Middle Rio Grande Endangered Species Collaborative Program

Est. 2000

Bibliography of Literature Published in 2020

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Archdeacon, T. P., T. A. Diver-Franssen, N. G. Bertrand, and J. D. Grant. 2020. Drought Results in Recruitment Failure of Rio Grande Silvery Minnow (*Hybognathus amarus*), an Imperiled, Pelagic Broadcast-spawning Minnow. *Environmental Biology of Fishes* 103, 1033–1044.

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Keywords: pelagic broadcast-spawning, GSI reproduction, flow-recruitment, regulated river, vital rates

Abstract: As precipitation and temperature patterns change, the resulting alterations in hydrologic conditions may adversely affect some stream fishes. The unique guild of freshwater, pelagic broadcast-spawning minnows found in the western United States appears to be particularly sensitive to low-flow conditions. We examined reproductive and recruitment patterns of one of these species, Rio Grande silvery minnow (*Hybognathus amarus*), over a three-year period, which included one year of extreme drought. We followed gonadal development from March through September each year, from 2017 to 2019, to determine if Rio Grande silvery minnow were reproductively active during extreme drought. The population structure was also monitored to confirm successful recruitment over the same period. We found that in all years Rio Grande silvery minnow were reproductively active in April through early June, including during extreme drought in 2018. However, almost no recruitment occurred in 2018, and by early 2019 the population was dominated by older, wild age-2 fish and hatchery-reared fishes. Our work supports previous research on pelagic broadcast-spawning minnows and confirms that extreme low-flows results in near-complete recruitment failure of Rio Grande silvery minnow. This work will help inform management and conservation of Rio Grande silvery minnow and other pelagic broadcast-spawning minnows during drought or low flows years.

DOI: 10.1007/s10641-020-01003-5

Archdeacon, T. P., T. A. Diver, and J. K. Reale. 2020. Fish Rescue During Streamflow Intermittency May Not Be Effective for Conservation of Rio Grande Silvery Minnow. *Water*

Keywords: thermal stress, salvage, climate change, drought, hypoxia

Abstract: Streamflow intermittency can reshape fish assemblages and present challenges to recovery of imperiled species. During streamflow intermittency, fish can be subjected to a variety of stressors, including exposure to crowding, high water temperatures, and low dissolved oxygen, resulting in sublethal effects or mortality. Rescue of fishes is often used as a conservation tool to mitigate the negative impacts of streamflow intermittency. The effectiveness of such actions is rarely evaluated. Here, we use multi-year water quality data collected from isolated pools during rescue of Rio Grande silvery minnow *Hybognathus amarus*, an endangered minnow. We examined seasonal and diel water quality patterns to determine if fishes are exposed to sublethal and critical water temperatures or dissolved oxygen concentrations during streamflow intermittency. Further, we determined survival of rescued Rio Grande silvery minnow for 3–5 weeks post-rescue. We found that isolated pool temperatures were much warmer (>40 °C in some pools) compared to upstream perennial flows, and had larger diel fluctuations, >10 °C compared to ~5 °C, and many pools had critically low dissolved oxygen concentrations. Survival of fish rescued from isolated pools during warmer months was <10%. Reactive conservation actions such as fish rescue are often costly, and in the case of Rio Grande silvery minnow, likely ineffective. Effective conservation of fishes threatened by streamflow intermittency should focus on restoring natural flow regimes that restore the natural processes under which fishes evolved.

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Archdeacon, T. P. and J. K. Reale. 2020. No Quarter: Lack of Refuge During Flow Intermittency Results in Catastrophic Mortality of an Imperiled Minnow. *Freshwater*

Biology **Keywords:** conservation, disturbance, drying, fish, intermittent stream

Abstract: Many once-perennial rivers have become intermittent. Channel drying can result in fish mortality if refuges are not available. Understanding where refuges occur and if fishes use these refuges can provide insight for species persistence and help stakeholders manage limited resources. Streamflow diversions in the Rio Grande of New Mexico can result in >60 km losses of aquatic habitat, affecting up to 30% of the range of imperiled Rio Grande silvery minnow (*Hybognathus amarus*). Potential refuges include areas with perennial flow below diversion dams, isolated pools, and irrigation return flows. We examined spatial and temporal patterns of both adult and young-of-year Rio Grande silvery minnow collected in isolated pools that formed during streamflow intermittency from 2009 to 2019. We hypothesised that: (1) Rio Grande silvery minnow would be more numerous in pools that persisted longer; (2) they would be more numerous in isolated pools located closer to upstream areas of perennial flow, due to upstream movement to escape drying; and (3) increased rate of aquatic habitat loss each day would result in more Rio Grande silvery minnow in isolated pools. During the 12 years of the study, we counted Rio Grande silvery minnow in 3,985 isolated pools that formed during streamflow intermittency. We related counts of Rio Grande silvery minnow in each pool to the maximum pool depth, rate of loss of aquatic habitat that occurred that day, and distance each pool was to an upstream barrier. In 2016, we examined persistence of 290 isolated pools until complete desiccation or reconnection with continuous flows occurred, and the factors that influenced pool persistence. Deeper pools persisted for longer, but depth had a small positive effect on counts of adult Rio Grande silvery minnow and no effect on counts of young-of-year in isolated pools. Adults were more numerous in upstream isolated pools, whereas young-of-year were more numerous in downstream isolated pools. Rate of channel drying had little effect on the numbers of adult Rio Grande silvery minnow in isolated pools, but more young-of-year were stranded when the rate of drying was faster. On average, pools persisted <4 days and 263 of 290 dried completely before continuous flows returned. Only 66 of 4,749 Rio Grande silvery minnow occurred in pools that did not dry completely. Rio Grande silvery minnow did not appear to escape channel intermittency; instead, they became stranded in shrinking isolated pools that did not persist long enough to act as refuges for fishes. Lack of refuge during channel intermittency would result in catastrophic mortality of fishes through complete desiccation of pools if there were no management actions, such as translocating fish. To increase persistence through streamflow intermittency, conservation actions should match the species response to intermittency by ensuring the availability of perennial-water refuges at the appropriate spatial and temporal scale.

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Archdeacon, T. P., J. K. Reale, E. J. Gonzales, and J. D. Grant. 2020. Effects of Seining Effort and Site Length on Variability of Small-bodied Fish Catch-rates in a Sand-bed River. *River Research and Applications*.

Keywords: effort, minnows, sampling, seines, small-bodied fishes

Abstract: Seines are a common sampling gear for monitoring small-bodied fishes in wadeable, sand-bed rivers. However, sampling effort within a site can vary among time and space, even within the same monitoring program. Determining and standardizing an adequate or optimal amount of effort within a site is an important step for designing fisheries monitoring programs. If budgets are limited, sampling intensity at a site is often a trade-off between less intense sampling at a greater number of locations or more intense sampling at fewer locations. Inadequate sampling at survey sites could introduce variability into estimates of density, species richness, or relative abundance because of within-site variability. We evaluated how variability of mean catch-rates of five species of small-bodied fishes changed with increasing effort at a fixed number of sites, and how variability changed as more sites were sampled. Focal species were Rio Grande silvery minnow, flathead chub, red shiner, fathead minnow, and western mosquitofish. We sampled 20 sites with 20 hauls in 200 m, 40 hauls in 200 m, and 40 hauls in 400 m. We observed little decrease in variability around expected catch-per-unit-effort [$\hat{E}(\mathrm{CPUE})$] when 40 seine hauls were performed per site compared to 20 hauls per site, regardless of site length or species, though a 25% increase in labour was required. However, we observed considerable variability around $\hat{E}(\mathrm{CPUE})$ when ≤5 seine hauls were performed at each site. We recommend a minimum of 10 seine hauls per 200 m site. Our results provide guidance and starting point for monitoring programs that use seining to collect information on small fishes.

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Bicknell, K., P. J. Regier, D. Van Horn, K. Feeser, and R. Gonzales-Pinzon. 2020. Linking Hydrobiogeochemical Processes and Management Techniques to Close Nutrient Loops in an Arid River. *Frontiers in Water.*

Keywords: nitrate dynamics, close nutrient loops, arid rivers, water management, hydrobiogeochemical processes, food-energy-water nexus

Abstract: In this study, we explore opportunities to optimize food-energy-water (FEW) resources by closing nutrient loops in arid-land rivers. Specifically, we evaluate source and sink behavior of nitrogen as nitrate (NO_3-N) in three characteristic channels in the Middle Rio Grande Basin (Delivery and Drain channels associated with agriculture and the main channel of the Rio Grande). All three channels are located downstream of a large wastewater treatment plant that is the main contributor of nutrients to this reach of the Rio Grande. We used a mass balance approach paired with stable isotope analysis to determine sources and processing of NO_3-N within the channels over time (a year) and through space (along ~15 to 50 km reaches). Results indicated the growing season was an important period of sink behavior for the Delivery channel and the Rio Grande, but the Drain channel was a year-round source. Stable isotope analysis of ^{15}N and ^{18}O found a distinct nitrate signature in the Drain associated with biological processing, as well as Rio Grande sites impacted by agricultural outflow, but no equivalent signature was present in the Delivery channel. Based on our findings, we provide recommendations to help close nutrient loops in the study system and analogous aridland irrigation networks by 1) minimizing loss during the transfer of nutrients from wastewater facilities to agricultural areas, and 2) minimizing enrichment to downstream aquatic ecosystems by sequestering nutrients that escape the nutrient loop.

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Briggs, M. K. and W. R. Osterkamp. eds., 2020. Renewing Our Rivers: Stream Corridor Restoration in Dryland Regions. *University of Arizona Press.*

Keywords: Book, no keywords listed.

Abstract: Book, no abstract, was unable to copy and paste introduction.

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https://books.google.com/books?hl=en&lr=&id=6D4LEAAAQBAJ&oi=fnd&pg=PP1&dq=Middle+rio+grande+river+restoration&ots=OsFkNKQCne&sig=o4NMT683AepZneBJ107S57AMeto#v=onepage&q=Middle%20rio%20grande%20river%20restoration&f=false

Carothers, S. W., R. R. Johnson, D. M. Finch, K. J. Kingsley, R. H. Hamre, tech. eds. 2020. Riparian Research and Management: Past, Present, Future: Volume 2. Gen. Tech. Rep. RMRS-GTR-411. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: riparian, ecosystem, ecology, riparian processes, riparian losses, restoration, aquatic, arid, semiarid, upland, freshwater, groundwater, hydrology, watershed, tamarisk, tamarisk leaf beetles (Diorhabda spp.)

Abstract: In the Preface to volume 1, we discuss the development of riparian ecology as one of the newest of ecological fields that gained significant momentum in the 1950s and 1960s as part of the general “riparian movement” in the United States. The field expanded rapidly throughout the latter half of the 1900s. Volume 2 involves more than two dozen authors - most with decades of experience - who expand upon riparian and other topics introduced in volume 1. Two important recent developments are global climate change and impacts of introduced tamarisk leaf beetles (Diorhabda spp.) in the American West. Other chapters in volume 2 that provide current information evaluate the losses of riparian habitat, including “extirpation” of a large number of mesquite bosques (woodlands) in the Southwest; the restoration of riparian ecosystems damaged by anthropogenic activities; the importance of a watershed; and the importance of riparian ecosystems to recreation. The combination of volumes 1 and 2 examines the evolving understanding of scientific implications and anthropogenic threats to those ecosystems from Euro-American settlement of the region to present.

DOI: 10.2737/RMRS-GTR-411

Carson, E. W., M. J. Osborne, and T. F. Turner. 2020. Relationship of Effective Size to Hatchery Supplementation and Habitat Connectivity in a Simulated Population of Rio Grande Silvery Minnow. *North American Journal of Fisheries Management.*

Keywords: No Keywords found.

Abstract: Simultaneous management actions often are used to improve the status of imperiled species, yet the effects of these actions can be difficult to determine. The endangered Rio Grande Silvery Minnow *Hybognathus amarus* is a short-lived fish with a dispersive life history and thus requires—but does not occupy—unfragmented habitat for recruitment and survival. We used Rio Grande Silvery Minnow as a model system for an individual-based simulation study to evaluate responses of genetic effective size to hatchery supplementation and fish passage in a managed population. Simulations were designed to test effects of fish passage on the relationship between estimates of inbreeding (N_{eI}) and variance (N_{eV}) effective sizes, which differ consistently ($N_{eI} >> N_{eV}$) in long-term genetic-monitoring data from hatchery-supplemented Rio Grande Silvery Minnow populations. Values of different effective population size measures should be identical in a demographically stable and connected (admixed) population but can differ substantially under nonequilibrium conditions. When a barrier prevented upstream dispersal, N_{eI} was associated negatively with rate of downstream dispersal and positively with supplementation rate, whereas N_{eV} was associated negatively with both. This mirrored observations from Rio Grande Silvery Minnow. Individual effects of dispersal and supplementation, however, were difficult to discern due to significant interaction between these factors. When connectivity was restored, N_{eI} and N_{eV} depended on supplementation rate, with positive association between N_{eI} and supplementation rate versus a negative association for N_{eV} and interaction terms, and effects of dispersal were nonsignificant. Although fish passage did not alter the difference between N_{eI} and N_{eV}, our study suggests that for Rio Grande Silvery Minnow, and potentially other intensively managed species in regulated rivers, fish passage may help to distinguish effects of management actions, such as supplementation, from effects of other demographic influences. More generally, explicit analytical consideration of differences in effective population size estimates can provide important details of genetic responses to management.

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Cubley, E. S., H. L. Bateman, D. M. Merritt, and D. J. Cooper. 2020. Using Vegetation Guilds to Predict Bird Habitat Characteristics in Riparian Areas. *Wetlands.*

Keywords: avian diversity, flow response guilds, dryland rivers, habitat heterogeneity, Verde River

Abstract: Within arid regions riparian forests support high bird diversity compared to surrounding uplands. In these same regions, water demands for agriculture, urbanization, and recreation have altered the structure and composition of riparian forests and degraded bird habitat. Along rivers, plants with similar responses to flood disturbance and water availability can be grouped into functional guilds using traits. The use of plant guilds can mechanistically link bird distributions to traits such as canopy height, specific leaf area, and growth form. We demonstrate that bird species richness, abundance, and diversity are related to the heterogeneity of vegetation structure and plant guilds along a perennial river in the southwestern U.S. High-quality habitat can be explained by canopy cover, foliage height diversity, and foliage cover in the understory. The tall tree guild (dominated by *Salix gooddingii*) was the strongest predictor of bird habitat followed by drought tolerant shrubs (dominated by *Prosopis velutina*) demonstrating that riparian shrublands should be considered for conservation alongside gallery forests. Projected changes in flow regimes may result in homogenization of riparian vegetation and reduce habitat quality for migratory and breeding land birds. Practitioners can use developed methods to group vegetation by guilds to focus bird conservation efforts in arid ecosystems.

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Dillon, K. G. and D. Moore. 2020. Avian Noise Disturbance. Bureau of Reclamation, Technical Service Center, Fisheries and Wildlife Resources.

Keywords: No Keywords found.

Abstract: Noise disturbance due to construction, traffic, and other anthropogenic activity has been found to have detrimental impacts on avian habitat occupancy, pairing success, and reproductive output. However, there is not a particular level of noise disturbance that is known to universally cause an impact. Currently, along the Rio Grande in central New Mexico, U.S. Fish and Wildlife Service guidelines require a one-quarter mile (approximately 400 meter) buffer between construction activities and known nests of two endangered birds - the Southwestern willow flycatcher (Empidonax traillii extimus) and Western yellow-billed cuckoo (Coccyzus americanus). However, data are lacking on whether this buffer distance is appropriate. Therefore, a noise disturbance study was initiated using non-federally listed proxy species to determine whether the current buffer distance is appropriate. No measurable impact of construction noise broadcasts on nesting birds was documented in the pilot year of the study. Further study is recommended in order to assess the impacts to breeding avian species from long-term and complex heavy equipment operation adjacent to occupied nesting habitat.

DOI: Report # ENV-2020-025 (from MRG project portal)

Diver-Franssen, T.A., Bertrand, N.G., Cardone, F., Watanabe, S., Hasegawa, T. and Lam, C., 2020. Advances in Environmental Biology of Fishes. ***Advances in Environmental Biology of Fishes.***

Keywords: No Keywords found.

Abstract: (for the book) Environmental Biology of Fishes is about studies on the ecology, life history, epigenetics, behavior, physiology, morphology, systematics and evolution of marine and freshwater fishes, which deals with the relationship between fishes and their external and internal environment. In the present book, fifteen typical literatures about Environmental Biology of Fishes published on international authoritative journals were selected to introduce the worldwide newest progress, which contains reviews or original researches on Environmental Biology of Fishes. We hope this book can demonstrate advances in Environmental Biology of Fishes as well as give references to the researchers, students and other related people.

Concerned with Chapter 1: Drought results in recruitment failure of Rio Grande silvery minnow (Hybognathus amarus), an imperiled, pelagic broadcast-spawning minnow**.**

DOI: URL:
https://www.scirp.org/book/detailedinforofabook.aspx?bookid=2718&pagespeed=noscript

Fogarty, C., 2020. Linking Morphodynamic Processes and Silvery Minnow Habitat Conditions in the Middle Rio Grande-Isleta Reach, New Mexico (Doctoral dissertation, Colorado State University).

Keywords: No keywords listed.

Abstract: The Middle Rio Grande, located in central New Mexico, is home to the Rio Grande Silvery Minnow (RGSM), an endangered species of fish. Much of the RGSM's historical range has been lost due to natural and human-caused alterations to the river. For this study, the availability of RGSM habitat is analyzed in the Isleta reach, a segment of the Middle Rio Grande extending approximately 42 miles from Isleta Diversion dam to the confluence of Rio Puerco. To better understand spatial and temporal trends in morphology and channel geometry, the Isleta reach is delineated into six subreaches (I1, I2, I3, I4, I5, and I6). The purpose of this study is to identify connections between hydraulics, geomorphology, and biology to better explain the changing biological conditions in the river. To assess changes in geomorphology along the Isleta reach, the geomorphic conceptual model developed by Massong et al. (2010) was applied to representative cross-sections in each subreach. The model proposes two pathways that changes in the Middle Rio Grande can follow: aggrading (A) or migrating (M). Through inspection of aerial imagery and cross-sectional geometry data, it appears that the Isleta reach is in stage 3 and migrating stages, M4-M8, indicating high sediment transport capacity. River form was further classified using Cluer and Thorne's (2013) stream evolution model. In 2012, all subreaches were in stage 3 (i.e. degradation) of the model. One-dimensional modeling techniques were used to assess habitat availability for the RGSM from 1962 to 2012. Using the Hydrologic Engineering Center's River Analysis System (HEC-RAS), flow distribution slices were used to compute velocity and depth along a cross-section. Hydraulically suitable RGSM habitat for larvae, juvenile, and adult stages is determined using velocity and depth criteria for the fish proposed by Mortensen et al. (2019). The results suggest that habitat availability follows three typical patterns. Earlier years (1962 and 1972) showed "rounded" habitat curves, while later years (1992, 2002, and 2012) showed "step" and "hook" habitat curves. Detailed maps were produced in ArcMap that aid in the visualization of where RGSM habitat is located within the Isleta reach. These maps suggest that subreaches I1 to I3 contain the most habitat for all life stages. However, much of the habitat is disconnected and far away from the main channel, making it inaccessible to the fish. Through an analysis of restoration potential, it was determined that subreaches I2 to I4 may be areas of focus for river management to increase RGSM habitat. Time-integrated habitat metrics, originally developed by Doidge et al. (2020), is a method of interpolating cumulative RGSM habitat for each year between 1992 and 2019. This method requires input of annual habitat curves and daily discharge data. These inputs are used in a summation of simple linear equations that results in habitat metrics for each of the RGSM's life stages. The results show that larval and juvenile habitat metrics are more sensitive to changes in daily discharge than adult habitat metrics. Ecological relationships were inferred based on plots created by Mortensen et al. (2020) that relate habitat metrics, discharge, occurrence probability and lognormal density. Overall, larvae proved to be strong predictors of population dynamics.

DOI: https://hdl.handle.net/10217/219529

Gaffke, A. M., S. E. Sing, T. L. Dudley, D. W. Bean, J. A. Russak, A. Mafra-Neto, R. K. Peterson, and D. K. Weaver. 2020. Establishing Diorhabda carinulata: Impact of Release Disturbances on Pheromone Emission and Influence of Pheromone Lures on Establishment. *Journal of Chemical Ecology.*

Keywords: aggregation, biological control, release protocol, biological invasion, weed control

Abstract: Before weed biocontrol insects are transported and released in a new area, they are commonly collected into small paper containers, chilled, and kept under dark conditions. This process can be termed a pre-release protocol. The influence of a pre-release protocol on establishment success of a gregarious biological control agent was assessed using the northern tamarisk beetle, *Diorhabda carinulata* (Desbrochers), and its exotic, invasive host plant saltcedar (*Tamarix* spp.). Pre-release protocol impacts on aggregation pheromone production by *D. carinulata* were characterized under controlled conditions. Additional experiments were undertaken to determine if deployment of aggregation pheromone lures might enhance the agent's persistence at release sites. Adults that experienced the pre-release protocol produced less aggregation pheromone compared to undisturbed adults. Olfactometer bioassays indicated that a cohort of adults subjected to the pre-release protocol were less attractive to other adults than a control cohort. Efficacy of aggregation pheromone-based lures to retain adults at release sites was evaluated by comparing capture numbers of adult beetles at paired treatment and control release sites, 10–14 days after the release of 300, 500, or 1000 individuals. A greater number of adult *D. carinulata* were captured where the pheromone lures had been deployed compared to control release sites. Application of aggregation pheromone when a new release of *D. carinulata* is planned should allow biological control practitioners to increase retention of beetles at a release site.

DOI: 10.1007/s10886-020-01176-4

Gaffke, A. M., S. E. Sing, J. G. Millar, T. L. Dudley, D. W. Bean, R. K. Peterson, and D. K. Weaver. 2020. An Herbivore-Induced Plant Volatile from Saltcedar (Tamarix spp.) Is Repellent to Diorhabda carinulata (Coleoptera: Chrysomelidae). ***Environmental Entomology*****.**

Keywords: olfactometer, coleoptera, chrysomelidae, biological control, Tamarix

Abstract: The leaf beetle *Diorhabda carinulata* Desbrochers (Coleoptera: Chrysomelidae) was introduced into the United States in 1999 for classical biological control of the exotic woody invader saltcedar (Tamarix spp. L. [Caryophyllales: Tamaricaceae]). The recent southern expansion of the range of *D. carinulata* in the United States has precipitated conflict between proponents of biological control of *Tamarix* and those with concerns over habitat conservation for avian species. Several semiochemicals that mediate aggregations by this species have been reported, but no repellent compounds have been recorded thus far. We now report a repellent compound, 4-oxo-(*E*)-2-hexenal, induced by adult *D. carinulata* feeding on saltcedar foliage. Collection of headspace volatiles, gas chromatography mass spectrometry, and electroantennographic analyses identified 4-oxo-(*E*)-2-hexenal as an insect-induced compound that is antennally active. Behavioral and exposure assays were conducted to test for repellency and toxicity in adults and larvae. Headspace volatiles were also collected from adult males exposed to 4-oxo-(*E*)-2-hexenal to determine the impact exposure might have on the emission of the aggregation pheromone. 4-Oxo-(*E*)-2-hexenal elicited electrophysiological responses in adults of both sexes. Behavioral responses indicated repellency across multiple doses for reproductive *D. carinulata* adults but not in nonreproductive adults. Exposure assays indicated altered behaviors in first instar larvae and adults, but not in third instar larvae. Collection of headspace volatiles indicated that exposure to 4-oxo-(*E*)-2-hexenal did not alter emission of the *D. carinulata* aggregation pheromone by adult males. The continued development and field deployment of this repellent compound may provide a new tool for the management of *D. carinulata*.

DOI: 10.1093/ee/nvaa079

González, E., P. B. Shafroth, S. R. Lee, S. M. Ostoja, and M. L. Brooks. 2020. Combined Effects of Biological Control of an Invasive Shrub and Fluvial Processes on Riparian Vegetation Dynamics. *Biological Invasions.*

Keywords: Arrow weed, biological control, defoliating beetle, large flood, saltcedar, Tamarisk, vegetation response

Abstract: Plant community responses to biocontrol of invasive plants are understudied, despite the strong influence of the composition of replacement vegetation on ecosystem functions and services. We studied the vegetation response to a folivore beetle (*Diorhabda* genus, Coleoptera) that has been introduced along southwestern US river valleys to control the invasion of non-native shrubs in the genus *Tamarix* (Tamaricaceae). We collected detailed plant compositional and environmental data during four different surveys over 7 years (2010–2017), including two surveys prior to when substantial beetle-induced dieback occurred in summer 2012, along the lower Virgin River, Nevada. The study river was of special interest because it is one of only a few largely unregulated rivers in the region, and a large flood of 40-year return period occurred between the first and second surveys, allowing us to study the combined effects of fluvial processes, which typically drive riparian plant community assembly, and biocontrol. Vegetation trajectories differed as a function of the dominant geomorphological process. *Tamarix* cover declined an average of 75% and was replaced by the native shrub *Pluchea sericea* as the new dominant species in the floodplain, especially where sediment deposition predominated. Following deposition, and especially erosion, opportunistic native herbs, *Tamarix* seedlings, and noxious weeds colonized the understory layer but did not increase in cover over time. Stands of the native shrub *Salix exigua*, a desirable replacement species following *Tamarix* control, only increased slightly and remained subordinate in the floodplain. Overall, our results showed that, by successfully controlling the target non-native plant, a biocontrol agent can substantially modify the replacement plant communities in a riparian system, but that fluvial processes also strongly influence the resulting communities.

DOI: 10.1007/s10530-020-02259-9

González, E., P. B. Shafroth, S. R. Lee, S. C. Reed, and J. Belnap. 2020. Riparian Plant Communities Remain Stable in Response to a Second Cycle of Tamarix Biocontrol Defoliation. *Wetlands.*

Keywords: biocontrol, defoliation, riparian plant community, Salix, Tamarix, Upper Colorado River

Abstract: Reduced abundance of non-native *Tamarix* shrubs in western U.S. riparian systems following biological control by a defoliating beetle has led to concerns that replacement plant communities could be dominated by other invasive species and/or not provide some of the ecosystem services that *Tamarix* was providing. In previous studies, *Tamarix* decline following biocontrol was accompanied by small increases in native and non-native herbaceous species, with variable responses of woody vegetation. However, none of these studies spanned periods longer than a decade since beetle release. This is an important caveat, given the cyclical nature of plant-herbivore interactions and potential lags in vegetation recovery. We report plant community response to an eight-year-long second cycle of *Tamarix* defoliation-refoliation in two reaches of the upper Colorado River in eastern Utah, 11–13 years after beetle arrival. *Tamarix* cover across sites initially declined an average of ca. 50% in response to the beetle, but then recovered. Changes in the associated plant community were small but supported common management goals, including a 47% average increase in cover of a native shrub (*Salix exigua*), and no secondary invasions by other non-native plants. We suggest that the effectiveness of biocontrol programs must be assessed case-by-case, and on a long-term basis.

DOI: 10.1007/s13157-020-01381-7

Hall, L. S., B. K. Orr, J. Hatten, A. Lambert, and T. L. Dudley. 2020. Southwestern Willow Flycatcher (Empidonax traillii extimus) and Western Yellow-billed Cuckoo (Coccyzus americanus occidentalis) Surveys and Habitat Availability Modeling on the Santa Clara River, California, 26 March 2020. Western Foundation of Vertebrate Zoology-Field Projects.

Kewords: No Keywords found.

Abstract: Our project aimed to conduct population surveys for Southwestern Willow Flycatcher (Empidonax trailii extimus; SWFL) and Yellow-billed Cuckoo (Coccyzus americanus; YBCU) in 2018 and 2019, apply existing habitat models to illustrate and predict past, current, and future habitat suitabilities for these two species, and update and standardize classification and mapping of riparian vegetation to reflect recent conditions along the lower 50 miles of the Santa Clara River. Models developed by Hatten and Paradzick (2003), Hatten, et al. (2010), Hatten (2016), and Johnson et al. (2016) were applied to the SCR to provide California Department of Fish and Wildlife (CDFW) and the U.S. Fish and Wildlife Service (USFWS) with useful tools for management of resources for SWFL and YBCU.

DOI: URI: https://pubs.er.usgs.gov/publication/70217199

Hartfield, K., W. J. Van Leeuwen, and J. K. Gillan. 2020. Remotely Sensed Changes in Vegetation Cover Distribution and Groundwater along the Lower Gila River. *Land.*

Keywords: salt cedar, GEOBIA, CART

Abstract: Introduced as a soil erosion deterrent, salt cedar has become a menace along riverbeds in the desert southwest. Salt cedar replaces native species, permanently altering the structure, composition, function, and natural processes of the landscape. Remote sensing technologies have the potential to monitor the level of invasion and its impacts on ecosystem services. In this research, we developed a species map by segmenting and classifying various species along a stretch of the Lower Gila River. We calculated metrics from high-resolution multispectral imagery and light detection and ranging (LiDAR) data to identify salt cedar, mesquite, and creosote. Analysts derived training and validation information from drone-acquired orthophotos to achieve an overall accuracy of 94%. It is clear from the results that salt cedar completely dominates the study area with small numbers of mesquite and creosote present. We also show that vegetation has declined in the study area over the last 25 years. We discuss how water usage may be influencing the plant health and biodiversity in the region. An examination of ground well, stream gauge, and Gravity Recovery and Climate Experiment (GRACE) groundwater storage data indicates a decline in water levels near the study area over the last 25 years.

DOI: 10.3390/land9090326

Hatch, M. D., F. Abadi, W. J. Boeing, S. Lois, M. D. Porter, and D. E. Cowley. 2020. Sustainability Management of Short-lived Freshwater Fish in Human-altered Ecosystems Should Focus on Adult Survival. *PloS one.*

Keywords: freshwater fish, fecundity, population growth, fresh water, marine fish, conservation science, rivers, ecosystems

Abstract: Fish populations globally are susceptible to endangerment through exploitation and habitat loss. We present theoretical simulations to explore how reduced adult survival (age truncation) might affect short-lived freshwater fish species in human-altered contemporary environments. Our simulations evaluate two hypothetical "average fish" and five example fish species of age 1 or age 2 maturity. From a population equilibrium baseline representing a natural, unaltered environment we impose systematic reductions in adult survival and quantify how age truncation affects the causes of variation in population growth rate. We estimate the relative contributions to population growth rate arising from simulated temporal variation in age-specific vital rates and population structure. At equilibrium and irrespective of example species, population structure (first adult age class) and survival probability of the first two adult age classes are the most important determinants of population growth. As adult survival decreases, the first reproductive age class becomes increasingly important to variation in population growth. All simulated examples show the same general pattern of change with age truncation as known for exploited, longer-lived fish species in marine and freshwater environments. This implies age truncation is a general potential concern for fish biodiversity across life history strategies and ecosystems. Managers of short-lived, freshwater fishes in contemporary environments often focus on supporting reproduction to ensure population persistence. However, a strong focus on water management to support reproduction may reduce adult survival. Sustainability management needs a focus on mitigating adult mortality in human-altered ecosystems. A watershed spatial extent embracing land and water uses may be necessary to identify and mitigate causes of age truncation in freshwater species. Achieving higher adult survival will require paradigm transformations in society and government about water management priorities.

DOI: 10.1371/journal.pone.0232872

Isaak, D. J., C. H. Luce, D. L. Horan, G. L. Chandler, S. P. Wollrab, W. B. Dubois, and D. E. Nagel. 2020. Thermal Regimes of Perennial Rivers and Streams in the Western United States. *JAWRA Journal of the American Water Resources Association.*

Keywords: regime, temperature sensor, thermal metrics, western United States, rivers, streams

Abstract: Thermal regimes of rivers and streams profoundly affect aquatic ecosystems, but are poorly described and classified in many areas due to the limited availability of annual datasets from extensive and representative monitoring networks. By mining a new temperature database composed of >23,000 site records that spans the western United States (U.S.), we extract annual monitoring records at 578 sites on perennial streams to describe regimes in this diverse region. Records were summarized using 34 metrics that described regime aspects related to magnitude, variation, frequency, duration, and timing. The metrics were used in a multivariate cluster analysis to classify streams into seven distinct regime types and in a principal components analysis (PCA) to examine patterns of redundancy among metrics. The PCA indicated that 2–5 orthogonal PC axes accounted for 74%–89% of the variation in thermal regimes at the monitoring sites. Most of the variation in PC scores that defined the two dominant axes was in turn predictable from a suite of geospatial covariates in multiple linear regressions that included elevation, latitude, riparian canopy density, reach slope, precipitation, lake prevalence, and dam height. Our results have parallels to previous flow regime analyses that describe the utility of small numbers of PCs or allied metrics in regime characterization, and can be used to better understand and parsimoniously represent thermal regimes in the western U.S.

DOI: 10.1111/1752-1688.12864

Johnson, M. F., C. R. Thorne, J. M. Castro, G. M. Kondolf, C. S. Mazzacano, S. B. Rood, and C. Westbrook. 2020. Biomic River Restoration: A New Focus for River Management. *River Research and Applications.*

Keywords: anthrome, biogeomorphology, biome, ecosystem engineering, river management, river restoration, working with natural processes

Abstract: River management based solely on physical science has proven to be unsustainable and unsuccessful, evidenced by the fact that the problems this approach intended to solve (e.g., flood hazards, water scarcity, and channel instability) have not been solved and long-term deterioration in river environments has reduced the capacity of rivers to continue meeting the needs of society. In response, there has been a paradigm shift in management over the past few decades, towards river restoration. But the ecological, morphological, and societal benefits of river restoration have, on the whole, been disappointing. We believe that this stems from the fact that restoration overrelies on the same physical analyses and approaches, with flowing water still regarded as the universally predominant driver of channel form and structural intervention seen as essential to influencing fluvial processes. We argue that if river restoration is to reverse long-standing declines in river functions, it is necessary to recognize the influence of biology on river forms and processes and re-envisage what it means to restore a river. This entails shifting the focus of river restoration from designing and constructing stable channels that mimic natural forms to reconnecting streams within balanced and healthy biomes, and so levering the power of biology to influence river processes. We define this new approach as *biomic river restoration*.

DOI: 10.1002/rra.3529

Mahoney, S. M., M. W. Reudink, B. Pasch, and T. C. Theimer. 2020. Song but not plumage varies geographically among Willow Flycatcher (Empidonax traillii) subspecies. *Journal of Avian Biology*.

Keywords: plumage variation, song variation, subspecies, willow flycatcher

Abstract: Plumage and song are important signals used by birds to attract mates and repel rivals. Divergence in sexual signals can lead to reproductive isolation among incipient species, but the relative importance of each modality may vary among taxa. Tyrannid flycatchers exhibit evolutionarily conservative plumage coloration but distinct song structure among subfamilies and species. Thus, tyrannids are an interesting group in which to study the relative role of plumage and song in contributing to population divergence. In this study, we assessed character divergence among four willow flycatcher *Empidonax traillii* subspecies by measuring spectral reflectance of plumage modeled in tetrahedral colorspace from museum specimens collected on putative breeding grounds. We also quantified differences in song structure based on publicly available and field-recorded songs across the species range. Using unsupervised and unbiased clustering algorithms that assigned group membership independent of a priori taxonomic designations, we found that currently recognized subspecies did not consistently sort in accordance with subspecies designation based on plumage color. However, song analyses grouped birds into two clusters; one that included 89% of all putative *E. t. extimus*, and another that included 100% of specimens designated as *E. t. adastus*, *E. t. brewsteri*, *E. t. traillii* and a small percentage of *E. t. extimus* (11%). Our results are consistent with previous hypotheses of conservative plumage evolution in tyrannids and species differentiation based on song, and support the subspecific status of *E. t. extimus*.

DOI: 10.1111/jav.02621

Mamo, L. T., M. A. Coleman, P. G. Dwyer, and B. P. Kelaher. 2020. Listing May Not Achieve Conservation: A Call for Proactive Approaches to Threatened Species Management. ***Aquatic Conservation: Marine and Freshwater Ecosystems.***

Keywords: algae, coastal, conservation management, endangered species, extinction risk, precautionary principle, reactive conservation, seaweed, urban development

Abstract: Species listing and subsequent conservation efforts are dependent on a number of political, social, and scientific factors, often to the disadvantage of uncharismatic taxa, such as small, cryptic, and rare species, and those that lack commercial value. This case study examined the listing, impact assessment and conservation process of the critically endangered marine seaweed *Nereia lophocladia* (*Nereia* hereafter), which is a small and sporadically occurring species. *Nereia* was initially listed as vulnerable, and upgraded to critically endangered, following the precautionary principle. Despite the elevation of its listing and the existence of a recovery plan, little conservation effort was devoted to *Nereia.* A major upgrade to a large breakwater adjacent to *Nereia*'s only known location triggered legislation and targeted searches for the species. Once found at the site, adaptive management actions, including modifications to the breakwater and some of the first targeted scientific surveys for this species took place. The targeted surveys quickly revealed a far greater population of *Nereia* with a broader distribution than was previously realized. Given this, the breakwater upgrade probably caused less extinction risk to *Nereia* than predicted and a costly redesign may not have been necessary to secure the species' survival. The case study argues for a proactive, evidentiary approach to species conservation, where conservation actions should be initiated as soon as species are listed and not when an immediate risk of extinction arises. Such approaches would improve conservation efforts and may also reduce the overall costs of saving species.

DOI: 10.1002/aqc.3256

Moore, D. 2020. 2019 Middle Rio Grande Southwestern Willow Flycatcher Study Results – Selected Sites Along the Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir, New Mexico. Bureau of Reclamation, Technical Service Center, Fisheries and Wildlife Resources.

Keywords: No Keywords found.

Abstract: During the summer of 2019, the Bureau of Reclamation (Reclamation) conducted surveys and nest monitoring of the Federally-listed endangered Southwestern Willow Flycatcher (SWFL). The surveys were completed in five distinct reaches along approximately 80 river miles of the Rio Grande in New Mexico between San Acacia Diversion Dam and Elephant Butte Reservoir. Surveys were performed to contribute to current baseline population data, monitor population trends, determine the current distribution of SWFLs along the Middle Rio Grande, and meet Reclamation's and the Corps of Engineers' Endangered Species Act compliance commitments. During 2019 surveys, 590 resident SWFLs were documented. These residents formed 264 pairs and established 326 territories. As in previous years, the San Marcial Reach of the Rio Grande was by far the most productive supporting 293 territories and 243 pairs. The Bosque del Apache Reach supported 24 territories. Overall, territory numbers in the Middle Rio Grande declined slightly in 2019 when compared to 2018. However, two reaches (Belen and Sevilleta/La Joya) that typically are occupied by resident SWFLs were not surveyed in 2019. Time permitting, nest monitoring was conducted at all sites where nesting pairs were detected. Nests were monitored for success rates, productivity, depredation, abandonment and Brown-headed Cowbird parasitism. The San Marcial Reach again proved most productive, producing 280 nests and fledging 272 SWFL young. The Bosque del Apache Reach produced 7 nests for which fates were all unknown due to limited site access caused by extensive flooding. Overall nesting success was 42 percent.

DOI: Report # ENV-2020-024 (from the MRG program portal)

Moran, C. J., M. O'Neill, and A. C. Gibb. 2020. Integrating Studies of Anatomy, Physiology and Behavior into Conservation Strategies for the Imperiled Cyprinid Fishes of the Southwestern United States. *Integrative and Comparative Biology*.

Keywords: No Keywords found.

Abstract: Over the last 100 years, fishes native to the Southwestern United States have faced a myriad of biotic and abiotic pressures which has resulted in most being federally listed as endangered or threatened. Most notably, water diversions and the introduction of non-native fishes have been the primary culprits in causing the downfall of native fish populations. We describe how recent studies of morphology, physiology, and behavior yield insights into the failed (occasionally successful) management of this vanishing biota. We describe how understanding locomotor morphologies, physiologies, and behaviors unique to Southwestern native fishes can be used to create habitats that favor native fishes. Additionally, through realizing differences in morphologies and behaviors between native and non-native fishes, we describe how understanding predator–prey interactions might render greater survivorship of native fishes when stocked into the wild from repatriation programs. Understanding fundamental form–function relationships is imperative for managers to make educated decisions on how to best recover species of concern in the Southwestern United States and worldwide.

DOI: 10.1093/icb/icaa031

Osborne, M. J., A. C. Cameron, B. P. Fitzgerald, S. A. McKitrick, M. R. Paulk, and T. F. Turner. 2020. The Complete Mitochondrial Genomes of Three Imperiled Cyprinid Fishes: Bonytail (Gila elegans), Rio Grande Silvery Minnow (Hybognathus amarus) and Loach Minnow (Tiaroga cobitis). ***Mitochondrial DNA Part B.***

Keywords: Bonytail, Rio Grande Silvery Minnow, Loach Minnow, mitogenomes, conservation genetics

Abstract: *Gila elegans*, *Hybognathus amarus*, and *Tiaroga cobitis* (Family Cyprinidae, Order Cypriniformes) are endemic and endangered fishes in the southwestern United States. We present complete mitochondrial genomes for each species. Each mitochondrion consisted of 13 protein-coding genes, 2 ribosomal (rRNA) genes, 22 transfer RNA (tRNA) genes, and a single control region (D-loop), and gene order was consistent with other cyprinid fishes. Total genome lengths were 16,593 base pairs (bp) for *G. elegans*, 16,705 bp for *H. amarus*, and 16,802 for *T. cobitis.* The GC content in *G. elegans* and *H. amarus* was 44%, but higher in *T. cobitis* at 48%. Phylogenetic trees were generated to confirm relationships inferred via novel mitogenomes, and best-supported trees were consistent with previous research.

DOI: 10.1080/23802359.2020.1774435

Osborne, M. J., T. E. Dowling, K. T. Scribner, and T. F. Turner. 2020. Wild at heart: Programs to Diminish Negative Ecological and Evolutionary Effects of Conservation Hatcheries. *Biological Conservation.*

Keywords: adaptation, captive breeding, conservation genetics, selection

Abstract: Hatchery programs are critical for conservation and management of many imperiled fishes. Most traditional aquaculture programs negatively affect ecological performance, genetic, and phenotypic diversity of hatchery-origin fish compared with wild counterparts. Here, we synthesize outcomes of three conservation programs aimed at enhancing 'wildness'. Each program focuses on a different species: lake sturgeon, razorback sucker, and Rio Grande silvery minnow. These species differ in key life history traits including size and age at sexual maturity, reproductive and migratory behavior, and habitat requirements. Threats to persistence of the focal taxa, however, exemplify common pressures experienced by freshwater fishes worldwide. Conservation hatchery programs for lake sturgeon, razorback sucker, and Rio Grande silvery minnow capitalize on natural spawning in the wild followed by collections of wild-fertilized eggs/larvae for hatchery rearing. Individuals are repatriated to the wild after rearing to body sizes less susceptible to mortality. Protocols include collections of eggs or larvae across the entire spawning period and at appropriate geographic scales to maximize retention of genetic diversity and, to increase the likelihood of preserving variation for heritable life history traits. Using direct and indirect evidence we show that hatchery programs that allow individuals to fulfill parts of the life-cycle in their native habitats can be conducted without compromising genetic diversity. Adoption of similar strategies in other imperiled fishes would improve understanding of species life history, and provide an incentive to protect native habitats so they may eventually support self-sustaining populations.

DOI: 10.1016/j.biocon.2020.108768

Peer, B. D., B. E. Kus, M. J. Whitfield, L. S. Hall, and S. I. Rothstein. 2020. Management of the Brown-Headed Cowbird: Implications for Endangered Species and Agricultural Damage Mitigation. *Human–Wildlife Interactions.*

Keywords: black-capped vireo, brown-headed cowbird, crop depredation, *Empidonax traillii extimus*, endangered species conservation, Kirtland's warbler, least Bell's vireo, Molothrus ater, *Setophaga kirtlandii*, southwestern willow flycatcher, *Vireo atricapilla*, *Vireo bellii pusillus*

Abstract: The brown-headed cowbird (Molothrus ater; cowbird) is unique among North American blackbirds (Icteridae) because it is managed to mitigate the negative effects on endangered songbirds and economic losses in agricultural crops. Cowbird brood parasitism can further affect species that are considered threatened or endangered due to anthropogenic land uses. Historically, cowbirds have often been culled without addressing ultimate causes of songbird population declines. Similar to other North American blackbirds, cowbirds depredate agricultural crops, albeit at a lower rate reported for other blackbird species. Conflicting information exists on the extent of agricultural damage caused by cowbirds and the effectiveness of mitigation measures for application to management. In this paper, we reviewed the progress that has been made in cowbird management from approximately 2005 to 2020 in relation to endangered species. We also reviewed losses to the rice (Oryza sativa) crop attributed to cowbirds and the programs designed to reduce depredation. Of the 4 songbird species in which cowbirds have been managed, both the Kirtland's warbler (Dendroica kirtlandii) and black-capped vireo (Vireo atricapilla) have been removed from the endangered species list following population increases in response to habitat expansion. Cowbird trapping has ceased for Kirtland's warbler but continues for the vireo. In contrast, least Bell's vireo (V. bellii pusillus) and southwestern willow flycatcher (Empidonax traillii extimus) still require cowbird control after modest increases in suitable habitat. Our review of rice depredation by cowbirds revealed models that have been created to determine the number of cowbirds that can be taken to decrease rice loss have been useful but require refinement with new data that incorporate cowbird population changes in the rice growing region, dietary preference studies, and current information on population sex ratios and female cowbird egg laying. Once this information has been gathered, bioenergetic and economic models would increase our understanding of the damage caused by cowbirds.

DOI: URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1706&context=hwi

Platania, S. P., J. G. Mortensen, M. A. Farrington, W. H. Brandenburg, and R. K. Dudley. 2020. Dispersal of Stocked Rio Grande Silvery Minnow (*Hybognathus amarus*) in the Middle Rio Grande, New Mexico. *The Southwestern Naturalist*.

Key words: Rio Grande; Silvery Minnow; Spawning

Abstract: Pelagic-broadcast spawning riverine fishes (pelagophils), species that produce eggs and larvae that drift laterally and downstream with the current, are declining throughout their native ranges in North America. Persistence and recolonization of pelagophils require upstream dispersal of later life stages; however, observations of dispersal are limited. We performed a mark–recapture study of stocked Rio Grande silvery minnow (Hybognathus amarus) in the Middle Rio Grande, New Mexico, during 2002 to assess dispersal of this imperiled pelagophil. Approximately 11,500 hatchery-reared Rio Grande silvery minnows marked with a fluorescent-colored visible implant elastomer were released by the Southwestern Native Aquatic and Technology Center (Dexter, New Mexico) at two locations in the 94.1-km San Acacia Reach of the Middle Rio Grande in January 2002. We recaptured 66 marked individuals (0.57%) through May 2002, upstream and downstream of both release locations. Distances traveled ranged from 0.0 to 25.2 km (0.3 – 5.3 km [mean – SD]), and movement rates ranged from 0.0 to 220 m/day (19 – 63 m/day). We recaptured two individuals >20 km upstream of their release location. Overall, stocked fish tended to disperse downstream. We often recaptured marked fish with wild conspecifics, implying repatriation of a portion of stocked fish. Gravid and spent marked female Rio Grande silvery minnows recaptured during April and May indicated that stocked fish were reproductively active concurrent with the wild population. Our study documented long-distance upstream dispersal of stocked Rio Grande silvery minnows and thus has conservation implications for restoring connectivity in the Middle Rio Grande to support the recovery of this federally listed endangered species.

DOI: 10.1894/0038-4909-64-1-31

Polvi, L.E., L. Lind, H. Persson, A. Miranda-Melo, F. Pilotto, X. Su, and C. Nilsson. 2020. Facets and Scales in River Restoration: Nestedness and Interdependence of Hydrological, Geomorphic, Ecological, and Biogeochemical Processes. ***Journal of Environmental Management.***

Keywords: Brazil, fluvial geomorphology, river ecology, river restoration, spatial scales, Sweden

Abstract: Although river restoration has increased rapidly, observations of successful ecological recovery are rare, mostly due to a discrepancy in the spatial scale of the impact and the restoration. Rivers and their ecological communities are a product of four river facets—hydrology, geomorphology, ecology and biogeochemistry—that act and interact on several spatial scales, from the sub-reach to the reach and catchment scales. The four river facets usually affect one another in predictable pathways (e.g., hydrology commonly controls geomorphology), but we show that the order in which they affect each other and can be restored varies depending on ecoregion and hydroclimatic regime. Similarly, processes at different spatial scales can be nested or independent of those at larger scales. Although some restoration practices are dependent of those at higher scales, other reach-scale restoration efforts are independent and can be carried out prior to or concurrently with larger-scale restoration. We introduce a checklist using the four river facets to prioritize restoration at three spatial scales in order to have the largest positive effect on the entire catchment. We apply this checklist to two contrasting regions—in northern Sweden and in southern Brazil—with different anthropogenic effects and interactions between facets and scales. In the case of nested processes that are dependent on larger spatial scales, reach-scale restoration in the absence of restoration of catchment-scale processes can frankly be a waste of money, providing little ecological return. However, depending on the scale-interdependence of processes of the river facets, restoration at smaller scales may be sufficient. This means that the most appropriate government agency should be assigned (i.e., national vs. county) to most effectively oversee river restoration at the appropriate scale; however, this first requires a catchment-scale analysis of feedbacks between facets and spatial scale interdependence.

DOI: 10.1016/j.jenvman.2020.110288

Regier, P. J., R. González-Pinzón, D. J. Van Horn, J. K. Reale, J. Nichols, and A. Khandewal. 2020. Water Quality Impacts of Runoff from Monsoon Storms on Arid-land Rivers: Comparing Urban and Non-urban Pulses in the Rio Grande. ***Science of The Total Environment.***

Keywords: high frequency monitoring, urban and non-urban runoff, hypoxia, river ecology, arid regions

Abstract: Urban surface runoff from storms impacts the water quality dynamics of downstream ecosystems. While these effects are well-documented in mesic regions, they are not well constrained for arid watersheds, which sustain longer dry periods, receive intense but short-lived storms, and where stormwater drainage networks are generally isolated from sewage systems. We used a network of high-frequency in situ water quality sensors located along the Middle Rio Grande to determine surface runoff origins during storms and track rapid changes in physical, chemical, and biological components of water quality. Specific conductivity (SpCond) patterns were a reliable indicator of source, distinguishing between runoff events originating primarily in urban (SpCond sags) or non-urban (SpCond spikes) catchments. Urban events were characterized by high fluorescent dissolved organic matter (fDOM), low dissolved oxygen (including short-lived hypoxia <2 mg/L), smaller increases in turbidity and varied pH response. In contrast, non-urban events showed large turbidity spikes, smaller dissolved oxygen sags, and consistent pH sags. Principal component analysis distinguished urban and non-urban events by dividing physical and biogeochemical water quality parameters, and modeling of DO along the same reach demonstrated consistently higher oxygen demand for an urban event compared to a non-urban event. Based on our analysis, urban runoff poses more potential ecological harm, while non-urban runoff poses a larger problem for drinking water treatment. The comparison of our results to other reports of urban stormwater quality suggest that water quality responses to storm events in urban landscapes are consistent across a range of regional climates.

DOI: 10.1016/j.scitotenv.2020.138443

Reiley, B. M. and T. J. Benson. 2020. Does Conservation Practice and Site Age Influence Vegetation Structure and Avian Abundance in Restored Fields?. *Wildlife Society Bulletin*.

Keywords: conservation practice, grassland habitat use, private lands, shrubland

Abstract: Farmland set-aside programs provide important habitat for many wildlife species, yet little information exists regarding how vegetation structure and species respond to conservation practice and site age. This information could provide managers with a guide for how to implement, enhance, and maintain wildlife benefits of conservation programs. We describe how vegetation structure and avian species respond to conservation practice and time since restoration at 172 sites enrolled in the Conservation Reserve Enhancement Program (CREP) in Illinois, USA. We surveyed 172 sites enrolled in 4 different conservation practices (CP) within CREP during the breeding seasons of 2012–2015 using avian point counts and vegetation surveys. Vegetation structure and composition varied among CPs, with hardwood tree plantings (CP3A) having the greatest amount of understory vegetation and tree cover. Conversely, permanent wildlife habitat (CP4D) had the greatest grass cover and least tree cover. Many bird species were found in similar numbers across CP types; however, only dickcissel (*Spiza americana*) density was greater in sites enrolled as permanent wildlife habitat. Bell's vireo (*Vireo bellii*) and yellow-billed cuckoo (*Coccyzus americanus*) were more numerous in hardwood tree plantings. Dickcissel density decreased and field sparrow (*Spizella pusilla*) density increased as fields aged, but the relationships were not consistent among CP types. Differences among CPs largely resulted from differences in dominance in woody vegetation due to initial habitat management and differential succession rates. Interestingly, many of our focal species had wider successional tolerances than previously suggested. Overall, our results demonstrate that conservation benefits change over time depending on the starting CP, that there can be considerable similarity in vegetation structure and bird communities among what appear to be very different conservation practices. This information can be used to target conservation benefits toward conservation priority species.

DOI: 10.1002/wsb.1131

Ritchie, A. B. and J. D. Pepin. 2020. Optimization Assessment of a Groundwater-level Observation Network in the Middle Rio Grande Basin, New Mexico (ver. 2, December 2020): *U.S. Geological Survey Scientific Investigations Report*.

Keywords: No Keywords found.

Abstract: The U.S. Geological Survey, in cooperation with the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), measures groundwater levels continuously (hourly) and discretely (semiannually and annually) at a network of wells and piezometers (hereafter called the observation network) within the Middle Rio Grande Basin in central New Mexico. Groundwater levels that are measured in this observation network provide a long-term hydrologic dataset that is heavily relied upon to make water management decisions. The desire to upgrade and perform maintenance on this observation network initiated this study, which assesses the spatial and temporal importance of measurements towards optimization of monitoring the observation network to reduce or redirect monitoring costs. This report describes the methods and results of the optimization assessment of this observation network, which included separate spatial and temporal methodologies and an evaluation using principal component analysis (PCA). Results from the spatial optimization assessment can be used to help identify observation network sites that do not significantly affect the generation of winter groundwaterelevation contour maps of the production zone. Results from the temporal optimization assessment and PCA can also be consulted when deciding which sites to remove from the network, especially for sites that are monitored more frequently than annually. Results from the temporal optimization assessment can be used to inform the minimum monitoring frequency at the observation network required to capture the trends shown in higher frequency monitoring. The PCA results distinguish spatially distributed characteristic water-level trends that can inform the management decisions that are made when using the spatial and temporal optimization assessment results. Reducing the temporal frequency or spatial density of monitoring is ultimately a management decision that depends on the amount of data loss or degradation that is deemed acceptable while still meeting the network objectives of the ABCWUA. This study can also serve as a starting point to a data gap analysis of local aquifer characteristics and help guide enhanced observation network design as needs arise or in advance of future water management decisions. The results of the spatial optimization assessment indicate that as many as about 20 specified sites can be removed from the observation network with a relatively small loss in the ability to represent the kriged groundwaterelevation surfaces of the production zone that were generated by using median groundwater elevations for two periods: the 2001 time interval and 2015 time interval. This analysis also demonstrated the importance of wells at the margin of the study area and in areas where there are large hydrologic gradients. At many of the 47 hourly monitored sites analyzed in the temporal optimization assessment, temporal trends were well represented for at least one of the reduced monitoring frequencies tested, indicating that a reduced frequency may be sufficient to adequately characterize seasonal and long-term trends. PCA and k-means clustering analysis of the 15

hourly monitored sites that are screened within the production zone indicate that the sites can be categorized into four groups, or clusters, of differing groundwater-level hydrograph characteristics. Except for one cluster, all of the clusters have the potential to be well represented by fewer index monitoring sites.

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Rood, S. B., M. L. Scott, M. Dixon, E. González, C. O. Marks, P. B. Shafroth, and M. A. Volke. 2020. Ecological Interfaces between Land and Flowing Water: Themes and Trends in Riparian Research and Management. *Wetlands.*

Keywords: bottomland, floodplains, human impacts, rivers, Salicaceae, Tamarix, vegetation

Abstract: This paper provides an overview of past, present and future themes for research and management of riparian zones, often relating to papers within this *Wetlands* Special Feature. Riparian research expanded in the United States around 1980 with themes that recognized (1) damage from excessive livestock, or (2) damage from river damming and diversion, and (3) the beneficial capacity of riparian buffers to intercept and assimilate nutrients and other water contaminants. Research expanded globally in the 1990s, with themes including (4) plant life history requirements and (5) reliance on fluvial geomorphic dynamics that enable riparian rejuvenation. Resource managers recognized that riparian areas provide (6) rich wildlife habitats (7) along with valued ecosystem services, (8) which encouraged conservation and restoration initiatives, (9) including environmental flow regimes. Floodplains are (10) vulnerable to invasive plants and management has included biocontrol such as for *Tamarix* in the American Southwest. Into the twenty-first century, (11) climate change is advancing, and riparian ecosystems may be especially impacted due to the compound challenges from increasing water demand and declining summer flows. As an emerging opportunity, (12) while reservoirs submerge floodplain vegetation, reservoir deltas may support compensatory riparian wetlands. (13) Studies increasingly utilize remote sensing tools including satellite imagery, LiDAR and unmanned aircraft systems, and (14) the coordination of large data sets invites digital ecology, including artificial intelligence and machine learning. Since riparian zones are centres for human activities, (15) there are opportunities for citizen science, social media and internet applications, which will increasingly democratize riparian research and management.

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Smith, C. B., 2020. A Conceptual Model Evaluation Framework for Adaptive Governance and Adaptive Management in Large-Scale Restoration Programs (*Doctoral dissertation, The University of Nebraska-Lincoln*).

Keywords: No Keywords found.

Abstract: Adaptive management (AM) has become a kind of plastic phrase applied as a formulaic panacea for most major species recovery and ecosystem restoration efforts now underway across the United States. AM emerged as an application of the scientific method to resource management, closely tying management to science learning through experimental actions. The phrase “learning by doing” best captures the premise behind developing an experimental management approach that could be applied on the larger scale of a river system or ecosystem. In nearly five decades application, however, examples of successful AM implementation at large scales are few and conflict remains over how to achieve the most essential elements of true adaptive management. Emerging theory on governance structures and the ability of those structures to adapt to a changing environment led to development of adaptive governance (AG). With a focus on polycentric structures, self-organization, and decision-making made more inclusive and less top-down, AG appears linked to the notions of AM grounded in constant learning, implementing management actions as experiments, and embracing uncertainty. AG has thus emerged as an integral approach to tackling the challenges of moving large-scale AM programs forward. But few analytical frameworks exist to evaluate governance performance and point to necessary reforms. Similarly, assessment frameworks for AM focus on improving the steps of the AM process but do not capture related linkages to the governance structure under which those AM processes are operated. The central proposition of my dissertation is that governance of a large-scale aquatic system adaptive management program is determinative in successful implementation of adaptive management thus predicating program success. To explore this proposition, I developed and field-trialed a new conceptual model restoration program evaluation framework that incorporates a performance assessment of multiple components and subcomponents of AG and AM; a risk assessment of these AG and AM components; and a typology to place restoration programs in quadrants of possible success, all resulting in recommendations for restoration program reform.

DOI: URL: https://search.proquest.com/openview/9734dfd59c58008e59d981d7fd5b7bdc/1?pq-origsite=gscholar&cbl=44156

Sprößig, C., S. Buchholz, and F. Dziock. 2020. Defining the Baseline for River Restoration: Comparing Carabid Beetle Diversity of Natural and Human-impacted Riparian Habitats. *Journal of Insect Conservation*.

Keywords: crabidae, functional diversity, ground beetles, lowland river ecosystem, Mulde river, riparian habitat

Abstract: Near-natural rivers and riparian ecosystems can represent biodiversity hotspots harbouring many highly specialised, rare and endangered species. During the past centuries, these habitats have been heavily degraded by anthropogenic use, and therefore river restoration is one of the most striking fields of action that is legally defined by the European Union Water Framework Directive. Successful restoration depends on realistic and specified targets that should be defined beforehand and founded on status quo surveys. We present a comparison of carabid beetle communities in riparian habitats of natural and managed river sites of the Mulde River in the Biosphere Reserve Middle Elbe. This endeavour is part of a unique multi-level revitalisation project. Pitfall trapping in 2016 and 2017 yielded 111 carabid species with many species of conservation concern in natural and managed habitats. However, Simpson diversity and functional diversity were lower in the latter. Both habitats harboured specific species assemblages with characteristic indicator species. Additionally, the trap location on slip-off slopes or cut banks was a significant driver of species composition. Our results indicate high ecological development potentials for the Mulde River, but restoration should consider differences between slip-off slopes and cut-off banks. We postulate that future restoration will foster population increases as well as a wider distribution of rare and endangered riparian habitat specialists.

DOI: 10.1007/s10841-020-00253-z

Steinberg, K. A., K. D. Eichhorst, and J. A. Rudgers. 2020. Riparian Plant Species Differ in Sensitivity to Both the Mean and Variance in Groundwater Stores. *Journal of Plant Ecology*.

Keywords: climate change, climate variability, riparian, Rio Grande, New Mexico, cottonwood, willow, tamarisk

Abstract: Aims-Determining the ecological consequences of interactions between slow changes in long-term climate means and amplified variability in climate is an important research frontier in plant ecology. We combined the recent approach of climate sensitivity functions with a revised hydrological 'bucket model' to improve predictions on how plant species will respond to changes in the mean and variance of groundwater resources.

Methods-We leveraged spatiotemporal variation in long-term datasets of riparian vegetation cover and groundwater levels to build the first *groundwater sensitivity functions* for common plant species of dryland riparian corridors. Our results demonstrate the value of this approach to identifying which plant species will thrive (or fail) in an increasingly variable climate layered with declining groundwater stores.

Important Findings-Riparian plant species differed in sensitivity to both the mean and variance in groundwater levels. Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii*) cover was predicted to decline with greater inter-annual groundwater variance, while coyote willow (*Salix exigua*) and other native wetland species were predicted to benefit from greater year-to-year variance. No non-native species were sensitive to groundwater variance, but patterns for Russian olive (*Elaeagnus angustifolia*) predict declines under deeper *mean* groundwater tables. Warm air temperatures modulated groundwater sensitivity for cottonwood, which was more sensitive to variability in groundwater in years/sites with warmer maximum temperatures than in cool sites/periods. Cottonwood cover declined most with greater intra-annual coefficients of variation (CV) in groundwater, but was not significantly correlated with inter-annual CV, perhaps due to the short time series (16 years) relative to cottonwood lifespan. In contrast, non-native tamarisk (*Tamarix chinensis*) cover *increased* with both intra- and inter-annual CV in groundwater. Altogether, our results predict that changes in groundwater variability and mean will affect riparian plant communities through the differential sensitivities of individual plant species to mean versus variance in groundwater stores.

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Stern, J. L. 2020. Determining Vegetation Metric Robustness to Environmental and Methodological Variables, and Coefficients of Conservatism for the Flora of the Middle Rio Grande, New Mexico (Doctoral dissertation).

Keywords: restoration ecology, coefficients of conservatism

Abstract: Common vegetation metrics used in monitoring of ecological restorations include measures of vegetation structure and measures of species diversity and composition. Metrics of species diversity and composition are often used as proxies for overall biological diversity of a site, but some metrics may be misleading in their ability to fully capture the integrity of ecological interactions of that site. Understanding metric sensitivity to external variables is deeply important to restoration ecology and applied land management. If a metric is influenced by changes in sample size, differences among community types, differences between regions, or potential observer bias, then it calls into question the metric's strength for measuring ecological integrity, specifically the metric's usefulness when comparing among sites or within a given site through time. I focused on vegetation metrics and their use in applied land management for my thesis. My research is based on vegetation data collected from four regions across the United States over two years, in collaboration with regional botanists, land managers, and land management agencies. In Chapter 2, I used the vegetation data collected across the four regions of the United States to answer two questions regarding commonly used vegetation metrics: 1) Are commonly used vegetation metrics robust, or insensitive to, common environmental variables and methodological choices used in different monitoring regimes, and 2) based on region, what is the adequate sample size for these commonly used vegetation metrics? To be able to adequately compare metrics among all regions, I first needed to create C-values within the study region in New Mexico that lacked those values. In Chapter 3, I collaborated with botanists from New Mexico to develop Coefficients of Conservatism for the Middle Rio Grande region. These values provide an easy and accessible tool for land managers to use when evaluating sites for riparian restorations, or for long term monitoring of previously restored sites. For this study, I compiled a comprehensive floral species list within the Middle Rio Grande floodplain, and assigned Coefficients of Conservatism to 624 of those species.

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Szałkiewicz, E., J. Sucholas, and M. Grygoruk. 2020. Feeding the Future with the Past: Incorporating Local Ecological Knowledge in River Restoration. *Resources.*

Keywords: river restoration, local ecological knowledge, traditional ecological knowledge, stakeholders, stakeholders' participation, ecological restoration

Abstract: Despite many years of experience in the river restoration field, which has become one of the most promising areas of water resources management, significant challenges and problems remain. These include the scope and scale of restoration measures, developing the reference model, assessment of restoration success, and the engagement of local stakeholders. Progress in addressing these challenges to river restoration could be achieved by changes in current approaches through the appreciation and integration of local communities and their local ecological knowledge (LEK). The results of discussion on ecological restoration indicate that ecological knowledge, which combines the interests of local communities and the environment, could be used in restoration projects. However, in the case of river restoration, this type of knowledge is systematically overlooked. In our paper, we discuss common river restoration problems and supportive elements that may be found in LEK. We conclude that the local stakeholders' involvement and strong establishment of their position in the river restoration processes should be reconsidered. We believe that the application of LEK has large potential for improving water resources management and restoration of aquatic ecosystems and remains a key factor in a successful future of river restoration.

DOI: 10.3390/resources9040047

Theodoropoulos, C., A. Stamou, L. Vardakas, C. Papadaki, E. Dimitriou, N. Skoulikidis, and E. Kalogianni. 2020. River Restoration is Prone to Failure Unless Pre-optimized within a Mechanistic Ecological Framework| Insights from a Model-based Case Study. *Water Research.*

Keywords: aquatic restoration, habitat use, habitat suitability, droughts, temporary rivers, climate change

Abstract: River restoration with the use of in-stream structures has been widely implemented to maintain/improve physical habitats. However, the response of aquatic biota has often been too weak to justify the high costs of restoration projects. The ecological effectiveness of river restoration has thus been much debated over claims that large-scale environmental drivers often overshadow the potential positive ecological effects of locally placed in-stream structures. In this study, we used a two-dimensional hydrodynamic-habitat model to evaluate the ecological effectiveness of habitat restoration with the use of in-stream structures in various water discharges, ranging from near-dry to environmental flows. The habitat suitability of benthic macroinvertebrates and of three cyprinid fish species was simulated for six restoration schemes and at four discharge scenarios, and was compared with a reference model, without in-stream structures. We found that the ecological response to habitat restoration varied by species and life stages, it strongly depended on the reach-scale flow conditions, it was often negative at near-environmental flows, and when positive, mostly at near-dry flows, it was too low to justify the high costs of river restoration. Flow variation was the major environmental driver that our local habitat restoration schemes attempted -but mostly failed-to fine-tune. We conclude that traditional river restoration, based on trial and error, will likely fail and should be ecologically pre-optimized before field implementation. Widespread use of in-stream structures for ecological restoration is not recommended. However, at near-dry flows, the response of all biotic elements except for macroinvertebrates, was positive. In combination with the small habitat-suitability differences observed among structure types and densities, we suggest that sparse/moderate in-stream structure placement can be used for cost-effective river restoration, but it will only be ecologically effective -thus justifying the high implementation costs-when linked to very specific purposes: (i) to conserve endangered species and (ii) to increase/improve habitat availability/suitability during dry periods, thus proactively preventing/reducing the current and future ecological impacts of climate change.

DOI: 10.1016/j.watres.2020.115550

Uhey, D. A., A. K. Rowe, and D. Kendall. 2020. Tamarisk Alters Arthropod Composition, but has Little Negative Effect on Richness and Abundance in Southwestern Colorado. *Southwestern Entomologist.*

Keywords: No Keywords found.

Abstract: Riparian corridors are vulnerable to invasion by non-native plant species that can alter arthropod communities and ecological functions. Tamarisk (Tamarix spp. L.) replaced native riparian vegetation on 1.6 million acres in the southwestern United States. Our study investigated arthropod communities in three riparian habitats, two dominated by native vegetation (willow (Salix exigua Nutt.) in lower floodplain and mixed-native xeroriparian shrubs in upper floodplain) and one invaded by non-native tamarisk in lower floodplain. Tamarisk was predicted to lessen arthropod abundance and richness, change composition, and associate with nonnative arthropods. We sampled 41,124 arthropods identified to 258 taxa and seven functional groups during 2 years along the Dolores River in Colorado. Richness and abundance were not less in tamarisk, but composition differed among the three habitats. Trends varied across taxonomic and functional groups. Lower floodplain habitats, tamarisk and willow, were relatively similar in composition, with large numbers of beetles, hemipterans, detritivores, and herbivores. More ants, pollinators, and greater diversity were in upper floodplain shrub habitat. Tamarisk hosted several non-native arthropods: Armadillidium vulgare (Latreille), Cylisticus convexus (De Geer), Diorhabda carinulata (Desbrochers), and Coniatus splendidulus (Fabricius), while willow housed non-native weevils (Otiorhynchus spp. Germar). Tamarisk was favored by some non-native arthropods and altered community composition but did not lessen abundance or richness of functional or taxonomic groups. The results highlighted effects of non-native plants on arthropod communities and have implications for conservation of insectivorous riparian wildlife.

DOI: 10.3958/059.045.0301

Valdez, R. A., S. A. Zipper, S. J. Kline, and G. M. Haggerty. 2020. Use of Restored Floodplains by Fishes of the Middle Rio Grande, New Mexico,USA. *Ecohydrology.*

Keywords: habitat, larvae, mainstem banklines, Middle Rio Grande, pelagophils, restored floodplains, Rio Grande silvery minnow

Abstract: Nearly 1600 ha of habitat have been restored at 300 floodplain sites of the Middle Rio Grande (MRG), New Mexico, USA, as part of a cooperative effort of the Middle Rio Grande Endangered Species Collaborative Program to conserve the endangered Rio Grande silvery minnow (RGSM). These riverside sites are designed to inundate during spring run-off and create ephemeral habitats for other aquatic and riparian species. This study of four restored floodplain sites in May–June 2017 found that of 14 fish species captured with fyke nets, common carp (41%), red shiner (32%), RGSM (16%) and white sucker (9%) dominated total numbers. Adult RGSM included 42% gravid females, 36% ripe males and 22% spent females, suggesting that this endangered species was spawning in and near these floodplains. Larval sampling also showed that restored sites and adjacent mainstem banklines were being used as nursery habitats, where RGSM larvae dominated six and nine species with 80% and 74% of total numbers, respectively. System-wide proportions of RGSM larvae by phase suggest that larvae leave the floodplains and move to mainstem banklines beginning as late mesolarvae and metalarvae (14–22 days post-hatch), and most depart by the juvenile stage. Altogether, 15 fish species were encountered in restored floodplain sites in 2017, compared to 16 species reported in concurrent annual mainstem monitoring. This study and others show that most fish species of the MRG move onto restored and natural floodplains equally in spring, and many use these habitats for spawning and as larval nurseries.

DOI: 10.1002/eco.2262

Wohner, P. J., S. A. Laymon, J. E. Stanek, S. L. King, and R. J. Cooper. 2020. Challenging our understanding of western Yellow-billed Cuckoo habitat needs and accepted management practices. *Restoration Ecology*

Keywords: California, natural regeneration, restoration, South Fork Kern River Valley, spot mapping, successional dynamics, vertical structure

Abstract: Riparian restoration in the southwestern United States frequently involves planting cottonwood (*Populus* spp.) and willow (*Salix* spp.). In the absence of flooding and gap-forming disturbance, planted forests often senesce without further young tree recruitment. This has largely been the case in California riparian systems that historically supported state endangered western Yellow-billed Cuckoo (*Coccyzus americanus*; Cuckoo). A decline in Cuckoo population numbers in the past thirty years has been associated with forest maturation. Other riparian species of concern show a concomitant decline, indicating the problem is not specific to Cuckoos. Although varying hypotheses exist for recent decline, alternative management practices have not been sufficiently explored to rule out breeding ground habitat quality as a major contributing factor. Few intensive Cuckoo datasets exist to test hypotheses about breeding habitat quality due to extremely low populations in the remaining occupied sites. We used a historical (1986–1996) spot mapping dataset from the South Fork Kern River Valley, CA to identify vegetation characteristics related to Cuckoos and five other sensitive riparian bird territory densities. We found Cuckoo densities were positively associated with increased vertical vegetative structure 1–5 m above ground with a threshold for mean tree height. Sensitive species densities were also related to vertical structure and started to decline with stand height greater than 6–8 m. Naturally regenerated sites had higher densities of most sensitive bird species than planted sites. We provide ideas for restoring mature forest with little vertical structure.

DOI: 10.1111/rec.13331

Yang, Y. E., K. Son, F. Hung, and V. Tidwell. 2020. Impact of Climate Change on Adaptive Management Decisions in the Face of Water Scarcity. *Journal of Hydrology.*

Keywords: Upper Colorado River Basin, adaptive capacity, agent-based model, drought contingency plans, tribal water rights

Abstract: Reoccurring drought through the early 2000s has caused a serious water scarcity issue in the Colorado River Basin. Previous modeling studies have focused on the impact of climate change without considering the adaptive behaviors of farmers and under-utilized Indian water rights. In this paper, we use a coupled agent-based water resource model (ABM) to investigate how the adaptive decisions of farmers can affect water resource management under both climate change impacts and fully utilized Indian water right conditions. We used five General Circulation Model projections with RCP8.5 scenarios for the study. The results of farm-level decision-making showed different responses in irrigated areas that were changing due to climate change impact. While winter precipitation changes might partially explain the behavior changes, no specific pattern could be concluded based on their location. Also, farmers' responses about annual water diversion showed more significant inter-year variation compared to irrigated areas. Basin-level metrics showed that climate change impacts will generally worsen water scarcity issues as measured in Navajo Reservoir storage, flow to Lake Powell, and instream flow requirement. But these basin-level water scarcity metrics cannot reflect individual farm-level impacts under climate change, which is why modeling the bottom-up management actions is necessary. When the under-utilized Indian water rights are fully used, it is more likely to trigger the shortage sharing agreement due to the higher tribal water depletion. Evaluation of model uncertainty and a more realistic setup for adaptive actions under drought contingency plans are suggested for future research.

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