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Recent coastal disasters (e.g., Hurricane Sandy, Typhoon Haiyan) and chronic issues (e.g., Florida's "nuisance flooding") provide numerous examples of coastal communities struggling to adapt in the face of climate change impacts. Decision-makers and the public alike must reconcile the lack of "fit" between a rapidly changing environment and the effects of sea level rise, changes to storminess patterns, and possible variations in the frequency and magnitude of major El Niño events with relatively rigid and static governance structures. Work to reduce the impacts of coastal hazards and climate change has occurred periodically in disjointed and disconnected ways in many coastal communities, including those along the Oregon coast. In this thesis, I describe the efforts of a volunteer knowledge to action network within Tillamook

[1] Lipiec, E., Ruggiero, P., Mills, A., Serafin, K., Corcoran, P., Bolte, J., Stevenson, J., Lach, D., Zanocco, C., and the Tillamook County KTAN. in preparation. Assessing Coastal Community Adaptation Scenarios in the Face of Climate Change: A Tillamook County, Oregon, Example, to be submitted to Ocean and Coastal Management.

County, Oregon, to comprehensively examine alternative future coastal climate and policy scenarios through the use of extensive stakeholder engagement and the spatially explicit modeling framework *Envision*.

Six co-developed coastal adaptation policy scenarios and three climate change scenarios (with 15 random sub-climate simulations each) are evaluated here through a mixed-methods approach. First, the impacts of policy scenario implementation on stakeholder-identified metrics are statistically assessed in comparison to current land use policies (Status Quo). Next, I characterize the feasibility of implementing policy scenarios by reviewing current federal, Oregon state, Tillamook County, and local regulations and by interviewing relevant coastal organizations. The combination of stakeholder engagement, a powerful modeling framework, and the robust evaluation of policy scenario statistical significance and implementation feasibility provides a compelling opportunity to inform decision-making within the coastal communities of Tillamook County and elsewhere.

Assessing Coastal Community Adaptation Scenarios in the Face of Climate Change: A Tillamook County, Oregon Example

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Eva Lipiec, Author

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1. INTRODUCTION

Increasing population densities and the growing consequences of a warming world provide abundant examples of coastal communities struggling to adapt and thrive (Hugo, 2011; IPCC, 2013; Neumann, et al., 2015; Smalls & Nicholls, 2013; Moss, et al., 2013). Many coastal communities have yet to fully recover from recent devastating hurricanes along the U.S. East Coast (e.g., Hapke, et al., 2013) and extreme high water levels experienced during the El Niño winters of 1997-1998 and 2009-2010 along the U.S. West Coast (Allan & Hart, 2008; Barnard, et al., 2011). Resulting impacts from these types of climate events range from the physical (chronic to catastrophic coastal flooding and erosion) to the economic (i.e., increased costs to construct and maintain engineered backshore protection structures (BPS), beach nourishment, etc.), to the social (i.e., beach closures, reduced scenic value, etc.). 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 the El Niño events (ENSO) (NRC, 2012; Allan & Komar, 2006; Ruggiero, et al., 2010; Cai, et al., 2014; Hemer, et al., 2013).

The struggle to manage the effects of future climate change and variability and an expanding coastal population is confounded by the lack of "fit" between the dynamic economic, social, environmental, and geological characteristics of coastal communities, and the relatively static and inflexible governance and planning structure (Folke, et al., 2007; Johnson & Schell, 2013). This mismatch between natural system dynamics and natural resource governance generates barriers to implementing adaptation policies; the same policies necessary to improve the adaptive capacity or the ability of any system to increase and/or maintain the quality of life of its members

(Dutra, et al., 2015; Pittman, et al., 2015; Millenium Ecosystem Asessment, 2006; Galaz, et al., 2008; Pittman, et al., 2015; Gallopin, 2006).

This thesis is built upon the work done by the Tillamook County Coastal Futures (TCCF) project, an undertaking focused on co-producing information and assessing efforts to increase coastal community adaptive capacity within Tillamook County, Oregon (OR). 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). The focus here is to evaluate the significance and feasibility of the stakeholder co-developed policy scenarios under varying climate scenarios and over time using a mixed-methods approach. Policy scenarios are assessed to determine the timing and magnitude of sustained statistical differences between continuing current policy versus alternative future policy strategies. Policy scenarios are then characterized by their implementation feasibility via a review of regulatory documents and interviews. These evaluations may help decision-makers and stakeholders alike in determining if implementing policy scenarios with beneficial results, but many barriers to implementation, are worth the effort in comparison to other policy scenarios.

The thesis is organized as follows. The background section introduces the geographic, climatological, theoretical, legal, and historical context of coastal adaptive capacity and adaptation planning within Tillamook County, focusing on the work of the Knowledge-to-Action Network (KTAN). Next is a description of the mixed methods approach used for evaluation of adaptation policy implementation under different future climate scenarios. Presented results focus on the timing, magnitude, and rationale behind statistical differences between coastal flooding and erosion under varying adaptation policies, and the existing regulatory and governance barriers to alternative policy implementation. The discussion section highlights the most statistically "beneficial" and "detrimental" policy scenarios, and a framework for understanding the feasibility and factors of successful adaptation policy implementation in Tillamook County. We end with a summary of concluding remarks and broader implications of our findings.

2. BACKGROUND

The following sections introduce the geographic and climatological setting of Tillamook County and historical approaches and current regulations to increase adaptive capacity and 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*.

2.1 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 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). These extreme total water levels (TWLs) are typically a consequence of the combinations of high winds driving big waves and storm surge during large storm events, increases in sea level due to El Niño events, and astronomical tides.

In the long-term (1800s - 2002), Tillamook County has experienced shoreline change rates ranging from -0.5 to 0.3 meters per year (m/yr), and short-term (1960s - 2002) shoreline change rates of between -1.1 m/yr to 0.6 m/yr (Ruggiero, et al., 2013). During the last few decades over 65% of the coast has been eroding with approximately 40% of the coast eroding at rates exceeding 1 m/yr. Shoreline change rates are expected to continue to vary in the future due to climate change factors including SLR, changes to storm wave heights, and possible variance in the magnitude and frequency of El Niño events (NRC, 2012; Ruggiero, et al., 2013; Ruggiero, et al., 2010; Allan & Komar, 2006; Strauss, 2013). The strong tectonic activity in the PNW creates alongshore variations in vertical land motions that impact relative SLR. Tillamook County has been experiencing approximately 1 millimeter per year of relative SLR over the last several decades (Komar, et al., 2011). When local factors such as fingerprinting and vertical land motion are accounted for, 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 vertical land motions due to the Cascadia Subduction Zone offshore, however, the impacts of earthquake and tsunamis on coastal flooding and erosion are not considered in this manuscript.

The PNW currently experiences severe winter storms, with approximately one event per year with 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 strongest storms increased between the late 1970s and mid-2000s at a greater rate (0.093m/yr) than the winter average wave heights (0.023m/yr). These increases in wave height have been shown to have a more significant role in the growing frequency of coastal flooding and erosion than the concurrent SLR (Ruggiero, et al., 2013).

Characterizing future coastal hazards in the region is further complicated by the occurrence of major El Niño events, which temporarily raise sea levels as much as 30 centimeters (cm), change incident wave direction, and cause increased coastal erosion and inundation (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).

2.2 Adaptive Capacity, Laws and Regulations, and Adaptation Efforts

2.2.1 Adaptive Capacity

Historically, efforts to minimize 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). Actions to increase a community's broader adaptive capacity are a relatively recent phenomenon, a part of the recognition that coastal SESs are complex settings with growing exposure and sensitivity (Folke, 2006; Garmenstani, et al., 2013; Coletti, et al., 2013). Community adaptive capacity is influenced by a variety of factors, including "managerial ability, access to financial, technological, and informational resources, infrastructure, the institutional environment[…], political influence, and kinship networks" (Smit & Wandel, 2006). Adaptation, or the process of adjusting, coping with, or managing some actual or expected condition, stress, hazard, risk or opportunity, can potentially influence these factors and support a community's adaptive capacity (IPCC, 2013; Smit & Wandel, 2006).

The governance or management of local social, ecological, and economic resources found within a coastal community is a combination of the institutional environment and the organizations working within the institutions (Dutra, et al., 2015). The former is composed of the laws, policies, regulations, norms, customs, cultural processes, and other rules that control human action, while the latter is made up of actors who act together, such as a community or business (Dutra, et al., 2015; IDGEC Scientific Planning Committee, 1999). Adaptation policies that seek to modify laws and regulations in the face of uncertainty, complexity, and change affect the institutional component of adaptive capacity (Pittman, et al., 2015). However, the inherent rigidity of institutions creates barriers and impedes the implementation of adaptive policies (Gupta, et al., 2010). Ultimately, improving the "fit" between governance and a changing environment increases adaptive capacity at the community level (Dietz, et al., 2003; Pittman, et al., 2015).

2.2.2 Federal and Oregon State Coastal Law and Regulations

Federal, state, and county agencies are increasingly encouraging strategic approaches to improve community adaptive capacity (Mason, et al., 2015; Flood & Schechtman, 2014). At the federal level, the Coastal Zone Management Act (CZMA) of 1972 requires coastal state and local governments to be responsible 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. Common law accommodates incremental changes to public ownership and access by shifting MHW line levels, for example, and causing a subsequent reduction in size of coastal properties unless movement of the beach is impeded by the existence of BPS (Neuman, 2012). However, sudden losses of sand, due to winter storms or the like, pose a different problem and would permanently fix property lines to their pre-change locations. Coastal property owners and the public alike would end up with land underwater, as illustrated by the loss of properties due to sudden breaching along Bayocean Spit in the 1950s (Neuman, 2012).

The 1967 Oregon State Legislature Beach Bill (Or. Rev. Stat. § 390.605 et seq.) strengthens the public rights of the common law, and aims to preserve the public's right to recreate on both the wet and dry portions of Oregon's beaches. The 1969 decision, State ex rel. Thornton vs. Hay, further supported the public's right to beach access and holds that beachfront property owners cannot prohibit or obstruct the public's access to the dry sand beach (Wheatley, 2012).

Several state agencies, such as the Department of Land Conservation and Development (DLCD) assisted by the citizen's Land Conservation and Development Commission, 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 (Goal 18) (DLCD, 2010). The Oregon Parks and Recreation Department (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 yet ineligible for construction of BPS for protection.

2.2.3 Recent Coastal Adaptation Efforts

Recent attempts at statewide coastal adaptation, the 2009 Climate Ready Communities program, the 2010 Oregon Climate Change Framework, 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 changing inadequate current county regulations and local land use ordinances (Johnson & Schell, 2013).

Efforts in the unincorporated community of Neskowin (~5km of coast) in southern Tillamook County have been considered one of the best examples of adaptation planning 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 their community (Neskowin Coastal Hazards Committee, 2013). Strategies included the adoption of coastal hazard zones and construction requirements including siting within the "safest" location within the parcel and at a minimum elevation. After several years of work, the plan was adopted by the county for use within Neskowin in October 2014.

2.3 Tillamook County Coastal Futures

The coastal adaptation process and final planning documents in Neskowin highlighted the need for state, county, and local agency involvement in forging strong coastal hazard adaptation policies to increase adaptive capacity. Momentum from the effort spurred the formation of the Tillamook County Coastal Futures (TCCF) knowledge to action network (KTAN) in 2012, consisting of interested volunteer participants from varying departments of state, county, and local agencies, non-governmental organizations (NGOs), private citizens, along with researchers, students, and outreach specialists (Appendix D - Table D1).

The KTAN was interested in understanding how different policies, such as those 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 policy and climate 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).

The use of alternative future scenarios, in combination with stakeholder engagement, can provide the framework and information necessary to evaluate adaptation strategies in light of future uncertainty (Clarke, et al., 2013; Tompkins, et al., 2008; Mason, et al., 2015; Poumadere, et al., 2015; Evans, et al., 2013). Further, stakeholder participation helps to ensure that *Envision* results are scientifically “credible”, “salient, and “legitimate” (i.e., respectful to the stakeholders’ values and beliefs), and ultimately useful to the participants and decision-makers (Cash, et al., 2003; Tompkins, et al., 2008).

Initial KTAN meetings focused on identifying stakeholder values, desired endpoints, and goals for the community and potential adaptation policies to reach these goals. The adaptation policies were iteratively grouped to create four original 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) (Table 1).

In addition to the four original policy scenario narratives, two more policy scenarios have been developed to model within *Envision*. After the ratification of the Neskowin Coastal Adaptation Plan, KTAN members were interested in examining model results from a county-wide implementation of the plan. Hence, the set of Neskowin adaptation policies were added as the fifth policy scenario narrative modeled within *Envision* (Table 1). Flooding and erosion outcomes under the five policy scenarios were presented to stakeholders at several large workshops as well as in targeted sub-group meetings in order to incorporate stakeholder suggestions and clarifications, and vet model assumptions. The sixth and final policy scenario was formed via rankings of stakeholders’ most and least ideal policy scenarios and individual policies. The highest ranked policy scenarios and underlying policies were combined and reviewed to form the Hybrid policy scenario (Table 1).

3. METHODS

A mixed-methods approach was developed to appropriately analyze both the quantitative and qualitative information generated by *Envision* and the TCCF process. Below we present methods for (1) modeling future projections of Tillamook County development, coastal flooding, and coastal erosion under a variety of climate and policy scenarios in *Envision*, (2) assessing the timing and magnitude of statistically significant differences between the Status Quo and alternative policy scenarios, and (3) characterizing the regulatory and universal barriers to adaptation policy scenario implementation.

3.1 Modeling the coastal system 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 (Figure 2). 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.

3.1.1 *Population Growth and Development*

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). This population growth is allocated on the Tillamook County landscape based on current zoning ordinances and the present-day distribution of population within community growth boundaries and more generally on county lands. Growth is further regulated by individual policies within the policy scenarios (i.e., the Status Quo policy scenario reflects current development patterns).

3.1.2 Coastal Hazards Modeling

Projections of coastal flooding and erosion are dependent on the elevation of the total water level (TWL), relative to elevations of important backshore features such as BPS/dune toe or crest.

$$Total\ Water\ Level\ (TWL) = MSL + \eta_A + \eta_{NTR} + R \qquad (1)$$

MSL is the mean sea level, η_A is the deterministic astronomical tide, η_{NTR} is the non-tidal residuals, and R is the wave-induced runup (Ruggiero, et al., 2001; Serafin & Ruggiero, 2014; Stockdon, et al., 2006). Multiple, synthetic records of each TWL component, and their dependencies, are 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.

In this study, the potential for flooding and erosion was first determined using the storm impact scaling approach of Sallenger (2000). Flooding occurred when the TWL was higher than the backshore crest (dune or BPS) and erosion occurred when the TWL was between the backshore feature's toe and crest. Beach and dune morphometrics, such as the dune crest and beach slope, were extracted from high resolution lidar datasets and topographic surveys (NOAA Coastal Services Center, 2002; Mull & Ruggiero, 2014).

We assessed the impacts of flooding and erosion, at every alongshore model grid node (100m resolution), from the highest daily maximum TWL each year. Flooding extents, if the TWL exceeds the backshore elevations, were computed using a simple bathtub model.

A general expression for cross-shore erosion projections in meters (Baron, et al., 2014) can be written as

$$CCH_p = (CCR_{SB} + CCR_{SLR}) * T + CC_{event} \qquad (2)$$

where CCH_p is the coastal change hazard projection associated with a particular year of interest, T, and the maximum yearly storm event (e.g., 2040 and the maximum annual event; CC_{2040_1}). CCR_{SB} is the long-term (internannual- to decadal-scale) coastal change rate associated with sediment budget and climate factors, not including SLR (e.g., gradients in sediment transport, changes in sediment supply due to engineering structures) and was modeled simply by linearly extrapolating observed historical shoreline change rates (Ruggiero, et al., 2013). CCR_{SLR} is the long-term coastal change rate associated with SLR and was modeled here via the Bruun Rule (Bruun, 1962). Conservatism is built into the approach by the inclusion of an event-based coastal erosion term associated with a significant storm event, CC_{event}, added to the expected long term evolution (Baron, et al., 2014; Revell, et al., 2011). Estimates of event-based potential foredune erosion were computed using the equilibrium dune erosion model of Kriebel and Dean (1993). Mull and Ruggiero (2014) assessed the efficacy of several simple dune erosion models and found that the Kriebel and Dean (1993) model was most well suited to conditions in the PNW. Using this model, event-based erosion is computed as

$$CC_{event} = \frac{TWL\left(x_b - \frac{h_b}{tan\beta_f}\right)}{D + h_b - TWL/2} \quad (3)$$

where x_b is surf zone width, h_b is breaking wave depth, β_f is the foreshore beach slope, and D is the backshore feature height taken as the elevation of the dune/BPS crest minus the elevation of the dune/BPS toe (Kriebel & Dean, 1993). While the coastal flooding and change hazards models we have implemented are relatively simple, the approach is designed to be modular and more sophisticated models can be implemented if warranted.

3.1.3 Policy and Climate Scenarios

The adaptation policies co-developed by the TCCF KTAN encompassed a range of local to internationally successful measures, such as coastal retreat of development and population centers, the construction of engineered BPS, and beach nourishment to protect infrastructure. Quantitatively modeling these qualitative policies requires 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. Many additional assumptions were made within the model and are discussed throughout the manuscript as they impact the results.

Each policy scenario was modeled for 95 years (2005-2099) under three climate change impact scenarios (low, medium, and high) based on SLR projections with 15 random variations of wave heights/ El Niño conditions (or sub-climates), for a total of 45 simulations per policy scenario (Figure 3). The three climate scenarios were created based on National Research Council (NRC) SLR estimates for Oregon and Washington, ranging from 0.11m to 1.42m by the end of the century (NRC, 2012) (Figure 4). Changes to the mean and maximum significant wave heights

(SWH) were estimated using statistically and dynamically downscaled global climate model projections by the end of the century (Hemer, et al., 2013; Wang, et al., 2014). These changes ranged from +/- 30cm by the end of the century and were incorporated in the TWL-FSM (Figure 5). The frequency of major El Niños was modeled in three ways; its frequency remains the same as present-day conditions, doubles, or occurs half as frequently. Of the 15 sub-climate simulations run under every SLR scenario, three were comprised of specified SWHs and El Niño frequencies (historic SWH and El Niño frequency, low SWH and ½ El Niño frequency, and high SWH and 2x El Niño frequency) and the remaining 12 simulations contained indiscriminately selected increases or decreases in SWHs from the wave distributions and random changes to the frequency of major El Niños.

Almost 120 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* (Appendix A - Table A1). Of the ~120 metrics, stakeholders identified eight metrics of most importance now and into the future (Table 2):

Beach Accessibility (%): *Beach accessibility* is defined as the ability to traverse areas of wet and dry sand in the alongshore direction. Accessibility was determined by spatially averaging the percentage of each year that maximum daily TWLs did not impact the base of the dune/BPS within each model grid cell.

Length of Road Impacted by Flooding (km): This metric keeps track of the length of local, county, and state roads affected by flooding in each year.

Length of Road Impacted by Erosion (km): Similar to the *Length of Road Impacted by Flooding*, this metric tracks the length of roads affected by erosion per year.

Number of Buildings Impacted by Flooding: This metric tallies the number of building that are impacted by flooding per year.

Number of Buildings Impacted by Erosion: Similar to the *Number of Buildings Impacted by Flooding*, this metric keeps track of the number of buildings impacted by event-based erosion per year.

Number of Buildings 'Destroyed' by Erosion: In addition to event-based erosion that may impact buildings (tracked by the *Number of Buildings Impacted by Erosion* metric), *Envision* computes the number of buildings "destroyed" each year as chronic erosion shifts the shoreline landward through beachfront properties.

Value of Property Impacted by Flooding ($): This metric tracks the total yearly assessed value of flood impacted properties in 2010 dollars.

Value of Property Impacted by Erosion ($): Similar to the *Value of Property Impacted by Flooding* metric, this metric tracks the total yearly assessed value of properties impacted by erosion in 2010 dollars.

These metrics served as the basis for further statistical assessments described below.

3.2 Statistical Assessment of *Envision* Outcomes

The differences in metric values under various policy scenarios can be appreciated visually; however, statistical methods were used to gain a better understanding of the timing and magnitude of divergence between policy scenarios. Simple (two-sample t-tests) and more complex (multiple linear regressions) statistical tools were used to assess the impacts of the Status Quo and alternative policy scenarios on the eight metrics most important to stakeholders. Since both methods produced similar results, in the interest of space, only the multiple linear regression (MLR) method is described here (refer to Appendix B for t-test methodology).

MLR attempts to model the relationship between a single response variable and two or more explanatory variables by fitting a linear equation to the data (Lacey, 1997; Ramsey & Schafer, 2002). In this case, we used MLR to compare the mean of metric values (response variables) for one year, one climate scenario, and the Status Quo policy scenario (explanatory variables) to the mean of metric values for the same year, the same climate scenario, but an alternative policy scenario to determine the timing of statistical difference as well as the magnitude of the differences. To avoid cluster or serial effects, comparisons between policy scenarios were restricted to the metric mean within a single year and a specific climate (versus comparing groups of years or climate scenarios) (Ramsey & Schafer, 2002).

To account for differences in the type of metric value (discrete versus continuous) and the possibility of unequal variance between policy scenarios, values were quasi-Poisson (discrete) and log (continuous) transformed. A more robust statistical method (least squares regression) could have been utilized to allow errors to be correlated and/or have unequal non-zero variances (Ramsey & Schafer, 2002), however several years of metric values contained instances of zero variance between simulations within a single or multiple policy scenarios. For example, policy scenarios that result in zero impacts to metrics across all climate scenarios, such as the number of buildings "destroyed" by erosion, cannot be compared to the Status Quo, and would have to be manually removed from each yearly regression comparison in order to appropriately utilize the least squares regression method, and therefore was not feasible for this project.

Alternative policy scenarios were considered statistically different from the Status Quo policy scenario when a period of statistically significant difference was present and sustained. This period was defined as a 95% confidence level of statistical difference between the metric values for at least nine of the subsequent ten years. This definition of a statistical different period allowed for the inclusion of random climate variability to occur (e.g., metric value trajectories overlap) but ensured that policy outcomes significantly differed on a decadal scale. The condition also allowed for the identification of the “first instance” of sustained significance.

A second condition was imposed to ensure that statistically significant differences between the Status Quo and alternative policy scenarios were sustained or composed the majority of the remaining time after the first instance of significance. For example, if the first instance of sustained significance occurred in 2015 and continued for the next 70 years, the metric would be statistically sustained for 70 of the 85 remaining years (or ~82% of the time). Conversely, if the first instance of sustained significance occurred in 2015 but only lasted 15 years or became variable for a total of 15 statistically different years, the metric would only be statistically sustained for 15 of the 85 remaining years (or ~18% of the time). Metrics that remained statistically sustained over 67% ($2/3^{rd}$) of the remaining time after the first instance of significant difference were chosen for further analysis and were later rated in terms of benefit to the community.

Beneficial policy scenarios were defined as those that lessened the impact of flooding or erosion on a metric. For example, beneficial policy scenarios improved or increased the Beach Accessibility in comparison to the Status Quo. A ratio of benefits for each metric was calculated by dividing the number of metrics with beneficial and statistically sustained impacts due to the policy scenario by the eight metrics of highest interest.

To not only understand the timing and benefits of policy scenario implementation, the magnitude of statistically sustained difference between the Status Quo metric values and alternative policy scenario metric values was determined by calculating the mean percent magnitude of difference from the first instance of sustained significance to the end of the century. This calculation helped to describe the average differences between the policy scenarios over time and across climate variability.

3.3 Policy Feasibility Assessment

While determining the timing and magnitude of sustained statistical difference between policy scenarios is important, decision-makers and stakeholders are also interested in the feasibility of implementing various adaptation policies in the current regulatory environment. A first order characterization of barriers to the implementation of the co-developed coastal adaptation policies was completed through a review of current incorporated and unincorporated city planning documents, the Tillamook County Comprehensive Plan and Land Use Ordinances, Oregon Statewide Planning Goals, and federal agency [i.e., Federal Emergency Management Administration (FEMA), U.S. Army Corps of Engineers, etc.] regulations.

To more deeply assess the feasibility of specific policies, a total of 10 semi-structured interviews were conducted with senior managers, planners, stakeholders, and scientists from 15 agencies and organizations involved in planning, management, and research along Oregon's coast at the state, county, and local levels. Several interview respondents had served in more than one role presently or in the past, and could therefore speak from more than one perspective. Several KTAN members served as the initial interviewees; however the snowball method helped to identify additional organizations to interview. Interviewees were chosen to represent the variety of geographical scales, interest groups, and governmental levels of the coastal environment. Soliciting additional interviews ceased once a relatively equal distribution of scales and groups were represented. The interviews focused on:

1. Characterizing the feasibility of implementing coastal adaptation policies at the federal, state, county, and local levels;
2. Identifying the greatest challenges to policy implementation; and
3. Describing the factors contributing to successful coastal adaptation policy implementation (see specific question text in Appendix C).

In addition, interviewees were asked to indicate whether government approval or modifications to regulatory documents would be necessary to implement the adaptation policies at five levels of governance: incorporated city, unincorporated community, county, state, and federal.

Information collected from the reviewed documents and interviews assisted in assessing and rating the feasibility of each policy under current regulations and laws. Policies that would require governmental approval or modifications to regulatory documents at a level of government were assigned a value of one, while those that did not, received a value of zero. If the need for approval or modifications was not able to be specifically determined, the policy was assigned a score of 0.5. Once rated, the policies were ranked by their total average (an average across the five levels of government) individually, as well as part of their respective policy scenario. Higher averages indicated more government approval or modifications to regulations were necessary and therefore the policy scenario was less feasible. Conversely, policy scenarios with lower averages contained few barriers to approval and were more feasibly implemented.

Once the barriers and factors of success to policy implementation were identified via the document review and interviews, results were categorized and further evaluated through the use of a framework provided by Dutra, et al. (2015). The Dutra et al. (2015) framework was based on interviews with stakeholders in coastal organizations within Australia, a location with a different system of governance and a distinctive set of climatic and environmental conditions. However, the types of organizations interviewed represented a similar spread of geographical and jurisdictional scales, and interviewees echoed many of the sentiments to describe efforts within Tillamook County.

4. RESULTS

In the following sections, we describe and differentiate the projected time-series of the eight Tillamook County-wide metrics of interest across six policy and three climate scenarios. *Envision* is capable of generating data on multiple geographic scales, since the policy scenarios are to be implemented on a county-scale, only county-wide metric values were generated and analyzed. Next, we characterize the policy scenarios that achieved sustained statistical differences, and finally, we catalog the barriers to and components of success necessary for policy implementation as suggested by the literature review and interview process.

4.1 *Envision* Modeling Results

Results were generated by *Envision* for each year (2005-2099) across almost 120 metrics, six policy scenarios, and three climate scenarios. A total of 45 climatic simulations were run for each policy scenarios to include 15 wave height and major El Niño variations per SLR estimate. The eight metrics of primary interest displayed considerable annual-decadal variability and more general trends. For example, the *Number of Buildings Impacted by Flooding* metric exhibited high annual variability due to the impacts of randomized SWHs and El Niño frequency for each of the policy scenarios over the course of the century (Figure 6). Meanwhile, increased sea level from 2005 to 2099 and across the three climate scenarios resulted in higher numbers of buildings impacted across the majority of policy scenarios (Figure 6). The lowest impacts to buildings by flooding occurred in the low climate impact scenario under the ReAlign and Hybrid policy scenarios (Figure 6). The ReAlign and Hold the Line policy scenarios show pronounced decreases in the number of buildings impacted over time due to the influence of a policy that limits of the construction of BPS (Table 3). When SLR and BPS construction co-occur, the beach slope steepens and TWLs are higher. The ReAlign and Hybrid policy scenarios move buildings away from the shoreline as they are impacted by hazards and therefore the observed significant reductions in the number of impacted buildings were expected.

The number of buildings impacted by either flooding or erosion generally increased over time for the majority of policy scenarios. Below we briefly describe some general results for each metric:

- *Beach Accessibility* decreased under all climate and policy scenarios over the course of the century, with the highest average percentages of accessibility observed under the ReAlign and Hybrid policy scenarios (Table 3).

- The *Length of Road Impacted by Flooding* increased across the three climate scenarios over time, with about 5-10kms of length of road difference between the policy scenario maximum values (Table 3).
- The *Length of Road Impacted by Erosion* increased under all climate scenarios over time, but was nearly half the length of the length impacted by flooding. The greatest increases in the length of road impacted by erosion were observed in the ReAlign and Hybrid policy scenarios (Table 3).
- The *Number of Buildings Impacted by Erosion* was a fraction of the number impacted by flooding (typically 6-19% of the number impacted by flooding), with the most buildings impacted under the Hybrid policy scenario, and the least under the Laissez-Faire policy scenario under all climate scenarios over time (Table 3).
- The *Number of Buildings 'Destroyed' by Erosion* was much less than the number impacted by flooding or event-based erosion under all climate scenarios over time, and was highest in the Status Quo, Hold the Line, and Neskowin policy scenarios. No buildings were destroyed under the Laissez-Faire, ReAlign, and Hybrid policy scenarios (Table 3).
- The *Value of Property Impacted by Flooding* per year grew with rising sea level over the course of the century and across climate scenarios, and ranged from ~$2.3M to ~$353M. The highest total values per year were observed under the Status Quo and Laissez-Faire policy scenarios (Table 3).
- The total *Value of Property Impacted by Erosion* was only a fraction of the value impacted by flooding maximum total value (~$100,000 to ~$49M). The highest total

values were observed under the ReAlign and Hybrid policy scenarios across climate scenarios and over time, with the lowest total value impacted under the Laissez-Faire policy scenarios (Table 3).

4.2 Results of the Statistical Assessment

Multiple linear regressions (MLR) were performed to compare the mean values of the Status Quo policy scenario, under one climate scenario, metric, and year to the mean values of the five alternative policy scenarios for the same climate scenario, metric, and year. MLR results were further evaluated through the use of two conditions to identify the timing and magnitude of sustained statistical differences between policy scenarios. Magnitudes were calculated as a percent change from the Status Quo value, therefore flooding and erosion impacts under each alternative policy scenario may still occur even with a large percent decrease. Continuing with the *Number of Buildings Impacted by Flooding* example from above, the ReAlign and Hybrid policy scenarios achieved statistical difference from the Status Quo policy scenario before 2020 in all three climate scenarios and sustained the difference through the rest of the century (Figure 7). The Hold the Line policy scenario was more variable, with longer periods of statistical difference in the low and medium climates than in the high climate scenario. The Laissez-Faire and Neskowin policy scenarios were the most variable in their comparisons to the Status Quo and never reached sustained statistical difference with the exception of the last two decades in the Neskowin policy scenario under a high climate scenario.

If every policy scenario achieved sustained statistical difference from the Status Quo, the eight metrics under three climate scenarios could change in potentially 120 ways (eight metrics x three climate scenarios x five alternative policy scenarios) (Figure 8). Instead, the policy scenarios achieved sustained statistical difference from the Status Quo across the climate scenarios in 56 instances, with the most policy scenarios (21) statistically different than the Status Quo within the high climate scenario and the least (17) within the medium climate scenario (Figure 8).

Overall, four types of general metric trends were observed across the climate scenarios:

Metric Trend 1: No sustained statistical difference between metric values of the Status Quo and the alternative policy scenarios (Figure 8 - *Length of Road Impacted by Flooding*);

Metric Trend 2: Moving from low to high climate scenarios, an increasing number of policy scenarios achieved sustained statistical difference from the Status Quo (Figure 8 – *Beach Accessibility*, *Number of Buildings Impacted by Flooding*, and *Value of Property Impacted by Flooding*);

Metric Trend 3: Moving from a low to high climate scenario, a decreasing number of policy scenarios achieved sustained statistical difference from the Status Quo from low to high climate scenarios (Figure 8 – *Number of Buildings Impacted by Erosion*); and

Metric Trend 4: A constant number of policy scenarios achieved sustained statistical difference from the Status Quo from low to high climate scenarios (Figure 8 - *Length of Roads Impacted by Erosion, Number of Buildings Destroyed by Erosion*, and *Value of Property Impacted by Erosion*).

Metrics related to flooding generally experienced Trend 1 and Trend 2 behavior, while those associated with erosion experienced Trend 3 and Trend 4. No policy scenario achieved sustained statistical difference from the Status Quo in all eight of the metrics of interest (Figure

8). As the magnitude of SLR increased across the climate scenarios, a greater number of metrics contained sustained statistical difference between the Status Quo and alternative policy scenarios (Table 4). The Hybrid policy scenario was statistically different than the Status Quo in five to seven metrics (across the climate scenarios), the highest amount of metrics across the alternative policy scenarios (Table 4). The remaining policy scenarios were statistically different than the Status Quo in three to six (ReAlign), three to five (Neskowin), three to four (Laissez-Faire), and one to three (Hold the Line) metrics (Table 4).

To determine which policy scenarios were the most beneficial in terms of their impacts to the eight metrics in comparison to the Status Quo policy scenario, we calculated the ratio of the number of improved metrics (i.e. greater *Beach Accessibility* in comparison to the Status Quo) to the total number of metrics. The Laissez-Faire policy scenario was most beneficial in terms of positive metric outcomes (41.7%) and the Hold the Line policy scenario was least beneficial (only a 20.8% positive influence) across the three climate scenarios (Table 4). The three remaining policy scenarios were calculated as 33.3-37.5% beneficial across the policy scenarios. The sustained statistical benefits of the ReAlign, Neskowin, and Hybrid policy scenarios grew as the magnitude of SLR increased from low to high climate scenarios. Conversely, the Hold the Line and Laissez-Faire policy scenarios became less beneficial as SLR increased.

The first year of sustained significance within each metric varied across the policy and climate scenarios. The Hold the Line, Laissez-Faire, and Neskowin policy scenarios experienced earlier first instances with greater magnitudes of SLR, contrary to the timing of first instances for the ReAlign and Hybrid policy scenarios which occurred later in the century (Table 5). When averaged across the metrics and climate scenarios however, all five alternative policy scenarios experienced an average first instance of sustained significance before the year 2035 (Table 5).

The magnitude of statistically sustained difference between the Status Quo and alternative policy scenarios varied based on the metric of interest (Table 6). The Hold the Line and Laissez-Faire policy scenarios statistically lowered several coastal hazards impacts across all climate scenarios in comparison to the Status Quo. Hold the Line lowered flooding and erosion by 62.9-96.4% on average in comparison to the Status Quo, while Laissez-Faire lowered erosion impacts by 56-61.8% (but was not statistically different than the Status Quo in terms of flooding impacts) (Table 6). The remaining three policy scenarios both statistically decreased and/or increased coastal hazards by varying magnitudes depending on metric (Table 6):

ReAlign – lower by 90.5-96% (*Number of Buildings* and *Value of Property Impacted by Flooding*, and *Number of Buildings Destroyed by Erosion*), higher by 128-191.5% (*Length of Road* and *Value of Property Impacted by Erosion*);

Neskowin – lower by 36-44% (*Number of Buildings Impacted by Flooding*, *Number of Buildings Destroyed by Erosion* and *Value of Property Impacted by Flooding* and *Erosion*), higher by 4-5% (*Length of Road Impacted by Erosion*); and

Hybrid – lower by 93-94% (*Number of Buildings* and *Value of Property Impacted by Flooding*, and *Number of Buildings Destroyed by Erosion*), higher by 167-257.3% (*Length of Road*, *Number of Buildings*, and *Value of Property Impacted by Erosion*).

Of the eight metrics, the metrics *Value of Property Impacted by Flooding* and *Erosion* experienced the greatest changes from the Status Quo, with several changes greater than 100%. In sum, alternative policy scenarios were different than the Status Quo on average across the climate scenarios in three ways. Either very helpful or moderately helpful in lowering erosion with no statistically sustained impacts on flooding metrics (Hold the Line, Laissez-Faire, and Neskowin), or greatly beneficial in lowering flooding impacts, but dramatically increasing the erosional impacts in comparison to the Status Quo (ReAlign and Hybrid) (Figure 9).

4.3 Policy Assessment Results

Fifteen organizations within the state (3), county (3), and local (3) governments as well as non-governmental organizations (6) were interviewed over the course of three months (Table 7). The interviews focused on the current and future coastal impacts of most concern, feasibility of adaptation policies as co-developed by the KTAN, challenges or barriers to the implementation of the policies, examples and factors of successful implementation, and the organization's expectations of future policy adaptation work (See Appendix C for interview guidance).

4.3.1 Question 1- What kinds of current and future impacts to the coast is your organization most worried about?

Organizations were most concerned about the current and future impacts of erosion (10 responses), tsunami hazards (9), beach accessibility (7), and flooding (7) (Appendix D - Table D2). Additional impacts included earthquakes (5), aesthetic or scenic value of the coast (2), landslides (2), and construction of BPS (2) (Appendix D - Table D2). The 10 remaining concerns each received one mention by state and county agencies, and NGOs (Appendix D - Table D2).

4.3.2 *Question 2 - From your organization's perspective, what is the feasibility of [adaptation policy] implementation at the local, county, state, and federal levels? Are we missing other potential policies that your organization feels might be effective?*

The organization representatives were asked to characterize the implementation feasibility of the co-developed KTAN adaptation policies. Not all of the policies were discussed, however respondents commented on the ease or difficulty in implementing 11 policies, including repetitive repair limits and subsequent creation of easements (10), the elevation/safest site requirement (6), and the establishment of property inventories for future use (4) (Appendix D - Table D3). Additional policies garnered three responses or less during the interview (Appendix D - Table D3).

The feasibility of implementing policies was further investigated through an extensive literature and legal document review of state, county, and local land use planning ordinances to identify regulatory barriers to implementation (Appendix E). Together with information from the interviews, each adaptation policy was rated in terms of implementation difficulty. Policies within the Status Quo policy scenario were, obviously, identified as the most feasible; conversely the Laissez-Faire policy scenario was rated as the least feasible (Table 8). The remaining four policy scenarios were bracketed by Status Quo and Laissez-Faire, with moderate regulatory barriers to Hold the Line and more difficult implementation for the Neskowin, ReAlign, and the Hybrid policy scenarios (Table 8).

Respondents also identified five additional potential adaptation policies that could be effective, including both reactive measures (i.e. alternative coastal protection structures) and proactive efforts (i.e. increased setbacks during building construction) (Appendix D - Table D4). While interesting and possibly beneficial, the alternative adaptation policies were outside the scope and abilities of the TCCF project and were not modeled as part of the assessed policy scenarios.

4.3.3 *Question 3 - What, in your organization's experience, are the greatest challenges or barriers to the implementation of policies like these?*

Respondents identified a total of 18 general barriers in addition to the specific regulatory restrictions to adaptation policy implementation identified in Question 2. All respondents (15) noted a general opposition to land use restrictions or fear of regulatory takings as a significant barrier to policy implementation (Appendix D - Table D5). Over half of the organizations (8) also noted the lack of public education about or knowledge of current land use policies, climate literacy, and coastal hazards as an additional barrier (Appendix D - Table D5). The remaining 16 challenges identified received four or less mentions during the interviews (Appendix D - Table D5).

4.3.4 *Question 4 - What recent examples of coastal adaptation policy implementation has your organization been involved with in Oregon or elsewhere where barriers like this have been overcome? What kinds of resolutions were reached?*

Eighteen examples of successful Tillamook County and regional coastal policy implementation were identified by the interviewed organizations. The highest cited example of success was the process and results of the Neskowin Coastal Hazards Committee (and the County's adoption of their suggested policy changes), as well as small measures adopted in Lincoln County, OR and the work being completed to restore wetlands along Highway 101 in Clatsop County, OR (Appendix D - Table D6). Sixteen factors that led to success were also identified, and included: bottom-up efforts using state and federal funding (6), the knowledge and use of existing funding, technical support, and best available information (5), change in population demographics (4), and outreach and education to increase public understanding (4) (Appendix D - Table D7). The remaining 12 factors were stated three or less times during the interviews (Appendix D - Table D7).

4.3.5 *Question 5 - When your organization plans for the future, does it expect to handle these kinds of policies and challenges more often? Why or why not?*

All 15 organizations expected to be engaged in adaptation policies and their challenges more often in the future (Appendix D - Table D8). Interviewees provided eight reasons for why and how they expect to address these issues including the requirements of recent state and federal legislation (4), intensified climate change impacts (4), increased requests for both location specific and general information about climate change (3), and more proactive efforts at the federal, state, and local levels (3) (Appendix D - Table D9). The remaining four tactics were cited by interviewees two or less times (Appendix D - Table D9).

4.3.6 *Question 6 - Which other organizations should I talk with?*

Organizations identified 44 additional organizations and coastal professionals to interview (a total of 78 with repeated organizations). The top three most suggested resources included a local unincorporated and incorporated city planner, a city manager, and a citizen advisory committee lead from a variety of Tillamook County communities. Highly recommended organizations and professionals were then contacted for interviews. State, county, local, and non-governmental organizations each suggested 12 to 28 additional groups to interview (Appendix D - Table D10).

5. DISCUSSION

The following sections detail the rationale behind and implications of the results from the *Envision* modeling, the statistical analysis, and the implementation feasibility characterization. It is important to keep in mind that the complexity of the coastal environment introduces uncertainty in different forms. Uncertainty can be found in the underlying datasets utilized (e.g., climate projections), the methods selected to model future population growth and development, coastal processes and associated hazards, and human behavior (i.e. adaptation policies), the limited number of model simulations, and the necessary transformations performed to the resulting metric values (Ramsey & Schafer, 2002).

The *Envision* framework generated 95 year long time-series for eight stakeholder-identified metrics, six policy scenarios and three climate scenarios (with 15 random climatic simulations of each). The range of metric values associated with flooding (*Length of Road, Number of Buildings, and Value of Property*) were significantly larger than those associated with erosion (*Length of Road, Number of Buildings Impacted and Destroyed, and Value of Property*) (Table 3). The difference between metric values is related to the underlying parameters and models utilized to quantify impacts, and the way adaptation policies were modeled. These effects are later propagated into differences within the statistical analysis.

5.1 Statistical Analysis

The timing, benefits, and magnitude of sustained statistical difference between policy scenarios varied across each metric of interest with several patterns observed across climate scenarios and time. Since no policy scenarios achieved sustained statistical difference from the Status Quo in the *Length of Road Impacted by Flooding* metric (Metric Trend 1) it is not discussed further.

5.1.1 Metric Trend 2

As the magnitude of SLR increased across the climate scenarios, the impacts of each adaptation policy accelerated, and metrics related to flooding (*Number of Buildings* and *Value of Property Impacted by Flooding*) experienced a corresponding increase in the amount of policy scenarios with a sustained statistical difference from the Status Quo. Hence restrictions to BPS construction quickly lowered the impact of higher TWLs (ReAlign and Hybrid), properties were converted into easements more rapidly (ReAlign and Hybrid), and new buildings were sited outside of the coastal hazard zones at a greater rate (Neskowin).

Only the Hold the Line policy scenario statistically lowered the total value of property impacted by flooding under low and medium climate scenarios, however, all four policy scenarios (Hold the Line, ReAlign, Neskowin, and Hybrid) lowered the impacted value within the high climate (Table 6).

Beach Accessibility also experienced a growing number of policy scenarios achieving sustained statistical difference than the Status Quo as the magnitude of SLR increased. The beach nourishment strategy under the Hold the Line policy scenario increased the odds of *Beach Accessibility* under the low climate scenario but could not keep pace with greater SLR (Table 6). Policy scenarios which removed the barriers to natural beach migration (ReAlign and Hybrid) were statistically effective in raising the odds of *Beach Accessibility* in the medium and high climate scenarios.

5.1.2 Metric Trend 3

Metrics associated with erosion experienced unchanged or lower numbers of statistically significant policy scenarios as SLR increased across the climate scenarios. Erosion impacts to buildings were lower than the Status Quo in the low climate scenario under policy scenarios that permitted beach nourishment and the construction of additional BPS (Hold the Line and Laissez-Faire), due to the model assumption that inhibits erosion through BPS. These same policies could not keep pace with SLR in the medium and high climate scenarios; thus there was no sustained statistical difference between the Hold the Line/Laissez-Faire policy scenarios and the Status Quo. Policy scenarios that do not allow any additional BPS construction (ReAlign) experienced either no sustained statistical difference from the Status Quo, or increased the numbers of buildings impacted by erosion (Hybrid) as the creation of easements and removal of buildings along the coast was not rapid enough to keep up with SLR.

5.1.3 Metric Trend 4

The number of policy scenarios which achieved sustained statistical difference from the Status Quo for the remaining erosional metrics (*Length of Road Impacted, Number of Buildings Destroyed*, and *Value of Property Impacted by Erosion*) was consistent under all climate scenarios. The *Length of Road Impacted by Erosion* was marginally lower in policy scenarios that relax all BPS construction restrictions (Laissez-Faire), was slightly higher in policy scenarios that allow some BPS construction (Neskowin), and was significantly higher in policy scenarios that prohibit any new BPS (ReAlign and Hybrid). The number of buildings “destroyed” by erosion was lower than the Status Quo across four policy scenarios (Laissez-Faire, ReAlign, Neskowin, and Hybrid) as newly constructed BPS and the creation of easements manage to keep pace with chronic erosion. In contrary to the *Value of Property Impacted by*

Flooding, four policy scenarios statistically changed the total *Value of Property Impacted By Erosion* across all climate scenarios. The lower total value impacted was due to increased BPS and/or development siting restrictions (Laissez-Faire and Neskowin), while the lack of BPS and a slow conversion to easements (ReAlign and Hybrid) increased the total value impacted in comparison to the Status Quo.

While many of these changes in magnitude may seem drastic, the initial Status Quo values were generally low (i.e., 100% lower numbers of buildings *"Destroyed" by Erosion* resulted in seven buildings impacted under the Status Quo and zero under the Laissez-Faire, ReAlign, and Hybrid policy scenarios).

5.1.4 Benefits and Timing of Policy Scenarios:

Policy scenarios achieved sustained statistical difference from the Status Quo in seven of the eight metrics of interest (with the exception of the *Length of Road Impacted by Flooding*). The Hybrid policy scenario statistically altered the greatest number of metrics (seven in the high climate scenario), while the Hold the Line policy scenario changed the least (one metric in the high climate scenario) in comparison to the Status Quo (Table 4). The differences between the statistical influence of these two policy scenarios can be explained by their constituent policies. Hold the Line contains five policies, one of which (the continued construction of BPS) is the same as within the Status Quo policy scenario. The remaining four individual policies failed to lower the impacts of coastal hazards whether due to a resource limitation (cost and frequency of beach nourishment) or trivial effect on future development (few beachfront locations left on which to implement restrictions). The Hybrid policy scenario contains seven policies, all different than the Status Quo, and more aggressive in moving buildings away from hazards (e.g., safest site and minimum elevation requirements for buildings needing significant repairs and eventual conversion into easements).

Policy scenarios sustained statistical difference from the Status Quo in both beneficial and detrimental ways due to the influence of specific adaptation policies and underlying assumptions. It is important to remember that the analysis was based on only eight of the nearly 120 metrics tracked within Envision. Timing, magnitude, and especially the benefits of each policy scenario were dependent on the eight metrics chosen and could potentially change in a variety of ways if alternative metrics were selected for further analysis. All alternative policy scenarios achieved sustained statistical difference from the Status Quo within the first third of the century, indicating the necessity of implementing policies in the short-term. The most beneficial policy scenario was the Laissez-Faire, which became, on average, statistically significant ~2020 across the climate scenarios (Tables 5 and 5). The Laissez-Faire policy scenario lowered all erosion impacts by 56-61.8% across the climate scenarios due to the complete armoring of the coast (Table 6). The unregulated construction of additional BPS (as permitted in the Laissez-Faire policy scenario), did not cause statistically sustained lower odds of *Beach Accessibility* or higher flooding impacts in comparison to the Status Quo.

The least beneficial policy scenario was the Hold the Line, which became, on average, statistically significant in 2033. Hold the Line lowered the impacts of flooding and erosion by ~62.9-96.4% across the climate scenarios due to the combined use of BPS and beach nourishment. However, the individual policies within the Hold the Line policy scenario were most helpful in the low climate scenario and were not as influential under higher magnitudes of SLR in the medium and high climate scenarios.

The remaining policy scenarios contained 33.3-37.5% a ratio of beneficial metrics. The ReAlign and Hybrid policy scenarios are comprised of alternative policies to armoring the coast (i.e., required minimum elevation/safest site, the creation of easements, etc.), which allow the beach to migrate by limiting the construction of BPS (Table 4). These policy scenarios became statistically different than the Status Quo in ~2018, have higher odds of *Beach Accessibility* (in a medium and high climate), and lowered several metrics (*Number of Buildings* and *Value of Property Impacted by Flooding* and *"Destroyed" by Erosion*) ~90.5-96% across the three climate scenarios (Tables 5 and 6). However, several constituent policies within each policy scenario raised the remaining erosion-related metrics (*Length of Road, Number of Buildings* and *Value of Property Impacted)* approximately 128-257.3% above Status Quo values over time across the climate scenarios (Table 6). While the percentage increase only impacted 5-8 more kilometers of road and ~10 additional homes, the value of property impacted leapt from a maximum of ~$15.9M in the Status Quo to between $36.6M to $50M under the ReAlign and Hybrid policy scenarios (Table 3). The final alternative policy scenario, Neskowin, was beneficial within 33.3% of the metrics, and became statistically different than the Status Quo in ~2035 (Tables 5 and 5). The benefits of Neskowin were very similar to the ReAlign and Hybrid policy scenarios, with ~36-44% less erosion and flooding and only 4-5% higher impacts of erosion to roads in comparison to the Status Quo (Table 6).

Overall, the number of metrics which received beneficial improvement due to the implementation of alternative policy scenarios ranged from one to four of the total of eight metrics, depending on the policy scenario. Therefore, the ratio of benefits of each policy scenario are similar, especially when comparing the Neskowin, ReAlign, and Hybrid policy scenarios, and relatively close to the most beneficial policy scenario, Laissez-Faire (Table 6).

5.2 Policy Analysis

To assess both the Tillamook County specific and more universal barriers to implementing adaptation policies, a distinction was made between regulatory and governance based challenges. Regulatory barriers are those that associated with specific legislation or ordinances currently in place at the local, county, state, or federal level. Changing or adding to these regulations would require government approval. Barriers within the structure of governance refer to limitations within the institutions and organizations themselves, range from the current concerns of public and governmental agencies to the lack of planning frameworks.

5.2.1 Regulatory Barriers

A total of 15 organizational perspectives were examined (Table 7). All four stakeholder sectors (state, county, local, and non-governmental) were concerned with current and future impacts of erosion, tsunamis, beach accessibility, and flooding, in addition to other natural hazards and ecosystem services (Appendix D – Table D2). Adaptation policies co-developed during the Tillamook County Coastal Futures KTAN process were rated based on their regulatory feasibility as characterized during the interviews and review of legal documents. As expected, the Status Quo policy scenario, which requires no alterations to current regulation and policy, was deemed the most straightforward to implement (Table 8). Conversely, the Laissez-Faire policy scenario, which requires the greatest changes to current regulation, was rated the most difficult to implement. The Hold the Line policy scenario was rated the second most straightforward set of policies to implement, buoyed by the lack of regulatory barriers to continued BPS construction and beach nourishment (Table 8). Ratings for the three remaining policy scenarios (ReAlign, Neskowin, and Hybrid) were relatively similar, an artifact of multiple overlapping policies which restrict land use and move development away from the coastline (Table 8).

5.2.2 Governance Barriers

All of the policy implementation and adaptive capacity barriers revealed during the Tillamook County interviews have been identified previously and categorized (Dutra, et al., 2015; Dietz, et al., 2003; Pittman, et al., 2015; Gupta, et al., 2010; Aylett, 2014). Dutra et al. (2015) provides a particularly useful framework for identifying and characterizing barriers to implementation within the two components of community governance, institutions and organizations, and the relationships between these components, including (in order of number of responses from the Tillamook County interviewees): 1. Interests and Motivation, 2. Information and Knowledge, 3. Organizational Structures, 4. Power Relations/Leadership, and 5. Resources. Within these five overarching barriers, organization representatives provided 59 different limitations to implementing adaptation policies within Tillamook County (Table 9).

5.2.2.1 Interests and Motivation

Interests and motivation, comprised of limited learning capacity and perceptions and assumptions (Dutra, et al., 2015), were identified as the most common challenges (26 responses) to implementing adaptation policies (Table 9). Limited learning capacity refers to a mismatch between identifying successful interventions and implementing the measures. This was expressed by Tillamook County interviewees (3) as a general fatigue associated with discussing and managing climate change issues leading to public and organization inaction (Table 9). Perceptions and assumptions are defined as the worldviews and cognitive styles that control how individuals perceive, store, and structure information (Dutra, et al., 2015). Fifteen respondents described the public's poor opinion of government involvement including a general opposition to any land use restrictions, fear of regulatory takings, and general governmental distrust (Table 9), a sentiment echoed in other U.S. locations, as well as other democratic societies (Clarke, et al., 2013; Milligan & O'Riordan, 2007). Additional barriers of perception and assumption were noted in terms of a lack of proactive or anticipatory thinking and an emphasis on disaster-driven policy creation (Godschalk, et al., 1998) (4), hesitant community residents, due to their socio-economic status, occupation, political affiliation, length of residency, etc. (2), the perceived future timing of climate change effects (1), and the cultural or social differences between coastal communities with latitudinally varying levels of climate change impact and adaptation knowledge (1).

5.2.2.2 Information and Knowledge & Organizational Structures

The next most common categories of barriers expressed by Tillamook County interviewees were the limitations imposed by inadequate information and knowledge and the present structure of organizations (11 responses each) (Table 9). Limited knowledge exchange or misinformation can inhibit the adoption of policies. In Tillamook County, as elsewhere, interviewees noted a lack of education/knowledge of land use policies, climate literacy, and coastal hazards (8) (Sheppard, et al., 2011; Aylett, 2014; Clarke, et al., 2013), poor understanding of the differences between coastal flooding/erosion and tsunami hazard zones (2), and issues with inadequately prepared practicing geologists/engineers (1) (Table 9).

In terms of organizational structures, Dutra et al. (2015) and Aylett (2014) point to a spatial mismatch between management jurisdiction and ecological boundaries, and the superficial collaboration between government and stakeholders as limiting factors. No Tillamook County interviewees remarked on the potential for spatial mismatch between regulatory and ecological boundaries (Table 9). Instead, several noted the structural inflexibility of state agencies and county regulations (4), and the resulting problem of "fit" between the governance structure and coastal environment (Folke, et al., 2007).

Superficial collaboration between government and stakeholders can be defined as the "limited integration and coordination of coastal management activities due to the involvement of several levels of governments and a variety of agencies and organizations within each level of government…" (Dutra, et al., 2015; Sheppard, et al., 2011; Aylett, 2014; Clarke, et al., 2013). Respondents characterized Tillamook County initiatives as poorly coordinated or "siloed" between agencies and groups due to financial or bureaucratic constraints (3), a disconnect between decision-makers at the state and county levels (2), and separate regulations between city and unincorporated areas (2) (Table 9). Integration and coordination, however, between the government and the public is ensured by Oregon's Statewide Planning Goal 1, which requires public participation in land use policy creation and implementation.

5.2.2.3 Power Relations/Leadership

Six barriers related to power relations/leadership were identified in Tillamook County and can be divided into the limiting factors of a lack of leadership and external pressures. Respondents noted a general lack of political will or fear to use the political capital necessary to support potentially controversial policy (4 responses) (Table 9). Elected officials at a variety of levels often fear losing political connections or public support, especially when under pressure from the development and/or real estate communities (2) (Table 9).

5.2.2.4 Resources
The lack of financial, technical, and human resources were cited as challenges to managing the current coastal environment or implementing adaptation policies in Tillamook County by four interviewees (Table 9). This was deemed especially true as local governments are often tasked to manage day-to-day issues as well as more long-term concerns (Aylett, 2014).

5.2.2.5 Other
An additional Tillamook County-specific limitation not cited within the Dutra et al. (2015) framework was frustration with the unpredictable receptiveness to change in the State Legislature (Table 9). Agencies are perceived as unlikely to attempt to change state-level policy due to the fear that the political environment of the State Legislature may cause unexpected alterations to regulations.

5.2.3 Attributes of Success
Tillamook County interviewees identified several strategies to successfully increase the adaptive capacity within and between organizations and institutions, similar to those found in earlier studies by Dietz, et al. (2003), Gupta, et al. (2010), and Pittman, et al. (2015). Attributes of success included (from Dutra, et al. 2015): 1. Leadership, 2. Cross-sectoral cooperation and coordination, 3. Effective integration of knowledge and insights, 4. Human capacity and coordinated participation in decision-making, and 5. Learning approach to natural resource management and governance. Respondents provided a total of 18 components of success, several of which fell into more than one category.

5.2.3.1 Leadership
Successful leadership includes communication and collaboration, trust, and transparency in the management process (Table 10). Tillamook County interviewees and organizations elsewhere

believed leading “champions” and organizations have the responsibility to help foster ongoing conversations to ensure that the decision-making process is inclusive and fair (Folke, et al., 2005) Effective leaders were able to identify and disseminate available funding, information, and man-power resources (5 responses), increase and maintain public understanding and focus through outreach and education measures (4), and facilitate discussion through low-controversy methods (1). Interviewees observed that well-educated participants, as seen within the Neskowin community, often led to more successful initiatives since stakeholders knowledgeable about coastal hazards, climate change, and current policy interactions were more likely to support, modify, or create new strategies to protect and sustain their communities at the local level.

Trust between the various stakeholders is the second critical component of leadership. Respondents identified the need for trusted “champions” at the local, county, and state levels of government (3) to encourage the engagement of the general public, facilitate communication between stakeholder groups, aid in agency support of the effort, and direct the creation and implementation of adaptation policies (Dutra, et al., 2015). This trust is further strengthened by the use of political capital or the political will to sponsor community-supported initiatives in a potentially politically-charged environment (2) (Table 10).

The third component of leadership is transparency in management to ensure that the information used and decision-making process is fair and equitable (Dutra, et al., 2015). No organization noted this as a requirement of success, possibly due to the open nature of Oregon policy-making as guaranteed by Statewide Planning Goal 1.

5.2.3.2 Cross-Sectoral Cooperation and Coordination

The next most highly cited attribute of success in Tillamook County was cross-sectoral cooperation and coordination (11 total responses) (Table 10). Cross-sectoral cooperation and coordination is comprised of autonomy and redundancy in authority and capability, flexibility, and definition of roles and responsibilities (Dutra, et al., 2015; Gupta, et al., 2010; Milligan & O'Riordan, 2007). Tillamook County respondents, and coastal managers in other locations, noted the need for top-down guidance combined with autonomy at the local level (7 responses) and the flexibility to use alternative strategies and tailor regulations to a variety of scales (4), (Kettle & Dow, 2014; Gupta, et al., 2010). Clearer definitions of agency roles and responsibilities were not cited as necessary successful factors by the interviewees, which may be due to the existence of the Statewide Planning Goals and required comprehensive county land use plans.

5.2.3.3 Effective Integration of Knowledge and Insights

The effective integration of knowledge and insights refers to the use of local, traditional, and scientific information in decision-making, and is comprised of a planning framework and sense of resource ownership. Effective integration ensures that decision-makers consider and share the best available information from a variety of trusted sources and adapt regulations as necessary (Dutra, et al., 2015; Clarke, et al., 2013) and that decision-making is scientifically "credible", "salient", and "legitimate" (Cash, et al., 2003). However, respondents noted that public and agency outreach, engagement, and education and the use of visual and sensitive communication methods supported successful initiatives (6 responses) (Table 10). No respondents cited the need for a better for a better planning framework.

5.2.3.4 Human Capacity and Coordinated Participation in Decision-Making

The fourth attribute of success identified in Tillamook County, human capacity and coordinated participation in decision-making, is comprised of available funding, organizational knowledge, and bridging organizations and received five responses (Table 10) (Dutra, et al., 2015; Folke, et al., 2005; Gupta, et al., 2010). Tillamook County respondents rated these components as important (5 responses), especially in successful initiatives, such as the Neskowin Coastal Hazards Adaptation plan (Neskowin Coastal Hazards Committee, 2013).

5.2.3.5 Learning Approach to Natural Resource Management and Governance

A learning approach to natural resource management and governance works to create an adaptive management structure that allows interested stakeholders to learn from each other and regularly review procedures and policies (Dutra, et al., 2015; Clarke, et al., 2013). No respondents noted this attribute as necessary to successful adaptation policy in Tillamook County. This may be due to the fact that in Oregon state, county, and local agencies are relatively well-connected and receptive to engaging with each other and the public as required by a variety of state regulations and programs.

5.2.3.6 External Changes

Respondents noted external forces and changes as a necessary factor of success, an attribute not cited as part of the Dutra, et al. (2015) framework. External forces (7 responses) included changes in county demographics, pressure to adapt via insurance regulations, and the presence or absence of a receptive State Legislature (Table 10).

The characterization of policy implementation feasibility indicated that policy scenarios most similar to the Status Quo were more feasible than those that altered current regulations or instituted considerable amounts of restrictive land use policies. Tillamook County respondents noted the governance barriers of implementing adaptation policies were mostly due to the interests and motivations of poorly informed residents, as well as inadequate coordination between agencies and decision-makers. Conversely, one of the least cited barriers, power relations/leadership, corresponded to the most noted factor of success. Interviewees recognized that communicative and trustworthy community leadership was the prime component necessary to success in recent initiatives, such as the Neskowin Coastal Hazards Adaptation plan. Additionally, interviewees noted higher levels of success in instances where poor cooperation and coordination between agencies and organizations was rectified. These insights point to clear opportunities for motivated government agencies and NGOs at all levels to increase the success of adaptation policy implementation.

6. CONCLUSIONS

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 that is poorly matched with the current relatively static system of governance.

Interested volunteers in Tillamook County, Oregon, known as the Tillamook County Coastal Futures knowledge to action network, have worked to resolve this lack of fit within their coastal system through the use of substantial stakeholder engagement and the spatially explicit modeling framework *Envision*. *Envision* allowed for the integration of spatially explicit natural, social, and environmental landscape conditions and projections of evolving coastal hazards under future climate change conditions, or the physical drivers, with co-developed coastal community adaptation policy scenarios, or the human drivers, of the coastal system to create alternative future scenarios. Outcomes under the five alternative policy scenarios (Hold the Line, Laissez-Faire, ReAlign, Neskowin, and Hybrid) were evaluated to determine if results (impacts to stakeholder defined metrics from coastal flooding and erosion) were statistically different than the Status Quo and to characterize the feasibility of implementing the adaptation policies within Oregon's current state, county, and local regulatory environment. Results, including the characterization of the timing, benefits, and magnitudes of policy scenario impacts, are dependent on the underlying datasets, model assumptions, stakeholder-identified metrics, and uncertainty inherent to model the future interactions of physical and social drivers.

Policy scenarios produced varying results across the climate scenarios, stakeholder-identified metrics, and over time. On average, all five alternative policy scenarios became statistically different than the Status within the first third of the century (2018-2035) across the three climate scenarios, indicating the need for early century policy implementation to limit future hazard impacts. The impacts of implementing alternative policy scenarios can be described in three ways: 1. Greatly beneficial in lowering future erosion (Hold the Line and Laissez-Faire) with no statistically different flooding impacts , 2. Moderately beneficial in lowering future erosion and raising flooding impacts minimally (Neskowin), and 3. Greatly beneficial in lowering future flooding, but exceptionally detrimental in terms of future erosion (ReAlign and Hybrid). Alongside the statistical evaluation, implementation feasibility ratings characterized policy scenarios as relatively feasible (Hold the Line), moderately difficult (ReAlign, Neskowin, and Hybrid) and relatively impossible (Laissez-Faire).

The results of the statistical and policy assessments are contrary with the most “beneficial” , as we have defined it, policy scenario considered to be the least feasible, however, 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 in this paper. Both decision-makers and the public will need to consider: 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 barriers to climate change adaptation policy creation and implementation due to the current system of governance. Many of the barriers identified in Tillamook County are analogous to those found in the rest of the world. Success in implementing adaptation policies will rely on overcoming major institutional and organizational barriers related to the mixed interests and motivations of the public and governmental organizations, as well as the potential for limited information and knowledge exchange. County and state level governance can look to the success of the Neskowin community’s efforts, especially the leadership and cross-sectoral cooperation and coordination that facilitated policy creation and, of critical importance, implementation.

Significant stakeholder 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. Further statistical and regulatory assessment of alternative policy scenarios, and the characterization of and comparison with governance barriers and success factors of other coastal communities will continue to help identify and implement beneficial and feasible coastal hazard adaptation policies in the face of climate change.

Although the results of the process expressed in this thesis are unique to Tillamook County, I describe a robust example of useful methods and tools available to communities to apply to pressing problems. 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.

7. FIGURES

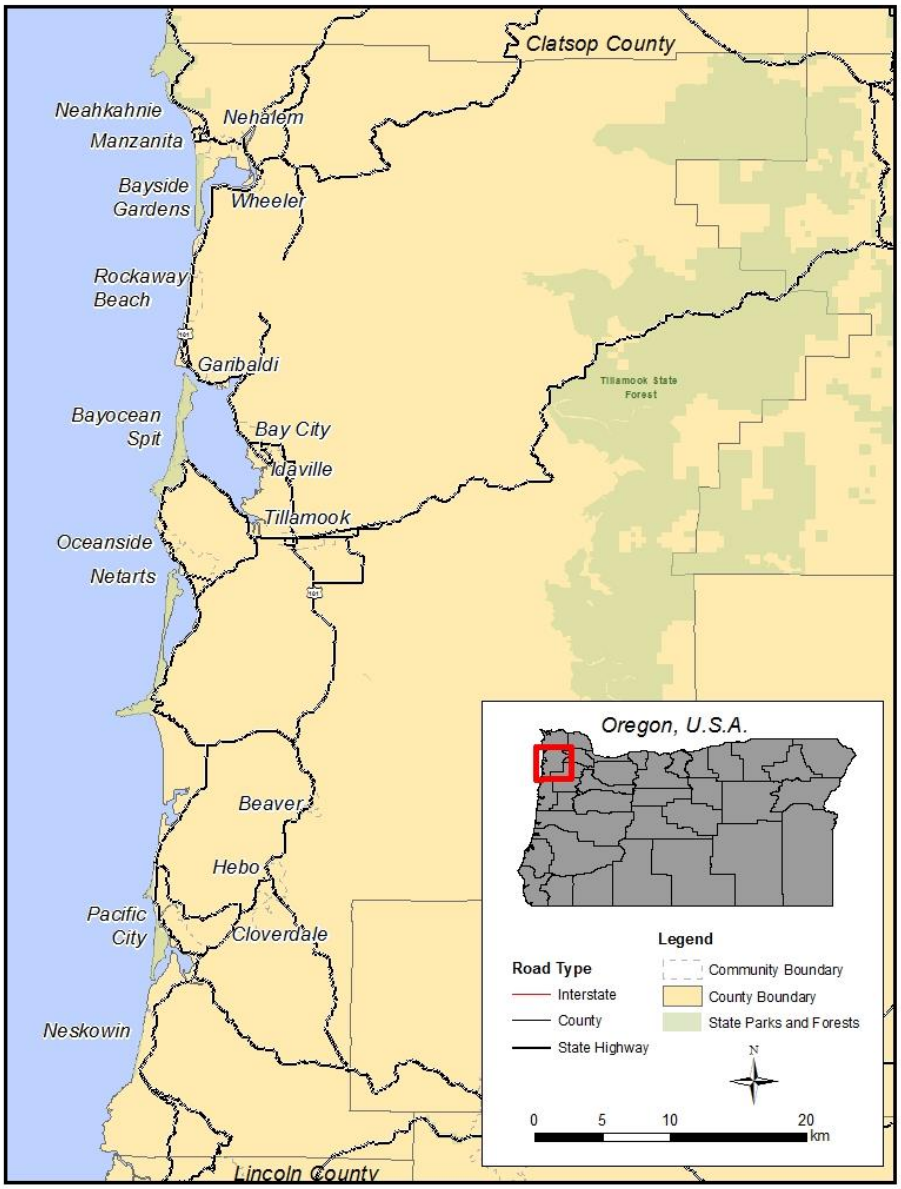

Figure 1. Map of Tillamook County, Oregon, showing the location of coastal communities and roads.

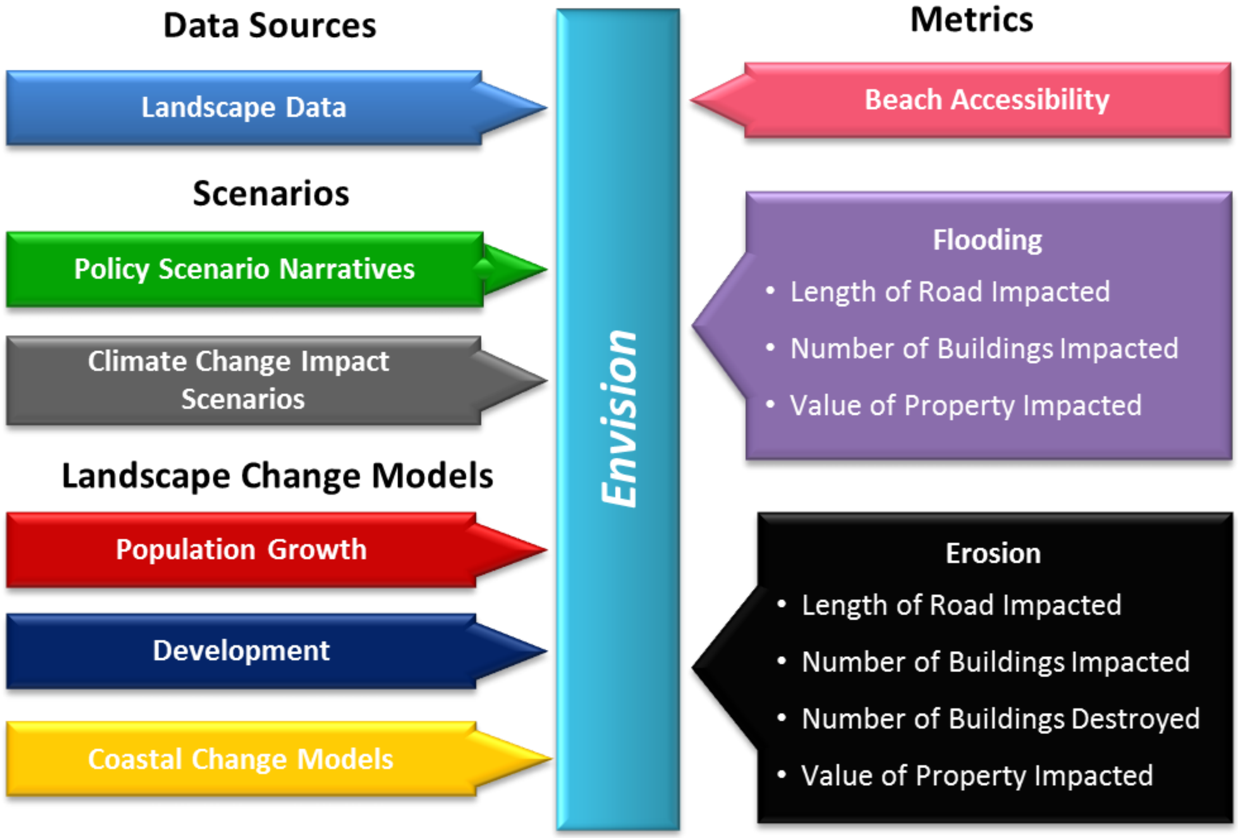

Figure 2. Datasets, models, and metrics utilized within the modeling framework *Envision*, modifed from Bolte (2007).

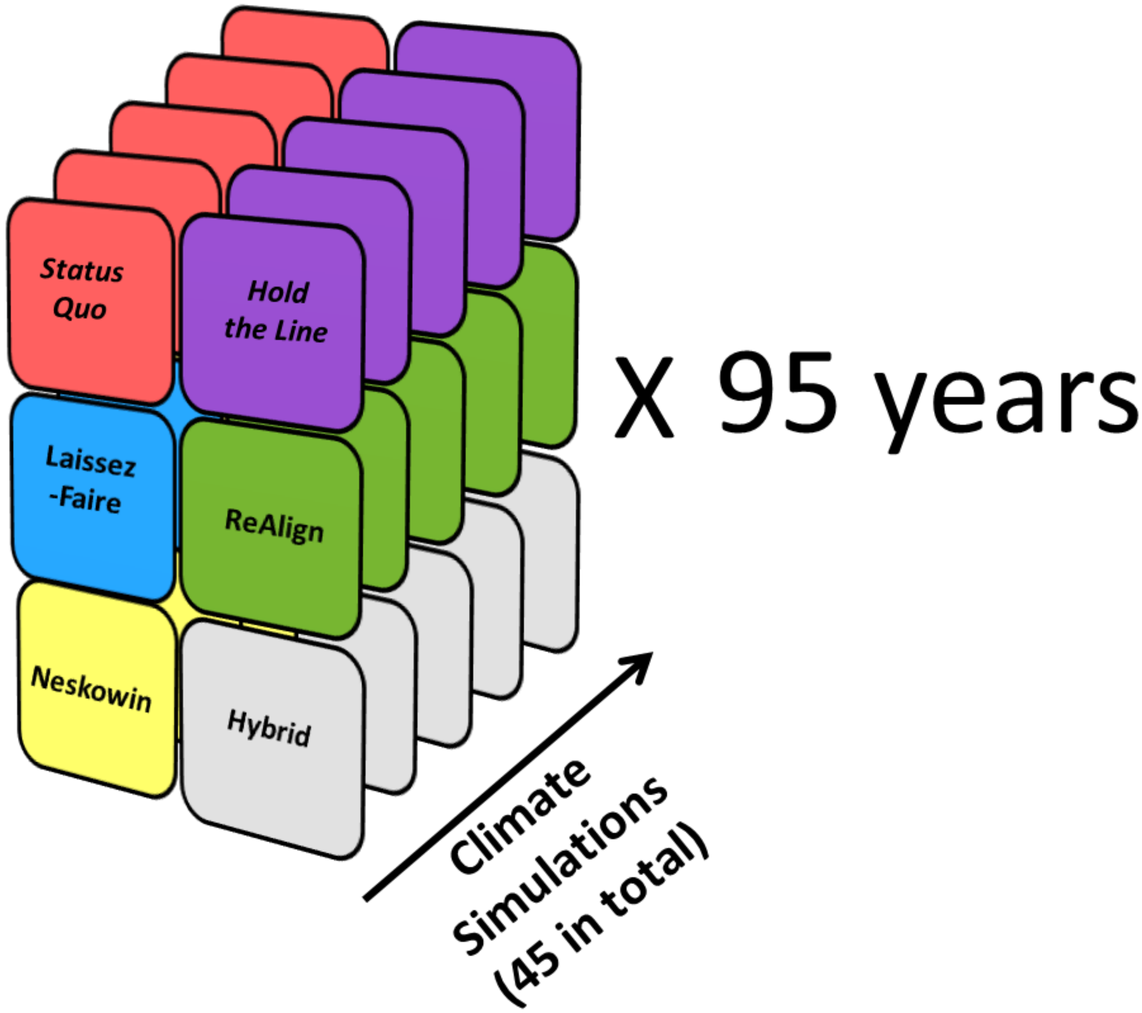

Figure 3. Representation of the total number of policy narrative scenarios, climate impact scenarios, and years of information generated for each metric of interest.

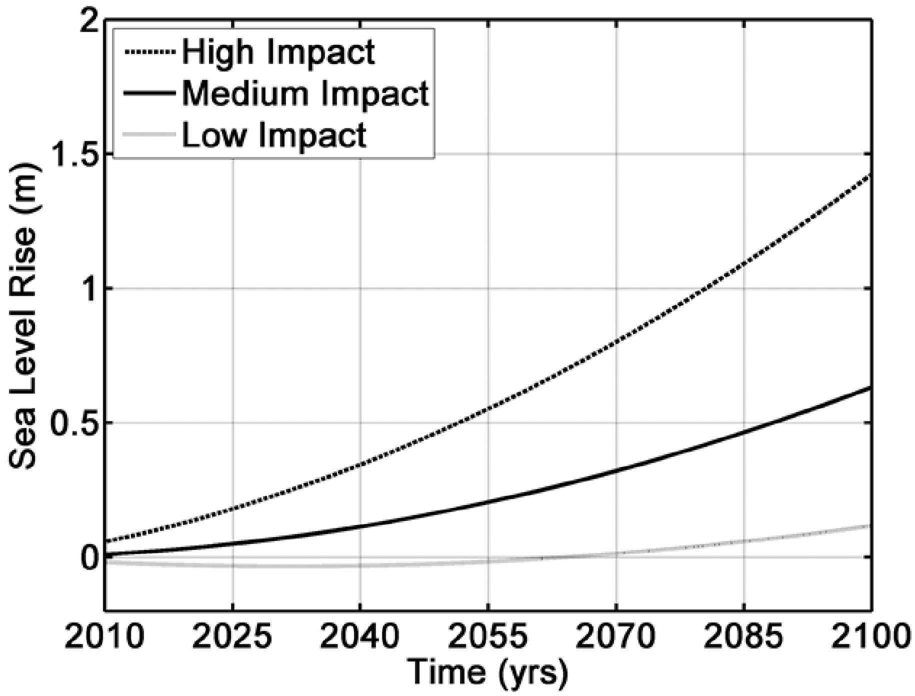

Figure 4. The three lines represent low, medium, and high estimates of SLR for the Oregon and Washington coast for 2010 to 2100 as estimated by the National Research Council (NRC, 2012).

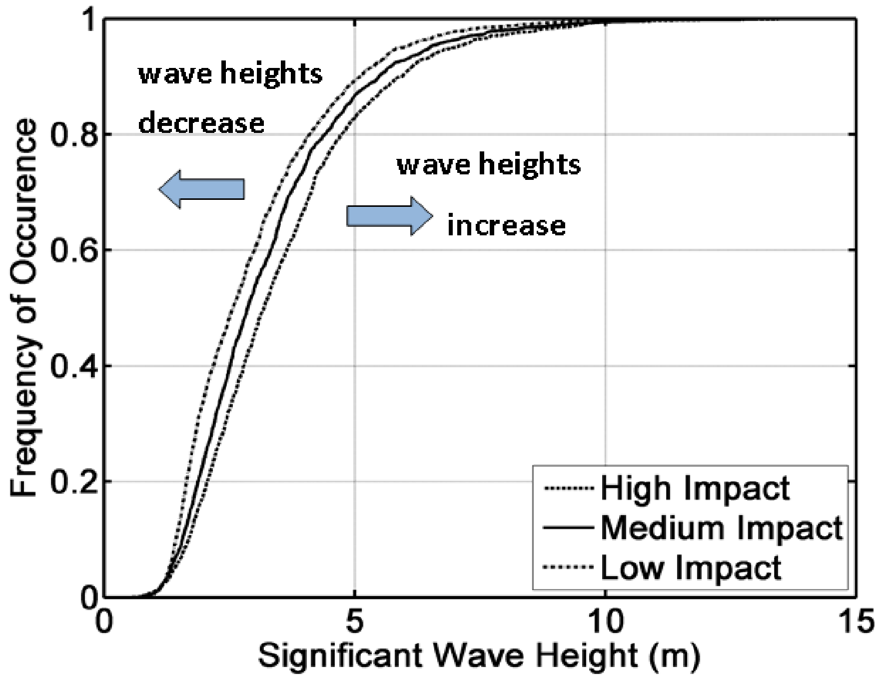

Figure 5. Wave height distributions by 2100 utilized to account for a variety of SWHs in the future. The solid line represents the present-day cumulative distribution function statistically and dynamically downscaled from global climate model projections (Hemer, et al., 2013; Wang, et al., 2014). The wave heights are allowed to shift +/- 30cm in either direction randomly within each sub-climate simulation.

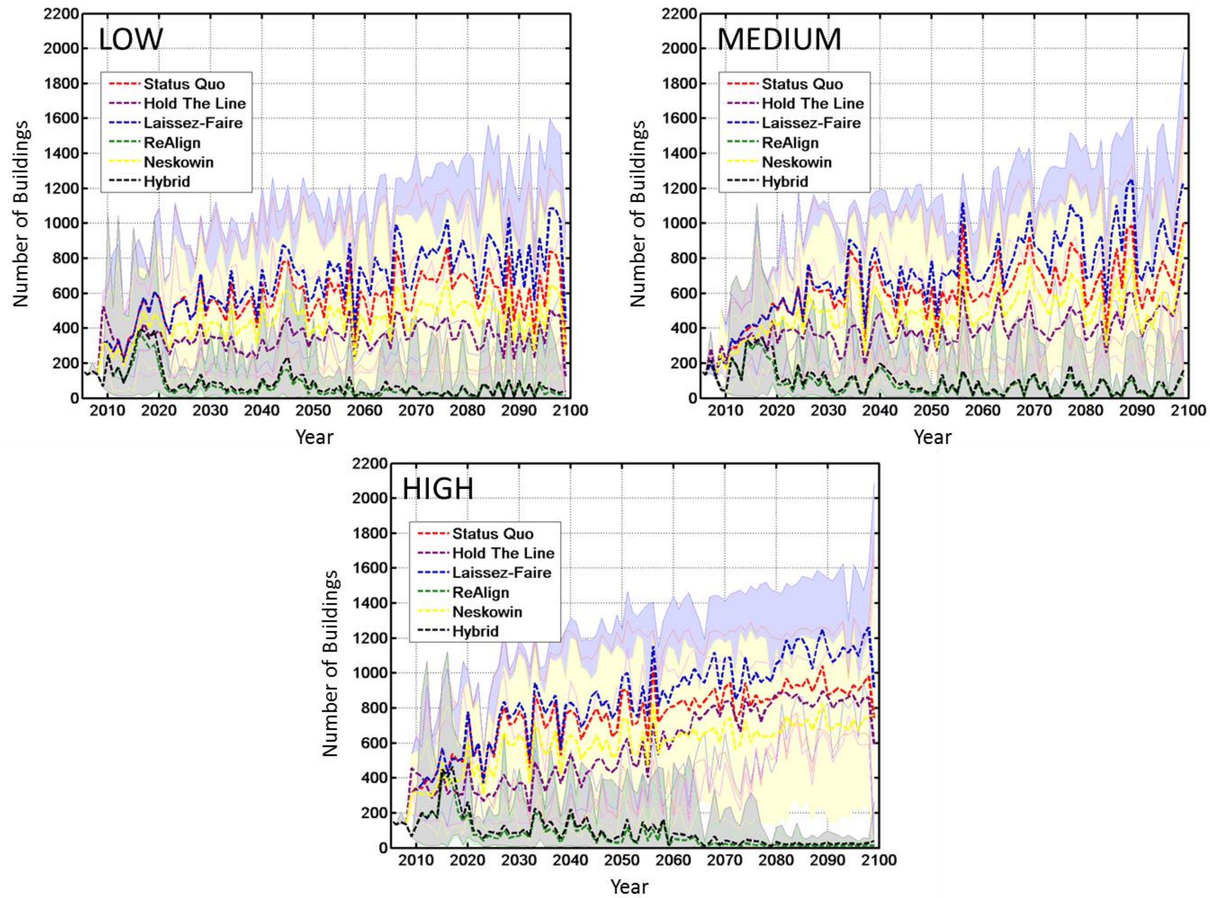

Figure 6. The number of buildings impacted by flooding under the six policy scenarios, and low, medium, and high climate scenarios (with 15 simulations in each). The dashed bold lines for each policy scenario denote the mean metric values under each climate scenario. The shaded areas highlight the average minimum and maximum values under each climate scenario, e.g., within the lowclimate scenario, the green shaded area denotes the range of buildings impacted by flooding between the average highest values of 15 sub-climate simulations and the average lowest values of the 15 sub-climate simulations.

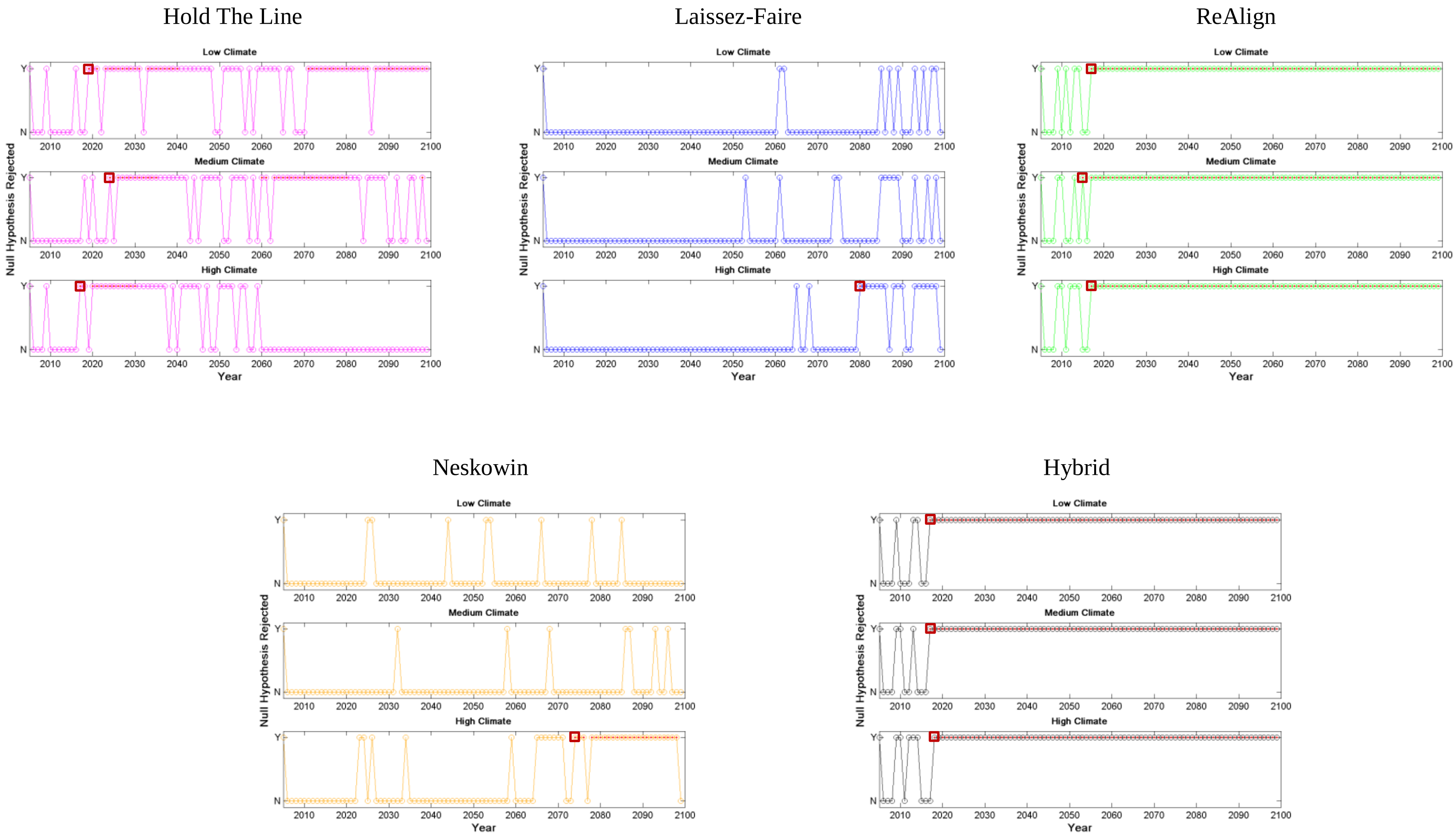

Figure 7. The first instance (red box) and sustained statistical difference achieved (red dots) for each policy and climate scenario in the *Number of Buildings Impacted by Flooding* metric.

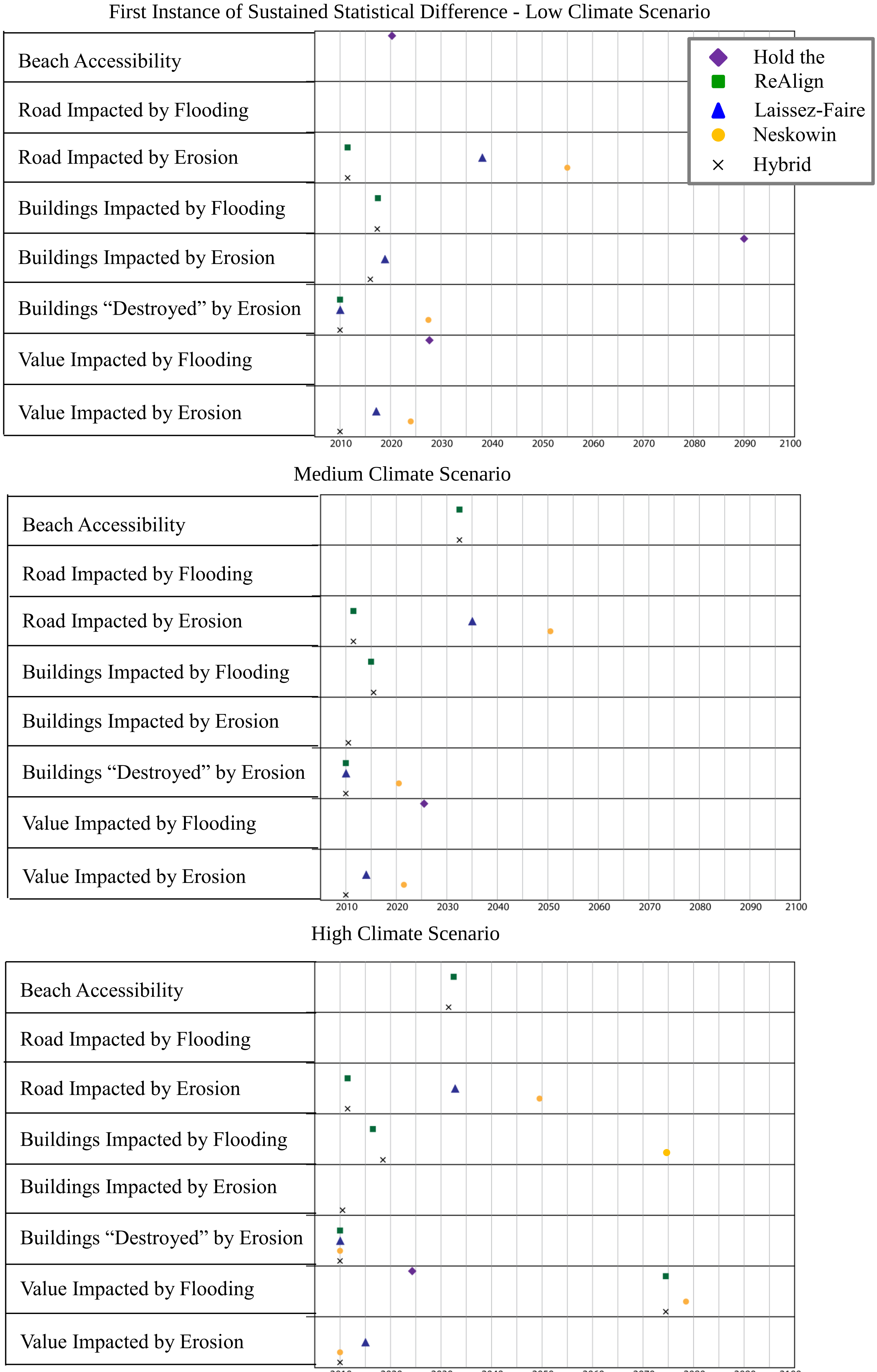

Figure 8. First instance of sustained statistical difference between the Status Quo and alternative policy scenarios for the eight metrics of interest and low, medium, and high climate scenarios.

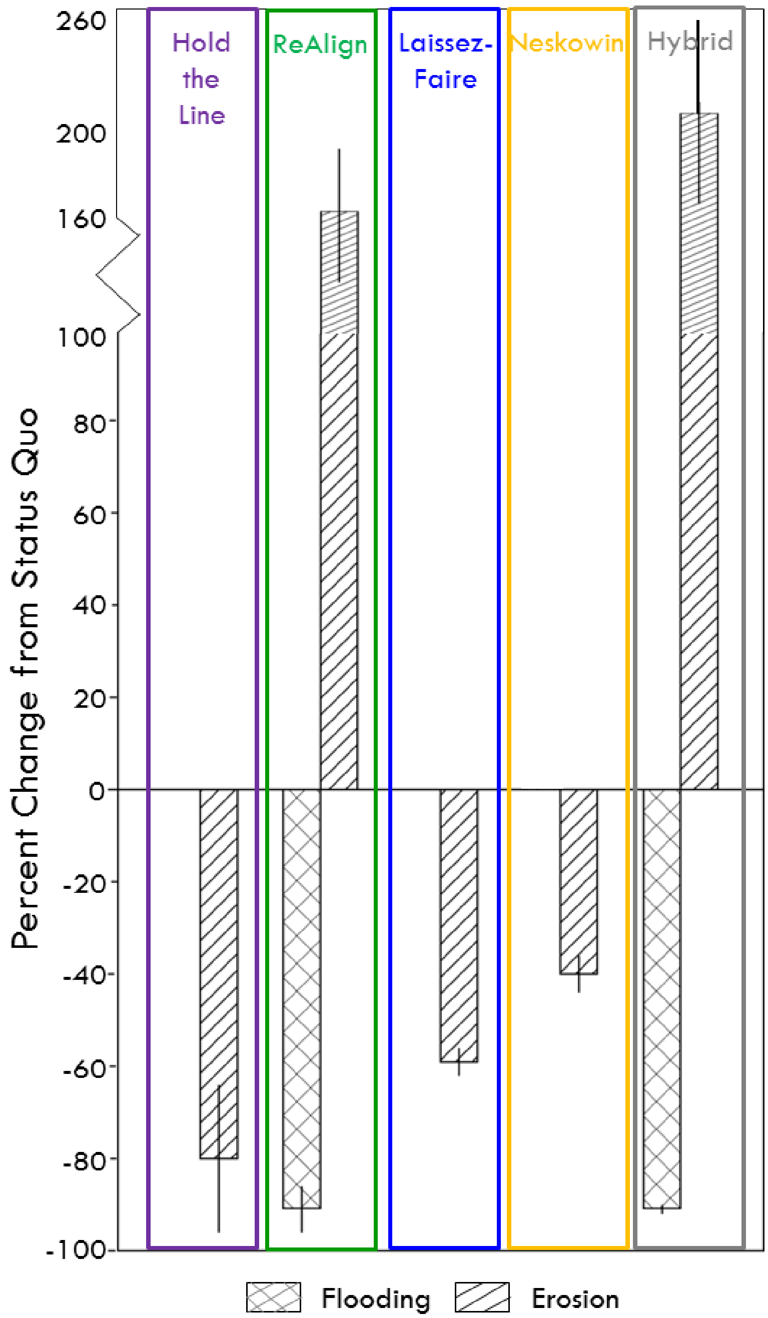

Figure 9. The percent magnitude of difference between the Status Quo and each policy scenario in terms of flood or erosion metrics. All metrics of interest were accounted for in the above figure with the exception of Beach Accessibility.

8. TABLES

Table 1: Policy scenario narratives and associated adaptation policies modeled within *Envision*.

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.

Table 2: Eight stakeholder-identified metrics of coastal flooding and erosion in Tillamook County, Oregon.

Stakeholder Identified Metrics of Interest
Beach Accessibility
Length of Road Impacted by Flooding
Length of Road Impacted by Erosion
Number of Buildings Impacted by Flooding
Number of Buildings Impacted by Erosion
Number of Buildings “Destroyed” by Erosion
Value of Property Impacted by Flooding
Value of Property Impacted by Erosion

Table 3. Average of the minimum and maximum couinty-wide metric values by policy and climate scenario over 95 years. Table values were calculated by averaging the minimum, mean, or maximum value of each year across the 15 simulations of each policy and climate scenario for each metric. The metrics values that show an improvement over the Status Quo are in bold. Values were rounded to the nearest hundred thousand dollars.

SQ- Status Quo, HTL – Hold the Line, LF – Laissez-Faire, RA – ReAlign, NESK – Neskowin, and HYBR – Hybrid.

Metric	Policy Scenario	Average Minimum, Mean, and Maximum of Metric Values by Climate Scenario								
		Low			Medium			High		
Beach Accessibility (%)	SQ	58	69	82	48	63	82	40	56	82
	HTL	**64**	**73**	82	**49**	**64**	82	40	**57**	82
	LF	57	69	82	47	63	82	38	56	82
	RA	**62**	**72**	82	**55**	**67**	82	**47**	**61**	82
	NESK	58	69	82	**49**	63	82	40	56	82
	HYBR	**62**	**72**	82	**55**	**67**	82	**47**	**61**	82
Length of Road Impacted by Flooding (km)	SQ	10	19	24	11	20	27	12	23	30
	HTL	**7**	**16**	**20**	11	**17**	**23**	12	**21**	30
	LF	10	19	25	11	20	27	12	23	**29**
	RA	10	**16**	**19**	11	**18**	**25**	12	**21**	38
	NESK	10	19	24	11	20	**26**	12	23	30
	HYBR	10	**16**	**19**	11	**18**	**25**	12	**21**	37
Length of Road Impacted by Erosion (km)	SQ	1	3	6	1	4	7	1	5	7
	HTL	1	3	6	1	4	7	1	5	7
	LF	1	3	**5**	1	**3**	**5**	1	**4**	**6**
	RA	1	7	14	1	8	16	1	11	20
	NESK	1	4	6	1	4	7	1	5	7
	HYBR	1	7	14	1	8	16	1	11	20

Table 3. Continued.

Metric	**Policy Scenario**	**Average Minimum, Mean, and Maximum of Metric Values by Climate Scenario**								
		Low			**Medium**			**High**		
Number of Buildings Impacted by Flooding	SQ	135	549	864	121	602	1,004	134	728	1,042
	HTL	**121**	**344**	**524**	121	**390**	**773**	134	**568**	**899**
	LF	135	647	1,085	121	704	1,255	134	828	1,261
	RA	**4**	**69**	**388**	**5**	**82**	**332**	**4**	**75**	**423**
	NESK	135	**432**	**673**	121	**485**	**909**	134	**576**	**826**
	HYBR	**6**	**86**	**392**	**10**	**97**	**343**	**11**	**94**	**465**
Number of Buildings Impacted by Erosion	SQ	2	14	70	3	15	67	3	17	70
	HTL	2	**13**	70	3	**14**	67	3	**16**	70
	LF	**0**	**6**	70	**0**	**7**	67	**0**	**7**	70
	RA	3	14	70	5	17	67	7	21	70
	NESK	**0**	**13**	70	**1**	**14**	67	**0**	**16**	70
	HYBR	7	24	70	11	30	67	13	37	72
Number of Buildings 'Destroyed' by Erosion	SQ	0	7	22	0	10	29	0	17	51
	HTL	0	7	22	0	11	30	0	17	51
	LF	0	**0**	**0**	0	**0**	**0**	0	**0**	**0**
	RA	0	**0**	**0**	0	**0**	**0**	0	**0**	**0**
	NESK	0	**4**	**14**	0	**7**	**22**	0	**12**	**45**
	HYBR	0	**0**	**0**	0	**0**	**0**	0	**0**	**0**

Table 3. Continued.

Metric	**Policy Scenario**	**Average Minimum, Mean, and Maximum of Metric Values by Climate Scenario**								
		Low			**Medium**			**High**		
Value of Property Impacted by Flooding ($ in millions)	SQ	2.8	72.1	188.1	3.1	101.9	220.4	5.8	157.6	300.8
	HTL	2.8	**29.1**	**99.0**	3.1	**37.8**	**124.4**	**3.8**	**77.3**	**245.0**
	LF	**2.2**	88.4	230.0	**2.7**	120.9	257.0	6.4	180.3	353.0
	RA	**2.7**	**20.2**	**99.2**	6.2	**24.4**	**99.2**	6.9	**28.2**	**99.2**
	NESK	**2.5**	**45.6**	**108.9**	**2.6**	**62.5**	**123.0**	**4.0**	**88.3**	**164.5**
	HYBR	3.2	**20.6**	**99.2**	5.6	**24.7**	**99.2**	6.5	**29.1**	**99.2**
Value of Property Impacted by Erosion ($ in millions)	SQ	2.6	5.2	15.9	3.1	6.7	15.9	3.3	6.6	15.9
	HTL	2.6	**5.1**	15.9	**2.6**	**6.1**	15.9	**3.0**	**6.1**	15.9
	LF	**0.1**	**3.0**	15.9	**0.01**	**3.2**	15.9	**0**	**3.2**	15.9
	RA	5.7	12.7	19.2	5.2	16.3	25.0	6.2	21.2	36.6
	NESK	**1.3**	**3.2**	15.9	**1.3**	**3.5**	15.9	**1.7**	**3.9**	15.9
	HYBR	6.0	17.0	25.2	5.8	23.4	38.5	6.5	30.4	49.4

Table 4. Benefit ratio, average benefit, and total number of policy scenarios which have sustained statistical difference from the Status Quo under low, medium, and high climate scenarios.

	Hold the Line			ReAlign			Laissez-Faire			Neskowin			Hybrid		
Climate Scenario	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Number of Statistically Sustained Metrics	3	1	1	4	5	6	4	3	3	3	3	5	5	6	7
Ratio of Beneficial Metrics to All Metrics	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{2}{8}$	$\frac{3}{8}$	$\frac{4}{8}$	$\frac{4}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{2}{8}$	$\frac{2}{8}$	$\frac{4}{8}$	$\frac{2}{8}$	$\frac{3}{8}$	$\frac{4}{8}$
Percent Beneficial?	37.5	12.5	12.5	25	37.5	50	50	37.5	37.5	25	25	50	25	37.5	50
Average across Climates	20.8%			37.5%			41.7%			33.3%			37.5%		
Total Number of Metrics Impacted	3			6			4			5			7		

Table 5. Average first instance of sustained statistical difference between the Status Quo and alternative policy scenarios under low, medium, and high climate scenarios and overall.

Policy Scenario	Low	Medium	High	Average
Hold the Line	2048	2026	2024	2033
ReAlign	2013	2016	2026	2018
Laissez-Faire	2021	2020	2019	2020
Neskowin	2036	2031	2037	2035
Hybrid	2013	2016	2024	2018
Average	**2026**	**2022**	**2026**	

Table 6. Average magnitude of sustained statistical difference between the Status Quo and alternative policy scenarios by metric and climate scenario. NSSD indicates where there was no sustained statististical difference between the Status Quo and alternative policy scenario for this metric and climate scenario. The year in parentheses denotes the first instance of sustained significance.

Hold The Line			
Metric of Interest	**Average Magnitude by Climate Scenario**		
	Low	**Medium**	**High**
Beach Accessibility (%)	1.30x odds of SQ (2026)	NSSD	NSSD
Length of Road Impacted by Flooding (km)	NSSD	NSSD	NSSD
Length of Road Impacted by Erosion (km)	NSSD	NSSD	NSSD
Number of Buildings Impacted by Flooding	NSSD	NSSD	NSSD
Number of Buildings Impacted by Erosion	26% lower (2090)	NSSD	NSSD
Number of Buildings 'Destroyed' by Erosion	NSSD	NSSD	NSSD
Value of Property Impacted by Flooding ($)	99.8% lower (2028)	96.4% lower (2026)	79% lower (2024)
Value of Property Impacted by Erosion ($)	NSSD	NSSD	NSSD
Average Lower	62.9%	96.4%	79%

Laissez-Faire			
Metric of Interest	**Average Magnitude by Climate Scenario**		
	Low	**Medium**	**High**
Beach Accessibility (%)	NSSD	NSSD	NSSD
Length of Road Impacted by Flooding (km)	NSSD	NSSD	NSSD
Length of Road Impacted by Erosion (km)	10% lower (2037)	11% lower (2035)	15% lower (2033)
Number of Buildings Impacted by Flooding	NSSD	NSSD	NSSD
Number of Buildings Impacted by Erosion	83% lower (2019)	NSSD	NSSD
Number of Buildings 'Destroyed' by Erosion	100% lower (2010)	100% lower (2010)	100% lower (2010)
Value of Property Impacted by Flooding ($)	NSSD	NSSD	NSSD
Value of Property Impacted by Erosion ($)	54% lower (2017)	57% lower (2014)	61% lower (2015)
Average Lower	61.8%	56%	58.7%

Table 6. Continued.

ReAlign			
Metric of Interest	**Average Magnitude by Climate Scenario**		
	Low	**Medium**	**High**
Beach Accessibility (%)	NSSD	1.24x odds of SQ (2033)	1.29x odds of SQ (2032)
Length of Road Impacted by Flooding (km)	NSSD	NSSD	NSSD
Length of Road Impacted by Erosion (km)	75% higher (2012)	84% higher (2012)	98% higher (2012)
Number of Buildings Impacted by Flooding	81% lower (2017)	88% lower (2015)	92% lower (2017)
Number of Buildings Impacted by Erosion	NSSD	NSSD	NSSD
Number of Buildings 'Destroyed' by Erosion	100% lower (2010)	100% lower (2010)	100% lower (2010)
Value of Property Impacted by Flooding ($)	NSSD	NSSD	90.3% lower (2074)
Value of Property Impacted by Erosion ($)	181% higher (2011)	187% higher (2011)	285% higher (2011)
Average Lower	90.5%	94%	96%
Average Higher	128%	135.5%	191.5%

Neskowin			
Metric of Interest	**Average Magnitude by Climate Scenario**		
	Low	**Medium**	**High**
Beach Accessibility (%)	NSSD	NSSD	NSSD
Length of Road Impacted by Flooding (km)	NSSD	NSSD	NSSD
Length of Road Impacted by Erosion (km)	5% higher (2055)	4% higher (2051)	4% higher (2049)
Number of Buildings Impacted by Flooding	NSSD	NSSD	22% lower (2074)
Number of Buildings Impacted by Erosion	NSSD	NSSD	NSSD
Number of Buildings 'Destroyed' by Erosion	43% lower (2028)	34% lower (2021)	29% lower (2010)
Value of Property Impacted by Flooding ($)	NSSD	NSSD	48% lower (2078)
Value of Property Impacted by Erosion ($)	45% lower (2023)	52% lower (2022)	45% lower (2010)
Average Lower	44%	43%	36%
Average Higher	5%	4%	4%

Table 6. Continued.

Metric of Interest	Hybrid Average Magnitude by Climate Scenario Low	Medium	High
Beach Accessibility (%)	NSSD	1.24x odds of SQ	1.29x odds of SQ
Length of Road Impacted by Flooding (km)	NSSD	NSSD	NSSD
Length of Road Impacted by Erosion (km)	75% higher (2012)	84% higher (2012)	98% higher (2012)
Number of Buildings Impacted by Flooding	88% lower (2017)	87% lower (2017)	90% lower (2018)
Number of Buildings Impacted by Erosion	146% higher (2016)	207% higher (2011)	224% higher (2011)
Number of Buildings 'Destroyed' by Erosion	100% lower (2010)	100% lower (2010)	100% lower (2010)
Value of Property Impacted by Flooding ($)	NSSD	NSSD	89% lower (2074)
Value of Property Impacted by Erosion ($)	280% higher (2010)	359% higher (2010)	450% higher (2010)
Average Lower	94%	93.5%	93%
Average Higher	167%	216.7%	257.3%

Table 7. Role, sector, and jurisdiction of interviewed coastal professionals and organizations

Role	Sector	Jurisdiction
Researcher	State agency	State
Senior member	State agency	State
Senior member	State planner	State
Leader	Non-governmental	State
Researcher	Non-governmental	State
Senior member	Non-governmental	State
Member	County government	County
Leader	County planner	County
Senior member	County planner	County
Senior member	Non-governmental	County
Leader	Non-governmental	County
Leader	Local government	Local Incorporated Community
Member	Local government	Local Incorporated Community
Leader	Local government	Local Unincorporated Community
Researcher	Non-governmental	NA

Table 8. Average policy scenario implementation feasibility rating. Higher averages indicate more difficulty in implementing the policy due to a regulatory barrier at the local, county, state, or federal level.

Policy Scenario Narrative		Policy	Is approval and/or modification necessary to implement this policy at this level? Local: Incorporated	Local: Unincorporated	County	State	Federal	Average Rating
Status Quo	**1**	Determine urban/community growth boundaries (U/CGB) in accordance with present-day policy.	No	No	No	No	No	**0**
	2	Maintain current backshore protection structures (BPS) and allow more BPS to be built on State Goal 18 eligible lots.	No	No	No	No	No	
Hold the Line	**3**	Determine urban growth boundaries (UGB) in accordance with present-day UGB policy but with development restricted as described below	Yes	No	Yes	No	No	**0.3**
	2	Maintain current backshore protection structures (BPS) and allow more BPS to be built on State Goal 18 eligible lots.	No	No	No	No	No	
	4	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).	No	No	No	No	No	
	5	Construct new buildings or developments only on lots with State Goal 18 BPS eligibility.	Yes	Yes	Yes	No	No	
	6	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.	Yes	Yes	Yes	No	No	
	7	Require property laws to disclose information about coastal hazards at the point of sale.*	No	No	No	Yes	No	

Table 8. Continued.

	3	**Determine urban growth boundaries (UGB) in accordance with present-day UGB policy but with development restricted as described below**	**Yes**	**No**	**Yes**	**No**	**No**	
	8	Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones.	Yes	Yes	Yes	No	No	
	9	Prohibit construction of BPS on additional properties, regardless of Goal 18 eligibility, but maintain previously constructed BPS.	Yes	Yes	Yes	Yes	No	
	5	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.	Yes	Yes	Yes	No	No	
ReAlign	**10**	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.	Yes	Yes	Yes	Maybe	No	0.56
	11	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.	Yes	Yes	Yes	No	No	

Table 8. Continued.

	6	**Require property laws to disclose information about coastal hazards at the point of sale.***	**No**	**No**	**No**	**Yes**	**No**	
Laissez Faire	**12**	Permit increased proportion of development outside the U/CGB.	Yes	Yes	Yes	Yes	No	**0.8**
	13	Eliminate provisions of State Goal 18 that limits BPS eligibility and Oregon Parks and Recreation Department BPS construction requirements.	Yes	Yes	Yes	Yes	No	
Neskowin	**2**	Maintain current backshore protection structures (BPS) and allow more BPS to be built on State Goal 18 eligible lots.	No	No	No	No	No	**0.5**
	3	Determine urban growth boundaries (UGB) in accordance with present-day UGB policy but with development restricted as described below.	Yes	No	Yes	No	No	
	8	Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones.	Yes	Yes	Yes	No	No	
	5	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.	Yes	Yes	Yes	No	No	
	14	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.	Yes	Yes	Yes	No	No	

Table 8. Continued.

	15	**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.)**	**Yes**	**Yes**	**Yes**	**No**	**No**	
	16	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.	Yes	Yes	Yes	No	No	
	17	Apply new specified runoff and drainage standards, especially for oceanfront property.*	Yes	Yes	Yes	No	No	
Hybrid	**7**	Determine urban growth boundaries (UGB) in accordance with present-day UGB policy but with development restrictions within hazard zones.	Yes	No	Yes	No	No	**0.61**
	8	Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones.	Yes	Yes	Yes	No	No	

Table 8. Continued.

	9	**Prohibit construction of BPS on additional properties, regardless of Goal 18 eligibility, but maintain previously constructed BPS.**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	
	11	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.	Yes	Yes	Yes	No	No	
	5	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.	Yes	Yes	Yes	No	No	
	15	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.)	Yes	Yes	Yes	No	No	

Table 8. Continued.

	18	**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.**	**Yes**	**Yes**	**Yes**	**Maybe**	**No**	

* This policy is currently not modeled within the *Envision* framework.

Table 9. Barriers to, components of, and Tillamook County-specific limitations of adaptation policy implementation (adapted from Dutra et al., 2015).

Barrier/Challenge	Component	Tillamook County Specific Limitation	# of Responses
Interests and Motivation	Limited Learning Capacity	Issue fatigue within the public and agencies	3
	Perceptions and Assumptions	General opposition to any land use restrictions/fear of regulatory takings/ governmental distrust	15
		Lack of proactive thinking	4
		Conservative community residents	2
		Perceived distance of climate change effects	1
		Cultural differences between coastal communities	1
		TOTAL	**26**
Information and Knowledge	Limited knowledge/knowledge exchange	Lack of education/knowledge of policies, climate literacy, and coastal hazards	8
		Poorly prepared geologists/engineers	1
		Poor connection between coastal and tsunami hazard zones	2
		TOTAL	**11**
Organizational Structures	Spatial mismatch between management jurisdiction and ecological boundaries	NA	0
	Superficial collaboration between government and stakeholders	Poor coordination between agencies and/or groups ("siloing")	3

Table 9. Continued.

		Disconnect between decision-makers at the state and county levels	2
		Regulatory separation between city and unincorporated areas	2
	Structural Inflexibility	OPRD decision-making structure	2
		State Goal 18 requirements	2
		TOTAL	**11**
Power Relations/Leadership	Lack of leadership	Limitations of politicians/lack of political will	4
	External pressures	Resistance to property hazard disclosure by development and real estate communities	2
		TOTAL	**6**
Resources	Different capacities to respond to changes in the environment	Lack of resources (i.e. funding, location-specific information, man-power)	4
		TOTAL	**4**
Other		Unpredictable receptiveness to change in the State Legislature	**1**

Table 10. Attributes, components, and Tillamook- County-specific examples of success in adaptation policy implementation (adapted from Dutra et al., 2015).

Attribute	Component	Tillamook County Specific Suggestion	# of Responses
Leadership	Communication and collaboration	Knowledge and use of available resources (i.e. funding, best available science, university researchers) to support efforts	5
		Outreach and education to increase and maintain public understanding and focus	4
		Use of low-controversy methods to frame conversations (i.e. no use of the term "climate change")	1
	Trust	Champions at the local, county, and state levels	3
		Political will	2
	Transparency in management processes	NA	0
		TOTAL	**15**
Cross-sectoral cooperation and coordination	Autonomy and redundancy in authority and capability	Efforts on a local scale (i.e. emergency management and preparedness) with state and federal funding	6
		Use of local level regulation to make changes	1
	Flexibility	Tailored policies to incorporated/UGB areas	1
		Spatially consistent decisions (i.e. covering a larger spatial area than individual parcels)	1

Table 10. Continued.

		Use of easements and buyouts to create public spaces	**1**
		Provide alternatives for locations without BPS constructed	1
	Definition of roles and responsibilities	NA	0
		TOTAL	**11**
Effective integration of knowledge and insights	Planning framework	NA	0
	Sense of resource ownership	Outreach and education to increase and maintain public understanding and focus	4
		Use of local level visualizations	1
		Use of low-controversy methods to frame conversations .(i.e. no use of the term "climate change")	1
		TOTAL	**6**
Human capacity and coordinated participation in decision-making	Funding	Knowledge and use of available resources (i.e. funding, best available science, university researchers) to support efforts	5
	Organizational knowledge		
	Bridging organizations		
		TOTAL	**5**
Learning approach to natural resource management and governance	Adaptive management	NA	0
		TOTAL	**0**
Other	External Changes	Changes in county demographics	4
		Changes spurred by the insurance industry	2
		Receptive State Legislature	1
		TOTAL	**7**

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Appendices

APPENDIX A: SELECTION OF METRICS TRACKED WITHIN *ENVISION*

Table A11. Selection of metrics tracked within the model *Envision*. Metrics in bold were deemed most important by stakeholders.

Buildings Impacted by Flooding	Number of Properties Transitioned into Easements
Buildings Impacted by Yearly Event-Based Erosion	Number of Surface Structures Impacted by Flooding
Buildings Destroyed by Long-Term Erosion	Number of Surface Structures Impacted by Erosion
Road Impacted by Flooding	Number of Support Structures Impacted by Flooding
Road Impacted by Erosion	Number of Support Structures Impacted by Erosion
Beach Accessibility	Percent of Shoreline Hardened
Value of Flooded Property	Population
Value of Eroded Property	Portion of Population Growth Added Inside Hazard Zone
Cost of BPS ($)	Portion of Population Growth Added Outside UGB
Cost of BPS Removal ($)	Portion of Population Growth Added Within A Half Mile of the Shoreline
Cost of Nourishment ($)	Portion of Population Growth Added Within UGB
Flooded Area (square meters)	Spatially Averaged Dune Overtopping Days per Year
Length of BPS [meters (m)]	Spatially Averaged Dune Toe Impact Days per Year
Number of BPS Projects	Spatially Averaged Maximum Yearly TWL
Number of Buildings	Total Cost of BPS Maintenance ($)
Number of Goal 18 Eligible Lots with BPS	Unconstrained Expenditure ($)
Number of Goal 18 Ineligible Properties with BPS	Value of Developed Land Impacted by Erosion ($)
Number of New Buildings	Value of Developed Land Impacted by Flooding ($)
Number of New Buildings in DOGAMI Moderate Hazard Zone	Value of Properties Transitioned into Easements ($)
Number of New Buildings on Goal 18 Ineligible Beachfront Properties	Volume of Nourishment (cu m)
Number of Nourishment Projects	

APPENDIX B: TWO-SAMPLE T-TEST METHODOLOGY

To assess the impacts of co-developed adaptation policies on the landscape in the future, we focused on eight metrics identified as important by KTAN stakeholders. The differences in metric values under various policy scenarios can be appreciated visually, however, statistical methods were used to gain a better understanding of the timing and magnitude of divergence between policy scenarios. *Envision* produces a value for every metric of interest, under a specific climate scenario, sub-climate (or simulation), policy scenario narrative, and year. The subsequent array describes 95 years (2005-2099) of climate and policy impacts on the landscape, on a variety of user-specified spatial scales (community to county-wide).

Statistical tools, such as the two-sample t-test, help to determine if the means of two sets of data are significantly different from each other. They require the data to be normally distributed and assume that observations are independent of one another (Ramsey & Schafer, 2002). Distribution plots of the yearly metric values indicated that the data was moderately skewed, either positively or negatively, from normal. Consequently, before performing the t-tests all metric results were log transformed to account for this skewness.

An additional assumption of the two-sample t-test is equal variance of metric values across sub-climates within a single year. To manage unequal variance, Welch's t-test was utilized at a 1% significance level (effectively changing the standard error formula) to determine statistical differences between Status Quo and alternative policy scenarios. Welch's t-tests compared the means of each policy scenario (Hold the Line, ReAlign, Laissez Faire, Neskowin, and Hybrid) to the mean of the Status Quo policy scenario one year at a time. Alternative policy scenarios were not compared to each other. To avoid cluster or serial effects due to similarities of climate and temporal spacing that could have introduced issues of dependence, comparisons were restricted to metric values within a single year and a specific climate (Ramsey & Schafer, 2002). Within a single year and specific climate, the 15 sub-climates were considered different enough to consider each sub-climate a replicate of the metric value for each policy scenario.

APPENDIX C: *ENVISION* TILLAMOOK COUNTY COASTAL FUTURES PROJECT - POLICY IMPLEMENTATION DISCUSSIONS

Objective of Discussions: To begin to characterize the feasibility of implementing the coastal climate change adaptation policies as co-developed by the Tillamook County Coastal Futures knowledge to action network (see attached matrix).

Questions:

1. What kinds of current and future impacts to the coast (i.e. metrics such as number of structures impacted by eroding/flooding) is your organization most worried about?

2. Attached are policies that have been suggested as approaches for adapting to climate change and coastal hazards. From your organization's perspective, what is the feasibility of their implementation at the local, county, state, and federal levels?
    a. Are we missing other potential policies that your organization feels might be effective? Please comment on the feasibility of these additional policies.

3. What, in your organization's experience, are the greatest challenges or barriers to the implementation of policies like these?

4. What recent examples of coastal adaptation policy implementation has your organization been involved with in Oregon or elsewhere where barriers like this have been overcome?
    a. What kinds of resolutions were reached?

5. When your organization plans for the future, does it expect to handle these kinds of policies and challenges more often? Why or why not?

6. Which other organizations should I talk with?

APPENDIX D: ADDITIONAL TABLES

Table D1. 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 D2. Question 1 - What kinds of current and future impacts to the coast is your organization most worried about?

Impacts	State	County	Local	NGO	Total
Erosion	2	2	2	4	**10**
Tsunami hazards	3	2	1	3	**9**
Beach accessibility	2	3	1	1	**7**
Flooding	0	2	2	3	**7**
Earthquake	0	2	1	2	**5**
Aesthetics/Scenic values	1	0	0	1	**2**
Landslides	0	2	0	0	**2**
BPS construction	0	0	1	1	**2**
Homes impacted	0	0	1	0	**1**
Personal safety	0	1	0	0	**1**
Extreme storms	1	0	0	0	**1**
Sea level rise	1	0	0	0	**1**
Winter wind storms	0	0	0	1	**1**
Wildfire	0	0	0	1	**1**
Ecological quality	0	0	0	1	**1**
Water quality	0	0	0	1	**1**
Economic costs	0	0	0	1	**1**
Natural beach resources	1	0	0	0	**1**

*No response from the non-governmental (NA jurisdiction) for this question

Table 123. Question 2 - From your organization's perspective, what is the feasibility of their implementation at the local, county, state, and federal levels?
(The number totals indicate how often the policy was discussed during the interviews)

Discussed Policy	**State**	**County**	**Local**	**NGO**	# of Responses
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.	0	2	2	6	10
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.	0	2	1	3	6
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.	0	2	1	1	**4**
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).	1	0	1	1	**3**
Construct new buildings or developments only on lots with State Goal 18 BPS eligibility.	1	2	0	0	**3**
Determine urban growth boundaries (UGB) in accordance with present-day UGB policy but with development restrictions within hazard zones.	0	0	0	2	**2**

Table D3. Continued.

Permit increased proportion of development outside the U/CGB.	0	0	1	1	**2**
Prohibit construction of BPS on additional properties, regardless of Goal 18 eligibility, but maintain previously constructed BPS.	0	0	1	1	**2**
Implement DOGAMI coastal hazard zones and restrict further development within the active, high, and moderate zones.	0	0	1	1	**2**
Require property laws to disclose information about coastal hazards at the point of sale.	1	0	0	0	**1**

Table D4: Question 2a - Are we missing other potential policies that your organization feels might be effective?

Issues	**State**	**County**	**Local**	**NGO**	**# of Responses**
Use of alternative coastal protection structures	1	0	0	0	**1**
Creation of post-tsunami development areas	0	0	0	1	**1**
Inclusion of tsunami threat/coastal hazard disclosure within the requirement for significant repair permitting	0	0	0	1	**1**
Use of increased setbacks	1	0	0	0	**1**
Decoupling dynamic revetments from Goal 18 eligibility requirements	1	0	0	0	**1**

Table D5: Question 3 - What, in your organization's experience, are the greatest challenges or barriers to the implementation of policies like these?

Challenges/Barriers	**State**	**County**	**Local**	**NGO**	**# of Responses**
General opposition to any land use restrictions/Fear of regulatory takings/Governmental distrust	3	4	3	5	**15**
Lack of education/knowledge of policies, climate literacy, and coastal hazards	0	6	1	1	**8**
Limitations of politicians/lack of political will	1	1	1	1	**4**
Lack of proactive thinking	1	2	0	1	**4**
Lack of resources (i.e. funding, location-specific information)	1	0	0	3	**4**
Poor coordination between agencies and/or groups ("siloing")	0	0	0	3	**3**
Issue fatigue within the public and agencies	0	0	0	3	**3**
OPRD decision-making structure	1	0	0	1	**2**
State Goal 18 requirements	2	0	0	0	**2**
Poor connection between coastal and tsunami hazard zones	0	0	0	2	**2**
Disconnect between decision-makers at the state and county levels	0	2	0	0	**2**
Conservative community residents	0	0	1	1	**2**
Regulatory separation between city and unincorporated areas	0	0	1	1	**2**
Resistance to property hazard disclosure by development and real estate communities	2	0	0	0	**2**
Poorly prepared geologists/ engineers	1	0	0	0	**1**
Perceived distance of climate change effects		0	0	1	**1**
Unpredictable receptiveness to change in the State Legislature	1	0	0	0	**1**
Cultural differences between coastal communities	1	0	0	0	**1**

Table D6: Question 4 - What recent examples of coastal adaptation policy implementation has your organization been involved with in Oregon and elsewhere, where barriers like this have been overcome?

Examples	State	County	Local	NGO	# of Responses
Neskowin	4	1	2	3	**10**
Lincoln City	1	1	1	1	**4**
Tillamook 101 wetland restoration	0	0	2	2	**4**
Gold Beach	0	1	1	0	**2**
Newport	2	0	0	0	**2**
Pacific City	0	2	0	0	**2**
Oceanside	0	2	0	0	**2**
Cannon Beach	0	0	1	1	**2**
DLCD adaptation framework	0	0	1	1	**2**
Success in WA and CA	0	0	1	1	**2**
Clatsop Spit	1	0	0	0	**1**
Hatfield Marine Center	1	0	0	0	**1**
Ventura Beach, CA	0	0	0	1	**1**
Coos Bay	0	0	0	1	**1**
Breaker Point	0	0	0	1	**1**
Sebastian Shores	0	0	0	1	**1**
Cape Lookout	1	0	0	0	**1**
Texas Open Beaches Act	1	0	0	0	**1**

Table D7: Question 4a - What kinds of resolutions were reached?
(What were the factors that allowed for successful implementation?)

Success Factors	State	County	Local	NGO	# of Responses
Efforts on a local scale (i.e. emergency management and preparedness) with state and federal funding	0	4	0	2	6
Knowledge and use of available resources (i.e. funding, best available science, university researchers) to support efforts	0	4	0	1	**5**
Change in county demographics	0	2	1	1	**4**
Outreach and education to increase public understanding	0	2	1	1	**4**
Champions at the public, local, county, and state levels	1	0	0	2	**3**
Political will		1	1		**2**
Change spurred by the insurance industry	0	1	1	0	**2**
Tailored policies to incorporated/UGB areas	0	2	0	0	**2**
Spatially consistent decisions (i.e. covering a larger spatial area than individual parcels)	1	0	0	0	**1**
Use of local level regulation to make changes	1	0	0	0	**1**
Use of easements and buyouts to create public spaces	1	0	0	0	**1**
Use of local level visualizations	0	0	0	1	**1**
Use of low-controversy methods to frame conversations (i.e. no use of "climate change")	0	0	0	1	**1**
Receptive State Legislature	0	0	0	1	**1**
Provide alternatives for locations without BPS	1	0	0	0	**1**
Efforts on a local scale (i.e. emergency management and preparedness) with state and federal funding	1	0	0	0	**1**

Table D8: Question 5 - When your organization plans for the future, does it expect to handle these kinds of policies and challenges more often?

More Policy Implementation/ Challenges in the Future?	State	County	Local	NGO	# of Responses
Yes	3	3	3	6	**15**
No	0	0	0	0	**0**

Table D9: Question 5a - Why or why not?

How/why organizations will address the issues?	State	County	Local	NGO	# of Responses
Current bills within state and federal legislature	0	2	0	2	**4**
Intensified climate change impacts	1	0	1	2	**4**
Increased requests for location specific as well as general information about coastal change	1	2	0	0	**3**
Become more proactive at federal, state, and local levels	0	2	0	1	**3**
Encourage media coverage of the issues	0	1	1	0	**2**
Avoid the pitfalls of Netarts 1990s efforts	0	1	1	0	**2**
Additional population	0	0	0	2	**2**
Help in the creation and identification of champions	0	0	0	1	**1**

Table D10: Question 6 - What other organizations should I talk with?
(Types of organizations suggested by state, county, local, and non-governmental organizations)

Organizations	State	County	Local	NGO	# of Responses
Federal	0	0	0	4	**4**
State	7	1	1	8	**17**
County	0	1	2	1	**4**
Local	3	19	4	4	**30**
NGO	2	4	6	11	**23**
Total	12	25	13	28	**78**

APPENDIX E: REVIEWED LEGAL AND REGULATORY DOCUMENTS

Federal:

Environmental Protection Agency (EPA), 2011. Climate Ready Estuaries Program: Rolling Easements. http://www. water.epa.gov/type/oceb/cre/upload/rollingeasementsprimer.pdf

Federal Emergency Management Administration (FEMA), 2015. National Flood Insurance Program Floodplain Management Requirements. https://www.fema.gov/floodplain-management-requirements

FEMA, 2007. Managing Floodplain development Through the National Flood Insurance Program.

FEMA, 2004. Increased Cost of Compliance Coverage. https://www.fema.gov/floodplain-management-requirements

State:

Department of Land Conservation and Development, 2010. Oregon's Statewide Planning Goals and Guidelines.
http://www.oregon.gov/LCD/docs/goals/compilation_of_statewide_planning_goals.pdf

Oregon House Bill HB1601, 1967.

Oregon House Bill HB2633, 2015.

Oregon Senate Bill SB765, 2015.

Oregon Senate Bill SB778, 2015.

Oregon Senate Bill SB802, 2015.

Statewide Planning Program (Rhode Island), 2013. Coastal Transfer of Development Rights in Rhode Island.

County:

Tillamook County Department of Community Development – Planning, 2004. Tillamook County Comprehensive Plan. http://www.co.tillamook.or.us/gov/ComDev/Planning/compplan.htm

Tillamook County Department of Community Development – Planning, 2015. Tillamook County Land Use Ordinance. http://www.co.tillamook.or.us/gov/ComDev/Planning/luo.htm

Local:

Tillamook County Department of Community Development:

2013. OA-14-01 Neskowin Coastal Hazards Adaptation Plan. http://www.co.tillamook.or.us/gov/ComDev/documents/planning/Website%20Forms/Revised%20Neskowin%20Adaptation%20Plan%2025Jun14.pdf

2002. Barview/Watseco/Twin Rocks Community Plan Tillamook County, Oregon.

1999. Community Plan for the Unincorporated Community of Neskowin.

1999. Netarts Community Plan.

1999. Pacific city/Woods Community Plan.

1998. Oceanside Community Plan.

1997. Neahkahnie Community Plan.