laissez-Faire (LF)	• Permit increased proportion of development outside the U/CGB. • Eliminate provisions of State Goal 18 that limits BPS eligibility and Oregon Parks and Recreation Department BPS construction requirements.
Neskowin (NESK)	• Determine U/CGB in accordance with the present-day policy but with development restrictions within hazard zones (described below). • Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones. • Construct new buildings above the FEMA BFE plus an additional 3ft and in the safest site of each respective lot. • Subject land divisions to several standards, including a requirement of creating new parcels with building sites outside of the DOGAMI coastal active, high, and moderate hazard zones. • Require conformance to new coastal hazard zone development requirements, including safest site, when performing substantial repairs due to coastal hazard impacts. (Caveat: current National Flood Insurance Program (NFIP) regulations state that “substantial” repairs refer to repairs that cost more than 50% of the pre-damaged market value of the building. Because *Envision* cannot currently quantify damages to buildings, frequency of building exposure to coastal hazards is used as a proxy.) • Require all new construction on bluff-backed sites to be sited beyond the 50-year annual erosion rate (as determined by a geologic report) plus an additional 20ft buffer distance. • Apply new specified runoff and drainage standards, especially for oceanfront property.
Hybrid (HYBR)	• Determine U/CGB in accordance with the present-day policy but with development restrictions within hazard zones (see below). • Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones. • Prohibit construction of BPS on additional properties, regardless of Goal 18 eligibility, but maintain BPS already

	constructed. • Inventory lots located outside of the DOGAMI active, high, and moderate coastal hazard zones and re-zone to permit future higher density development (i.e. low density residential areas become medium density residential lots) within the UGB. • Construct buildings above the FEMA BFE plus an additional 3ft and in the safest site of each respective lot. • Require conformance to new coastal hazard zone development requirements, including safest site and elevation requirements, when performing significant repairs due to coastal hazard impacts. (Caveat: current NFIP regulations state that "significant" repairs refer to repairs or improvements that cost more than 50% of the pre-damaged market assessment of the building. Because *Envision* cannot currently quantify damages to buildings, frequency of building exposure to coastal hazards is used as a proxy.) • Require movement of buildings impacted by a coastal hazard (flooding or erosion) three times in the past years to a location above the FEMA BFE plus an additional 3ft and in the safest site of each respective lot as determined by a geologic/surveyor's report. If the building is again impacted by a coastal hazard (flooding or erosion) three times in the past five years, remove the building from the shoreline and establish conservation, open space, or recreation uses within the coastal hazard zones, via buyouts, conservation easements, covenants, the creation of defeasible estates/future interests (when properties change owners), cluster development requirements, or transfer of development rights.