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From Mountains to Tidal Marshes:

A Comparison of Beaver Hydrogeomorphology in the Pacific Northwest

Dredging earth, felling trees, and building dams are all in a day's work for the beaver. Known as the original landscape architects, beavers have been reshaping the environment for millions of years.[1] From the boreal forests of Canada to the Chihuahuan Desert in Northern Mexico, beavers roamed most of North America, with estimates of 60-400 million before the fur trade decimated their population.[2] Nearly 100 years later, the population has resurged to nearly 10 million, notwithstanding a precarious relationship with humans and the built environment.[3] This is partly because, as keystone species, beavers greatly impact the hydrogeomorphology and ecology of their environment. Today, only one species—*Castor canadensis*—survives in North America. Typically found in rivers and lakes, beavers are often associated with freshwater habitats. However, emergent research suggests that beavers may occupy tidal marshes in similar densities, if not greater, than their freshwater counterparts (Figure 1).[4] This paper will compare mountain beavers and tidal marsh beavers in the Pacific Northwest, starting with habitat preferences for beaver colonization, shifting to case studies

[1] American Society of Landscape Architects, Interview with Caroline Frasier, https://www.asla.org/ContentDetail.aspx?id=30160/ (Feb. 13, 2017).
[2] Frances Backhouse, *Once They Were Hats: In Search of the Mighty Beaver* (Toronto: ECW Press, 2015), ix.
[3] Michael Pollock, Gregory Lewallen, Kent Woodruff, Chris Jordan and Janine Castro (Editors), *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains*. Version 1.0. United States Fish and Wildlife Service, Portland, Oregon, 3.
[4] W. Gregory Hood, "Beaver in Tidal Marshes: Dam Effects on Low-Tide Channel Pools and Fish Use of Estuarine Habitat," *Wetlands* 32 (2012): 401.

that explore hydrogeomorphological impacts, and ending with implications for restoration and conservation.

Figure 1. Comparison of beaver dams built by mountain beavers and tidal marsh beavers

Beaver dam built by mountain beaver[5]

Beaver dam built by tidal marsh beaver[6]

Habitat Preferences for Beaver Colonization. When beavers are scouting land to determine habitat suitability, they evaluate the physical characteristics of the water channel, and check for riparian areas that provide vegetation and construction materials for dams and lodges.[7] But all things are not equal in search of the perfect dam site—physical characteristics outweigh vegetative characteristics.[8] The gradient of the water channel is typically less than 6%.[9] Beavers prefer to build dams on gentle slopes, around 1-2%, but they have built dams on slopes as high as 10%.[10] This pattern is supported by Suzuki and McCombs who studied beaver habitats in the Drift Creek Basin of the Oregon Coast Range. Their findings demonstrate that

[5] Ted Guzzi, "Beaver dam on Mill Creek in Lundy Canyon" (2010), Wikimedia Commons, photograph, (https://commons.wikimedia.org/wiki/File:Lundy_Canyon_Beaver_Dam.jpg).
[6] W. Gregory Hood, "Beaver in Tidal Marshes: Dam Effects on Low-Tide Channel Pools and Fish Use of Estuarine Habitat," photograph.
[7] Pollock, Lewallen, Woodruff, Jordan and Castro, 3.
[8] Nobuya Suzuki and William C. McComb, "Habitat Classification Models for Beaver (Castor canadensis) in the Streams of the Central Oregon Coast Range," *Northwest Science* 72 (1998): 109.
[9] Pollock, Lewallen, Woodruff, Jordan and Castro, 3.
[10] Suzuki and McComb, 109.

wide valley floors, especially if greater than 10 m wide, and narrow, low-gradient water channels were positively associated with dam sites.[11] When beavers colonize near high-gradient water channels, it may be because population densities are so high that they are willing to consider less desirable locations.[12] In these cases, they seek off-channel habitats where stream velocity is lowest. These regions, typically next to or beneath a stream bed, are known as hyporheic zones where surface water mixes with shallow groundwater.[13]

Beavers are abundant throughout the freshwater rivers of mountain valleys, but they are also plentiful, though often unnoticed, in lakes, wetlands, estuaries, and tidal marshes.[14] While the presence of beavers in freshwater rivers is well documented, their presence in brackish water is poorly understood. This may be because estuaries and tidal marshes have experienced massive anthropogenic losses over the last 200 years. For example, in the Skagit Delta of Puget Sound, 65% of tidal herbaceous marshes and 95% of tidal shrub marshes have disappeared, largely due to Euro-American settlements that converted marshes to farmland.[15] The ramifications of these losses will be discussed later through Greg Hood's research on beavers in tidal marshes, namely dam effects on low-tide channel pools and the prevalence of fish in estuarine habitats.

For food, beaver prefer willows, cottonwood, and aspen, but they will consume other plants if these are unavailable. They are less discerning when it comes to construction materials for dams and lodges. Wood is top choice, especially if the diameter of the tree is less than 40

[11] Ibid.
[12] Pollock, Lewallen, Woodruff, Jordan and Castro, 3.
[13] Ibid.
[14] Hood, 401.
[15] Hood, 408.

cm, though some beavers have been known to gnaw through a tree that is 1 m in diameter.[16] They will travel as far as 60 m from the water's edge to forage and collect construction materials, but they prefer being closer, typically within 15 m.[17] If wood is unavailable, the ever so resourceful beaver will build a dam out of aquatic plants, sage brush, boulders, and even plastic or metal refuse.[18]

Hydrogeomorphological Impacts of Beavers. Both mountain beavers and tidal marsh beavers build dams, but their environmental impacts are unique. Or, in academic terms, they respectively influence the hydrogeomorphology of their habitats. Hydrology refers to the distribution and movement of water, and geomorphology refers to the study of forces that change landforms. Together, they comprise hydrogeomorphology, the lens through which we will evaluate the differences between mountain beavers and tidal marsh beavers.

Mountain Beavers. The hydrogeomorphological impacts of mountain beavers are best understood through the evolution of the beaver dam complex, a process of morphologic adjustment that ranges from decades to hundreds of years.[19] When a beaver completes a dam on a freshwater river, the dam impounds water upstream. Sediment then builds upstream of the dam. Over time, sediment accumulates, gradually elevating the streambed. If stream banks are shallow, then the river widens, stream velocity decreases, and often, ponds develop. This not only expands the riparian area, but also enhances stream channel complexity. Periodically,

[16] Backhouse, 219.
[17] Ibid.
[18] Backhouse, 180.
[19] C. Nash, G. Grant, and S.D. Campbell, "A Model of Beaver Meadow Complex Evolution in the Silvies River Basin, Oregon," *American Geophysical Union, Fall Meeting 2014, Abstract #EP33D-06* 72 (2014).

the dam breaks or the river floods, depositing alluvium at higher elevations above the riparian area and recharging the groundwater supply. The cycle of dam building, channel widening, dam breaching, flooding, and sediment deposition can take up to 200-300 years.[20] What starts as a beaver pond transforms into an open meadow with multithreaded channels and a complex ecosystem remarkably different from the adjacent riparian forest.

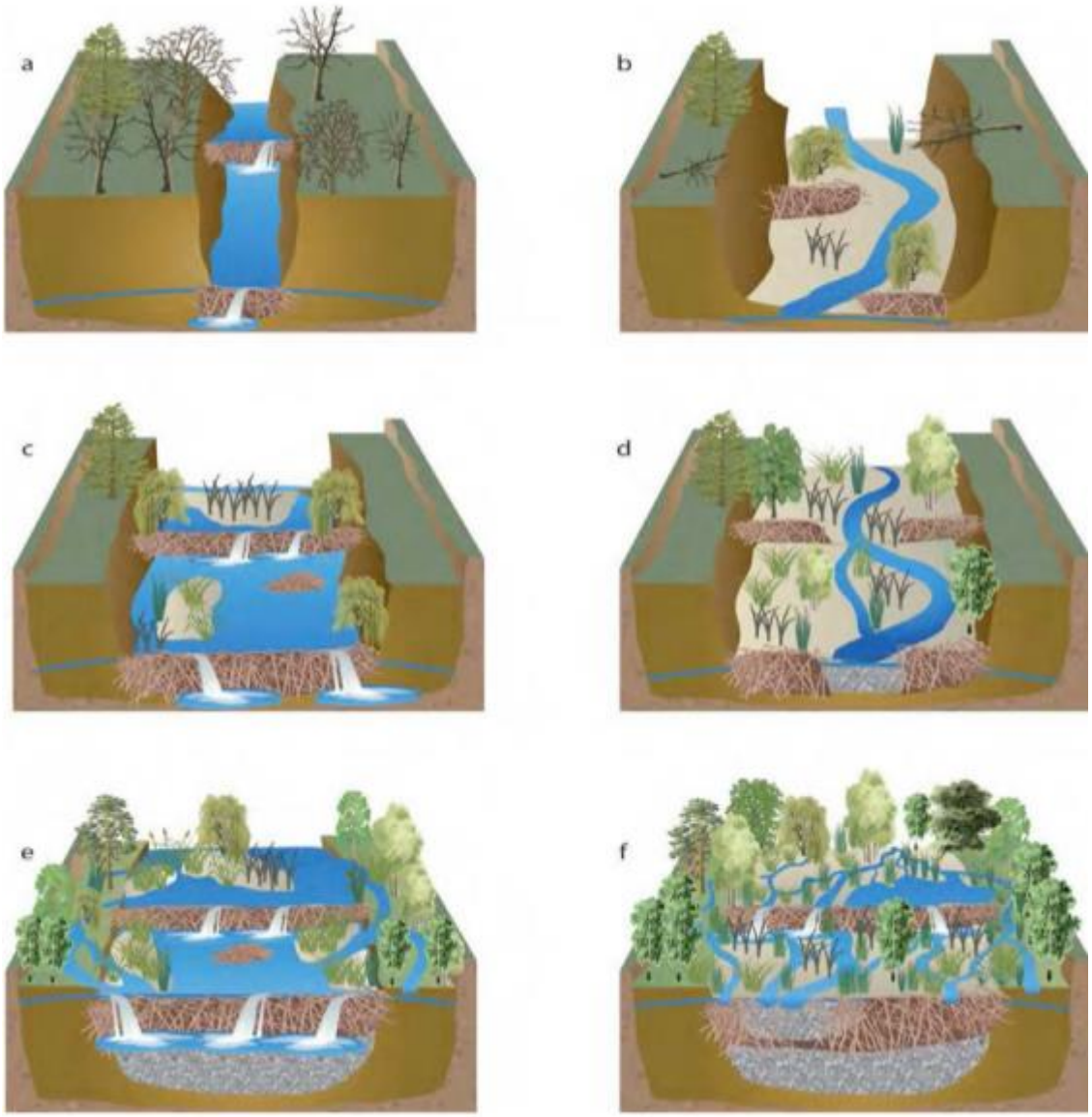
In the above example, the scenario applies to shallow stream banks only. If stream banks are incised, then the beaver dam complex may follow a different sequence (Figure 2). Channel incision is a process of deepening the channel bed elevation. It can be caused by a decrease or increase in sediment supply. In both cases, the stream bank erodes, the channel bed sinks, and stream velocity may increase. Mountain beavers will still build dams in incised streams. However, dams may be subject to greater hydraulic pressure, hastening their inevitable failure. When they do fail, floods may not be high enough to deposit alluvium on adjacent river banks or recharge the groundwater supply. They will, however, be strong enough to further erode the stream bank walls, allowing a widened incision trench to form. Within the inset floodplain, stream velocity is lower. Now, mountain beavers can rebuild dams within a more stable environment, and the cycle of the beaver dam complex resumes similar to the first scenario.

In addition to building dams and lodges, mountain beavers reshape the earth through excavating canals and burrowing into river banks. To the mountain beaver, canals are essentially transportation corridors that facilitate floating sticks and logs to the dam site. They

[20] Pollock, Lewallen, Woodruff, Jordan and Castro, 11.

also provide a regulating mechanism for the mountain beaver to manipulate pond depth by diverting water when the pond becomes too deep.[21] Canal length can be as narrow as 1 m or as

Figure 2. Conceptual model of beaver dams affecting the development of incised streams



From incised trench to complex wetlands reconnected with their floodplain[22]

[21] Cheri Westbrook and David Butler, "Beaver Hydrology and Geomorphology," in John F. Shroder, ed., *Treatise on Geomorphology* (San Diego: Academic Press, 2013), 301.

[22] Michael Pollock, Timothy J. Beechie, Joseph M. Wheaton, Chris. E Jordan, Nick Bouwes, Nicholas Weber, and Carol Volk, "Using Beaver Dams to Restore Incised Stream Ecosystems," in *Bioscience* 64 (2014): 285.

wide as 100 m. Canal width is typically between 35 cm and 41 cm.[23] In cases where building dams is unsuccessful, mountain beavers may burrow into banks along the water's edge, destabilizing the shore and weakening the root system of trees.[24] Both acts, excavating canals and bank burrowing, displace sediment into the stream. This is an important point to keep in mind because sediment deposition is often conceived as a result of building dams, but the causes may be more complex.

Tidal Marsh Beavers. Compared to mountain beavers, research on tidal marsh beavers is quite sparse. When spotted in marine environments, beavers are typically swimming through microtidal systems. Until recently, they were rarely seen dwelling in mesotidal and macrotidal systems.[25] In microtidal systems, river discharge influences water levels that fluctuate between 0-2 m. In mesotidal systems, the tidal range is between 2-4 m; and in macrotidal systems, the tidal range exceeds 4 m. As tidal range increases, the water becomes increasingly brackish as ocean water mixes with river water in estuaries. In fact, the salinity of brackish water can be up to ten times higher than the salinity of freshwater.[26] If beaver can inhabit mesotidal and macrotidal systems, that means beaver live, and possibly thrive, in brackish water, challenging the notion that beavers are riverine or lacustrine animals.[27]

During high tide, tidal marsh beaver dams are completely submerged. It's when the tide ebbs that dams become useful. At low tide, beaver dams impound water, keeping lodge entrances continually underwater, providing safe swimming routes through tidal channels, and

[23] Ibid.
[24] Ibid.
[25] Hood, 401.
[26] Backhouse, 175.
[27] Hood, 401.

incidentally, creating low-tide channel pools that provide a safe habitat for juvenile fish.[28] These recent discoveries are the work of Greg Hood, a senior research scientist with the Skagit River System Cooperative in Washington State, whose findings will be explored further in the Skagit County case study.

Case Study 1: Mountain Beavers in Bridge Creek, Oregon. Pollock, Beechie and Jordan explore the hydrogeomorphological impacts of mountain beavers through an investigation of localized aggradation in Bridge Creek, an incised stream and tributary to the John Day River. Located in eastern Oregon, Bridge Creek is in a semi-arid region of the interior Columbia River basin where erosion has increased the prevalence of incised streams. Channel incision in semi-arid regions can lower water tables, disconnecting groundwater from surface water, and in the process, reducing stream velocity to a trickle. Since groundwater is the cooling mechanism that reduces stream temperature, less groundwater translates to higher stream temperatures which are inhospitable for many fish species.

The study aims to measure the volumetric and vertical aggradation rates of beaver ponds in Bridge Creek, then forecast the time estimated for sediment accumulation to raise the elevation of the streambed, reconnecting the river with the floodplain.[29] Aggradation refers to the increase in elevation of the streambed due to sediment accumulation. This is important because if aggradation rates are significant, then beaver populations could be increased in an

[28] Backhouse, 175.

[29] Michael M. Pollock, Timothy J. Beechie and Chris E. Jordan, "Geomorphic Changes Upstream of Beaver Dams in Bridge Creek, an Incised Stream Channel in the Interior Columbia River Basin, Eastern Oregon," *Earth Surface Processes and Landforms* 32 (2007): 1174.

effort to spur dam building that decreases stream velocity and accelerates the recovery of riparian vegetation.

Pollock, Beechie and Jordan performed sediment depth measurements using a sediment corer along every 5 m of a transect, calculated slopes above and below dams, mapped contour bands of riparian vegetation through LiDAR data, and researched the Bureau of Land Management database for age of the beaver dams.

Slope calculations confirmed that sediment accumulation behind dams reduced the slope by 1.3%, or by a factor of 4.5.[30] Furthermore, LiDAR data revealed that land upstream and downstream of beaver dams experienced significant riparian growth. For example, if beaver dams were absent, the width of the riparian area, within a 0.5 m elevation of the creek, averaged 8.6 m.[31] However, if beaver dams were present, the width of the riparian area averaged 44 m.[32] Their final test compared sediment depth measurements with age of dams to calculate an aggradation rate of 0.05 m/year, assuming beaver dams are continuously present. The aggradation rate was then used to predict the increase in riparian area, within a 0.5 m elevation, over a 90 year period. Their findings demonstrate that the area of riparian vegetation could increase by factor of two to six, depending upon river channel characteristics, if beavers continually occupied each site for 90 years.[33]

These results reinforce the theory that beaver dams significantly alter the hydrogeomorphology of freshwater streams in mountain valleys. Furthermore, they suggest

[30] Pollock, Beechie, and Jordan, 1179.
[31] Ibid.
[32] Ibid.
[33] Pollock, Beechie, and Jordan, 1181.

beaver dams can accelerate the recovery of incised streams, an increasingly worrisome occurrence in the dry Columbia River basin. And last, the findings suggest that beaver dams can improve fish habitats by lowering stream velocities and expanding riparian vegetation that shades and cools the creek in the summer.

Case Study 2: Tidal Marsh Beavers in Skagit Delta, Washington. Hood investigates the hydrogeomorphological impacts of tidal marsh beavers through dam effects on low-tide channel pools and fish habitats in the Skagit Delta of Puget Sound. Skagit River, providing 34% of the freshwater that pours into Puget Sound, is the largest river that feeds into it.[34] Likewise, Skagit Delta is the largest delta, even though 90% of the wetlands have been converted to farmland.[35] With semi-diurnal tides of up to 4.5 m, the Skagit Delta is a macrotidal system. Tidal marsh vegetation consists of a mix of herbaceous grasses and shrubs.[36]

The study aims to answer four questions. In tidal marshes, do beaver prefer herbaceous or shrub vegetation? What are the hydrogeomorphic consequences of beaver dams in tidal channels? Does the tidal channel habitat promote a safer environment for juvenile fish? Are beavers equally abundant in tidal marshes and non-tidal rivers?

Hood mapped the delta using a combination of orthophotography and tidal channel surveys, performed with hip chains to determine channel length and stadia rods to measure channel depth (Figure 3). Intertidal beaver dams were then plotted on the map. The map demonstrates that tidal marsh beavers significantly prefer building dams in shrub vegetation. In

[34] Hood, 402.
[35] Ibid.
[36] Ibid.

8.6 km of channels in tidal shrub zones, 125 beaver dams and 14 lodges were discovered.[37] Not a single dam or lodge was present in the tidal herbaceous zone.[38]

With respect to hydrogeomorphology, Hood discovered that shrub zones with beaver dams contain significantly more pools when compared to herbaceous zones. For the purposes

Figure 3. Map of beaver dams and vegetation in the Skagit Delta

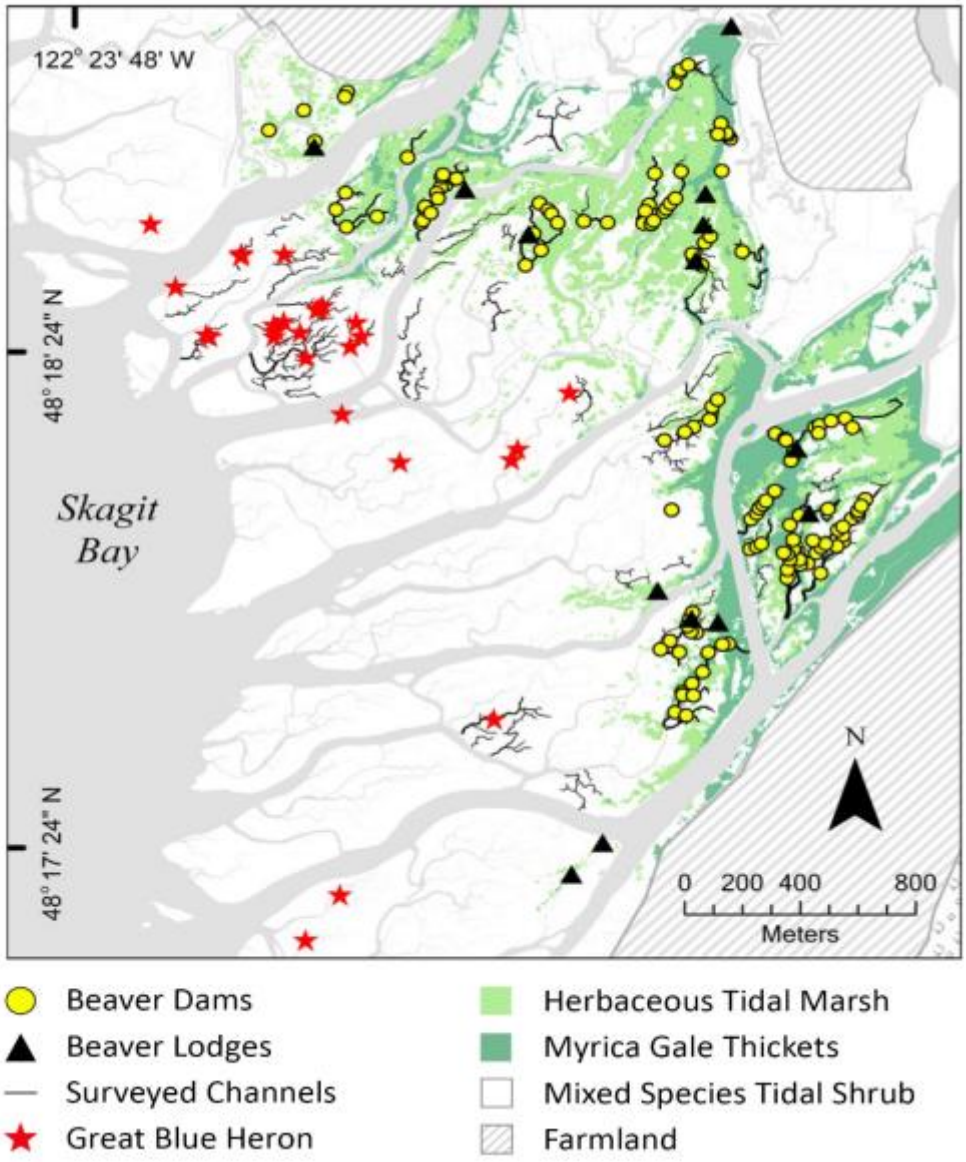


Image: All beaver dams found in shrub zones; none were found in herbaceous zones.[39]

[37] Hood, 403.
[38] Ibid.
[39] Hood, 404.

of this study, pools were defined as tidal channels with a minimum 20 cm depth at low tide, and shallows were defined as tidal channels less than 20 cm depth. In tidal herbaceous marsh, only 16.4% of channel length consisted of low-tide pools.[40] In tidal shrub marsh, 65.5% of channel length was comprised of low-tide pools. Of this 65.5%, beaver dam pools account for 47.7% of tidal shrub length.[41] Beaver-dam pools were also three times longer (mean = 44.9 m) when compared to pools formed by logs, bank slumps, meander bends, and tributary junctions in both vegetative zones (mean = 14.2 m).[42] As predicted, the large, protected beaver-dam pools also provided safe harbor for juvenile fish. This was confirmed through fish sampling, from early March to late June. Hood discovered that tidal channels with beaver-dam pools quadrupled the fish habitat in comparison to tidal channels without dams.[43]

Most striking is the discovery that beavers are as abundant in the tidal marshes of the Skagit Delta as they are in non-tidal rivers. Hood measured the density of dams and lodges in the Skagit Delta, then compared these values to densities recorded for non-tidal rivers in an extensive literature search. Similar to densities in non-tidal North American rivers, beaver dam density in the Skagit tidal shrub zone was 8.9 km^{-1}.[44] With respect to lodges, tidal shrub zones have a lodge density of 10.2 km^{-2}, whereas non-tidal rivers have a lodge density between 0.2–0.9 km^{-2}.[45] Considering that a single beaver colony can build multiple lodges, colony and lodge densities cannot be extrapolated from each other. That said, the magnitude of difference

[40] Hood, 404.
[41] Ibid.
[42] Ibid.
[43] Hood, 406.
[44] Ibid.
[45] Ibid.

between lodge densities suggest that tidal marshes beavers may, in fact, have significantly higher populations than mountain beavers.[46]

These findings suggest that we should reconceive our priorities and strategies for restoring coastal habitats. For example, current restoration efforts in Puget Sound focus on the rehabilitation of tidal herbaceous marshes, not tidal scrub zones. While both zones are rapidly diminishing, likely due to global warming, tidal scrub zones are experiencing greater losses. Moreover, tidal scrub zones are ecologically complex, providing safe habitats for beavers that, in turn, create estuarine habitats that protect juvenile fish, especially Chinook salmon.[47] Managing the restoration of tidal shrub habitat is essential if ecological relationships are to be maintained within the tidal marshes.

Conclusion. This paper aimed to compare mountain beavers and tidal marsh beavers in the Pacific Northwest, mostly focusing on their respective hydrogeomorphological impacts, and briefly discussing the implications for restoration and conservation. Mountain beavers build dams that accumulate sediment, flood adjacent lands and transform streams into meadows. On the contrary, tidal marsh beavers build dams that surface only when the tide is low, twice daily, allowing pools and shallows to form briefly before the tide rises again. Their temporal and spatial influence differs greatly with respect to one another. Nonetheless, as keystone species, both mountain beavers and tidal marsh beavers live up to their reputations, dramatically altering their environment in ways that benefits fish, birds, plants and trees.

[46] Ibid.
[47] Hood, 409.

We also discovered that beavers occupy tidal marshes in similar densities, if not greater, than beaver in freshwater rivers, but has this always been the case? It's possible that beavers were historically plentiful in both locations, but shrinking habitats reduced where they could build dams and lodges. Remember, we've already discussed the fact that Euro-American settlements converted 95% of tidal shrubs marshes to farmland in the Skagit Delta. Another theory is that beavers may have been pushed out to tidal marshes as freshwater rivers became less hospitable through damming or incision. For now, their historical footprints will remain a mystery until additional investigations reveal more about what draws the beaver to suitable habitats.

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