Dynamic multibenefit solutions for global water challenges

Melissa M. Rohde1 | Mark Reynolds2 | Jeanette Howard2

1The Nature Conservancy, Santa Cruz, California
2The Nature Conservancy, San Francisco, California

Abstract
Increasing water scarcity and extreme weather due to climate change have implications for securing water for food, drinking, and the environment. These 21st century global water challenges are often co-located, yet the solutions to these issues are often decoupled. To efficiently address global water challenges, implementing dynamic multibenefit solutions is needed to respond rapidly and nimbly to diverse and multiple water needs simultaneously. In this article, we provide an example of how dynamic multibenefit solutions have been used to provide “pop-up” wetland habitat for migratory birds, while replenishing depleted aquifers to create environmental and water supply benefits. Additionally, this article outlines six design principles that can enhance the scalability of multibenefit solutions through the use of recent technological advances borrowing concepts from the shared economy that enable scarce water resources to be dynamically shared between people and nature when and where it is needed.

KEYWORDS
agriculture, big data, global, groundwater, habitat, migratory birds, multibenefit solutions, sustainability, water management, wetlands

1 INTRODUCTION

Water scarcity is a large global challenge with one-fifth of the world’s population facing physical water scarcity and almost one-quarter facing economic scarcity (e.g., insufficient infrastructure to access water; United Nations Development Program, 2006). Increasing water scarcity has also compromised freshwater ecosystems by fragmenting river migration corridors, reducing streamflow, lowering groundwater levels in aquifers, degrading habitat with deteriorated water quality, and placing more species on the verge of extinction (Abramovitz, 1996; Ramsar Convention on Wetlands, 2018). How we address water scarcity in the 21st century will ultimately affect food security, safe and clean access to water, social and gender equity, and environmental sustainability that are the underpinnings for successfully achieving the Millennium Development Goals. Over the past century, water use has been growing at more than twice the rate of population growth resulting in higher levels of water stress due to water demands exceeding available supplies (Amarasinghe & Smakhtin, 2014; World Resources Institute, 2019). In an era of increasing water scarcity and extreme weather events due to climate change, global water challenges are often co-located, yet the solutions to these issues are often decoupled. For example, the intensification of agricultural lands is often accompanied by higher water use that depletes groundwater and surface water supplies in many

Received: 15 February 2019 Revised: 16 October 2019 Accepted: 19 October 2019
DOI: 10.1111/csp2.144

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2019 The Authors. Conservation Science and Practice published by Wiley Periodicals, Inc. on behalf of Society for Conservation Biology
of the world’s river basins (e.g., Nile River, Murray-Darling Basin, Colorado River, and Mekong River). This has resulted in competing water demands for food production, safe and affordable water for drinking and sanitation, and freshwater ecosystems. While solutions that simultaneously address global water challenges for agriculture, drinking water, and the environment are needed, traditional disciplinary divides across sectors have often resulted in siloed policy and decision making. For example, agricultural policies (e.g., subsidized crop prices for water-intensive crops, fertilizers, and energy costs to extract water) intended to increase food security also can cause unintended consequences for communities and freshwater ecosystems by simultaneously deteriorating water quality and reducing water supplies. This is highly problematic as it leaves agricultural, water management, and conservation interests unaligned and often at odds with each other.

In 2018, the United Nations declared nature as a solution to overcome 21st century water challenges, creating a dialog shift away from “gray” infrastructure (e.g., dams, canals, and pumps) towards “green” infrastructure (e.g., wetlands, floodplains, aquifers). Nature-based solutions, approaches which utilize and reinforce natural processes, are now promoted as a new opportunity to address multiple people-nature benefits simultaneously as a means to efficiently address global challenges, such as climate change, food and water security, disaster risk reduction, and social and economic development (European Commission, 2015; IUCN, 2012). By recognizing the role of ecosystems, conservation practitioners, policy makers, investors, and other stakeholders can unlock the capabilities of nature to create multibenefits while contributing to water management outcomes (United Nations World Water Assessment Program, 2018). However, implementing nature-based solutions to achieve multibenefits is challenging since it requires the use of sound multidisciplinary and transdisciplinary knowledge, an evaluation of short- versus long-term effectiveness compared with traditional engineered approaches, stakeholder involvement, and the ability to minimize conflict to equitably distribute trade-offs (Nesshover et al., 2017). The wide variability in spatial and temporal scales of global water challenges requires a dynamic approach for efficient and scalable solutions.

### 2 | DYNAMIC MULTIBENEFIT SOLUTIONS

Dynamic management, which relies on the integration of real-time data to inform management decisions rapidly in space and time, originated in marine systems such as fisheries and boat-based shipping in the ocean (Lewison et al., 2015; Maxwell et al., 2015) and has been also recently been applied to terrestrial strategies for migratory bird conservation (Reynolds et al., 2017) as an innovative and cost-effective addition to traditional management approaches. Traditional approaches that permanently protect ecosystems often rely on static management schemes that result in governmental, non-governmental, or private interest groups purchasing or restoring land in the form of a land trust, preserve, refuge, or public park. While this approach can be effective, permanent land protection in itself has not been expedient or nimble enough to counterbalance the staggering decline of global freshwater ecosystems and water resources (Abramovitz, 1996; Ramsar Convention on Wetlands, 2018). The integration of dynamic conservation and permanent protected areas, particularly in highly human-modified and fragmented landscapes, is increasingly being recognized as a critical strategy to provide temporary or transient protection for migratory or critical species in response to climate change (D’Aloia et al., 2019). Since the effectiveness of protected areas is dependent upon the surrounding landscape, working agricultural lands that can provide buffer zones and transitions between protected areas can help enhance sustainability and resilience (Kremen & Merenlender, 2018). In addition to addressing biodiversity and conservation challenges, the integration of dynamic design principles has the potential to surmount some of the aforementioned challenges by reframing how we utilize our working agricultural landscape, so land and water resources can simultaneously serve the needs of multiple water users. With so many regions of the globe plagued by water scarcity, aging infrastructure, and degraded ecosystems, we see a global opportunity to deploy dynamic management to achieve multibenefits and flexibly respond to our water challenges.

### 3 | CASE STUDY EXAMPLE: POP-UP WETLANDS INCREASE MIGRATORY BIRD HABITAT AND WATER SUPPLY

Balancing the water needs of multiple water users is an optimization challenge that relies upon demand reductions and supply increases to meet diverse needs that often compete with one another. Addressing this challenge is proving even more difficult with climate change, existing water policies (e.g., water rights), and aging gray infrastructure (e.g., surface water storage and conveyance infrastructure, such as dams and canals) that limit options. Due to unprecedented and rapid groundwater
use worldwide (Famiglietti, 2014), depleted aquifers provide vast quantities of decentralized “green” storage space underground that can cost-effectively store alternative water sources (e.g., flood water from rivers, urban stormwater, and treated wastewater) that would otherwise require high energy costs to convey to centralized storage infrastructure, such as dams and reservoirs, located farther upstream (Perrone & Rohde, 2016). Storing water in underground aquifers by storing water in times of plenty to be later used in drier times can enhance the resiliency and reliability of water supplies. Storing water into depleted underground aquifers also provides multiple benefits such as increasing water supply, improving groundwater quality, reducing land subsidence, preventing seawater intrusion, and reconnecting groundwater in aquifers with surface water to support instream flows and groundwater-dependent ecosystems. The integration of dynamic management principles and water resource management can potentially yield more sustainable results with multiple benefits, while flexibly responding to the water needs for different users with less water.

To improve the alignment of human and environmental interests, we tested whether the practice of renting or temporarily utilizing appropriated agricultural land and water to create “pop-up” habitat can offer a new way to deliver water to serve multiple water users simultaneously. This program, known as BirdReturns, was developed by The Nature Conservancy and operates in California’s Central Valley. The Central Valley is a major agricultural corridor, where a century of unregulated groundwater use, over-appropriation of surface water, and the conversion of 1.6 million ha of wetland habitat to agriculture and urban development, has resulted in critically overdrafted groundwater basins and 5–10% of wetland habitat remaining today (Frayer, Peters, & Pywell, 1989; The Bay Institute, 1998; Central Valley Joint Venture, 2006). BirdReturns operates by compensating farmers for costs to apply water to their fields to a suitable depth (~10 cm) for migratory shorebirds over 2- to 8-week periods during critical spring and fall migration. Through this work, The Nature Conservancy established a series of “pop-up” habitats along this highly fragmented and human-modified portion of the Pacific Flyway by relying on crowd-sourced bird data and satellite-based water maps to pinpoint where habitat is needed. Crowd-sourced bird data were sourced through Cornell Lab of Ornithology’s eBird program (Sullivan et al., 2014). In partnership with The Nature Conservancy, shorebird abundance models were created from eBird data (Johnston et al., 2015). In partnership with Point Blue Conservation Science, probability of surface water was estimated based on NASA Landsat imagery (Reiter et al., 2015). Model predictions for several shorebird species and water availability were then combined to construct a “shorebird conservation value” surface for the Central Valley for each day of the year (Reynolds et al., 2017).

The Central Valley is one of the largest agroecosystems on earth and is highly plumbed and engineered with water infrastructure. Surface water moves throughout the Central Valley at all times of the year, resulting in altered flow regimes (Zimmerman et al., 2017) that are used for flood irrigated crops (e.g., rice, alfalfa), flushing salts, decomposing stubble, flood protection, water storage, flooding areas for duck hunting clubs, among other uses (Reiter et al., 2015). BirdReturns was accomplished by repurposing surface water that would have otherwise not been on the fields (in early fall) or would have been drained off and sent downstream after winter to prepare for spring planting. Since the inception of BirdReturns in 2014, the enrollment of 82,960 ha with 100 participating farmers has created temporary habitat for hundreds of thousands of migratory birds (e.g., 325,952 target shorebirds were censused in 2014 and 2015 on 11,526 ha of fields enrolled in the BirdReturns program; Golet et al., 2018). This “Air-BnB approach” leverages the existing agricultural landscape and irrigation conveyance infrastructure by “renting” land and water to replenish groundwater in depleted aquifers while supporting biodiversity conservation for a suite of targeted species (dunlins, dowitchers, small sandpipers, and other shorebirds) (Reynolds et al., 2017). Water applied to fields flows back into waterways, evaporates, or infiltrates into the ground to provide water supply benefits to the region, helping alleviate undesirable results from groundwater exploitation and building resiliency to climate change by storing water in aquifers. In comparison to traditional approaches of managed aquifer recharge and storage that involve the conveyance of surface water to either agricultural fields for on-farm managed aquifer recharge or to designated detention basins (recharge ponds), we were able to dynamically redesign managed aquifer recharge to simultaneously achieve conservation benefits. In future projects, The Nature Conservancy plans to evaluate the water quality benefits of this practice, since recharging aquifers on some agricultural soils that have been heavily fertilized can flush out nutrients and cause nitrate contamination in groundwater. The infiltration water volume from the BirdReturns work was two-thirds the total amount of the annual rainfall over the same land area over a 2- to 3-week time frame (Matsumoto, Rohde, & Heard, 2019). This was simultaneously accomplished while providing migratory bird habitat—reducing the threat of habitat loss to one of the major migratory flyways in North...
America by complementing existing efforts of permanent habitat protection. In contrast, with the spatial certainty of permanent protected areas, pop-up habitat in this area currently provides increased temporal certainty for migratory birds as the rental pool of available agricultural land is large enough to change year-to-year based on landholder needs and water availability. In addition, “renting” land and water to create migratory bird habitat is 0.5—1.5% the cost of purchasing and maintaining land and is a fraction of the cost in comparison to other water supply projects (Matsumoto et al., 2019; Reynolds et al., 2017).

4 | SIX DYNAMIC DESIGN PRINCIPLES

From the above case study, we derived six essential principles for designing dynamic multibenefit conservation strategies:

4.1 | Data and technology

Near real-time data collection and sharing via technology can enable information sharing and decision making that can ensure an equitable distribution of benefits and risks. Knowing where and when water is available and needed by beneficiaries is the first step to dynamically distribute water across the landscape. Relying on pre-existing datasets, such as crowd-sourced data, global remote sensing (aerial or satellite imagery) data, has never been easier with the internet and cloud computing. In the case of the BirdReturns example, big pre-existing datasets (i.e., Landsat satellite imagery, eBird crowd-sourced data, crop mapping from aerial imagery, soil suitability maps for aquifer recharge, statewide groundwater basin maps) were combined to identify where and when migratory habitat was needed, which agricultural fields are most suitable for on-farm recharge, and which groundwater basins have depleted aquifers.

4.2 | Financial incentives

Leveraging existing infrastructure requires a payment for services. This has been observed in the emergence of the shared economy, such as AirBnB for homeowners and Outdoorsy for recreational vehicle (RV) owners, where individually owned assets can be shared with others through a market exchange platform that provides financial compensation and some level of legal protection and insurance in doing so. In the case of BirdReturns, a reverse auctioning system allowed individual landowners to free up land and water assets in exchange for financial compensation. Other financial incentive structures, such as receiving water credits or reimbursements for replenishing groundwater into depleted aquifers—similar to how the net metering has been used to compensate roof-top solar energy production—can also provide incentives that are sustainable in the long-term yet dynamic enough to catalyze short-term benefits (Kiparsky et al., 2018).

4.3 | Measurement and monitoring

Quantification of benefits and routine monitoring are necessary to support compensation structures. For example, knowing how much water is necessary to create habitat and how much recharge can result from applying water can aid the development of financial incentive structures. Environmental targets also need to be included and monitored. While low-cost monitoring may be financially attractive initially, capacity building and deployment can be time intensive and data quality compromised. For example, low cost photo-monitoring may document animal use of habitat but not identification of similar species with subtle differences (e.g., similar shorebird species like long-billed dowitcher *Limnodromus scolopaceus* versus short-billed dowitcher *Limnodromus griseus*). Investment in and experimentation with monitoring infrastructure that can reduce transaction costs (e.g., remote sensing of land and water, telemetry for water meters, acoustic sensors to monitor birds) should be prioritized as it facilitates more accountability, data transparency, and scalability. In the case of BirdReturns, acoustic sensors are currently being tested as a supplement and eventual replacement to bird monitoring conducted by field technicians.

4.4 | Scalability

Transformational changes to meet water and ecosystem challenges need to be scalable. This will depend on the development and implementation of appropriate institutional arrangements/designs. Transboundary solutions that span a diversity of legal and institutional arrangements may have to rely more heavily on designs that depend upon market-based approaches or non-governmental institutions operating across multiple jurisdictions.

4.5 | Adaptability

Uncertainty is inevitable. Flexible approaches that can respond to climate change and changing enabling
conditions are necessary. In the case of BirdReturns, by relying on a large rental pool of agricultural land, pop-up wetlands are robust enough to nimbly respond to year-to-year changes based on landholder needs and water availability.

4.6 | Risks and tradeoffs

Dynamic multibenefit solutions can help increase water supply but need to be coupled with good water accounting and demand management. Measurement of groundwater inputs and outputs, as well as regulatory mechanisms (e.g., well permitting, pricing) are prerequisites for evaluating potential tradeoffs between efficiency and equity. This is particularly a challenge in countries where water use is unregulated or monitoring is inadequate, and the transaction costs associated with deploying monitoring infrastructure is cost prohibitive. Deploying dynamic management to achieve multibenefits effectively will require evaluating and managing trade-offs among competing societal water uses (e.g., agriculture and urban uses) as well as among ecological systems (e.g., wetlands and instream ecosystems). Dedicated water for groundwater storage means that it is being taken from some other potentially beneficial use (e.g., surface water users, instream flows, and flushing out sediments in rivers). For example, reallocating surface water to flood fields for creating migratory bird “pop-up” habitat, could divert water from instream habitat at critical times of the year. Creating the greatest good for the greatest number of beneficial users, while equitably distributing scarce water resources across user groups requires knowledge on where the water will come from, how it is being used, and its quality. This is particularly relevant when replenishing aquifers in agricultural areas, which can leach pesticides and excess nutrients locked up in soils into groundwater. Routine monitoring that can be used to adaptively manage groundwater is a key step to reducing risk and increasing local resilience and groundwater sustainability.

5 | ENABLING CHANGE

Globally, half of wetlands are already lost and many migratory flyways are under threat (Kirby et al., 2008). Creative multibenefit solutions that work nimbly across protected areas (such as wetlands protected under the Ramsar Convention on Wetlands of International Importance) and human-dominated landscapes are needed. This is particularly true for the East Asian-Australasian flyway, which contains more near threatened or globally threatened birds than any other major flyway with annual rates of species decline of up to 8% (BirdLife International, 2018). While only 9% of wetlands protected under the Ramsar Convention exist within the East Asian-Australasian flyway, there are 74.5 million ha of agricultural land equipped for irrigation (Food and Agriculture Organization, 2014) that could be used to create and stitch together temporary pop-up habitat for migratory birds across this fragmented landscape. Rapid and extensive habitat degradation, particularly coastal habitat conversion, throughout this region are creating an urgent need for the management of alternative artificial habitats for shorebirds and other migratory waterbirds to compensate for the loss of wetlands and mudflats (Jackson et al., 2019; Mehlman, Fitzsimons, Irving, Irving, & Hancock, 2019). Shorebirds and other waterbirds have been shown to make use of artificial habitats created from agricultural fields, aquaculture, or subsidence ponds within the East Asian-Australasian flyway (Jackson et al., 2019; D. Li et al., 2013; C. Li, Yang, Zha, Zhang, & de Boer, 2019; Wood et al., 2010). Managing these agro-ecosystems for multiple benefits can help complement habitat protection efforts and create a landscape that is both more resilient to climate change and has more options for species adaptation. In addition to ecosystem benefits, the farm fields and existing irrigation infrastructure provide the enabling conditions to efficiently deliver excess surface or recycled water for on-farm managed aquifer recharge to replenish groundwater in depleted aquifers or to manage seawater intrusion in coastal areas (Figure 1). Water supply benefits will vary spatially depending on aquifer conditions, soil type, and water availability, as will the trade-offs. The application of dynamic design principles to achieve multibenefit solutions highlights the opportunities for scalable and efficient solutions that can respond to water challenges, while achieving multiple benefits for people and nature.

There is no panacea for solving 21st century water challenges, but the global challenges we face require rapid and nimble responses. Recent technological advances in remote sensing, geospatial information systems, artificial intelligence, smart phones and data sharing offer an opportunity to dynamically respond to 21st century water challenges. In this new digital age, the application of dynamic design can deliver scarce water resources to multiple water users on an on-demand basis. This is similar to how the “shared economy” has been able to change the way goods and services are delivered—so that instead of owning a car, bike or scooter one can “dynamically” rent one as needed via a smartphone app such as Zipcar, Jump, or Bird.

The integration of near real-time biological, hydrological, societal and/or economic data into the hands of
water users can spur innovative solutions that extend beyond traditional management approaches that have previously been limited to water resource agencies. The implementation of dynamic multibenefit solutions with near real-time data can enhance the integration of biodiversity conservation objectives into water supply projects to optimize funding, adapt water supplies to climate change impacts, and scale benefits to multiple water users. Dynamic multibenefit solutions offer promise for helping address water challenges of the 21st century. Through our experience in implementing dynamic multibenefit solutions with multiple stakeholders in California, we have demonstrated how this solution can provide multibenefits for a diversity of water interests. However, enabling these synergies, also requires the development and implementation of institutional arrangements to foster our society’s ability to capture, store and manage our water resources for ecosystems and society. In doing so, we can secure water supplies for people and nature.

ACKNOWLEDGMENTS
We thank The Nature Conservancy’s BirdReturns team and the participating farmers in Sacramento Valley and Merced Irrigation District. We also thank our colleague Megan Webb for creating the figure. The authors would like to thank the S.D. Bechtel, Jr. Foundation for their philanthropic financial support to The Nature Conservancy’s ongoing research on sustainable groundwater management and dynamic conservation.

CONFLICT OF INTEREST
The authors declare no competing interests.

FIGURE 1  Global map indicating which regions are best suited for using dynamic nature based solutions that use cropland to create temporary “pop-up” wetland habitat while replenishing depleted aquifers

Data sources: Migratory Bird Flyways (BirdLife International, 2010), Cropland (European Space Agency, 2015), and Depleted Aquifers (Gleeson, Wada, Bierkens, & van Beek, 2012)

AUTHOR CONTRIBUTIONS
M.M.R., M.R., and J.H. conceived and framed the paper. M.M.R. developed the initial analysis and visualization and wrote the initial draft of the paper. M.M.R., M.R., and J.H. were responsible for revising the manuscript, and provided final approval of version to be published.

DATA AVAILABILITY STATEMENT
We thank Tom Gleeson for granting us permission to use his groundwater footprint dataset and BirdLife International for granting us access to the global flyway spatial data.

ORCID
Melissa M. Rohde https://orcid.org/0000-0002-1252-0711
Mark Reynolds https://orcid.org/0000-0001-9958-6360

REFERENCES
Abramovitz, J. N. (1996). Imperiled waters, impoverished future: The decline of freshwater ecosystems. (Worldwatch Paper #128). Washington, DC: Worldwatch Institute.
Amarasinghe, U. A., & Smakhtin, V. (2014). Global water demand projections: Past, present and future (Res. Rep. 156). Colombo, Sri Lanka: International Water Management Institute. https://doi.org/10.5337/2014.212
BirdLife International. (2010). Migratory bird flyways. Retrieved from http://datazone.birdlife.org/species/requestdis
BirdLife International. (2018). Migratory birds and flyways. Retrieved from https://www.birdlife.org/worldwide/programme-additional-info/migratory-birds-and-flyways
Central Valley Joint Venture. (2006). Central Valley joint venture implementation plan: Conserving bird habitat. Sacramento, CA: U.S. Fish and Wildlife Service.
D’Aloia, C. D., Naujokaitis-Lewis, I., Blackford, C., Chu, C., Curtis, J. M. R., Darling, E., ... Fortin, M. (2019). Coupled networks of permanent protected areas and dynamic conservation areas for biodiversity conservation under climate change. *Frontiers in Ecology and Evolution*, 7, 27.

European Commission. (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities*. Final Report of the Horizon 2020 Expert Group on ‘Nature-based solutions’ and re-naturing cities. Directorate-General for Research and Innovation.

European Space Agency. (2015). *ESA land cover CCI, v2.0*. Retrieved from http://maps.elie.ucl.ac.be/CCI/viewer/download.php

Famiglietti, J. S. (2014). The global groundwater crisis. *Nature Climate Change*, 4, 945–948.

Food and Agriculture Organization. (2014). *AQUASTAT, FAO’s global water information system*. Retrieved from http://www.fao.org/nt/water/aquastat/didyouknow/index3.stm

Frayer, W. E., Peters, D. D., & Pywell, H. R. (1989). *Wetlands of the California Central Valley: Status and trends*. Portland, OR: U.S. Fish and Wildlife Service. https://doi.org/10.3936/012014-jfwm-003.s10

Gleeson, T., Wada, Y., Bierkens, M. F. P., & van Beek, L. P. H. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature*, 488, 197–200.

Golet, G. H., Low, C., Avery, S., Andrews, K., McColl, C. J., Laney, R., & Reynolds, M. D. (2018). Using ricelands to provide temporary shorebird habitat during migration. *Ecological Applications*, 28, 409–426.

IUCN. (2012). The IUCN Global Programme 2013–16. Adopted by the IUCN World Conservation Congress.

Jackson, M. V., Carrasco, L. R., Choi, C. Y., Li, J., Ma, Z., Melville, D. S., ... Zhang, L. (2019). Multiple habitat use by declining migratory birds necessitates joined-up conservation. *Ecology and Evolution*, 9, 2505–2515.

Johnston, A., Fink, D., Reynolds, M. D., Hochachka, W. M., Sullivan, B. L., Bruns, N. E., ... Kelling, S. (2015). Abundance models improve spatial and temporal prioritization of conservation resources. *Ecological Applications*, 25, 1749–1756.

Kiparsky, M., Fisher, A. T., Hanemann, W. M., Bowie, J., Kantor, R., Coburn, C., & Lockwood, B. (2018). *Recharge net metering to enhance groundwater sustainability* (p. 4). Berkeley, CA: Center for Law, Energy & the Environment, UC Berkeley School of Law. Retrieved from https://www.law.berkeley.edu/research/clee/research/wheeler/renem/

Kirby, J. S., Stattersfield, A. J., Butchart, S. H. M., Evans, M. J., Grimmett, R. A., Jones, V. R., ... Newton, I. (2008). Key conservation issues for migratory land- and waterbird species on the world’s major flyways. *Bird Conservation International*, 18, S49–S73.

Kremen, C., & Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. *Science*, 362, eaau6020.

Lewison, R., Hobday, A. J., Maxwell, S., Hazen, E., Hartog, J. R., Dunn, D. C., ... Crowder, L. B. (2015). Dynamic ocean management: Identifying the critical ingredients of dynamic approaches to ocean resource management. *Bioscience*, 65, 486–498.

Li, C., Yang, S., Zha, D., Zhang, Y., & de Boer, W. F. (2019). Waterbird communities in subsidence wetlands created by underground coal mining in China: Effects of multi-scale environmental and anthropogenic variables. *Environmental Conservation*, 46, 67–75.

Li, D., Chen, S., Lloyd, H. U. W., Zhu, S., Shan, K. A. I., & Zhang, Z. (2013). The importance of artificial habitats to migratory waterbirds within a natural/artificial wetland mosaic, Yellow River Delta, China. *Bird Conservation International*, 23, 184–198.

Matsumoto, S., Rohde, M. M., & Heard, S. (2019). Nature-friendly economic tools to achieve groundwater sustainability: Two experimental case studies from California. *Water Economics and Policy*, 5, 1971002. https://doi.org/10.1142/S2382624X19710024

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., ... Crowder, L. B. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Marine Policy*, 58, 42–50.

Mehlman, D. W., Fitzsimons, J. A., Irving, A., Irving, J., & Hancock, B. (2019). Selecting a suite of potential partner sites for the Adelaide International Bird Sanctuary to aid shorebird conservation in the East Asian–Australasian Flyway. *Pacific Conservation Biology*. https://doi.org/10.1071/PC18084

Nesby, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., ... Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, 579, 1215–1227.

Perrone, D., & M.M. Rohde. (2016). Benefits and economic costs of managed aquifer recharge in California. *San Francisco Estuary & Watershed Science*, 14, 4.

Ramsar Convention on Wetlands. (2018). *Global wetland outlook: State of the world’s wetlands and their services to people*. Ramsar Convention Secretariat: Gland, Switzerland.

Reiter, M. E., Elliott, N., Veloz, S., Jonesmijt, D., Hickey, C. M., Merrifield, M., & Reynolds, M. D. (2015). Spatio-temporal patterns of open surface water in the Central Valley of California 2000–2011: Drought, land cover, and waterbirds. *Journal of American Water Resources Association*, 51, 1722–1738.

Reynolds, M., Sullivan, B. L., Hallstein, E., Matsumoto, S., Kelling, S., Merrifield, M., ... Morrison, S. A. (2017). Dynamic conservation for migratory birds. *Science Advances*, 3, e1700707.

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., ... Kelling, S. (2014). The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation*, 169, 31–40.

The Bay Institute. (1998). *From the sierra to the sea: The ecological history of the San Francisco Bay–Delta watershed*. San Francisco, CA: The Bay Institute.

United Nations Development Program. (2006). *Coping with water scarcity*. *Challenge of the twenty-first century*. Rome, Italy: UN-Water, FAO.

United Nations World Water Assessment Program. (2018). The *United Nations world water development report 2018: Nature-based solutions for water*. Paris, UNESCO. Retrieved from http://unesdoc.unesco.org/images/0026/002614/261424e.pdf
Wood, C., Qiao, Y., Li, P., Ding, P., Lu, B., & Xi, Y. (2010). Implications of rice agriculture for wild birds in China. *Waterbirds, 33*, 30–44.

World Resources Institute. (2019). *Aqueduct water risk atlas*. Retrieved from https://www.wri.org/aqueduct

Zimmerman, J. K. H., Carlisle, D. M., May, J. T., Klausmeyer, K. R., Grantham, T. E., Brown, L. R., & Howard, J. K. (2017). Patterns and magnitude of flow alteration in California, USA. *Freshwater Biology, 63*, 859–873.

**How to cite this article:** Rohde MM, Reynolds M, Howard J. Dynamic multibenefit solutions for global water challenges. *Conservation Science and Practice*. 2020;2:e144. [https://doi.org/10.1111/csp2.144](https://doi.org/10.1111/csp2.144)