Impacts of Predicted Global Sea-Level Rise on Oregon Beaches and Tidelands

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PLANNING FOR GLOBAL SEA LEVEL RISE IN OREGON, USA

Forward
by:
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The Oregon Shores Conservation Coalition’s “Coastal Climate Change Adaptation Project” is under development as an experiment in grassroots organizing for adaptive planning for expected climate change impacts. Oregon Shores is a regional conservation group with a 40-year history of working to protect marine, shoreline, estuarine and other coastal habitats. The organization’s board and staff came to recognize that the likely effects of climate change—rising sea levels, more intensive storm surges, increased erosion, lower-river flooding, among others—would affect every aspect of the group’s work. Consequently, a new program, the Climate Action Program, was created to address the need for long-range adaptive planning to preserve the resilience of communities, both human and natural. Oregon Shores’ premise in developing the Coastal Climate Change Adaptation Project is that for adaptive planning to be meaningful, broad community acceptance and support are necessary. The project is thus designed as a grassroots effort, with the aim of developing broad support before any proposal should be submitted to local governments.

IMPACTS OF PREDICTED GLOBAL SEA LEVEL RISE ON OREGON BEACHES AND TIDELANDS

Curt Peterson*

INTRODUCTION:

Two background sections on the expected impacts from predicted sea level rise on the Oregon coast were prepared for Oregon Shores Conservation Coalition’s ‘Coastal Climate Change Adaptation Project’ (see Forward above). The two sections are developed for broad distribution to coastal residents, community leaders, government agencies, and other interested parties. The two non-technical sections use geometric or gradient change approaches to illustrate potential impacts of shoreline retreat and tideland submergence under conditions of accelerated global sea level rise, as predicted for the next century or two. The Oregon coast contains unusual geologic records of prehistoric beach erosion and tidal wetland submergence from both cyclic and progressive rises of relative sea level. These geologic records can be used to calibrate the simple geometric methods of estimating potential impacts of sea level rise on the diverse sandy beaches and tidal wetlands in Oregon (Figure 1). Additional background papers on 1) other climate change induced impacts to the Oregon coast, 2) history of coastal zone management in Oregon, and 3) legal aspects of proposed adaptive planning for the Oregon coastal zone will become available from Oregon Shores Conservation Coalition.

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Figure 1: Map of Oregon coastline with positions of beaches and estuaries named in the background sections.
Impacts of Predicted Global Sea Level Rise on Oregon Beaches

Future global sea level rise of 1-2 meters (3-6 feet), predicted to occur during the next century or two (Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009), will impact Oregon beaches through beach sand erosion and sea cliff retreat. Some of the most susceptible beaches in Oregon are showing evidence of the initial impacts of renewed beach erosion after several thousand years of relative stability (Hart and Peterson, 2007) (Figure 2). Some of the beach sand loss might be attributed to changes in storm wave direction (Peterson et al., 1990), height, and/or frequency (Ruggiero et al., 2010), but the long-term sand loss to the continental shelf and other submerging sand sinks will eventually impact all of Oregon’s sandy coastlines.

Figure 2: Eroding beach with exposed tilted bedrock strata in the exposed wave cut platform (photo background). Site is located south of Ona Beach, Oregon. A prehistoric dune ramp 10-15 m thick at this location has washed away leaving beach cobble and a thin layer of beach sand (< 1.0 m thick) over the wave cut platform (bedrock). Photo was taken June 24, 2002. In May 2012 no sand was present above the wave cut platform in the area located landward of tilted bedrock strata. See Figure 1 for location of Ona Beach, Oregon.

The onset of net sand loss is apparent at many Oregon beaches where “mystery tree stumps” are being exposed by episodic erosion, after having been buried by beach sand for several thousand years (Figure 3). From north to south, some of these beaches are those at Arch Cape, Cape Lookout, Neskowin, Beverly Beach, Seal Rock, and Nesika Beach (Hart and Peterson, 2002). The most recent exposures of the mysterious stumps were documented following strong El Niños in 1983 and 1998 (Hart and Peterson, 2007). Stumps from some beach platforms located north of Yachats, Newport, Neskowin, Cape Lookout, and Arch Cape are now exposed during most winter periods of large storm surf. The regular seasonal exposure of the surf zone stumps and the wave-cut beach platforms in which they are rooted demonstrates the shallow depths of beach sand along much of the Oregon coast.
Figure 3: Mystery surf zone tree stumps at Neskowin, Oregon (photo date winter 1988). Stumps are radiocarbon dated at 2-4 ka demonstrating protective burial under beach sand until recent times. By 2007 the stumps were largely eroded away.

Many of the wide beaches that are readily apparent during summer low tide conditions actually represent very thin layers of sand (1-2 m in thickness) above gravel or sedimentary rocks (Peterson et al., 1991; Peterson et al., 1994). The wide summer beaches shown in many scenic photographs of Cannon Beach, Agate Beach, Port Orford, and Gold Beach, among others, will not exist when the remaining thin layer of beach sand is permanently lost from the beach face within the next century or two.

Historically, the Oregon beaches were thought to be in dynamic seasonal equilibrium, as summarized by Fox and Davis (1978). This theory proposed that offshore and northward transport of beach sand during winter months was balanced by onshore and southward transport of sand during summer months. However, longer-term records of sand supply to many Oregon beaches do not support the equilibrium theories. For example, alongshore net littoral drift is indicated by dune sand accumulations at the northern ends of littoral cells in northern Oregon and at the southern ends of littoral cells in southern Oregon (Peterson et al., 2009). The episodic export of sand from one littoral cell to another might account for long-term loss of sand from some of these cells including Lincoln City, Neskowin, and Arch Cape in northern Oregon and Gold Beach and Brookings in southern Oregon.

Observations from some littoral cells in central Oregon focus on areas that do not experience any net alongshore littoral drift, yet they show long-term loss of beach sand. In addition to the mystery stumps that are being exposed along some of these beaches, such as Newport and
Bandon, the large sand dune ramps that backed up against the sea cliffs in those beaches have been largely eroded away (Figure 4) (Hart and Peterson, 2007). The broader list of eroded prehistoric sand ramps includes exposed sea cliffs at Oceanside, Cape Lookout, Cape Kiwanda, Lincoln Beach, Nye Beach, Yaquina Point, Seal Rock, Waldport, Tilicum, Silver Surf, Yachats, Washburne, Heceta Head, Whiskey Run, Bandon, Blacklock Point, Nesika, Otter Point, and Crook Point (Hart and Peterson, 2007).

![Image of a sea cliff near Seal Rock, Oregon, showing Holocene dune sand (top 3-4 m of sea cliff) above forest soil (black layer) at top of Pleistocene dune sand (light shaded strata) above uplifted Pleistocene wave cut platform (dark bedrock). The modern beach platform was likely cut at 4-7 ka (ka is thousand years). The Holocene dune ramp is younger than the underling forest soil, which is dated at about 3 ka. The late Holocene dune ramp that reached the terrace top has eroded away during the last 2 ka, re–exposing the middle to late Holocene sea cliff.](image)

The wide-scale planting of European dune grass has caused historic foredune accretion in some Oregon beaches (Reckendorf et al., 1998). However, the artificially produced foredune accretion presents a false impression of long-term beach stability. The foredunes have not continued to accrete seaward at either Coos Bay or Florence since their development several decades ago. In some localities, including Port Orford, Ona Beach, and Neskowin, the artificially accreted foredunes are undergoing modern erosion.

With the important exception of the Clatsop Plains, and a few other beaches located near large rivers, most of the Oregon’s beach sand originated from onshore transport of continental shelf sand (Clemens and Komar, 1988). That onshore transport of sand peaked during the middle Holocene transgression five to eight thousand years ago (Peterson et al., 2007). During the last several thousand years of minimal sea level rise of 1.0 meter per thousand years (Darienzo et al.,
1994), the ocean waves pushed ashore the remaining shelf sand that was within their reach of water depth, known as “wave base.” There are no significant sources of new sand other than eroding sea cliffs that are now available to supply the beaches of the central Oregon coast. The predicted increase of sea level rise (1-2 meters) from ongoing global warming (Vermeer and Rahmstorf, 2009) will effectively raise the depth of wave base and thus allow eroding beach sand to backfill the deepening inner continental shelf (Bruun, 1962). This reversal of net across-shore sand supply from early transgressive onshore transport to post high-stand offshore transport has already been reported from some of the world’s most susceptible shorelines, such as in the Netherlands. The submergence of estuarine tidal flats in some of Oregon’s bays will provide a smaller sink for eroding beach sand. Longshore transport of beach sand will temporarily benefit downdrift beaches at the expense of updrift beaches in some littoral cells (Peterson et al., 2009). However, the lack of new sand supply, under a regional condition of rapidly rising sea level (1-2 meters in the next century or two), will ultimately impact all of the Oregon beaches.

There are different methods of predicting the shoreline retreat that will occur from global sea level rise along the Oregon coast. Probably the simplest methods are based on lateral shifts of equilibrium across-shore profiles, i.e., assumptions that the current shape, slope, and annual sand replenishment cycle of a beach (its “equilibrium profile”) will be maintained and this whole system will simply move inland as the sea level rises. The “Bruun rule” equates beach shoreline retreat distance to a landward shift of the equilibrium profile (Figure 5), based on the rise of relative sea level (Bruun, 1988).

![Figure 5](image.png)

Figure 5: Bruun’s relation showing the short term response to a minor change in sea level from a storm event versus the long term response to a major sustained change in sea level from global sea level rise (SLR). Figure modified from Bruun (1988).

Calculated ratios of retreat distance to sea level rise range from 100:1 or 200:1 for sand-bottomed beaches in the northern Oregon coast (Peterson et al., 2000). A sea level rise of 1-2 meters could therefore be expected to yield 100-200 meters (~300-600 feet) of beach retreat. Such retreat distances in Oregon are confirmed by evidence from coseismic subsidence events following the last Cascadia great earthquake in AD 1700 (Figure 6). In some locales, during the
earthquake the land surface at the coast dropped 1 to 2 meters, causing widespread beach erosion in southern Washington and northernmost Oregon (Meyers et al., 1996).

![Ground penetrating radar profiles at Nehalem spit, Oregon showing erosional retreat scarps 130 m in length (black sloping lines) produced from coastal subsidence (1.5 m) that accompanied the last Cascadia earthquake at AD 1700 (Peterson et al., 2010).](image)

Figure 6: Ground penetrating radar profiles at Nehalem spit, Oregon showing erosional retreat scarps 130 m in length (black sloping lines) produced from coastal subsidence (1.5 m) that accompanied the last Cascadia earthquake at AD 1700 (Peterson et al., 2010).

Most of Oregon’s beaches are narrower than the potential retreat distances that are calculated for predicted sea level rise of 1-2 m during the next century or two. Most Oregon beaches lack sufficient sand buffers to accommodate 100 meters of beach retreat without exposing sea cliffs and associated wave-cut platforms or flat areas of rock that extend seaward from the foot of the sea cliffs, to wave attack. Steeply sloped wave-cut platforms provide cliffs with more protection against sea level rise than do gently sloped (“low gradient”) wave-cut platforms. An equilibrium profile method can be used to estimate the retreat of wave-cut platforms and sea cliffs that are cut into weak Pleistocene strata, layers of cliff that are common along the coast. A 1.5 meter rise in sea level is estimated to result in 30 to 60 meters (90-180 feet) of landward shifts of representative sea cliffs that are cut into weakly cemented sand or mudstone strata, based on the present wave cut platform gradients of 3.0 and 1.5, respectively. Such low gradient platform slopes have been measured in Cannon Beach, Lincoln City, Otter Rock, Newport, Yachats, Whisky Run, and Garrison Beach, among other locations (Peterson et al., 1994).

These geometric methods do not provide rates of shoreline retreat, or how quickly the shoreline will move landward, but only the long-term response to a prolonged change of sea level.
Nevertheless, the estimates provided above demonstrate the potential for widespread loss of existing sandy beaches (> 80%) and destabilization of sea cliffs (> 50%) along the Oregon coastline in response to predicted sea level rise of 1-2 meters during the next century, or two (Figure 7).

Figure 7: Eroded beach face at Cove Beach, Oregon, showing beach cobble above a wave cut platform (bedrock not exposed in this photo). The lack of beach sand represents shoreline conditions that probably existed in mid-early Holocene time during periods of rapid sea level rise. Similar conditions are expected to prevail during the next century or two of rapid sea level rise (1-2 m) as predicted to occur from global warming.

Impacts of Predicted Global Sea Level Rise on Oregon Tidelands

Future global sea level rise of 1–2 meters (3–6 feet), predicted to occur during the next century or two (Pleffer et al., 2008; Vermeer and Rahmstorf, 2009), will impact Oregon tidelands through increased flooding and salinity intrusion (Figure 1). Estuary tidelands in Oregon range from freshwater spruce bogs growing 2 meters (6 feet) above mean (average) sea level to freshwater-brackish marsh (1–2 meters above mean sea level) (Figure 8) to brackish-marine marsh (0–1 meters above mean sea level) to mud and sand tidal flats below mean sea level (Figure 9). These tidelands, also known as tidal wetlands, provide unique conditions for biological productivity and habitat in Oregon estuaries.
During the last several decades much work in Oregon has gone into the restoration and protection of these valuable coastal wetlands (PNCERS: Oregon Sea Grant, 2003). Additional submergence of the tidal wetlands by 1–2 meters (3–6 feet) of sea level rise will kill the lowest spruce bogs, bury the salt marshes under mud, and erode some tidal channel banks (Peterson et al., 2000). The higher sea levels will also increase winter flooding in upper estuarine reaches, impacting dikes, tide gates, roads, and combined sewer outfalls (Barnett, 1997).
The long-term ecological impacts of global sea level rise will occur in estuaries where human-built dikes have cut off the enclosed floodplains from tidal influence (Borde et al, 2003). The extensive dikes in the Columbia River estuary, Tillamook Bay, and Coos Bay will prohibit the creation of new spruce bogs or tidal marshes (no tidal wetland “re-colonization”) under the conditions of predicted global sea level rise (Figure 10). Shallow tidal creeks used by juvenile salmonids (PNCERS, 2003) will be lost, as well as the nutrient organic matter that is produced in tidal marshes (Ruesnick et al., 2003) when the few remaining natural salt marshes are submerged by predicted sea level rise.

Figure 10: Current extent of natural or non-diked tidal marsh (yellow lines) in Tillamook Bay, Oregon. Rapid sea level rise will submerge these natural bay shoreline wetlands, but new tidal marsh will not develop in most of the preexisting floodplains, due to extensive dike and tidal gate restrictions of tidal flow. The remaining natural salt marsh in Tillamook Bay will be largely eliminated by global sea level rise of 1-2 m in the next century.

The recent geologic record of coastal wetland response to rapid submergence in Oregon and Washington is well established (Figure 11). These abrupt burials of tidal marshes by bay mud and sand have occurred repeatedly from episodic lowering of coastal land elevations by 1–2 meters (3–6 feet) during great Cascadia earthquakes (Atwater et al., 1995). These “coseismic subsidence” events, reoccurring every few hundred years in Oregon (Darienzo et al., 1994), provide direct analogs to the expected impacts from predicted global sea level rise in Oregon tidelands. Earthquake-caused lowering of the shoreline in the Nehalem, Tillamook, Netarts, Siletz, and Yaquina Bays killed 80-90 % of the pre-existing tidal marshes in those bays (Barnett, 1997).
Figure 11: Vegetation zones relative to mean tidal level datum in Oregon estuaries. A rapid rise in sea level will submerge tidal marshes. Most supratidal settings (> 2.5 m above mean tidal level) in Oregon estuaries enclosed by dikes, so they are not expected to provide refuge for the colonization of new tidal marshes following predicted global sea level rise. Core log shows expected geologic record of peat buried by mud following abrupt sea level rise (see Figure 12 for examples). Figure drafted from Peterson et al. (2000).

Tectonic rebound and uplift of 0.5–1.5 meters eventually permitted the prehistoric tidal marshes to recolonize the barren mudflats within a century or two (Figure 12) (Darienzo, 1991; Darienzo and Peterson, 1990). Unlike these prehistoric earthquake cycles, the predicted global sea level rise is not expected to reverse in the foreseeable future. In the worst-case scenario a global sea level rise of 1–2 meters could be augmented by earthquake-generated coseismic subsidence, resulting in an additional 0.5 to 1.5 meters of relative sea level rise in Oregon following the next Cascadia megathrust rupture (Peterson et al., 2000), yielding a combined submergence or relative sea level rise of 1.5–3.5 meters.
Figure 12: Episodically submerged peat horizons (dark) buried by bay mud (light) from great earthquake subsidence events (mean recurrence interval 400–500 years) in Coos Bay, Oregon. Each burial event represents about 1.0 m of rapid sea level rise (see Figure 11 for details). Interseismic uplift and sedimentation permit the mudflat to convert back to a marsh, before the next earthquake subsidence (Barnett, 1997).

In addition to the submergence of tidelands the predicted global sea level rise will also impact estuaries, small coastal creeks, and shallow beach sand aquifers by salinity intrusion. Salinity intrusion following global sea level rise is of concern around the world, but the potential impacts in Oregon have not been widely reported.

Salinity wedges or layers of salt water extend inland from the tidal inlets to the upriver limit of salinity intrusion in all of Oregon’s estuaries. The small shallow estuaries of the Oregon coast are partially mixed (vertically) on a seasonal basis. The salinity wedges reach maximum landward distances of 22–49 kilometers (km) in the Columbia River estuary (Columbia River Intrusion, 2011), 21–31 km in the Nehalem, Yaquina, Alsea, Siuslaw, Umpqua and Coos Bays (Percy et al., 1974), and 3 km in the Sixes River (Boggs and Jones, 1976). The landward extents of salinity wedges are controlled by many factors including tidal basin bathymetry, tidal prism or volume of tidal exchange, and seasonal fluvial discharge. However, increased distances of salinity intrusion can be simply estimated from current salinity gradients and predicted global sea level rise (Figure 13).
Figure 13: Diagram of salinity wedge and extended salinity intrusion of 6 km, assuming 0.00035 salinity gradient and a predicted global sea level rise of 2 m during the next century or two.

The salinity gradients are measured from maximum salinity and mean depth at the bay mouth to minimum salinity and mean depth at the maximum salinity intrusion distance. Using the current salinity gradients for the central Oregon estuaries (Nehalem to Coos Bay) and a predicted global sea level rise of 2 meters, the salinity intrusions could extend an additional 5 to 7 km in landward distance. Both submergence and increased salt wedge intrusion could displace marine, brackish, and freshwater tidal habitats following a 1–2 m sea level rise predicted for the next century or two (Figure 14).
Figure 14: Prehistoric spruce forest stumps in the Coquille estuary were killed by submergence and/or increased salinity intrusion in the lower reaches of the Coquille River following coseismic subsidence (estimated 0.5–1.0 m sea level rise) from the AD 1700 rupture of the Cascadia subduction zone fault (Barnett, 1997). The spruce forest edge has been replaced by brackish salt marsh habitat.

Saltwater wedges also occur in subsurface aquifers that are hosted in sand barriers and beach plains. Measurements of current salinity gradients in barrier beach plains of the Columbia River littoral cell (Peterson et al., 2007) range about 0.03-0.003 (Peterson et al., 2002). Assuming a maximum global sea level rise of 2.0 meters and a minimum salinity gradient of 0.003, the salinity intrusion in low gradient coastal sand barriers could extend an additional 0.6 km inland. Though of limited distance, the saltwater intrusions into shallow sand aquifers could impact water quality in ponds, wetlands, and shallow water wells that are located in narrow sand spits and beach plains of the Oregon coast.
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