Coastal Hazards

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The changing climate will continue to affect hazards along the coast and estuarine shorelines of Oregon, with social and economic effects on coastal communities. Property owners, businesses, and local governments will need to respond to these hazards and impacts while evaluating trade-offs between public and private interests. Recent assessments, analyses, and reports have documented increasing rates of sea-level rise and erosion along Oregon's coasts, and measures are being implemented or considered to adapt to these changes.

Observed and Projected Trends in Sea Level

The Oregon coast is within Cascadia, which is defined by the subduction of the Juan de Fuca Plate under the North American Plate. The imminent rupture of the Cascadia Subduction Zone will greatly affect the Oregon coast's inhabitants, infrastructure, and ecosystems. The probability of a Cascadia-wide, tsunami-generating earthquake in the next 50 years is approximately 15–25 percent, and the probability of a partial rupture on the southern Oregon coast is about 37–43 percent (Atwater 1987, OSSPAC 2013, Frankel et al. 2015). Tectonics has a substantial effect on the region's exposure to chronic coastal hazards through its influence on geomorphology and rates of relative sea-level rise (Burgette et al. 2009, Komar et al. 2011).

Primarily due to tectonic uplift, relative sea-level rise rates are slower in Oregon than in many other coastal regions of the United States. In some areas of the Oregon coast, tectonic uplift has kept pace with increases in sea level. However, relative sea-level rise rates along much of the Oregon coast are at least 1 mm per year less than the current global average (~3.4 mm [0.13 in] per year; Sweet et al. 2022). For example, whereas relative sea level in southern Oregon (Coos Bay and south) and northern Oregon (Cannon Beach and north) is either falling slightly or stable, relative sea-level rise rates in central Oregon have been 1–3 mm (0.04–0.12 in) per year since at least the 1970s (Komar et al. 2011). Developing high-resolution estimates of alongshore vertical uplift rates, which affect local projections of relative sea-level rise and chronic coastal hazards, is a high priority.

The National Oceanic and Atmospheric Administration (NOAA) recently released regional sea-level rise scenarios for the United States coastline from 2000–2150 that incorporate the best estimates of uplift at a resolution of one degree (about 111 km [69 mi]) (Sweet et al. 2022). By 2050, the expected rise in sea level will cause total water levels to increase and change coastal flood regimes throughout the United States, with major and moderate high-tide flood events occurring as frequently as moderate and minor high-tide flood events occur today. The emissions-based, probabilistic sea-level rise projections included low (0.3 m [1 ft] of global mean sea level rise by 2100), intermediate-low (0.5 m [1.6 ft.]), intermediate (1.0 m [3.3 ft]), intermediate-high (1.5 m [4.9 ft]), and high (2.0 m [6.6 ft]) scenarios. These projections (Table 1), combined with observed sea-level rise at NOAA tide gauges in South Beach and Astoria, Oregon, highlight the wide range of sea-level rise expected along this tectonically active coastline (Figure 1).

Effects of Climate Change on Storminess Patterns

Substantial uncertainties hamper quantification of how climate change will affect storminess patterns. The El Niño-Southern Oscillation is a key driver of interannual global climate variability. El

	Year								
	2040			2070			2100		
City	**Low**	**Intermediate**	**High**	**Low**	**Intermediate**	**High**	**Low**	**Intermediate**	**High**
Port Orford	6	11	16	11	32	78	16	79	182
Charleston	7	11	17	13	33	78	18	81	183
Newport	9	14	19	17	37	82	25	87	187
Astoria	3	7	12	6	25	68	9	69	167

Table 1. Projected sea-level rise (cm) over time at four cities in Oregon given scenarios of low (0.3 m [1 ft]), intermediate (1.0 m [3.3 ft]), and high (2.0 m [6.6 ft]) global sea-level rise (Sweet et al. 2022).

Niño events, which are characterized by considerable warming of sea surface temperatures in the central and eastern equatorial Pacific (Lindsey 2009), affect the physical drivers of coastal hazards during winter storms in the Pacific Northwest, such as variation in wind direction, increased wave energy, and elevated water levels along the coast (Barnard et al. 2015). The frequency, intensity, and location of El Niño events vary within the Pacific Ocean basin, and forecasting of El Niño events and their future climatology is an area of active research (e.g., Yan et al. 2020). Historically, major coastal flooding and erosion along the Oregon coast was more likely during El Niño years (e.g., Barnard et al. 2015). Due to anomalies in physical processes, such as elevated water levels and higher wave energy from the southwest, local erosion along the west coast of the United States tends to be high during major El Niño seasons. For example, many of the beaches in Tillamook County eroded substantially and either took many years to recover, or have not yet recovered, from the effects of the 1997–1998 El Niño and the severe winter of 1998–1999 (Ruggiero et al. 2013). Areas of erosion included the village of Neskowin immediately north of Cascade Head, Rockaway Beach, and Cape Lookout State Park (Ruggiero et al. 2013). The most recent major El Niño event (2015–2016) caused the average seasonal erosion on the Oregon coast to be up to 30 percent greater than the previous year. Coastal flooding and erosion deplete sand from beaches and make them more susceptible to elevated water levels and enhanced wave energy during future storms. Higher precipitation rates during El Niño seasons can increase runoff and compound flooding hazards by elevating the local sea surface.

Despite growing attention to improving data and modeling techniques, there is considerable uncertainty about climate change-induced shifts in long-term trends in the frequency and intensity

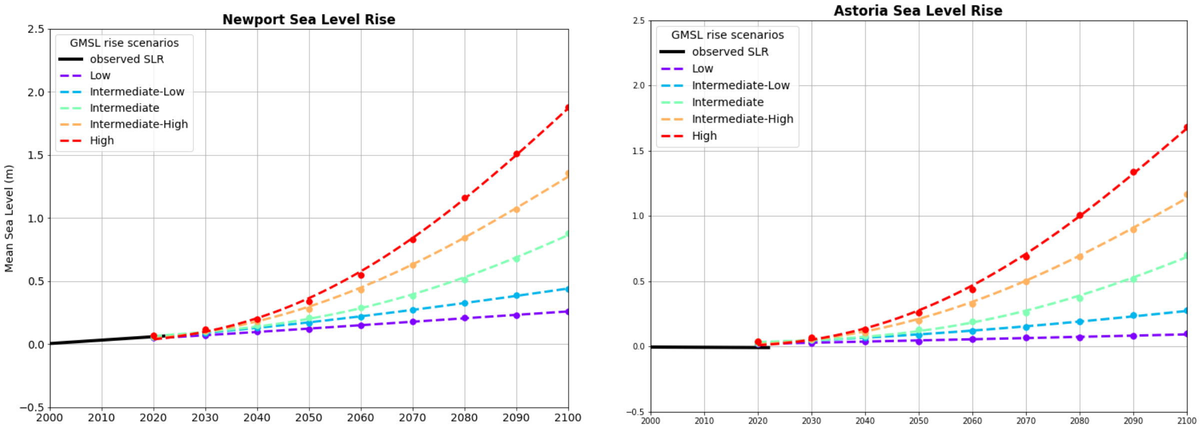

Figure 1. Observed and projected regional sea-level rise (Sweet et al. 2022) from 2000 through 2100 at two tide gauges in Oregon. Local tectonic and hydrodynamic processes affect differences among local projections.

of extreme El Niño events (Collins et al. 2010). One study projected that the magnitude of El Niño events in the twenty-first century would be indistinguishable from those in the twentieth century (Stevenson 2012), whereas another found that the frequency and intensity of extreme El Niño events may increase by as much as 100 percent by 2100 (Cai et al. 2015), potentially intensifying hazards along the Oregon coast. It also has been suggested that the strength of El Niño will weaken over millennia as carbon emissions increase (Callahan et al. 2021).

Effects of Climate Change on Coastal Erosion and Flooding

Relative sea-level rise narrows the gap in elevations between commonly occurring high tides and the thresholds above which coastal flooding and erosion begin. Therefore, increases in extreme coastal water levels along the Oregon coast increase coastal erosion and coastal flooding impacts.

			Percentage of transects eroded, 2002–2016		
Littoral cell (south to north)	**2002–2016 (m/year)**	**1967–2002 (m/year)**	**Total**	**More than -1 m / year**	**More than -3 m / year**
Brookings	-1.50 ± 0.04	-0.05 ± 0.10	90	59	18
Pistol	-1.10 ± 0.06	0.50 ± 0.10	75	56	11
Gold Beach	-1.60 ± 0.03	0.60 ± 0.10	83	63	22
Nesika	-0.70 ± 0.30	-0.40 ± 0.20	67	41	8
Humbug	-0.50 ± 0.03	-0.40 ± 0.10	81	24	0
Port Orford	-1.00 ± 0.03	-0.30 ± 0.10	64	41	23
Bandon	-0.60 ± 0.03	0.20 ± 0.10	65	40	7
Coos	-1.00 ± 0.03	0.03 ± 0.10	75	52	11
Heceta	-0.20 ± 0.05	-0.10 ± 0.10	60	26	0
Newport	0.20 ± 0.04	-0.50 ± 0.10	50	24	2
Beverly	-1.00 ± 0.08	-1.1 ± 0.10	84	55	0
Lincoln	-0.80 ± 0.03	-0.30 ± 0.10	71	50	10
Neskowin	-1.90 ± 0.06	-1.10 ± 0.10	85	70	27
Sand Lake	0.50 ± 0.10	-0.50 ± 0.10	36	20	1
Netarts	-0.40 ± 0.10	-1.00 ± 0.10	65	28	0
Rockaway	0.02 ± 0.06	0.60 ± 0.10	44	25	7
Cannon Beach	0.30 ± 0.08	-0.50 ± 0.10	39	13	4
Clatsop	0.30 ± 0.02	1.90 ± 0.10	40	19	1
Oregon average	-0.70 ± 0.01	0.03 ± 0.02	65	42	9

Table 2. Average rates of shoreline change (meters per year) along the Oregon coast from 2002–2016 and associated uncertainties (Light 2021). Red, statistically significant erosion; blue, statistically significant accretion. Average rates of shoreline change and values from 1967–2002 from Ruggiero et al. 2013.

A multi-decadal, statewide analysis identified both a general increase in shoreline erosion along the Oregon coast in recent decades and significant spatial variation within and among littoral cells (coastal compartments within which sediment movement is self-contained) (Light 2021). Shoreline change was statistically significant in seventeen of the eighteen primary littoral cells (all but Rockaway) along the Oregon coast from 2002–2016 (Table 2). Furthermore, the shoreline in five littoral cells in southern Oregon (Coos, Bandon, Gold Beach, Pistol, and Brookings) accreted from 1967–2002 but eroded from 2002–2016. By contrast, shorelines in three littoral cells in central and northern Oregon (Newport, Sand Lake, and Cannon Beach) eroded from 1967–2002 and accreted from 2002–2016. The average statewide rate of change from 2002–2016 was -0.7 m (-2.3 ft) per year; 65 percent of locations (transects) studied eroded, and 42 percent eroded at rates more than 1 m per year. The highest average erosion rates tended to be in southern Oregon. A larger percentage of transects in Oregon eroded during 2002–2016 (65 percent) compared to the 1967–2002 period (54 percent).

Figure 2. Coastal erosion at Gleneden Beach, Lincoln County, March 2021. Photograph by Hailey Bond.

Additionally, although erosion exceeded -1 m (-3.3 ft) per year in 18 percent of transects along the Oregon coast from 1967–2002, erosion exceeded -1 m per year in 42 percent of transects from 2002–2016 (Figure 2). Estimates of shoreline change from 2002–2016 (Light 2021) likely include the impacts of the major 2015–2016 El Niño event and are therefore biased toward erosion.

Taherkhani et al. (2020) used data from tide gauge stations and projections of future sea-level rise (Kopp et al. 2014) to investigate continuous shifts in flooding along coastlines in the United States. They found that approximately 7 cm (2.8 in) of sea-level rise along the Oregon coast doubles the odds that annual flood levels will exceed the 50-year event threshold (a level with a 2 percent chance of occurring in a given year). The odds of this magnitude of flooding double approximately every 6 years until 2075. These results were based on the high emissions scenario in Sweet et al. (2022) and assumed climate stationarity.

Effects of Coastal Hazards on Communities and Infrastructure

Increases in water levels due to sea-level rise and possible changes in patterns of storminess will increase the frequency and magnitude of coastal erosion and flooding (e.g., Figure 3). Below, we highlight potential effects on coastal communities and infrastructure and efforts being implemented or considered to adapt to these hazards.

Figure 3. Coastal flooding in Nehalem, Oregon, on 6 November 2021. Photograph by Tyler Sloan, Oregon King Tides Project (CC BY-NC-SA 2.0).

The U.S. Army Corps of Engineers used Climate Central's (2021) Surging Seas Risk Finder to estimate the potential effects of 1 and 2 feet (0.3 and 0.6 m) of sea-level rise on populations, land, property, and infrastructure within the United States (USACE 2022). On the Oregon coast, approximately 781 homes and 1318 people are within the area that would be inundated by 1 foot of sea-level rise (Table 3) (USACE 2022). An estimated 18 percent of those individuals have high social vulnerability as estimated on the basis of 29 variables related to wealth, racial and social status, ethnicity, age, health insurance, special needs, ethnicity, employment, and gender. An additional 307 homes and 627 individuals, 157 of them with high social vulnerability, are located within the area that would be inundated by 2 feet of sea-level rise.

	Below 1 foot	Below 2 feet
Population	1318	1945
High social vulnerability population	238	395
Homes	781	1088
Roads (miles)	30	51
Wastewater treatment sites	12	14
Land (square miles)	58	75
Protected land (square miles)	15	20

Table 3. People, infrastructure, and land in Oregon below 1 and 2 ft (0.3 m and 0.6 m) of sea-level rise (data source: Climate Central 2021; table adapted from USACE 2022). These estimates should be used for planning-level purposes only. The values in the table may overestimate or underestimate exposure to flooding. Protected land records are from the U.S. Geological Survey. Protected areas are those dedicated to the preservation of biological diversity and to other natural, recreational, and cultural uses, and managed for these purposes through legal or other effective means.

In 2018, the Oregon Department of Geology and Mineral Industries (DOGAMI) assessed the risks of natural hazards to the communities of Coos County, Oregon (Williams et al. 2021). This risk assessment estimated that 1870 buildings will be damaged by a 100-year flood scenario (i.e., 1 percent chance of flooding in a given year), causing an estimated loss of $125 million, damage to 13 critical facilities, and displacement of as many as 2116 individuals. For example, 95 percent of flood-exposed buildings in the City of Coos Bay are not elevated above the 100-year flood level. The assessment's analysis of whether a building is within or outside of a hazard zone also estimated the number of people whose mobility may be limited by floodwaters. Many residents in the cities of Coos Bay (773), Lakeside (253), and Myrtle Point (119) may need evacuation assistance during a flood.

Figure 4. Coastal erosion at Beverly Beach and U.S. Highway 101, Lincoln County, Oregon, February 2021. Photograph by Hailey Bond.

Sea-level rise on the Oregon coast also may lead to changes in navigation channels (e.g., leading to an increase in dredging and adjustment of channel location and dimensions), increased scouring at structure foundations, and decreased clearance under bridges and port infrastructure (USACE 2022). U.S. Highway 101 and other major transportation routes and facilities along the Oregon coastline will become increasingly susceptible to erosion, flooding, and landslides as climate changes (Figure 4). The Oregon Department of Transportation has supported research with the aim of enhancing the resilience of Highway 101 to coastal hazards (Box 1).

Approaches to Coastal Climate Change Adaptation

Many climate-change adaptation measures are being implemented or considered in coastal Oregon. These include hard structures (gray infrastructure), soft structures (natural and nature-based features), a combination of hard and soft structures, and nonstructural measures (e.g., policies and regulations) (Table 4). Hard structures are typically designed to armor the backshore to prevent erosion landward of the structure (e.g., riprap revetments). Soft structures, such as salt marsh restoration, beach nourishment, and dynamic cobble revetments, are intended to maintain or restore the shoreline by mimicking natural processes (USACE 2022). The function and performance of new hard and soft structures will be affected by sea-level rise. For example, increased wave attack associated with sea-level rise may reduce the stability of hard protective structures (USACE 2022). Sea-level rise will also likely erode foredunes, potentially necessitating repeated nourishment.

Substantial efforts are underway to use dredged sediments and soft structures (e.g., dynamic revetments, dune restoration) instead of shoreline hardening to maximize ecological benefits. For example, a dynamic revetment is dissipating wave energy and slowing erosion at Cape Lookout State Park (Figure 5) and the Columbia River South Jetty.

Structural adaptations		
Type	**Strategy**	**Description**
Hard structures	Jetties	Jetties extend into a body of water to direct and confine a stream or tidal flow to a selected channel and to limit shoaling of the channel. Jetties at the entrance of a bay or river also protect the entrance channel from storm waves and crosscurrents.
	Riprap revetments	A layer of stone intended to limit erosion and create hard armoring (Johannessen et al. 2014).
	Seawalls	Concrete structures that are built to withstand storm waves and protect costly infrastructure.
	Dredging	Primary method of managing sediment accretion along harbors, ports, and jetties to maintain draft for ship traffic and channel depth for navigation. In some cases, the dredged material is used rather than deposited offshore.
Soft structures	Wetland and salt marsh restoration, enhancement, or creation	Creation of a wetland on a site that was historically non-wetland, rehabilitation of a degraded wetland, or reestablishment of a wetland so that soils, hydrology, vegetative community, and habitat are a close approximation of the original natural condition that existed prior to modification to the extent practicable (USDA 2021). Among the benefits of wetlands and salt marshes are flood-risk reduction and buffering against erosion of adjacent uplands.
	Dune restoration, replenishment	Dune grass planting, fencing, and other techniques to trap sand.
	Beach nourishment	Replenish eroding beaches while maintaining recreational uses and habitat that would be lost with a hard structure. May involve use of dredged materials (Stronkhorst et al. 2018).
	Use of dredged materials	Intentional placement of dredged sediment to provide economic, environmental, and societal benefits by supporting beach nourishment, wetland construction, and replenishment of the littoral zone (Gailani et al. 2019).
	Dynamic revetments or cobble berms	Gravel or cobble beaches constructed at the shore in front of a property to be protected. The sloping, dynamic, porous cobble beach disrupts and dissipates wave energy (Allan et al. 2005).
Nonstructural adaptations		
Type	**Strategy**	**Description**
Policies	Zoning restrictions	Reduce the number of structures built in high-risk zones. Require developers to construct structures that are more resilient to erosion, flooding, or other expected impacts of climate change.
	Managed retreat	As the shoreline migrates inland, move people, critical facilities, and structures further inland to avoid coastal hazards.

Table 4. Approaches to coastal climate-change adaptation (modified from USACE 2022).

Knowledge Gaps and Adaptation Efforts

Knowledge Gaps and Needs

Figure 5. Dynamic revetment at Cape Lookout State Park, Tillamook County, Oregon, March 2021. Photograph by Hailey Bond.

The U.S. Army Corps of Engineers recently compiled research and management recommendations, actions, and needs from regional stakeholders and tribal partners to improve coastal resilience to current and future climate change in the Pacific Northwest (USACE 2022). Stakeholders indicated a clear need for sustained monitoring of shoreline change, increased frequency of airborne LIDAR surveys, and digital open-source repositories of regional shoreline-change data. High-priority research includes the prediction of future shoreline erosion and accretion from multiple stressors. Although concentrations of accretion and erosion are known, sediment sources, sinks, and transport pathways in Pacific Northwest estuaries are not well quantified. A better understanding of sediment movement and sediment budgets would improve overall sediment management, inform dredging in Pacific Northwest estuaries, and create opportunities for use of dredged sediments. Furthermore, standardized criteria for evaluating project success are needed to understand the geophysical, ecological, economic, and cultural impacts of projects.

In Oregon, over 3500 oceanfront parcels without shoreline armoring, about 40 percent of the oceanfront parcels in the state, are eligible to install armoring (Beasley and Dundas 2021) because they were developed before 1977. Ongoing public engagement and outreach are necessary to inform property owners about the anticipated evolution of the coastal zone and trade-offs associated with shoreline management options (Mills et al. 2018). Given that shoreline management decisions have diverse environmental, economic, and community impacts, a single infrastructure investment is unlikely to result in sustainable long-term shoreline management. Integrating shoreline management with coastal resilience planning can improve emergency response plans, habitat restoration plans, and community development.

Technical and financial support is needed by small, under-resourced, and traditionally under-represented communities that struggle to apply for planning and implementation grants to adaptively manage their shorelines. Barriers include matching-fund requirements and traditional National Economic Development Plan benefit-cost analysis ratios. Some of these communities have high relative social vulnerability and will face disproportionate burdens of coastal flooding and hazards.

Potential flood mitigation by wetlands is well established in the literature. However, reduction in flood risk by wetlands restoration in the region to date, and by potential future restoration under a range of sea-level rise scenarios, is not well understood. State and federal agencies and nongovernmental organizations participating in wetlands restoration in the region note that information is inadequate to support planning and engineering for natural and nature-based features in the Pacific Northwest (Janousek et al. 2019).

Box 1. Monitoring and adaptation along U.S. Highway 101

The Oregon Department of Transportation commissioned two research projects with Oregon State University to inform their proactive management of sea-level rise induced sea cliff erosion, landslides, and flooding on U.S. Highway 101. The first project used advanced sensors to monitor and evaluate stability and activity of steep sea cliffs and slopes due to climate change at five sites where erosion has been prevalent (Senogles et al. 2022). The second project evaluated hazards at over 70 sites on Highway 101 and prioritized the sites on the basis of their levels of risk (Alberti et al. 2022). At five of those sites, the project quantified the benefits and costs associated with alternatives such as no mitigation and eventual loss of that section of highway, rerouting, natural revetments, and different levels of structural accommodation.

Figure B1. Damage resulting from a landslide along an unstable, erosion-prone section of U.S. Highway 101 south of Port Orford, Oregon (June 2022). Photograph by Michael Olsen.

In addition to informing potential revisions of state planning goals, this research is building a common understanding of risks and needs associated with the management of coastal hazards and building partnerships among federal, state, and local stakeholders, which include the Federal Highway Administration, Oregon Department of Geology and Mineral Industries, Oregon Parks and Recreation Department, and Oregon Department of Land Conservation and Development. Furthermore, the research addresses the resilience and reliability of Oregon's transportation system for the traveling public.

Project and Resource Highlights

Many recent and ongoing efforts in Oregon aim to increase understanding and knowledge of the effects of climate change on coastal hazards and promote actions to create and maintain resilient coastal communities. These projects and resources target diverse audiences, including coastal homeowners, businesses, visitors, planners, scientists, communities, state agencies, and tribal staff.

The Oregon Climate Change Adaptation Framework identifies high-priority climate risks, their expected impacts, and short-term actions by which state agencies might reduce these risks. Actions addressing sea-level rise include updates to the state's residential design standards and building codes in floodplains and acquisition of homes at risk from coastal flooding. The updates to the floodplain design standards and residential building codes now require that structures constructed in coastal high-hazard areas be elevated by at least 1 foot (0.3 m) above the 100-year flood base elevation, and prohibit the construction of basements (DLCD 2021).

The Cascadia Coastlines and Peoples Hazards Research (CoPes) Hub, funded by the U.S. National Science Foundation, seeks to inform and enable integrated hazard assessment, mitigation, and adaptation—including comprehensive planning, policy-making, and engineering—through targeted scientific advances in collaboration with communities. The processes that the Cascadia CoPes Hub is studying include increasing total water levels due to climate change, coastal erosion trends, subduction megaquake frequency, movement of debris by tsunamis, best management practices to maintain connections among coastal communities and protect the communities from hazards, and exclusionary, regional risk governance processes. To achieve equitable and just outcomes, the Cascadia CoPes Hub strives to respect and incorporate traditional and local ecological knowledge.

The Oregon Department of Land Conservation and Development's Oregon Coastal Management Program received funding from the National Fish and Wildlife Foundation's Coastal Resilience Fund to engage coastal communities in Coos and Tillamook counties in identifying resilience needs and planning estuary restoration projects. The aims of the process include empowering local communities to implement coastal resilience activities and increasing local understanding of trade-offs among coastal resilience projects (M. Reed, personal communication).

In addition to clarifying what is and is not a beachfront protective structure, the Oregon Coastal Management Program's erosion control guidebook provides information on Statewide Planning Goal 18 (beaches and dunes), the policies and land-use goals most relevant to the Oregon coast, typical and atypical permitting processes for erosion control, and details about erosion control measures that are viable for the Oregon coast. Implementation requirement 5 of Statewide Planning Goal 18 limits the placement of beachfront protective structures to areas that were developed before January 1977. This policy effectively places a cap on the amount of ocean shore that may be hardened, and therefore limits the cumulative impacts of such hardening. Shoreline armoring fixes the shoreline in place, traps sediment, and causes scouring and lowering of the beach profile. Over time, these actions can lead to the loss of Oregon's public beaches. The Oregon Coastal Management Program also is developing a guide for local coastal jurisdictions to evaluate risks from sea-level rise and potential adaptation strategies consistent with Oregon's existing regulations (M. Reed, personal communication).

Information, strategies, and lessons learned from mitigation, adaptation, and preparedness projects along the Oregon coast are not always effectively shared among stakeholders. Therefore, Oregon Sea Grant developed the Oregon Coastal Hazards Ready (OCHR) Library & Mapper (bit.ly/OCHR-Mapper), an ArcGIS StoryMap that displays 39 case studies of coastal hazards preparedness (Oregon Sea Grant 2021). The Mapper is designed to assist individuals, communities, and tribal and local governments in identifying approaches to prepare for acute and chronic coastal hazards. In partnership with the Cascadia CoPes Hub and the Washington Department of Ecology, Oregon Sea Grant sends a monthly Pacific Northwest Coastal Hazards Resources Newsletter to the OCHR Mapper listserv, which has more than 100 subscribers.

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