frontiers | Frontiers in Environmental Science

PERSPECTIVE
published: 16 May 2022
doi: 10.3389/fenvs.2022.870488

Effective Conservation of Desert Riverscapes Requires Protection and Rehabilitation of In-Stream Flows With Rehabilitation Approaches Tailored to Water Availability

Casey A. Pennock[1], Phaedra Budy[2] and William W. Macfarlane[1]*

[1]*Department of Watershed Sciences and The Ecology Center, Utah State University, Logan, UT, United States,* [2]*United States Geological Survey, Utah Cooperative Fish and Wildlife Research Unit, Logan, UT, United States*

Desert riverscape rehabilitation practitioners must contend with compounding effects of increasing human water demand, persistent drought, non-native species establishment, and climate change, which further stress desert riverine ecosystems such as rivers in the Colorado River basin, United States. Herein, we provide our perspective on the importance of natural flows, large floods in particular, for successful conservation and rehabilitation of riverscapes. We present ideas developed from our experience with rehabilitation projects across multiple desert tributary rivers with varying levels of habitat degradation and water abstraction. We propose spatially extensive measures such as protection of in-stream flows, tailoring rehabilitation efforts to available annual water availability, and working with nature using low-tech process-based techniques to more completely address the mechanisms of habitat degradation, such as flow reduction and vegetation-induced channel narrowing. Traditionally, rehabilitation efforts in the Colorado River basin take place at relatively small spatial extents, at convenient locations and, largely focus on reducing non-native plant and fish species. We suggest that we need to think more broadly and creatively, and that conservation or recovery of natural flow regimes is crucial to long-term success of almost all management efforts for both in-stream and riparian communities.

Keywords: rivers, arid lands, climate change, flow regime, native species, environmental flow (e-flow)

OPEN ACCESS

Edited by:
Robert M. Hughes, Amnis Opes Institute, LLC, United States

Reviewed by:
Brett Roper, UDSA Forest Service Biophysical and Physical Resources, United States
Daniel Dauwalter, Trout Unlimited, United States

***Correspondence:**
Phaedra Budy
Phaedra.budy@usu.edu

Specialty section:
This article was submitted to Freshwater Science, a section of the journal Frontiers in Environmental Science

Received: *06 February 2022*
Accepted: *19 April 2022*
Published: *16 May 2022*

Citation:
Pennock CA, Budy P and Macfarlane WW (2022) Effective Conservation of Desert Riverscapes Requires Protection and Rehabilitation of In-Stream Flows With Rehabilitation Approaches Tailored to Water Availability. Front. Environ. Sci. 10:870488. doi: 10.3389/fenvs.2022.870488

THE ISSUE PART I

River-dwelling organisms, such as fishes, need adequate flow to complete their life histories and thrive. Whereas at least some minimum amount of water is required for fish to simply persist, flows of large enough magnitude and long enough duration to create and maintain physical habitat and provide lateral connection to productive floodplains are vital to thriving fish assemblages (Matthews 1998; Marchetti and Moyle 2001; Bunn and Arthington 2002). This simple fact is well established (Poff et al., 1997; reviewed by Palmer and Ruhi 2019), but management of river flows rarely follows this basic principle (e.g., Pennock et al., 2022a). Several challenges exist to the management of natural stream flows, particularly in arid-lands such as the Colorado River basin. Water in the Colorado River basin is overallocated (Kuhn and Fleck 2019); consequently, natural flow regimes are altered

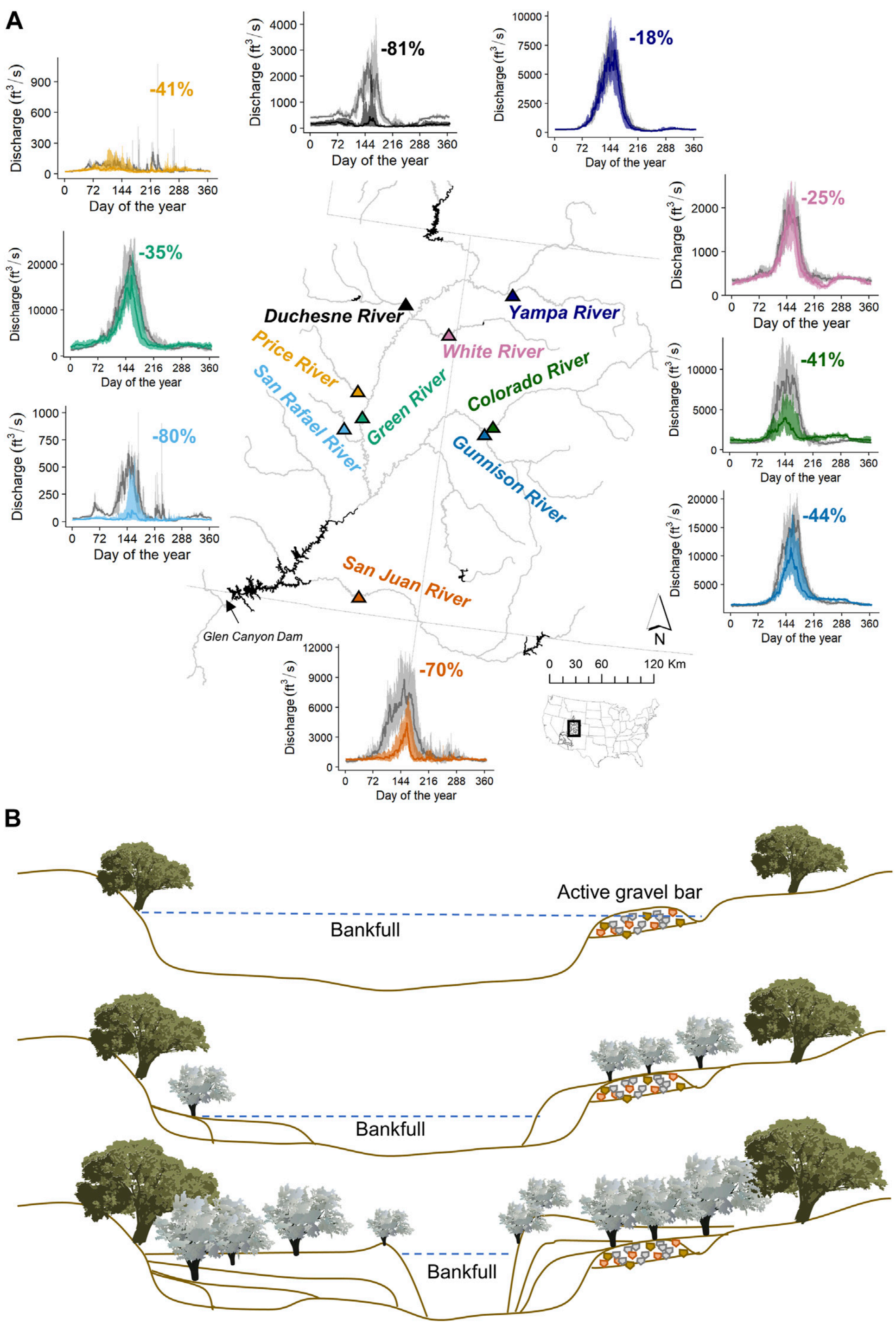

FIGURE 1 | (A) Flow regimes of mainstem and major tributary rivers in the upper Colorado River basin (upstream of Glen Canyon Dam). Historical flows (1929–1949) are in grey and present flows (2000–2021) are in color. Lighter bands represent 25th and 75th percentiles and bold lines represent 50th percentiles. Negative numbers represent the percent reduction in median daily spring flow (March-June) between historical and present. Approximate locations of United States Geological Survey gaging stations are represented by triangles (U.S. Geological Survey, 2022). **(B)** Typical channel changes over time as flows are reduced and non-native vegetation, such as Russian olive, establishes on deposited sediments in the floodplain (Laub et al., 2015).

across the upper Colorado River basin (**Figure 1A**). Overallocation is fed by implicit societal support, by some, of western water law used to dictate all river flows for upstream consumption (e.g., *The Law of the River*; Kuhn and Fleck 2019). Base flows fed by groundwater discharge contribute an average of 56% of surface flows in the upper Colorado River basin (Miller et al., 2016), which are threatened by groundwater mining, particularly during dryer periods (Castle et al., 2014). Moreover, human-induced climate change is causing basin-wide aridification leading to declining run-off basin-wide (Udall and Overpeck 2017; Overpeck and Udall 2020).

Reduction of large spring floods, and run-off in general, in desert rivers of the Colorado River basin (and elsewhere) has contributed to a positive feedback loop such that river channels have become aggraded and narrowed as stream power to erode sediment is lost (Allred and Schmidt 1999; Grams and Schmidt 2002; Dean and Schmidt 2011). Concomitantly, this process is often aided by encroachment and establishment of riparian vegetation on previously active alluvial surfaces, primarily by introduced, non-native species (**Figure 1B**; Manners et al., 2014; Laub et al., 2015; Scott et al., 2018). This feedback loop between declining flow and vegetation encroachment has resulted in the simplification and loss of habitats important for many native fishes and wildlife, such as floodplain wetlands and riparian gallery forests (Pennock et al., 2022a).

THE ISSUE PART II

Managers and researchers have attempted to remedy the loss of complex habitat by performing active rehabilitation and, in some instances, attempting to provide environmental flows (e.g., Gido and Propst 2012; Yarnell et al., 2015). Despite good intentions, many of these conservation and rehabilitation efforts take place over relatively small spatial and temporal extents, while the greater ecological degradation takes place over much broader extents, an issue alluded to more than a century ago (e.g., Marsh 1864; Fausch et al., 2002). Additionally, desert riverine fishes evolved in highly dynamic and connected riverscapes; within contemporary riverscapes, fishes are often highly mobile, moving amongst complementary habitat types (e.g., Cathcart et al., 2018; Hooley-Underwood et al., 2019; Pennock et al., 2020) to reproduce, feed and grow, and overwinter (Schlosser 1995; Fausch et al., 2002). Climate change induced flow reductions, water attenuation, increased human water demand, insufficient water releases from dams, groundwater mining, and failure to prioritize environmental flows over consumptive use have all stymied attempts to provide flows of adequate magnitude and duration to maintain habitat and inundate floodplains in the Colorado River basin.

Many of the challenges to the goal of conserving and recoverying riverscapes and native fishes are exemplified by a few specific examples from desert tributary systems where we are actively working. First, on two tributary rivers, the Price and San Rafael rivers, our own previous rehabilitation efforts have taken place on only several kilometers of river out of nearly 100 km per watershed. Although those smaller scale efforts have been critical to rehabilitating local habitats, they have not contributed to resolving the mechanism behind habitat degradation, a lack of water. Second, in the San Juan River, flow releases from an upstream dam are managed to mimic the natural flow regime, aided by major downstream tributary inputs (e.g., Gido and Propst 2012). However, because of infrastructure limitations, climate change, and increased consumptive water use, these managed flows have failed to truly mimic historical natural flows in terms of all attributes of the natural flow regime, as is seen by the reduction in magnitude and duration of the spring flood from the early 20th century to present day (**Figure 1A**; Pennock et al., 2022c). Third, current mitigation and management actions by two federal recovery programs in the upper Colorado River basin include stocking native fishes, habitat rehabilitation, non-native fish removal, and, in some limited cases, management of flow releases from dams. However, actions available to mitigate widespread habitat loss and fragmentation from dam construction and reservoir filling and consumptive water use are limited. The stated goal of these programs is recovering endangered fishes, while not hindering further water development (https://coloradoriverrecovery.org). The existence of the recovery programs suggests consistent compliance of current and future federal water projects with the Endangered Species Act (Benson 2010). Compliance is achieved through the above-mentioned mitigation and management actions, but achieving their stated goal of recovery is becoming more and more unlikely as water availability continues to decline (Williams et al., 2022). Further, the programs generally perform management actions in designated critical habitats, which for most listed species includes very little habitat in smaller tributaries widely used by many fishes (Bottcher et al., 2013; Webber et al., 2013; Laub et al., 2018), and so protections for tributary habitats is limited. Due in part to our demonstrated inability to manage desert rivers for natural flow regimes required for native fishes to thrive, we are witnessing widespread declines in distribution and abundance of native, and often endemic, fishes, including extirpation (Budy et al., 2015; Laub et al., 2018; Pennock et al., 2022a).

PERSPECTIVES ON POTENTIAL SOLUTIONS

We believe there are several promising ways to overcome some of the challenges described above. First, there is a need to scientifically evaluate ecological processes, such as fish and riparian vegetation population and community dynamics across large segments of riverscapes and prioritize conservation and rehabilitation actions across larger spatial extents, where these important ecological processes play out (Schlosser 1995; Palmquist et al., 2018). Moreover, the underlying causes of degradation must be remedied for long-term conservation to be successful, which for arid land rivers in the southwest United States requires at least some level of protection or recovery of natural flow regimes (Stromberg 2001; Pennock et al., 2022a). This approach would require working with states to modify laws to include water for environmental flows as a beneficial use, as a start. Establishment of incentive-based programs that pay water rights holders to not divert water (e.g., Van Kirk et al., 2020), or other promising approaches that leverage existing water law could also increase in-stream flows (e.g., Van Kirk et al., 2019; Van Kirk et al., 2020). For instance, using managed aquifer

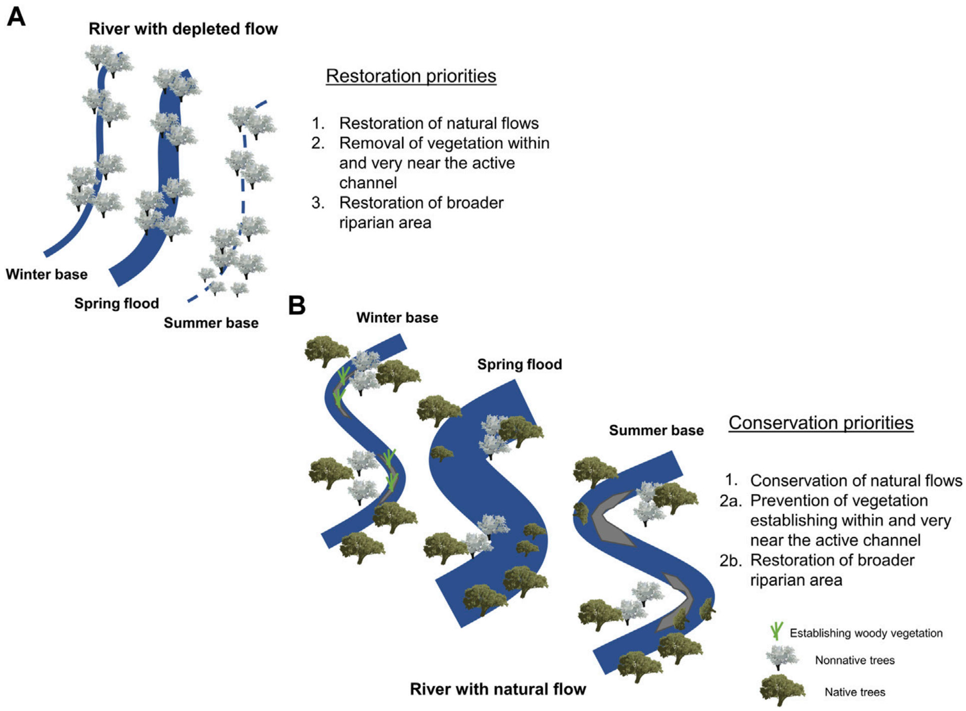

FIGURE 2 | (A) Seasonal regime of a typical desert river with severely depleted flow. Non-native vegetation has colonized newly deposited sediments in the floodplain and over time has restricted channel movement. Meanwhile, reductions in watershed runoff along with continued depletions lead to some reaches becoming intermittent during summer. The most effective rehabilitation priority in this type of river would be recovery of natural flows, particularly large floods. Only after that will removal of non-native vegetation and vegetation near the active channel have ecologically and geomorphologically meaningful effects on instream habitat at large spatial extents. **(B)** Seasonal regime of a desert river with natural flows. The spring flood is still large enough to scour active gravel bars of establishing woody vegetation, wet floodplain habitat for colonization by and survival of native trees, and cause channel migration and large wood recruitment into the active channel. Here the most effective priority is conservation of natural flows with prevention of vegetation establishment within the active channel and rehabilitation of the broader riparian area as equally important and effective secondary priorities.

recharge to bolster local groundwater resources along with joint management of groundwater and surface water could help maintain baseflows in severely depleted rivers (Castle et al., 2014; Van Kirk et al., 2020). We also suggest shifting to a more holistic approach, by leveraging annual flow variability, and partnering with nature using low-tech process-based restoration practices (Wheaton et al., 2019).

On some tributary rivers with severely depleted flow, prior rehabilitation efforts have focused primarily on removing localized monocultures of non-native riparian vegetation, such as Russian olive (*Elaeagnus angustifolia*) and tamarisk (*Tamarix* spp.), an important component of riverscape rehabilitation because of the impacts of non-native vegetation encroachment on in-stream and riparian habitat (Keller et al., 2014; Laub et al., 2015; Scott et al., 2018). We suggest the most effective approach in these depleted rivers will first require recovery of some level of natural flows (volume and timing), then accompanied removal of established vegetation within and near the active channel, followed by, rehabilitation of the broader riparian area by removal of non-native vegetation throughout the riverscape (**Figure 2A**). Recovery of natural flows would allow for dynamic geomorphic and biotic processes to return to the riverscape once non-native vegetation is removed, potentially even with spring floods of lower magnitude than observed historically. For instance, removal of vegetation near the active channel could allow for scour and lateral channel migration in years of modest to larger spring floods (e.g., Keller et al., 2014). Finally, recovery of in-stream flows and the broader riparian area at the riverscape-scale has a high probability to increase recruitment success of native vegetation, such as Fremont's cottonwood (*Populus fremontii*) and reduce propagule pressure of non-native vegetation (Schlatter et al., 2017; Scott et al., 2018; West et al., 2020).

In the White River in Utah, a river with a relatively natural flow regime, our approach is similar, but focuses more on conserving the natural ecological and geomorphological processes that still exist (**Figure 2B**; Pennock et al., 2022b). We predict the most effective strategy in rivers, such as the White River, is to first conserve natural flows (Pennock et al., 2022a; Pennock et al., 2022b). The simple fact here is that rivers with natural flow regimes still have a spring flood of large enough magnitude and long enough duration to scour bar features of emerging vegetation (non-native and native) and to provide lateral connection to floodplains. However, with climate change-induced declines in watershed runoff in the Colorado River basin, all rivers have experienced some degree of flow reduction from the 20th to 21st century and the predictions for the future are no better (Udall and Overpeck 2017; Williams et al., 2022). The second priority is rehabilitation of the riparian plant community across the riverscape by removing established non-native vegetation, as described above.

In light of basin-wide reductions in flow, even in rivers with natural flow, we are working with spring floods of lower magnitude, and as such, we propose conservation actions tailored to annual flows. We can do this by pairing annual conservation and rehabilitation actions with current annual flows, and in some cases, annual flows in prior years. For example, in years with back-to-back below average floods, we are focusing our efforts on preventing vegetation encroachment on the active channel, which would force the river towards a more aggraded and narrowed state (Grams and Schmidt 2002; Dean and Schmidt 2011; Laub et al., 2015). Conversely, in a year with an average or above average flood, we will focus efforts on recruiting large wood into the channel and regaining channel width in localized areas where aggradation has occurred.

Furthermore, we propose to partner with nature by using low-tech process-based restoration techniques that have recently become popular and demonstrated to be effective at rehabilitating physical, chemical, and biological processes in riverscapes (e.g., Beechie et al., 2010; Wheaton et al., 2019; https://lowtechpbr.restoration.usu.edu/). We are adapting some of the more popular of these techniques to larger rivers, but the long-term success of this strategy also likely hinges on the ability to conserve some degree of large spring floods. For example, recruitment of large wood into the active channel is an important process on the White River aided by its relatively natural flow regime, recruiting cottonwoods, and active beaver tree-felling, resulting in densities of large woody debris 2-6 × higher relative to other tributaries to the Green River (Pennock et al., 2022a). This large woody debris maintains and creates habitat complexity including scour pools, low-velocity areas, and colonization areas for macroinvertebrates, habitat benefitting fish and other wildlife. Thus, more specifically, one of our strategies is to mimic beaver activity on meander bends by selectively felling trees to promote hydraulic, hydrologic, and geomorphic effects similar to post-assisted-log structures (PALS) in wadeable streams (Wheaton et al., 2019).

In tributary systems across the upper Colorado River basin, we are incorporating natural flow conservation, tailoring of conservation and rehabilitation actions with annual water availability, and partnering with nature by implementing dynamic and low-tech, process-based techniques (versus hard engineering) in three different ways. A) In the White River, as discussed above, we are working to conserve the natural hydrograph and tailoring annual conservation and rehabilitation activities to the predicted water year and anticipated discharge and allowing the river to collect and use removed non-native trees to create habitat. B) On the San Juan River, where non-native Russian olive have established dense monocultures throughout the riverscape, we are experimentally adding semi-anchored Russian olive branches to the river channel to enhance habitat for native fishes. C) On the Price and San Rafael rivers, we are pairing the translocation of nuisance beavers with installation of high densities of PALS and non-native vegetation removal to increase habitat complexity (Doden et al., 2022), promote lateral channel movement, and increase water retention in the riverscape. In 2022, Utah's first ever water banking application was approved for the Price River, which allows for The Nature Conservancy, Trout Unlimited, and Utah Division of Wildlife Resources to lease water for environmental benefit. These entities are currently working to lease water for instream purposes including maintaining minimum flows and providing some semblance of a spring flood. For all of these examples, we combine our rehabilitation activities with structured monitoring programs such that we can learn from our successes and mistakes and manage future efforts based on lessons learned (Palmer et al., 2005). Although these rivers differ greatly in their level of degradation, and thus, the specific techniques we are implementing also vary widely, the long-term success of our efforts in each river still hinges on the ability to implement flow conservation and recovery, particularly moderate to large spring snowmelt floods.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CP and PB led writing of the manuscript with input from WM. All authors edited and approved the final version of the manuscript and developed the original ideas jointly.

FUNDING

Funding and support were provided by the Department of the Interior, Bureau of Land Management (Cooperative Agreement No. L17AC00322), Utah Division of Wildlife Resources Watershed Restoration Initiative (WRI# 5298), and both the United States Geological Survey Utah Cooperative Fish and Wildlife Research Unit (in-kind) and The Ecology Center at Utah State University (in-kind).

ACKNOWLEDGMENTS

We are grateful to J. Schmidt for insightful and educational discussions that contributed to ideas presented in the manuscript. L. Bruckerhoff and two anonymous reviewers contributed helpful comments that improved the manuscript. We would also like to thank J. Jimenez and J. Goodell for help with development of the conservation, restoration, and monitoring plan for the White River. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States Government.

REFERENCES

Allred, T. M., and Schmidt, J. C. (1999). Channel Narrowing by Vertical Accretion along the Green River Near Green River, Utah. *GSA Bull.* 111, 1757–1772. doi:10.1130/0016-7606(1999)111<1757:cnbvaa>2.3.co;2

Beechie, T. J., Sear, D. A., Olden, J. D., Pess, G. R., Buffington, J. M., Moir, H., et al. (2010). Process-based Principles for Restoring River Ecosystems. *BioScience* 60, 209–222. doi:10.1525/bio.2010.60.3.7

Benson, R. D. (2010). Avoiding Jeopardy, without the Questions: Recovery Implementation Programs for Endangered Species in Western River Basins. *Mich. J. Envtl. Admin. L.* 2, 473–534. doi:10.36640/mjeal.2.2.avoiding

Bottcher, J. L., Walsworth, T. E., Thiede, G. P., Budy, P., and Speas, D. W. (2013). Frequent Usage of Tributaries by the Endangered Fishes of the Upper Colorado River Basin: Observations from the San Rafael River, Utah. *North Am. J. Fish. Manag.* 33, 585–594. doi:10.1080/02755947.2013.785993

Budy, P., Conner, M. M., Salant, N. L., and Macfarlane, W. W. (2015). An Occupancy-Based Quantification of the Highly Imperiled Status of Desert Fishes of the Southwestern United States. *Conserv. Biol.* 29, 1142–1152. doi:10.1111/cobi.12513

Bunn, S. E., and Arthington, A. H. (2002). Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environ. Manag.* 30, 492–507. doi:10.1007/s00267-002-2737-0

Castle, S. L., Thomas, B. F., Reager, J. T., Rodell, M., Swenson, S. C., and Famiglietti, J. S. (2014). Groundwater Depletion during Drought Threatens Future Water Security of the Colorado River Basin. *Geophys. Res. Lett.* 41, 5904–5911. doi:10.1002/2014gl061055

Cathcart, C. N., Gido, K. B., McKinstry, M. C., and MacKinnon, P. D. (2018). Patterns of Fish Movement at a Desert River Confluence. *Ecol. Freshw. Fish.* 27, 492–505. doi:10.1111/eff.12364

Dean, D. J., and Schmidt, J. C. (2011). The Role of Feedback Mechanisms in Historic Channel Changes of the Lower Rio Grande in the Big Bend Region. *Geomorphology* 126, 333–349. doi:10.1016/j.geomorph.2010.03.009

Doden, E., Budy, P., Avgar, T., and Young, J. (2022). Movement Patterns of Resident and Translocated Beavers at Multiple Spatiotemporal Scales in Desert Rivers. *Front. Conserv. Sci.* 3, 1–16. doi:10.3389/fcosc.2022.777797

Fausch, K. D., Torgersen, C. E., Baxter, C. V., and Li, H. W. (2002). Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes. *BioScience* 52, 483–498. doi:10.1641/0006-3568(2002)052[0483:ltrbtg]2.0.co;2

Gido, K. B., and Propst, D. L. (2012). Long-term Dynamics of Native and Nonnative Fishes in the San Juan River, New Mexico and Utah, under a Partially Managed Flow Regime. *Trans. Am. Fish. Soc.* 141, 645–659. doi:10.1080/00028487.2012.683471

Grams, P. E., and Schmidt, J. C. (2002). Streamflow Regulation and Multi-Level Flood Plain Formation: Channel Narrowing on the Aggrading Green River in the Eastern Uinta Mountains, Colorado and Utah. *Geomorphology* 44, 337–360. doi:10.1016/s0169-555x(01)00182-9

Hooley-Underwood, Z. E., Stevens, S. B., Salinas, N. R., and Thompson, K. G. (2019). An Intermittent Stream Supports Extensive Spawning of Large-River Native Fishes. *Trans. Am. Fish. Soc.* 148, 426–441. doi:10.1002/TAFS.10141

J. M. Wheaton, S. N. Bennett, N. Bouwes, J. D. Maestas, and S. Shaverdian (Editors) (2019). *Low-Tech Process-Based Restoration of Riverscapes: Design Manual* (Logan, UT: Utah State University Restoration Consortium). Version 1.0. Available at: https://lowtechpbr.restoration.usu.edu/manual.

Keller, D. L., Laub, B. G., Birdsey, P., and Dean, D. J. (2014). Effects of Flooding and Tamarisk Removal on Habitat for Sensitive Fish Species in the San Rafael River, Utah: Implications for Fish Habitat Enhancement and Future Restoration Efforts. *Environ. Manag.* 54, 465–478. doi:10.1007/s00267-014-0318-7

Kirk, R. W. V., Contor, B. A., Morrisett, C. N., Null, S. E., and Loibman, A. S. (2020). Potential for Managed Aquifer Recharge to Enhance Fish Habitat in a Regulated River. *Water* 12, 673. doi:10.3390/w12030673

Kuhn, E., and Fleck, J. (2019). *Science Be Dammed: How Ignoring Inconvenient Science Drained the Colorado River*. Tuscon: The University of Arizona Press.

Laub, B. G., Jimenez, J., and Budy, P. (2015). Application of Science-Based Restoration Planning to a Desert River System. *Environ. Manag.* 55, 1246–1261. doi:10.1007/s00267-015-0481-5

Laub, B. G., Thiede, G. P., Macfarlane, W. W., and Budy, P. (2018). Evaluating the Conservation Potential of Tributaries for Native Fishes in the Upper Colorado River Basin. *Fisheries* 43, 194–206. doi:10.1002/fsh.10054

Manners, R. B., Schmidt, J. C., and Scott, M. L. (2014). Mechanisms of Vegetation-Induced Channel Narrowing of an Unregulated Canyon River: Results from a Natural Field-Scale Experiment. *Geomorphology* 211, 100–115. doi:10.1016/j.geomorph.2013.12.033

Marchetti, M. P., and Moyle, P. B. (2001). Effects of Flow Regime on Fish Assemblages in a Regulated California Stream. *Ecol. Appl.* 11, 530–539. doi:10.1890/1051-0761(2001)011[0530:eofrof]2.0.co;2

Marsh, G. P. (1864). *Man and Nature; or, Physical Geography as Modified by Human Action*. London: S. Low, Son and Matson.

Matthews, W. J. (1998). *Patterns in Freshwater Fish Ecology*. New York, USA: Chapman & Hall.

Miller, M. P., Buto, S. G., Susong, D. D., and Rumsey, C. A. (2016). The Importance of Base Flow in Sustaining Surface Water Flow in the Upper Colorado River Basin. *Water Resour. Res.* 52, 3547–3562. doi:10.1002/2015wr017963

Overpeck, J. T., and Udall, B. (2020). Climate Change and the Aridification of North America. *Proc. Natl. Acad. Sci. U. S. A.* 117, 11856–11858. doi:10.1073/pnas.2006323117

Palmer, M. A., Bernhardt, E. S., Allan, J. D., Lake, P. S., Alexander, G., Brooks, S., et al. (2005). Standards for Ecologically Successful River Restoration. *J. Appl. Ecol.* 42, 208–217. doi:10.1111/j.1365-2664.2005.01004.x

Palmer, M., and Ruhi, A. (2019). Linkages between Flow Regime, Biota, and Ecosystem Processes: Implications for River Restoration. *Science* 365, eaaw2087. doi:10.1126/science.aaw2087

Palmquist, E. C., Ralston, B. E., Merritt, D. M., and Shafroth, P. B. (2018). Landscape-scale Processes Influence Riparian Plant Composition along a Regulated River. *J. Arid Environ.* 148, 54–64. doi:10.1016/j.jaridenv.2017.10.001

Pennock, C. A., Bruckerhoff, L. A., Gido, K. B., Barkalow, A. L., Breen, M. J., Budy, P., et al. (2022c). Failure to Achieve Recommended Environmental Flows Coincides with Declining Fish Populations: Long-Term Trends in a Regulated and Unregulated River. *Freshw. Biol.* in review.

Pennock, C. A., Budy, P., Macfarlane, W. W., Breen, M. J., Jimenez, J., and Schmidt, J. C. (2022a). Native Fish Need a Natural Flow Regime. *Fisheries* 47, 118–123. doi:10.1002/fsh.10703

Pennock, C. A., Macfarlane, W. W., Budy, P., Jimenez, J., and Goodell, J. (2022b). Conservation, Restoration and Monitoring Plan for the Lower White River, Utah. *UTCFWRU* 2022 (1), 1–78. Available at: https://digitalcommons.usu.edu/eco_pubs/136/.

Pennock, C. A., McKinstry, M. C., Cathcart, C. N., Gido, K. B., Francis, T. A., Hines, B. A., et al. (2020). Movement Ecology of Imperilled Fish in a Novel Ecosystem: River-reservoir Movements by Razorback Sucker and Translocations to Aid Conservation. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 30, 1540–1551. doi:10.1002/aqc.3399

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., et al. (1997). The Natural Flow Regime: A Paradigm for River Conservation and Restoration. *BioScience* 47, 769–784. doi:10.2307/1313099

Schlatter, K. J., Grabau, M. R., Shafroth, P. B., and Zamora-Arroyo, F. (2017). Integrating Active Restoration with Environmental Flows to Improve Native Riparian Tree Establishment in the Colorado River Delta. *Ecol. Eng.* 106, 661–674. doi:10.1016/j.ecoleng.2017.02.015

Schlosser, I. J. (1995). Critical Landscape Attributes that Influence Fish Population Dynamics in Headwater Streams. *Hydrobiologia* 303, 71–81. doi:10.1007/bf00034045

Scott, M. L., Reynolds, L. V., Shafroth, P. B., and Spence, J. R. (2018). The Role of a Non-native Tree in Riparian Vegetation Expansion and Channel Narrowing along a Dryland River. *Ecohydrology* 11, e1988. doi:10.1002/eco.1988

Stromberg, J. C. (2001). Restoration of Riparian Vegetation in the South-Western United States: Importance of Flow Regimes and Fluvial Dynamism. *J. Arid Environ.* 49, 17–34. doi:10.1006/jare.2001.0833

Udall, B., and Overpeck, J. (2017). The Twenty-First Century Colorado River Hot Drought and Implications for the Future. *Water Resour. Res.* 53, 2404–2418. doi:10.1002/2016wr019638

U.S. Geological Survey (USGS) (2022). USGS Water Data for the Nation: U.S. Geological Survey National Water Information System Database. Available at: https://doi.org/10.5066/F7P55KJN (Accessed January, 2022).

Van Kirk, R. W., Hoffner, B., Verbeten, A., and Yates, S. (2019). "New Approaches to Providing Streamflow for Fisheries in the American West: Embracing Prior Appropriation and the Marketplace," in *Multispecies and Watershed Approaches to Freshwater Fish Conservation*. Editors D. C. Dauwalter, T. W. Birdsong, and G. P. Garrett (Bethesda, Maryland: American Fisheries Society), 515–564.

Webber, P. A., Bestgen, K. R., and Haines, G. B. (2013). Tributary Spawning by Endangered Colorado River Basin Fishes in the White River. *North Am. J. Fish. Manag.* 33, 1166–1171. doi:10.1080/02755947.2013.829142

West, N. M., Reinhold, A. M., Poole, G. C., and Espeland, E. K. (2020). Flood Dynamics Dictate Distributions of Elaeagnus Angustifolia L. (Russian Olive) on a Riverine Floodplain. *Biol. Invasions* 22, 3493–3499. doi:10.1007/s10530-020-02352-z

Williams, A. P., Cook, B. I., and Smerdon, J. E. (2022). Rapid Intensification of the Emerging Southwestern North American Megadrought in 2020-2021. *Nat. Clim. Chang.* 12, 232–234. doi:10.1038/s41558-022-01290-z

Yarnell, S. M., Petts, G. E., Schmidt, J. C., Whipple, A. A., Beller, E. E., Dahm, C. N., et al. (2015). Functional Flows in Modified Riverscapes: Hydrographs, Habitats and Opportunities. *BioScience* 65, 963–972. doi:10.1093/biosci/biv102

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.