Beavers, BDAs and Climate Change Mitigation

10 Data-driven facts showing how restoring rivers and streams with beavers and Beaver Dam Analogues (BDAs) can provide many wide ranging benefits for climate change mitigation.

1. **Carbon sequestration** - Beaver and BDA restored rivers and streams connected to the floodplain hold significantly more carbon than degraded rivers and streams, as well as grasslands. Active beaver complexes hold on average 10-30 times more carbon than grasslands.

    A. Yarnell, S.M., K. Pope, E.C. Wolf, R. Burnett, and K. Wilson. 2020. A Demonstration of the carbon sequestration and biodiversity benefits of beaver and beaver dam analogue restoration techniques in Childs Meadow, Tehama County, California. Center for Watershed Sciences Technical Report (CWS-2020-01), University of California, Davis. Prepared for CA Department of Fish and Wildlife. pp. 29.

    B. Wohl, E., Lininger, K. B., & Scott, D. N. (2017). River beads as a conceptual framework for building carbon storage and resilience to extreme climate events into river management. *Biogeochemistry*, **141**(3), 365–383.

    C. Laurel, D., & Wohl, E. (2019). The persistence of beaver-induced geomorphic heterogeneity and organic carbon stock in river corridors. Earth Surface Processes and Landforms, 44(1), 342–353.

    D. Wohl, E. (2013). Landscape-scale carbon storage associated with beaver dams. Geophysical Research Letters, 40(14), 3631–3636.

    E. Nummi, P., Vehkaoja, M., Pumpanen, J., & Ojala, A. (2018). Beavers affect carbon biogechemistry: Both short-term and long-term processes are involved. Mammal Review, 48(4), 298–311.

    F. Baldwin, J. (2015). Potential mitigation of and adaptation to climate-driven changes in California's highlands through increased beaver populations. California Fish and Game, 101(4), 218–240.

2. **Biodiversity** - Beaver and BDA restored rivers and streams support increased biodiversity and richness of plant and animal species.

    A. Romansic, J. M., Nelson, N. L., Moffett, K. B., & Piovia-Scott, J. (2021). Beaver dams are associated with enhanced amphibian diversity via lengthened hydroperiods and increased representation of slow-developing species. *Freshwater Biology*, **66**(3), 481–494.

    B. Silverman, N. L., Allred, B. W., Donnelly, J. P., Chapman, T. B., Maestas, J. D., Wheaton, J. M., & White, J. (2019). Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. *Restoration Ecology*, **27**(2), 269–278.

    C. Pollock, M. M., Castro, J., Jordan, C. E., Lewallen, G., & Woodruff, K. (2015). The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains (Version 1.02) (p. 189). United States Fish and Wildlife Service.

    D. Bellmore, J. R., & Baxter, C. V. (2014). Effects of geomorphic process domains on river ecosystems: A comparison of floodplain and confined valley segments. *River Research and Applications*, **30**(5), 617–630.

E. Stella, J. C., Hayden, M. K., Battles, J. J., Piégay, H., Dufour, S., & Fremier, A. K. (2011). The role of abandoned channels as refugia for sustaining pioneer riparian forest ecosystems. *Ecosystems*, **14**(5), 776–790.

F. Robinson, C. T., Schweizer, P., Larsen, A., Schubert, C. J., & Siebers, A. R. (2020). Beaver effects on macroinvertebrate assemblages in two streams with contrasting morphology. *Science of the Total Environment*, **722**, 137899.

G. Yarnell, S.M., K. Pope, E.C. Wolf, R. Burnett, and K. Wilson. 2020. A Demonstration of the carbon sequestration and biodiversity benefits of beaver and beaver dam analogue restoration techniques in Childs Meadow, Tehama County, California. Center for Watershed Sciences Technical Report (CWS-2020-01), University of California, Davis. Prepared for CA Department of Fish and Wildlife. pp. 29.

3. **Water Quantity** - Beaver and BDA restored rivers and streams support increased surface water storage, groundwater connectivity and recharge, and duration of surface water flow.

A. Burchsted, D., Daniels, M., Thorson, R., & Vokoun, J. (2010). The river discontinuum: Applying beaver modifications to baseline conditions for restoration of forested headwaters. *Bioscience*, **60**(11), 908–922.

B. Pollock, M. M., Castro, J., Jordan, C. E., Lewallen, G., & Woodruff, K. (2015). The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains (Version 1.02) (p. 189). United States Fish and Wildlife Service.

C. Thompson, S., Vehkaoja, M., Pellikka, J., & Nummi, P. (2021). Ecosystem services provided by beavers *Castor* spp. *Mammal Review*, **51**(1), 25–39.

D. Jordan, C. E., & Fairfax, E. (2022). Beaver: The North American freshwater climate action plan. *Wiley Interdisciplinary Reviews: Water*, e1592.

E. Pollock, M. M., Beechie, T. J., Wheaton, J. M., Jordan, C. E., Bouwes, N., Weber, N., & Volk, C. (2014). Using beaver dams to restore incised stream ecosystems. *BioScience*, *64*(4), 279-290.

F. Helton, A. M., Poole, G. C., Payn, R. A., Izurieta, C., & Stanford, J. A. (2014). Relative influences of the river channel, floodplain surface, and alluvial aquifer on simulated hydrologic residence time in a montane river floodplain. *Geomorphology*, **205**, 17–26

4. **Water Quality** - Beaver restored areas improve the water quality of the river or stream as well as lessen the pollutants that make it to the ocean. Beaver ponds create slow water to settle out pollutants such as heavy metals and excess nutrients. Then the beaver dams force water underground, binding pollutants to the soil where natural decomposition processes can convert excess nutrients.

A. Cornell, R., Andronescu, A., & Nguyen, K. (2011). *The effects of beaver dams on water quality and habitat*. Dept. of Earth and Atmospheric Sciences, Metropolitan State College of Denver.

B. Puttock, A., Graham, H. A., Cunliffe, A. M., Elliott, M., & Brazier, R. E. (2017). Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. *Science of the Total Environment*, **576**, 430–443

C. Puttock, A., Graham, H. A., Carless, D., & Brazier, R. E. (2018). Sediment and nutrient storage in a beaver engineered wetland. *Earth Surface Processes and Landforms*, **43**, 2358–2370.

D. Shepherd, N. L., & Nairn, R. W. (2020). Metals retention in a net alkaline mine drainage impacted stream due to the colonization of the North American beaver (*Castor canadensis*). *Science of the Total Environment*, **731**, 139203.

E. Induced mobilization of stored metal precipitates from beaver (*Castor canadensis*) created wetlands on a mine drainage impacted stream. *Wetlands Ecology and Management*, **30**, 127–137.

F. Lazar, J. G., Addy, K., Gold, A. J., Groffman, P. M., McKinney, R. A., & Kellogg, D. Q. (2015). Beaver ponds: Resurgent nitrogen sinks for rural watersheds in the northeastern United States. *Journal of Environmental Quality*, **44**(5), 1684–1693.

5. **Fire resiliency** - Beaver and BDA restored rivers and streams are proven to show enhanced fire resiliency, often creating large wetted areas that will not burn, thus creating fire refuge for wildlife. A restored river or stream network can also act as a fire break. Furthermore, restored streams aid in post-fire recovery - settling out harmful ash.

A. Fairfax, E., & Whittle, A. (2020). Smokey the beaver: Beaver-dammed riparian corridors stay green during wildfire throughout the western United States. *Ecological Applications*, **30**(8), 1–8.

B. Foster, C. N., Banks, S. C., Cary, G. J., Johnson, C. N., Lindenmayer, D. B., & Valentine, L. E. (2020). Animals as agents in fire regimes. *Trends in Ecology & Evolution*, **35**(4), 346–356.

C. Weirich, J. J. (2021). Beaver moderated fire resistance in the north cascades and potential for climate change adaptation (Masters thesis collection 660). Eastern Washington University.

D. Whipple, A. (2019). Riparian resilience in the face of interacting disturbances: Understanding complex interactions between wildfire, erosion, and beaver (Castor canadensis) in grazed dryland riparian systems of low order streams in North Central Washington State, USA (Masters thesis collection 586). Eastern Washington University.

E. Wohl, E., Marshall, A. E., Scamardo, J., White, D., & Morrison, R. R. (2022). Biogeomorphic influences on river corridor resilience to wildfire disturbances in a mountain stream of the Southern Rockies, USA. *Science of the Total Environment*, **820**, 153321.

F. Short, L. E., Gabet, E. J., & Hoffman, D. F. (2015). The role of large woody debris in modulating the dispersal of a post-fire sediment pulse. *Geomorphology*, **246**, 351–358.

6. **Water temperature** - Beaver dams and Beaver Dam Analogues (BDAs) drive surface water-groundwater interactions, cycling warmer surface water with colder groundwater, thus creating an overall cooler, heterogenous temperature mosaic that benefits wildlife, water quality and more.

A. Weber, N., Bouwes, N., Pollock, M. M., Volk, C., Wheaton, J. M., Wathen, G., Wirtz, J., & Jordan, C. E. (2017). Alteration of stream temperature by natural and artificial beaver dams. *PLoS One*, **12**(5), e0176313

B. Munir, T. M., & Westbrook, C. J. (2020). Beaver dam analogue configurations influence stream and riparian water table dynamics of a degraded spring-fed creek in the Canadian Rockies. *River Research and Applications*, **37**(3), 330–342.

C. Wade, J., Lautz, L., Kelleher, C., Vidon, P., Davis, J., Beltran, J., & Pearce, C. (2020). Beaver dam analogues drive heterogeneous groundwater–surface water interactions. *Hydrological Processes*, **34**(26), 5340–5353.

D. Scamardo, J., & Wohl, E. (2020). Sediment storage and shallow groundwater response to beaver dam analogues in the Colorado front range, USA. *River Research and Applications*, **36**(3), 398–409.

E. Majerova, M., Neison, B. T., & Roper, B. B. (2020). Beaver dam influences on streamflow hydraulic properties and thermal regimes. *Science of the Total Environment*, **718**(134853), 1–14.

7. **Drought resiliency** - The increased water storage, groundwater storage and hydrologic connectivity of the floodplain improves the drought tolerance of plant and animal communities, as well as human communities**.**

A. Johnson, M. F., Thorne, C. R., Castro, J. M., Kondolf, G. M., Mazzacano, C. S., Rood, S. B., & Westbrook, C. (2019). Biomic river restoration: A new focus for river management. *River Research and Applications*, **36**(1), 3–12.

B. Fairfax, E., & Small, E. E. (2018). Using remote sensing to assess the impact of beaver damming on riparian evapotranspiration in an arid landscape. *Ecohydrology*, **11**(7), 1–14.

C. Dittbrenner, B. J., Pollock, M. M., Schilling, J. W., Olden, J. D., Lawler, J. J., & Torgersen, C. E. (2018). Modeling intrinsic potential for beaver (Castor canadensis) habitat to inform restoration and climate change adaptation. *PLoS One*, **13**(2), e0192538

D. Silverman, N. L., Allred, B. W., Donnelly, J. P., Chapman, T. B., Maestas, J. D., Wheaton, J. M., & White, J. (2019). Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. *Restoration Ecology*, **27**(2), 269–278

E. Vivian, L. M., Godfree, R. C., Colloff, M. J., Mayence, C. E., & Marshall, D. J. (2014). Wetland plant growth under contrasting water regimes associated with river regulation and drought: Implications for environmental water management. *Plant Ecology*, **215**(9), 997–1011.

8. **Flood resiliency** - Beaver dams and BDAs act as speed bumps that slow and spread the water flow, which disperses the energy of the system, thus lessening the intensity of high flow events that cause flooding.

A. Silverman, N. L., Allred, B. W., Donnelly, J. P., Chapman, T. B., Maestas, J. D., Wheaton, J. M., & White, J. (2019). Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. *Restoration Ecology*, **27**(2), 269–278.

B. Puttock, A., Graham, H. A., Ashe, J., Luscombe, D. J., & Brazier, R. E. (2021). Beaver dams attenuate flow: A multi-site study. *Hydrological Processes*, **35**(2), e14017

C. Hood, G. A., & Bayley, S. E. (2008). Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. *Biological Conservation*, **141**(2), 556–567.

D. Jordan, C. E., & Fairfax, E. (2022). Beaver: The North American freshwater climate action plan. *Wiley Interdisciplinary Reviews: Water*, e1592.

9. **Erosion protection** - The introduction of beaver dams and BDAs into rivers and streams is shown to reverse the effects of erosion. The added in-channel structure dampens the erosive force of the water flow by slowing and spreading the water, while the structures catch sediment to help build the river or stream back up to the floodplain. Meanwhile increased riparian vegetation help stabilize the banks.

   A. Pearce, C., Vidon, P., Lautz, L., Kelleher, C., & Davis, J. (2021). Short-term impact of beaver dam analogues on streambank erosion and deposition in Semi-Arid landscapes of the Western USA. *River Research and Applications*, *37*(7), 1032-1037.

   B. Cluer, B., & Thorne, C. (2014). A stream evolution model integrating habitat and ecosystem benefits. *River Research and Applications*, **30**(2), 135–154.

   C. Sands, A., & Howe, G. (1977). Riparian forests in California, their ecology and conservation. Paper presented at the Importance, Preservation and Management of Riparian Habitat: A Symposium, Tuscon, AZ.

   D. Puttock, A., Graham, H. A., Carless, D., & Brazier, R. E. (2018). Sediment and nutrient storage in a beaver engineered wetland. *Earth Surface Processes and Landforms*, **43**, 2358–2370.

   E. Naiman, R. J., Decamps, H., & McClain, M. E. (2010). Riparia: Ecology, conservation, and management of streamside communities. Elsevier.

10. **Steelhead and salmonids** - Beaver and BDA restored sites improve the survival rate, health and population size of steelhead and salmonids. The slow moving water, regulated water temperature and increased water quality are some of the contributing factors that aid in their increased productivity.

   A. Bouwes, N., Weber, N., Jordan, C. E., Saunders, W. C., Tattam, I. A., Volk, C., Wheaton, J. M., & Pollock, M. M. (2016). Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Scientific Reports*, **6**, 28581.

   B. Pollock, M. M., Pess, G., & Beechie, T. J. (2004). The importance of beaver ponds to Coho Salmon production in the Stillaguamish River basin, Washington, USA. *North American Journal of Fisheries Management*, **24**, 749–760.

   C. Council, S. R. W. (2018). Restoring Priority Coho Habitat in the Scott River Watershed Modeling and Planning Report. *Prepared for National Fish and Wildlife Foundation*.

   D. Dauwalter, D. C., & Walrath, J. D. (2018). Beaver dams, streamflow complexity, and the distribution of a rare minnow, *Lepidomeda copei*. *Ecology of Freshwater Fish.*, **27**, 606–616.

   E. Wathen, G., Allgeier, J. E., Bouwes, N., Pollock, M. M., Schindler, D. E., & Jordan, C. E. (2019). Beaver activity increases habitat complexity and spatial partitioning by steelhead trout. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(7), 1086-1095.