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Reply to "Wolf-triggered trophic cascades and stream channel dynamics in Olympic National Park: a comment on East et al. (2016)" by Beschta and Ripple, for *Earth Surface Processes and Landforms*

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The original paper to which the comment refers is East et al., 2017, Channel-planform evolution in four rivers of Olympic National Park, Washington, USA: the roles of physical drivers and trophic cascades: Earth Surface Processes and Landforms 42, 1011–1032.

Please note that the reference East et al. (2016) should be changed to 2017 throughout Beschta and Ripple's comment.

Reply:

Beschta and Ripple disagree with conclusions from our recent analysis of river planform change in Olympic National Park (East et al. 2017). Beschta and Ripple (2008, and Comment) believe that a trophic cascade consisting of wolf eradication, increase in elk abundance, and herbivory impacts on riparian vegetation has been the paramount driver of geomorphic change. Although the trophic-cascade hypothesis is a valuable consideration for understanding riverine systems (Beschta and Ripple, 2006), we find that multiple physical processes have dominated river-planform change in the glaciated, temperate-rainforest valleys of Olympic National Park. In our view, the evidence does not support the Beschta and Ripple conceptual model that these rivers owe their sensitivity to physical drivers to overarching dominance of trophic cascades. Further, we caution against viewing patterns of change in complex, multicausal systems through the lens of a single favored explanation (Mech, 2012; Peterson et al., 2014).

The eventual geomorphic consequence of elk herbivory is a key uncertainty in deciphering factors that control river planform. Beschta and Ripple assert repeatedly that effects of elk herbivory on riparian vegetation structure and composition have become 'increasingly severe' throughout the past century, leading to unnatural channel widening and braiding. But other evidence suggests that despite little cottonwood recruitment (which is spatially variable in the Park, but commonly low in elk-frequented areas), browsing intensity likely decreased and understory-vegetation density increased in some heavily used elk ranges after elk populations gradually declined and domestic stock were removed after the 1930s (Sumner 1952; Jenkins 1981; Woodward et al., in review; Fig. 1). Although we readily acknowledge that cottonwood recruitment is negligible in the most densely used elk ranges, we know of no convincing evidence that the ecological and geomorphic functions of riparian vegetation diminished during the most recent decades, when rivers widened significantly. Many studies point to ecological dominance of trees other than cottonwood and maple in western Olympic Peninsula floodplains: Sitka spruce (*Picea sitchensis*), red alder (*Alnus rubra*), and willows (*Salix* spp.) have high stem densities and basal area, are abundant in developing floodplain communities, and are key players in vegetation successional pathways (Fonda, 1974; McKee et al., 1982; Balian and Naiman, 2005; Van Pelt et al., 2006; Naiman et al., 2010). We reason that these trees likely provide functional redundancy in the relative absence of cottonwood or maple recruitment. Even large trees do not guarantee bank stability or erosion resistance, though, as floods commonly erode beneath the rooting zone (Beechie et al., 2006).

The timing of river channel narrowing and widening corresponds clearly to changes in flood regime (our paper), in particular evidenced by channel narrowing in the 1970s—a period of low flows but no coincident relief from elk herbivory or increase in cottonwood recruitment. Despite these findings, Beschta and Ripple consider only cumulative channel widening and use this parameter to infer "consequences of long-term degradation of riparian plant communities." We consider that ignoring temporal width fluctuations in this way leads to misinterpretation of both the processes and causes of geomorphic change. Rivers in this setting are inherently dynamic; Naiman et al. (2010) identified "recurrent destruction and reformation of soils and vegetation" as a defining characteristic of alluvial floodplains in the Pacific coastal ecoregion. Viewing rivers as only widening, rather than widening and narrowing, misrepresents natural fluvial processes while disregarding strong evidence for flood activity being a dominant driver of channel change.

Beschta and Ripple contend that the inverse correlation we found between elk abundance and river width indicates that habitat loss from channel widening causes elk decline. We considered this possibility but discounted it (and judged the correlation likely spurious) because the relative abundance of vegetation patches has remained relatively constant over several decades at valley scale (Latterell et al., 2006). Elk populations in western Olympic National Park drainages have declined principally near the Park boundary, consistent with an alternative explanation that forest harvesting and regeneration, as well as changes in elk, cougar, and black-bear hunting along the Park boundary, likely have affected Park elk populations since at least the 1980s (Jenkins et al. 2015).

Beschta and Ripple also assert that our study would have greater utility if we had analyzed temporal change in the Clearwater and lower Quinault Rivers outside the Park where elk density may be lower due to hunting. As our paper noted, the Clearwater and lower Quinault have important differences in physical setting, especially connection to upstream sediment delivery, that challenge any geomorphic comparisons with the Hoh, Queets, and upper Quinault Rivers. The Clearwater carries little sediment as it does not drain high alpine terrain, unlike the other rivers discussed here. The lower Quinault is sediment-deficient because Lake Quinault traps sediment (and wood) from its upper watershed (Fig. 1D; O'Connor et al., 2003). The fluvial geomorphic contrast upstream vs. downstream of the lake is reasonably attributable to sediment-supply differences rather than elk use. We respectfully suggest that spatial comparisons of rivers in any setting, not only the Pacific Northwest, are susceptible to faulty inference if all factors affecting river morphology are not critically considered.

The contrasting views on physical vs. biological influence identified by our paper and Beschta and Ripple (2008) highlight the many challenges of assessing causation in the absence of experimental control and replication, and having limited data from which to assess historical variability. Our disagreements also reflect limitations of correlative studies for assigning cause in a multicausal world. We attempted to mitigate these deficiencies by considering multiple factors that might have affected river planform. For example, after discovering that the Hoh River was unique among the rivers we examined in having become significantly more braided since the 1930s, and that the Quinault was wider than the other rivers despite having similar gradient and less discharge, we explored various explanations for these observations.

We reasoned that increased braiding on the Hoh could be caused by increased sediment supply, particularly proglacial deposits recently exposed by rapid glacial retreat. Though sediment-load measurements do not exist to confirm or refute this idea, rivers in this setting are known to become more braided when sediment supply increases (from landslides and dam removals; East et al., 2015, 2017), as is common in gravel-bed rivers. The Hoh should be more sensitive to effects of glacial retreat than other watersheds as it drains by far the greatest proportion of Olympic Mountains ice volume (Riedel et al., 2015), and recent aerial imagery shows large proglacial sediment deposits in the Hoh headwaters. Beschta and Ripple object to this possibility, stating that the long (30 km) transport distance renders proglacial deposits a less important source of sediment (and thus braiding) than bank erosion caused by riparian-vegetation loss. Although all of these rivers recruit sediment from bank, terrace and floodplain erosion, the unique braiding increase on the Hoh is not likely attributable to an unusually large recent input from those local sediment sources. Despite Beschta and Ripple's suggestion, both our analysis and their independent analysis of our GIS data show that the Hoh has widened (i.e., eroded its banks) relatively less than the Quinault and to a similar degree as the Queets River (Comment Fig. 1). Moreover, we estimate that bedload could travel 30 km from the Hoh headwaters to our study reach in only 1–2 years, given that the Elwha River moved a massive bedload pulse 22 km from the former Lake Mills reservoir to the river mouth (Fig. 1A) in ~1 year after a large dam removal, even with flows less than the 2-year flood (Warrick et al., 2015) and in a channel with lower gradient than the upper Hoh watershed.

Although Beschta and Ripple attribute excessive widening on the Quinault River to elk-induced vegetation impairment, we attributed this unusual width to anthropogenic wood and riparian-forest removal having affected the Quinault more than the other rivers (details in our paper). Even ignoring temporary narrowing of the active channel in the 1970s (our Fig. 7), the unusually great cumulative terrace retreat on the Quinault (Comment Fig. 1) is not attributable to excessive elk effects on vegetation, as Beschta and Ripple suggest, because the density of elk use is no greater on the Quinault than on the other rivers studied (Jenkins and Manly, 2008).

In summary, Beschta and Ripple argue that the observed channel changes reflect long-term riparian vegetation degradation due to elk browsing. We agree that vegetation changes have been consistent with intensive elk use historically. We do not dismiss the importance of riparian vegetation in modulating geomorphic change. But while many factors have shaped river planform, the weight of currently available evidence indicates that floods and other physical drivers have dominated geomorphic change, whereas biological drivers have been subsidiary. We see no convincing evidence that the dominance of physical drivers occurs under an umbrella of trophic-cascades influence.

It is beyond our purview to recommend for or against wolf reintroduction. However, we feel that such decisions must be based on a comprehensive evaluation of the whole system—using all available data on both physical and ecological drivers—in order not to set up excessive or mistaken expectations of the possible consequences of restoring apex predators. Moreover, failure to recognize the importance of physical factors changing river morphology minimizes the ability of managers to adapt to projected effects of changing physical processes. Hydrology and sediment supply (from glacier retreat and landslides) are forecast to be affected significantly by changing climate, necessitating continued examination of their effects on future fluvial processes and dynamics.

Figure Caption

Figure 1. A, The Olympic Peninsula, Washington, USA. Green area shows modern extent of Olympic National Park; the Olympic Mountains occupy the central portion of the Park. Dark lines indicate watershed boundaries; for clarity, river channels are shown only for the Hoh, South Fork Hoh, Queets, Quinault, and Elwha Rivers. White boxes indicate study reaches of

East et al., 2017. “Frontal” refers to small, unnamed watersheds that drain directly to the coast. B and C, Photographs showing increase in understory vegetation cover between 1986 and 2017 outside of an ungulate exclosure in the Hoh basin. Exclosure is on an alluvial terrace ~4 km inside the Park boundary and ~200 m from the South Fork Hoh River, in known elk range (black dot in A). Arrows mark location of same fencepost. D, Contrasting morphology of the Quinault River upstream vs. downstream of Lake Quinault (location of aerial image shown by black box in A), which traps sediment and wood from the upper watershed. The river above the lake is wide and braided, whereas the river below the lake is a narrower, single-thread channel. In our view, this spatial contrast is reasonably attributable to sediment-supply difference rather than difference in the intensity of elk use.

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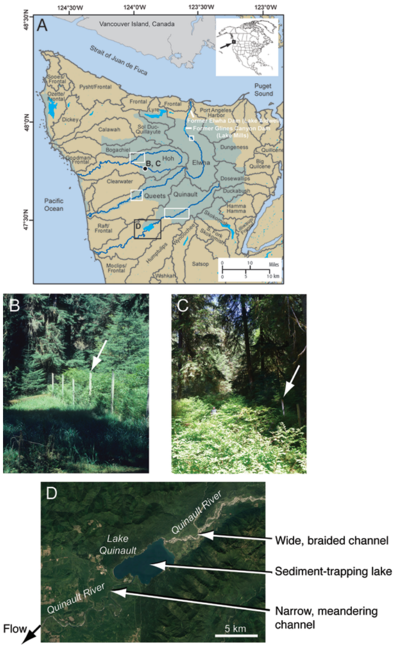

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