Beaver: The North American freshwater climate action plan

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PERSPECTIVE

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Beaver: The North American freshwater climate action plan

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Abstract

Rivers and streams, when fully connected to their floodplains, are naturally resilient systems that are increasingly part of the conversation on nature-based climate solutions. Reconnecting waterways to their floodplains improves water quality and quantity, supports biodiversity and sensitive species conservation, increases flood, drought and fire resiliency, and bolsters carbon sequestration. But, while the importance of river restoration is clear, beaver-based restoration—for example, strategic coexistence, relocation, and mimicry—remains an underutilized strategy despite ample data demonstrating its efficacy. Climate-driven disturbances are actively pushing streams into increasingly degraded states, and the window of opportunity for restoration will not stay open forever. Therefore, now is the perfect time to apply the science of beaver-based low-tech process-based stream restoration to support building climate resilience across the landscape. Not every stream will be a good candidate for beaver-based restoration, but we have the tools to know which ones are. Let us use them.

This article is categorized under:

- Science of Water > Hydrological Processes
- Water and Life > Nature of Freshwater Ecosystems
- Water and Life > Conservation, Management, and Awareness

KEYWORDS

beaver, climate change, floodplain connectivity, process-based restoration, water security, wildfire

1 | INTRODUCTION: BEAVERS, THE CLIMATE ACTION PLAN

Low-tech process-based stream restoration (LTPBR)—a suite of simple, low-cost practices focused on floodplain reconnection—is rapidly gaining traction in the face of looming climate and biodiversity crises (Ciotti et al., 2021;

The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect the views of NOAA or the Department of Commerce.

Davee et al., 2019; Davis et al., 2021; Johnson et al., 2019; Keeble-Toll, 2018; Munir & Westbrook, 2020; Pearce et al., 2021a, 2021b; Silverman et al., 2019; Wade et al., 2020; Weber et al., 2017; Wheaton et al., 2019). Though the implementation of these methods has a strong theoretical and technical foundation, skepticism lingers—particularly about the efficacy of hand-built, beaver-inspired structures, and beaver coexistence. In particular, recent publications have called into question the practicality of achieving watershed-scale changes through beaver landscape modifications or anthropogenic beaver mimicry (Nash et al., 2018; Nash et al., 2021; Pilliod et al., 2017). This is despite countless of years of Indigenous knowledge on sustainable riparian and beaver management (Albert & Trimble, 2000; Blackfeet Nation, 2018; Blackfeet Nation & Levitus, 2019; Feit, 1986; Gadgil et al., 1993; Keeble-Toll, 2018; Kimmerer, 2000; Kimmerer & Lake, 2001; Sherriff, 2021) and over a century of published data, experiments and analyses (Ives, 1942; Morgan, 1868; Neff, 1957; Ruedemann & Schoonmaker, 1938; Seton, 1929) documenting enhanced hyporheic engagement (Briggs et al., 2013; Janzen & Westbrook, 2011; X. Wang et al., 2018), improved water quality (Cornell et al., 2011; Lazar et al., 2015; Puttock et al., 2017, 2018; Shepherd & Nairn, 2020, 2021), naturalized flow timing (Burchsted et al., 2010), failure of traditional engineering approaches to restoration (D. M. Thompson & Stull, 2002), and wildfire resilience (Fairfax & Whittle, 2020; Foster et al., 2020; Weirich, 2021; Whipple, 2019). Fully floodplain-connected, beaver-occupied riverscapes (Brazier et al., 2021; Larsen et al., 2021) are natural process domains we can no longer afford to ignore.

It may seem trite to say that beavers are a key part of a national climate action plan, but the reality is that they are a force of 15–40 million (Naiman et al., 1988) highly skilled environmental engineers. We cannot afford to work against them any longer; we need to work with them. In most cases, the first step will be starting the physical restoration process before beavers move into a system—setting the stage for functioning floodplain processes (flow, space, structure; Beechie et al., 2010, Cluer & Thorne, 2014, Wheaton et al., 2019). Human intervention may be necessary to restore severely impacted floodplain processes to the point at which beavers and beaver mimicry can be applied (e.g., deeply incised channels, ongoing disruptive land-use practices). In other situations, our first step may be policy changes: for example, if floodplains are intact, but beaver management actions (e.g., the lethal removal of beavers that impact the built environment) prevent population persistence sufficient to further recover these landscapes. Regardless of our role in the conversation, beaver inspired or implemented process-based restoration should be a primary strategy to achieving healthy riverscapes (Macfarlane et al., 2015; Pollock et al., 2015). A stream where beavers thrive is a resilient, productive stream (Pollock et al., 2014). Flourishing beaver populations can be our partner in combating climate change and a bellwether of our progress.

2 | RIVERSCAPE RESTORATION IS THE LOW-HANGING FRUIT

A changing climate amplifies the impacts of impaired riverscapes: more frequent extreme precipitation events in over-capacity channels lead to more flooding (Stott, 2016); increasing air temperature and drier conditions stress valley-bottom vegetation already isolated from hyporheic aquifers, driving wildfires into "megafires" (Finco et al., 2012; Goss et al., 2020; Mori & Johnson, 2013; Swain, 2021; J. Williams, 2013; A. P. Williams et al., 2019); and snow-driven flow regimes shifting to rain-driven bring lower, warmer base-flows and further degraded biotic conditions (Beechie et al., 2013). However, we are not developing riverscape-scale nature-based climate action strategies (Skidmore & Wheaton, 2022). Restoring floodplain connectivity and function is both a climate change mitigation and adaptation strategy because it reverses degradation and recovers natural resilience (Johnson et al., 2019; Pollock et al., 2015; Silverman et al., 2019; Wheaton et al., 2019). Natural riverscape resilience is only achieved through a restoration of floodplain processes (Cluer & Thorne, 2014), not the engineering or imposition of form (ELI, 2016).

The US EPA's latest assessment rates the flowing waters of the United States (CONUS only) as being in less than good condition (e.g., 25%–50% in poor condition; USEPA, 2013). Human activity has drastically reduced floodplain connectivity across the continent, converting valley spanning wetlands to narrow riparian corridors. For example, in the Sacramento Valley of California, riparian forests on well-connected floodplains have been reduced from 24% to less than 0.5% of the land area (Sands & Howe, 1977). Our activities over the last two centuries have reduced active floodplain area by an order of magnitude and degraded half the flowing waters in the United States. Human degradation of riverscapes, left unchecked, creates positive feedback cycles of further degradation under a changing climate (Figure 1). However, beaver-based restoration creates profound opportunities for initiating positive feedback cycles and increasing riverscape resilience.

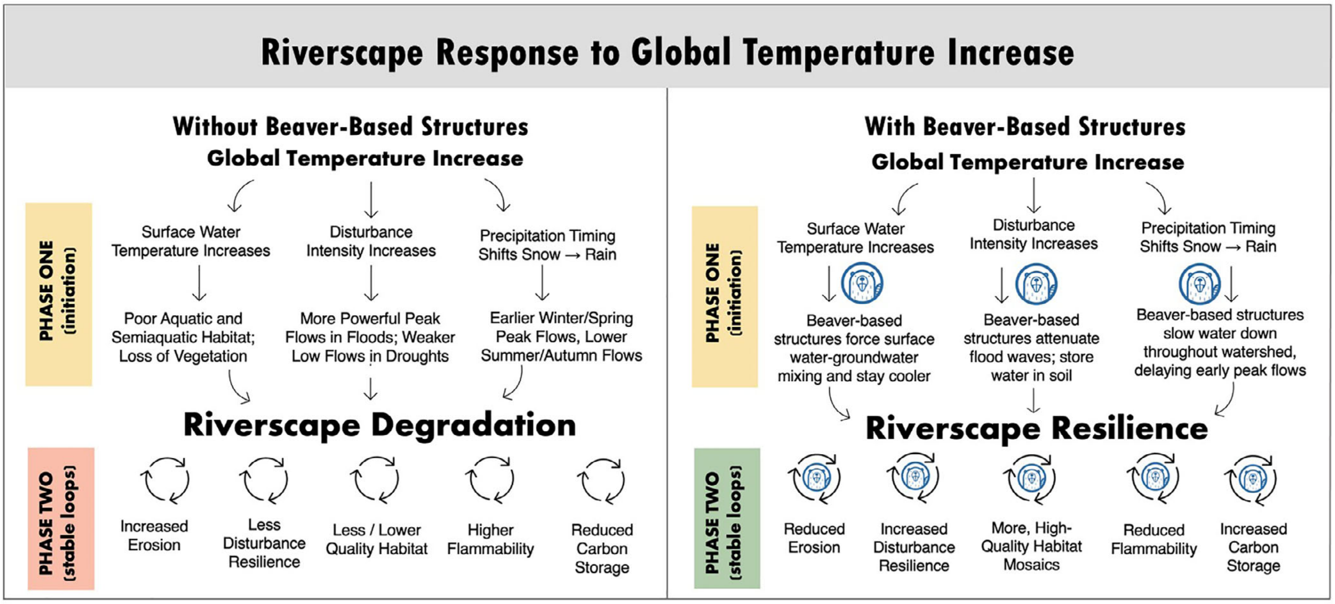

FIGURE 1 Comparison of riverscape feedback cycles with increased global temperature. Phase 1 indicates processes that are initiated by warming global temperatures and lead to either degradation or resilience. Phase 2 indicates processes that occur once riverscapes have already reached a degraded or resilient state. Left: Cycle of increasing riverscape degradation occurring without beaver or beaver mimicry. Right: Cycle of maintained riverscape resilience that can be achieved by partnering with beaver and utilizing beaver-based designs

3 | THE INTERCONNECTED BIOLOGY, HYDROLOGY, AND GEOMORPHOLOGY OF FLOODPLAIN RESILIENCE

Watersheds are typically described by the physical aspects (e.g., flow direction and rate, area, gradient, precipitation, geology) that are thought to drive all characterizing properties (Kasprak et al., 2016). However, watersheds are much more than the sum of their physical properties (Fausch et al., 2002). Watersheds, as riverscapes, are energetically rich, dynamic, bio-geomorphic systems. In temperate mesic climate zones, riverscapes have up to six orders of magnitude more potential energy (chemical) stored in organic material (both live and in the decomposer cycle) than the potential energy (physical) of the in-channel flow (Phillips, 2016). Connected floodplains are more productive than disconnected floodplains in part because of their ability to retain and extract the chemical potential energy of the watershed's biotic (organic) components (Puttock et al., 2018; Wegener et al., 2017). Functioning floodplains are connected because plan-form and longitudinal structures increase resistance to surface water movement, force water up onto floodplain surfaces, and form a diversity of flow paths across the entire valley-bottom (Pollock et al., 2014; Wheaton et al., 2019). This in-channel and across-floodplain hydraulic roughness dissipates flow energy, keeping the transport-deposition balance more to the deposition side, but more importantly, increasing the residence time of surface and hyporheic aquifer water, thereby shortening the length scales of nutrient spirals and increasing ecosystem productivity (Briggs et al., 2013; Helton et al., 2014). Connected-floodplain systems are hydrologically inefficient, a necessary, but often overlooked characteristic.

Many impaired streams, rivers, and associated floodplains are in a state that is physically stable, but simplified and degraded (Cluer & Thorne, 2014). Connected-floodplain systems are dynamic (Naiman et al., 2010). They are in a quasi-equilibrium state across many forcing processes, and thus are inherently more resilient to disturbance than impaired streams (Silverman et al., 2019; Wohl, 2021a; Wohl et al., 2017, 2021). But, maintaining the quasi-equilibrium condition of a connected floodplain requires continual energetic input. This situation is similar to many well-studied coastal marine bio-geomorphic systems—including fringing coral reefs, mangrove swamps, and salt marshes—systems driven by the physics of waves, tidal currents and flowing freshwater, but forced by their biological components (Alongi, 2008; Dame & Patten, 1981; Johnson et al., 2019; Pethick, 1992).

In bio-geomorphic systems, plants and animals form structures that modify the physical environment, resulting in a more productive ecosystem (biomass generated per unit area per unit time) than the same location would be without the structure (Viles, 1988; C. Wang et al., 2020). However, once a bio-geomorphic system has been degraded, it does not take much to keep it that way (Castro & Thorne, 2019). Restoring high-energy, simplified systems requires re-establishing the biological control of the geomorphic setting (Johnson et al., 2019). In floodplains many of the most important sources of external energy are biological inputs, including organic material deposition, vegetation growth, and beaver dam building. Therefore, embracing ecosystem engineers like beaver is the fast track to low-cost, high-impact sustainable riverscape connectivity (Brazier et al., 2021; Dittbrenner et al., 2018; Johnson et al., 2019; Pollock et al., 2007, 2014).

4 | BENEFITS OF FLOODPLAIN-CONNECTED RIVERS IN A WARMING WORLD

Restoring and reconnecting floodplains clearly provides a myriad of benefits. A floodplain-connected valley is inherently more diverse and productive, not only for aquatic species, but across the entire floodplain (Bellmore & Baxter, 2014). On the seasonally wet floodplain surface, vegetation productivity and plant and animal species richness and diversity are higher than on a disconnected, permanently dry terrace (Stella et al., 2011). In the channels of a connected floodplain reach, primary productivity is higher, macroinvertebrate communities are richer and more productive (Nummi et al., 2021; Robinson et al., 2020), and amphibian and fish productivity is higher (Anderson et al., 2015; Bouwes et al., 2016; Dauwalter & Walrath, 2018; Romansic et al., 2021; Wathen et al., 2019) than in simple channels of a disconnected reach. But, while these internal benefits are independently valuable, they are only a small fraction of the potential benefits that restored riverscapes can provide in the face of climate change. When we reconnect streams and rivers to their floodplains, we perform both climate mitigation work (slowing/stopping the trajectory of global warming) and climate adaptation work (building resilience and resistance to climate-driven disturbances that are already occurring; see Table 1).

4.1 | Slow water—flood, drought, and fire resilience

A diversity of water residence times in a river system enhances the riverscape's ability to attenuate peak flows during wet periods and release stored water as base flow during dry periods, simultaneously mitigating against both drought and flood (Fairfax & Small, 2018; G. A. Hood & Bayley, 2008; G. A. Hood & Larson, 2015; Puttock et al., 2021; Westbrook et al., 2006, 2020). This also helps keep water in the soil during periods of prolonged drought, where it is accessible to riparian vegetation (Amlin & Rood, 2003; Dittbrenner et al., 2018; Fairfax & Small, 2018; Puttock et al., 2021; Silverman et al., 2019; Vivian et al., 2014). However, floodplain-connected riverscapes function as speed bumps to fire spread because the soil, vegetation, and stream channels are wet throughout, and thus do not readily burn (Fairfax & Whittle, 2020; Weirich, 2021; Whipple, 2019; Wohl et al., 2022). Therefore, long stretches of restored floodplains could function as a network of firebreaks, slowing the spread of wildfires and giving humans time to contain runaway wildfires before they reach a dangerous, out-of-control state (Fairfax & Whittle, 2020).

4.2 | Clean, cool water—bolstered aquatic biodiversity

Floodplain-connected riverscapes have more large wood (loose wood, logjams) both on the ground and in the channel. Woody deposits in general increase the physical forcing of stream and floodplain structure and increase water residence time and primary productivity at the floodplain surface (Appling et al., 2014; Briggs et al., 2013; Collins et al., 2012; Helton et al., 2014; Magilligan et al., 2008; Osei et al., 2015; Poole et al., 2008). But, beaver-managed vegetation and stream hydraulic modification (dams, lodges, canals) function similarly, because they directly increase hydraulic diversity and vegetation productivity (Silverman et al., 2019). Thus, hydraulic inefficiency, no matter the source, results in longer water residence time and increased nutrient cycling, which in turn enhances biological productivity across all trophic levels.

Wetlands, inundated floodplains, deep pools, and other areas of slow water within riverscapes help sink out and process common aquatic pollutants such as nitrates, phosphates, metals, and excess sediments (Klotz, 1998, 2010; Kroes & Bason, 2015; Maret et al., 1987; Muskopf, 2007; Puttock et al., 2017, 2018; Shepherd & Nairn, 2020, 2021; Short et al., 2015). Some pollutants bind onto fine sediments which remain suspended in the water column until reaching

TABLE 1 Briefly summarizes how connected- and disconnected-floodplain riverscapes generally respond to several key aspects of climate change (with abbreviated selected references)

	Disconnected floodplains	Connected floodplains	Abbreviated selected references
Water temperature (adaptation)	Homogenous, warmer	Heterogenous, cooler	Majerova et al., 2015, Weber et al., 2017, Dauwalter & Walrath, 2018; Lowry, 1993, Romansic et al., 2021
Carbon (mitigation)	Lower sequestration potential	Higher sequestration potential	Wohl, 2013, Laurel & Wohl, 2019
Floods (adaptation)	Low capacity to accommodate flood waves, higher erosion rates on channel banks from more powerful peak flows	High capacity to accommodate flood waves, lower erosion on channel banks from dissipated peak flows	Westbrook et al., 2006, Westbrook et al., 2020, Puttock et al., 2021
Droughts (adaptation)	Low capacity to maintain primary productivity during extended dry periods	High capacity to maintain primary productivity during extended dry periods	G. A. Hood & Bayley, 2008, Fairfax & Small, 2018, Dittbrenner et al., 2018
Fires (adaptation)	Higher fuel flammability. Loss of riparian vegetation leads to intense post-fire debris entering river from surrounding area	Lower fuel flammability. Intact riparian vegetation slows debris entering river from surrounding area. In-stream structures trap sediment and aggrade within channel, reversing prior channel incision	Fairfax & Whittle, 2020, Wohl et al., 2022, Weirich, 2021, Whipple, 2019

low velocity reaches. Once these fine sediments are either deposited on the floodplain or settled at the bottom of ponds and wetlands, naturally occurring biogeochemical processes transform potent nutrients (e.g., nitrate) into inert compounds (e.g., gaseous nitrogen) or facilitate re-uptake in aquatic vegetation (Yousaf et al., 2021). But, systematic approaches to nature-based riverscape-scale pollution mitigation are lacking, and re-establishing the natural biogeochemical balance of recently restored stream-wetland systems takes time (Weigelhofer et al., 2018). Therefore, structures within streams and rivers, such as natural or artificial beaver dams or better floodplain connection can serve as a network-wide natural mitigation tactic. For example, implementation of LTPBR, especially Beaver Dam Analogs (BDAs), is gaining popularity as a post-fire, land-management strategy to attenuate post-fire debris flows and reduce the suspended ash and soot in the water column (Short et al., 2015).

Many aquatic species have strict water temperature requirements that are regularly exceeded as the climate warms. Structures within rivers, whether human built bio-geomorphic mimics (e.g., Post-Assisted Log Structure [PALS, BDAs]) or naturally occurring (beaver dams, woody debris), generate vertical hydraulic pressure gradients, forcing some of the streamflow down through the river bottom and into the hyporheic zone (Munir & Westbrook, 2020; Scamardo & Wohl, 2020; Wade et al., 2020). There, warm surface water and typically cooler subsurface water can mix before returning to the river downstream (Weber et al., 2017). The residence time of water on these flow paths varies; as a result, so does the temperature of the water as it returns to the river. However, the resulting highly heterogeneous thermal profile of the riverscape supports a variety of aquatic life with different temperature needs (Dauwalter & Walrath, 2018; Lowry, 1993; Majerova et al., 2015, 2020; Romansic et al., 2021). Therefore, in-stream structure, or connected floodplains are a critical component of naturally functioning riverscapes.

4.3 | Complex water pathways—carbon storage and habitat mosaics

Hydrologically complex riverscapes provide a diversity of intermingled habitats that support a vast array of plant and animal species. Naturally occurring beaver dam complexes are uniquely rich and varied components of riverscapes that contain highly heterogeneous water velocities, temperatures, depths, vegetation communities, and geomorphic structures within relatively small areas of the riverscape (Larsen et al., 2021; Rosell et al., 2005; Stringer & Gaywood, 2016). This heterogeneity results in particularly diverse and resilient habitats and is a large part of why beavers are keystone species (Hammerson, 1994; Naiman et al., 1986; Naiman et al., 1988; Pollock et al., 1995). But, this key bio-fluvial component of riverscapes is rare because a long history of anthropogenic impacts has simplified and disconnected streams from their floodplains (Fouty, 2018). Therefore, floodplain reconnection is often invoked to improve the quantity and quality of physical and biological habitat characteristics needed by fish, amphibians, waterfowl, and other aquatic and semi-aquatic species (Anderson et al., 2015; Baldwin, 2015; Dauwalter & Walrath, 2018; W. G. Hood, 2012; Kauffman et al., 1997; McKinstry et al., 2001; Pollock et al., 2004; Romansic et al., 2021; Snodgrass & Meffe, 1998; Wathen et al., 2019; Wohl, 2021b; Wohl et al., 2021).

The complexity of floodplain-connected rivers increases carbon storage via several mechanisms, including bolstered sequestration in riparian forests and enhanced deposition of organic-rich sediments and deposits of fibrous carbon in periodically and regularly flooded environments (Laurel & Wohl, 2019). But, beaver dam-building activity can increase carbon storage even further via additional streamflow velocity reduction, regular tree coppicing, the expansion of periodically flooded land area, and the frequent inundation of between 10% and 30% of the valley bottom at baseflow. Even relic/inactive beaver-dammed areas store significantly more carbon than those without a recent history of beaver. Recent research indicates that grasslands (which often replace riparian forest in degraded river systems) store on average 40–100 metric tons of carbon per hectare while active and inactive/relic beaver complexes store 1150–1400 and 300–400 metric tons of carbon per hectare, respectively (Wohl, 2013). However, the complete carbon budget of beaver modified floodplains is a spatially and temporally complex balance. Carbon locked up in dead standing vegetation and in organic material deposited in the stream and pond bed is offset by CO_2 and CH_4 emissions from the decomposer cycle. Though not well documented, the net balance is estimated to range from source to sink, depending on pond age, temperature, and soil and vegetation type (Nummi et al., 2018). Thus, riverscape restoration, particularly floodplain restoration with beaver, can support a significant increase in landscape carbon storage, and provide climate mitigation as well as adaptation benefits, though questions remain regarding the factors mediating net carbon storage and thus our ability to design and generalize across all settings.

4.4 | Floodplain dynamics

Overstory vegetation drives photosynthetically active radiation (PAR) levels at the surface of the floodplain terraces and in the stream channels. PAR levels, mediated by nutrient availability, determine the rates of primary productivity on the floodplain surface and in the stream channel. As such, a closed riparian forest canopy is less productive than a multi-level, diverse vegetation stature riparian floodplain plant assemblage of floodplain plants of diverse stature (Ecke et al., 2017). A mature, large-stature riparian plant assemblage only develops on a low disturbance, stable floodplain surface which, in turn, exists when channel migration and braiding rates are minimal. However, channel migration and braiding rates are reduced by processes that stabilize channel location, such as incision and deep, strong plant root growth (Hawley & MacMannis, 2019). Thus, a maximally productive riparian plant assemblage is one with a range of height and structure that tolerates disturbance due to channel migration and formation. But, beaver are also a key structuring agent for floodplain plants (Johnson et al., 2019; Westbrook, 2021). Beaver browse pressure selects for riparian plant species that tolerate the removal of stems, sprouts, or branches. Many browse-adapted plant species are more productive under browse pressure than not. Thus, beavers strongly alter stream and floodplain hydraulics through the digging of beaver canals, tunnels and burrows, and the constructions of dams, food caches, and lodges (G. A. Hood & Larson, 2015).

4.5 | Ecosystem services

Should we entrust a large rodent with such critical environmental engineering tasks? If restoring riverscapes is really such an important piece of our national climate action plan, should not we do it ourselves? Ultimately, the scale of changes that need to occur are beyond what we can accomplish and maintain on our own. However, beaver-based riverscape restoration has a high return on investment in both revenue and expense control (Baldwin, 2015; Blackfeet Nation, 2018; Blackfeet Nation & Levitus, 2019; Pollock et al., 2015; S. Thompson et al., 2021; Wheaton et al., 2019). Revenue generation typically results from increased tourism and outdoor recreation (e.g., hunting, fishing, hiking, camping, wildlife viewing), while expense reduction from lower expenditures in disaster mitigation, carbon management, water quality assurance, and water conservation. These ecosystem services by beaver, as well as many others not discussed in detail here, is estimated at $69,000 per square kilometer, per year (S. Thompson et al., 2021). Secondary economic benefits of utilizing beaver coexistence and beaver mimicry in riverscape restoration would help offset the already low cost of implementing beaver mimicry and managing human–beaver conflict (Boyles & Savitzky, 2009).

4.6 | Overcoming institutional constraints to beaver-based restoration

Our fish, water, and forests depend on our willingness to act. We cannot just continue to study the situation without also taking action. There is absolutely more research that needs to be done to optimize and quantify beaver-based restoration impacts across all spatial and temporal scales. In an ideal world, we could wait to act until every last detail was sorted out. However, given the trajectory of climate change and increasingly threatened water resources we simply do not have that kind of time. Thus, we should implement, and continue to study, process-based methods in degraded streams across the continent, now. We should start rewriting our beaver management policies today to actively support coexistence over lethal management so that if and when beavers arrive in a riverscape they can thrive. We should proactively educate wildlife managers, land managers, and the public about the incredible value that these ecosystem engineers bring to our communities. Science and practice can, and should, go hand-in-hand.

There are certainly barriers that stand in the way of implementing beaver-based restoration. In the United States, high-level economic questions linger about the legality of water rights on beaver-impacted streams and the economics of stream restoration credits and whether beaver-created wetlands would count toward those. On a more fundamental sociocultural level, landowners worry that beavers will cut down all the trees, flood the roads, introduce waterborne diseases, and eat threatened fishes if they are allowed to recolonize streams. Some of these worries are founded in reality, for example, beavers do cut down trees, but they will not cut down all of them and there are non-lethal management strategies like wire-wrapping to protect important trees. However, some of these worries are founded in myth, for example, beavers are herbivores and do not eat fish. Understanding the conflicts—both real and perceived—between beavers, humans, and human infrastructure is a critical step for successfully developing and promoting effective coexistence strategies (Auster et al., 2019; Auster et al., 2021; Auster et al., 2022; Charnley et al., 2020; McKinstry & Anderson, 1999; Siemer et al., 2013). Continued education and outreach efforts are key to incentivize beaver-based restoration work (Morzillo & Needham, 2015).

Questions linger on the physical and ecological impacts of beaver-based restoration as well. For example, it is not entirely clear whether the impacts of beaver-based restoration will produce a linear or nonlinear response in the landscape when done at larger scales than researchers have previously examined. The different configurations and constructions of BDAs are still being tested and compared against one another (Davis et al., 2021; Munir & Westbrook, 2020), and more research is needed to determine the optimal configurations for a specific site. There is no clear consensus on how to maximize the chances of success when performing beaver relocation—how to live-trap the beavers, how long to quarantine them, whether or not the relocation site is intentionally prepared or not, if the impacts of relocated beavers versus in situ beavers differ, are all important considerations, with relatively little rigorous research published in the scientific literature (Dittbrenner et al., 2018; McCreesh et al., 2019; McKinstry et al., 2001). These unknowns are valid, but they should not completely paralyze beaver-based river restoration efforts. Not every stream will have these issues, and not every project needs to achieve fully optimized maximum restoration on the first attempt. Small restoration gains are better than no restoration gains, and from a precautionary, risk mitigating perspective, incremental progress has enormous value. Focusing beaver-based restoration efforts on streams and rivers with the lowest potential for human conflict and highest potential for restoration gains is a prudent path forward. There are so many streams and rivers that need restoration—it will take time to complete just the simplest, most straightforward projects. But, as projects progress, more data can and will be collected to inform future projects. This is the nature of science and land management in general, and applying this philosophy to beaver-based restoration is not a radical idea.

5 | CONCLUSION: WE NEED (NATURE'S) ENGINEERS

To return the full process-based functionality of connected floodplain systems we must acknowledge the critical role that biological components play—particularly beaver. When we remove beaver from streams and rivers, or prevent them from re-establishing in their ancestral watersheds, the stream-floodplain system falls into disrepair (Wohl, 2021b). Once they are disconnected from their floodplain, down-cut, incised streams simplify into single-threaded channels.

Sediment and carbon are exported from long-term storage, water warms and becomes eutrophic, the landscape dries out and fires run for miles across a uniform expanse of fuel, all leaving little in the way of healthy habitat for fish and wildlife. But, beaver managed floodplains are biodiversity hotspots because beaver ponds and wetlands serve as sinks for carbon, processing centers for nitrogen and phosphorus, reservoirs for the storage and cooling of water, and mitigation sites for both drought and flooding. Thus, it is imperative that we foster beaver-dominated areas for the many services they provide.

We need to apply our knowledge of the physical and biological processes of functioning riverscapes and the role that beavers play to drive rapid, comprehensive, and durable action. Actions that address the pervasive degradation of North America's streams, rivers, and floodplains. Actions that rebuild the natural, functioning dynamics of riverscapes to permit robust responses to disturbance. Riverscape restoration, and in particular process-led and beaver-based restoration, should be the foundation of our national freshwater climate action plan.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Chris E. Jordan: Conceptualization (equal); project administration (equal); writing – original draft (equal); writing – review and editing (equal). **Emily Fairfax:** Conceptualization (equal); project administration (equal); writing – original draft (equal); writing – review and editing (equal).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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