Glacier Retreat and Pacific Salmon

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*Glaciers have shaped past and present habitats for Pacific salmon (*Oncorhynchus *spp.) in North America. During the last glacial maximum, approximately 45% of the current North American range of Pacific salmon was covered in ice. Currently, most salmon habitat occurs in watersheds in which glacier ice is present and retreating. This synthesis examines the multiple ways that glacier retreat can influence aquatic ecosystems through the lens of Pacific salmon life cycles. We predict that the coming decades will result in areas in which salmon populations will be challenged by diminished water flows and elevated water temperatures, areas in which salmon productivity will be enhanced as downstream habitat suitability increases, and areas in which new river and lake habitat will be formed that can be colonized by anadromous salmon. Effective conservation and management of salmon habitat and populations should consider the impacts of glacier retreat and other sources of ecosystem change.*

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Glaciers are retreating rapidly across Pacific salmon (*Oncorhynchus* spp.) landscapes, driven in large part by anthropogenic climate change (figure 1; Marzeion et al. 2014). In western North America, glaciers are predicted to lose up to 80% of their ice volume by 2100 (Radić et al. 2013) and have already lost up to 3% per year between 2006 and 2016 (Zemp et al. 2019). This rapid contemporary ice loss follows longer-term glacier retreat; most glaciers in North America have been retreating since the 1600s–1800s Little Ice Age maxima (Menounos et al. 2009).

Glacier retreat can increase or decrease wild Pacific salmon productivity by modifying downstream habitat conditions and by creating new habitat. Changes in glacier runoff (i.e., all water discharged from the glacier terminus) have important downstream effects on hydrology, sediment transport, water temperature, and biogeochemical fluxes, which alter conditions for salmon in freshwater and nearshore marine habitats (O'Neel et al. 2015, Milner et al. 2017). For example, a significant decrease of glacier contribution to total watershed runoff generally increases downstream water temperature, which could be either beneficial or stressful to salmon. In cold rivers (below 5 degrees Celsius [°C]), increases in water temperature could increase juvenile salmon growth potential (Fellman et al. 2014), whereas in warm rivers (more than 15°C), increases in water temperature could increase stress and mortality rates of adult salmon as they migrate upstream (Martins et al. 2012).

Glacier retreat can also directly create new habitat for salmon. For example, in Glacier Bay, Alaska, tidewater glacier retreat created new river systems that were colonized by pink salmon (*Oncorhynchus gorbuscha*) within 30 years of formation (Milner et al. 2011). Therefore, glacier change can affect salmon ecosystems through a variety of mechanisms (Moore et al. 2009, O'Neel et al. 2015, Milner et al. 2017). Overall, the net effects of glacier retreat on salmon will likely depend on the phase of glacier retreat, the life-history traits of salmon species, and a suite of local environmental, geographic, and ecological characteristics of watersheds.

Understanding how glacier retreat will affect Pacific salmon will help inform the management and conservation of these economically and culturally important species. There is growing understanding of the pathways by which glacier retreat alters aquatic environments (O'Neel et al. 2015, Milner et al. 2017) and a large body of research on how environmental variables influence salmon across their life cycle (Quinn 2018). By integrating these two fields of study, we offer a conceptual synthesis of how glacier retreat may affect Pacific salmon populations in North America and how these effects may vary by species and watershed context. Specifically, we review the historical interaction of glaciation and Pacific salmon in North America over geological time scales, propose a conceptual model for the evolution of salmon watersheds in response to glacier retreat, quantify the current status of glaciers in salmon watersheds, propose research frontiers, and highlight implications of glacier loss for salmon management and policy.

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