Opinion

Integrating biodiversity conservation and water development: in search of long-term solutions

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Fresh water, a resource necessary for most life on Earth, currently experiences impacts that reduce both water quality and quantity. These impacts compromise human wellbeing and threaten the existence of many nonhuman species, the latter including freshwater biodiversity as well as other species requiring water to survive. In response, development and conservation professionals strive to ensure that adequate fresh water is available for people and other organisms. Here we examine the need to coordinate efforts in these two areas of intervention to ensure long-term success for both. We begin by discussing how places needing water development and biodiversity conservation tend to be located in the same parts of the world, suggesting that projects in each subject area may well co-occur. We then summarize briefly the current challenges facing water development and freshwater-related biodiversity conservation, as well as the main approaches to address those challenges. The study examines potential strategies to provide improved access to water for both people and nature through integrated water resources management and less formal approaches to avoiding unintended impacts of one activity on the other. Example projects reveal several benefits of linking development and biodiversity conservation efforts to maintain water resources. The study closes by arguing for the need to coordinate water development and biodiversity conservation activities in a manner that seeks practical synchronized solutions for particular project settings.

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INTRODUCTION

Fresh water is necessary for human survival and increasingly a resource under stress. Although roughly 2.6 billion people have gained access to improved sources of drinking water since 1990 and 91% of the global population now uses such sources, there remain today 663 million who rely on unimproved sources for the water they drink.[1] Some 1.2 billion people live in areas where water is physically scarce, and nearly 2.0 billion face water shortages.[2] An estimated 1.8 billion use water that is fecally contaminated, a major reason for continuing high levels of child mortality due to diarrheal diseases.[3,4] As global population grows from the current total of 7.3 billion to 9.7 billion by 2050,[5] demand for water is anticipated to increase by 55% to support domestic, agricultural, and industrial uses.[2] Meeting growing fresh water needs, and providing access to safe drinking water amid rising human impacts, will be massive challenges in the next few decades.

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Less well known, but no less dire, is the decline of biological diversity in freshwater ecosystems, such as rivers, streams, and wetlands.[6] Comprising only about 0.8% of the earth's surface, freshwater ecosystems contain much of the earth's biodiversity.[7,8] Unfortunately, the freshwater biome also is the most threatened, with as much as 71% of the world's wetlands destroyed since 1900 and nearly 90% lost since 1700.[9] As a consequence, freshwater species experienced the greatest decline of any biome between 1970 and 2010, with an average reduction of 76% in the size of monitored populations[10]—a global pattern borne out for specific regions.[11–13] The impacts on freshwater biodiversity extend well beyond the conservation of aquatic species, to the many terrestrial and marine plants and animals that also rely on fresh water and the biodiversity it supports for their own survival, and, ultimately, to humans, who depend on functioning aquatic ecosystems for food, safe water, protection from floods, and other key ecosystem services.[14]

In the pages below, we argue that opportunities often exist to coordinate water development and biodiversity conservation actions that can benefit both. This study emerges from personal experience, trying to provide rural communities in less developed countries with safe drinking water and working on efforts to conserve freshwater biodiversity in similar settings. Although both fronts have enjoyed considerable success over the years, they also have witnessed failures, and individually we have experienced the frustration of involvement in projects that were not fully successful, at least in the long term. In response to what water development and conservation professionals began to recognize as shared challenges, an informal meeting convened in Washington, DC, in 2005 solicited insights from organizations engaged in both types of activity. Discussions at that and subsequent gatherings began to explore integrated solutions that could help achieve development and biodiversity conservation goals, serving to guide certain projects over the ensuing decade. This paper discusses general approaches to water development and freshwater biodiversity conservation that complement one another as a path to long-term solutions.

A BROAD PATTERN OF OVERLAPPING REAL ESTATE

Water development, through the planning and implementation of water projects, has been a focus of modern international development since its onset in the mid-20th century. This area of development became a major focus of attention with the establishment of the International Drinking Water Supply and Sanitation Decade (1981–1990), which had the ambitious goal of supplying water and sanitation to all people through replicable, self-reliant, and self-sustaining programs.[15] The need for water development usually reflects a broader need to address poverty and economic inequality,[1,2,16,17] as measured by income, such as gross domestic product, as well as by composite measures, such as the United Nations' human development index.[18] However, it is possible to focus more specifically on indicators of need for water development, such as access to improved sources of drinking water (the agreed-upon proxy for access to safe drinking water)—piped water on the premises, public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection.[1] Although much of the world now has access to improved water sources, as noted more than 660 million continue to lack such access, most living in rural portions of particular countries (Figure 1).[1]

Conservationists have devised a variety of templates to identify priority regions for maintaining biodiversity, including Biodiversity Hotspots, Centers of Plant Diversity, Crisis Ecoregions, Endemic Bird Areas, Frontier Forests, Global 200 Ecoregions, High Biodiversity Wilderness Areas, Last of the Wild, and Megadiversity Countries.[19] Most attempts to identify conservation priorities have focused on broadly defined taxa, and although freshwater species have been included in many prioritization efforts they have not received specific attention until relatively recently. The Global Amphibian Assessment represented a systematic attempt to identify the geographic ranges of amphibian species as well as conservation status,[20] while the definition of freshwater ecoregions included a geographic assessment of fish diversity.[21] A recent synthesis of data for nearly 7100 freshwater species of amphibians, crabs, crayfish, fishes, mammals, and reptiles revealed geographic patterns of species richness and conservation status in the freshwater biome.[11] The geographic distributions for freshwater conservation data are broadly consistent with the arrangement of terrestrial species and of most of the priority regions for biodiversity conservation mentioned (Figure 2).[22,a]

Although selection of project sites for water development or biodiversity conservation ultimately considers local circumstances and practicalities, such as the availability of capable partners, access to funds, local and national government support, security for project personnel, and policies of donor agencies, broad patterns reveal general cooccurrence

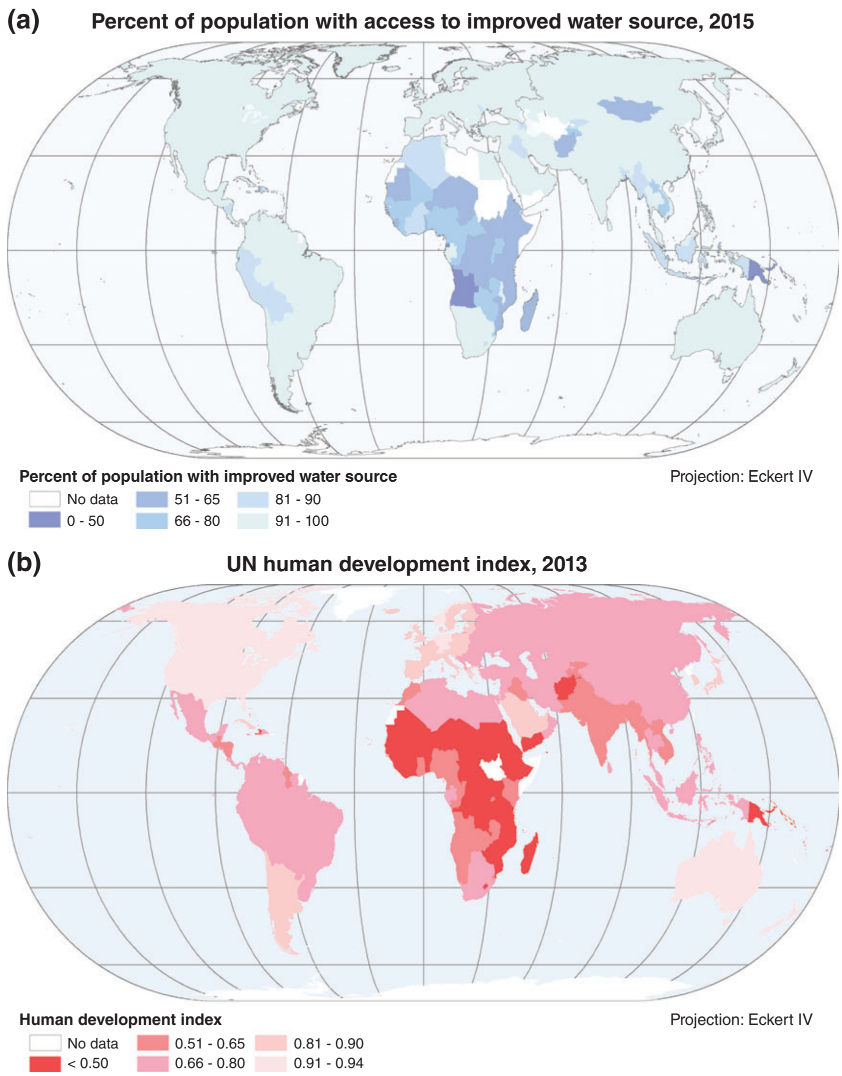

FIGURE 1 | Percent of population with access to improved drinking water, by country, 2015 (a) and United Nations Development Index, by country, 2013 (b). Geographic information system datasets developed by lead author.

consistent with those identified in other studies.[23] In localities where conditions invite both water development and biodiversity conservation actions, coordinated efforts emerge as an opportunity to join forces to achieve greater success in both.[24] In cases where activities in one area of intervention compromise those in the other, coordination of efforts becomes a necessity.

THE POTENTIAL OF COORDINATED DEVELOPMENT AND CONSERVATION EFFORTS

This study rests on the premise that not only do water development and biodiversity conservation often share geographic space, but they also share certain needs that that enable these very different types of endeavors to benefit through allied, complementary actions. At a minimum, we feel that these two activities can consider one another's efforts, allowing each to limit or entirely avoid impacts on the other. At a maximum, we envision integrated efforts on projects that seek related goals. The approach taken depends on particulars of any given project.

Most current challenges in water development are consequences of unsustainable activities and failures in governance.[2] Increasing human population ultimately drives much of the growing demand for water, with most of the demographic increase by 2050 anticipated to occur in less-developed countries where lack of access to safe drinking water already is a problem.[5] Irrigated agriculture accounts for 70%

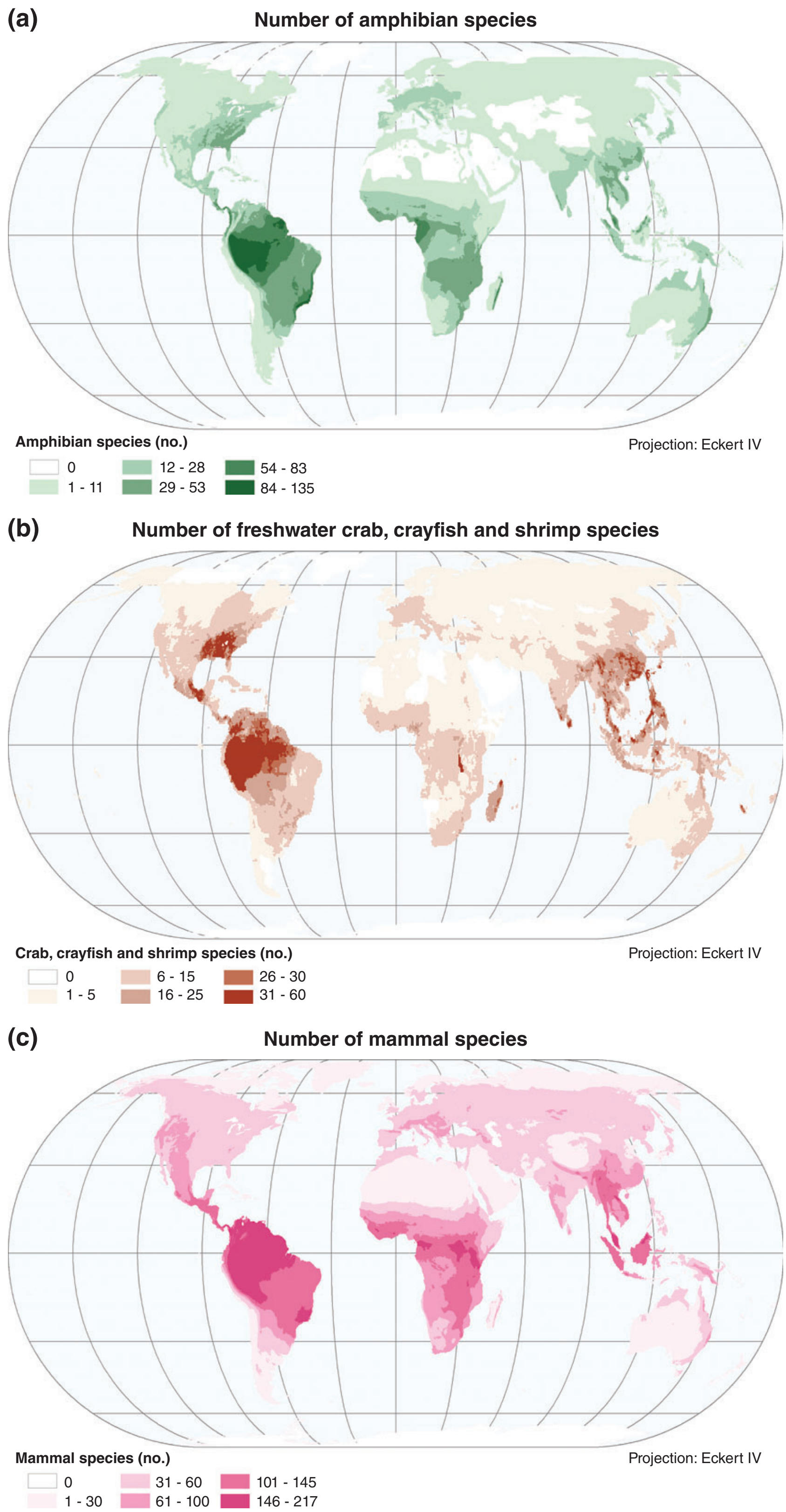

FIGURE 2 | Distribution of amphibian species (a), freshwater crab, crayfish, and shrimp species (b), and mammal species (c). Geographic information system datasets obtained from IUCN Redlist of Threatened Species, http://www.iucnredlist.org/technical-documents/spatial-data.

of freshwater withdrawals globally, and more than 90% of withdrawals in less-developed countries.[2] Energy production, in turn, currently accounts for 15% of water withdrawals, expected to witness a 20% increase by 2030 with growth again anticipated to emphasize less-developed countries.[25] Demands for water for these and other uses place enormous pressure on the fresh water resources, yielding shortfalls in many places that are projected to reach a 40% global deficit beyond accessible surface and subsurface sources by 2030.[26] Population growth and the expanding impacts that accompany it will affect water quality as well, helping to perpetuate the role of water-borne diseases as a leading cause of death world-wide.

Water development projects that address inadequate water quantity and quality typically fall into one of three categories: community uses, primarily involving drinking water and sanitation; productive uses, primarily involving irrigation for crop production but also including commercial and industrial uses; and environmental protection, consisting of watershed management and conservation activities.[27] Much development activity since the definition of the Millennium Development Goals in 2000 has focused on providing access to improved drinking water and improved sanitation.[28] Water, sanitation, and hygiene—or *WASH*—are seen as activities essential for improved human wellbeing, particularly as a means of reducing disease.[29] Improving the water available for people often has involved providing simple water collection technologies, improved springs, drilled wells, or protected dug wells.[30] Efforts to address productive uses frequently focus on introducing irrigation to increase agricultural yield and reduce risk, or improving irrigation through technologies such as drip irrigation which greatly increase the efficiency of water delivery.[31] Environmental protection has received much less attention, focusing on maintaining certain types of habitat.[32] Water development has enjoyed considerable success over the past several decades, notably in providing access to improved sources of drinking water, but there have been important shortcomings. Many water-related challenges—especially those affecting public health, local economies, and the natural environments of watersheds—inherently are long-term, but projects often involve short-term solutions as they seek immediate results and clearly measurable outcomes.

Although the focus of this essay is on fresh water, because of the reliance of many plants and animals on water any impacts on this resource extend well beyond aquatic species.[33] The decline or loss of species in general is a consequence of several possible threats: habitat degradation or loss, exploitation of the species in question, climate change, invasive species or genes, pollution, and disease.[10,34] Decline or loss of aquatic species, in particular, often is due to habitat loss or fragmentation, invasive species, and pollution, with habitat degradation affecting more than 80% of threatened freshwater species.[11] The primary causes of these threats all relate to land use, including agriculture, urbanization, infrastructure development (particularly dams), and logging, all *environmental* in one form or another.[35] Threats often result from complex, interrelated processes; e.g., logging can precede agricultural development, with both leading to surface water contamination. Inherent connectivity of hydrological systems adds further complexity, as adverse impacts on one location can affect other locations as well.[36]

Conservationists and their allies generally rely on some form of protection to help maintain biological diversity. Often this is achieved through the creation of *protected areas*: clearly delineated localities created and managed for the long-term conservation of nature along with associated ecosystem services and cultural values.[37] Protected areas, such as national parks, exist in terrestrial, marine, and freshwater settings and represent the cornerstones of biodiversity conservation.[38] As of 2014, protected areas covered about 12.5% of Earth's terrestrial surface.[39] This coverage includes freshwater protected areas,[36,40] though such reserves often extend to interconnected hydrological systems and associated terrestrial areas beyond the borders of the specific locality marked for conservation.[24,32,37,41]

To help address water challenges in both development and conservation, approaches to managing water resources that combine requirements of humans and nature have emerged. Generally termed *integrated water resources management* (IWRM), such an approach "… promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."[42] Attempts to balance human demand for water with the capability of nature to provide it date back centuries, with early examples ranging as broadly as Aztec management of hydrology in the prehistoric Basin of Mexico during the 14th and 15th centuries and regional development of water resources under the Tennessee Valley Authority beginning in the 1930s.[43,44] But the concept of systematic, multisector coordination of water resources that integrate both human and natural systems remerged in 1977 with the Mar del Plata conference in Argentina, and more formally in 1992 with two key conferences: the International Conference on Water and the Environment in Dublin, and the United Nations Conference on Environment and Development in Rio de Janeiro.[27] Agenda 21 recommendations for development adopted at the latter conference recognized water as a resource essential for humans and other species, the importance of the hydrologic cycle in producing and maintaining fresh water resources, and the need for a holistic approach to manage water that involves multiple stakeholders and considers water as an economic good. Particularly important criteria include the so-called *three pillars* of IWRM: achieve maximum economic efficiency in water use, promote the basic right for all people to have access to water, and reach environmental and ecological sustainability. The belief that an integrated approach can address current water problems in a sustainable manner has led to broad acceptance of IWRM.[2,27,45]

For water development, IWRM can contribute to maintaining both water quantity and quality. The essential component is water resource planning that considers all potential effects on water sources through broad investigations and soliciting input from relevant stakeholders. Such input can be important in avoiding overdrafts of water for one use at the expense of another, as well as in excluding activities that are incompatible with long-term water resource sustainability. Prohibiting intensive agriculture upstream from a rural village, for instance, enables avoidance of excessive withdrawals that reduce amounts of water available for community use below acceptable levels, in addition to reducing impacts on villagers from agrochemicals. Restricting timber harvesting near a hydroelectric dam, in turn, reduces increased erosion and siltation that would compromise electricity production. Implementing wastewater recycling increases the supply of useable water while reducing the discharge of contaminants. Using multisector decision-making that considers immediate and future impacts of water management helps to avoid unintended or undesirable impacts from one or more uses.

For biodiversity conservation, IWRM seeks to safeguard aquatic habitat and species through environmental actions that help to maintain the hydrologic cycle. The focus on aquatic ecosystems must consider surface and subsurface systems; it also must employ a broad geographic perspective that protects freshwater habitat from activities that can indirectly degrade it. In protected areas that host no or very limited human activity, IWRM obviously can help to maintain water quality and quantity through maintaining hydrologic systems and related terrestrial resources. In areas that host multiple uses, IWRM can help to integrate development and conservation through ensuring that the former focuses on environmental considerations. For example, habitat conversion that avoids streams as well as riparian buffers serves to maintain the quality of surface hydrology and associated species. Harvesting freshwater fish and other resources at levels below those required to maintain species populations helps to establish sustainable levels of use. Irrigation and other water uses that limit the amount withdrawn and schedule off-takes consistent with natural fluctuations of water flow contribute to maintaining stream ecology.

IWRM emerges as a strategy for implementing projects that accommodate the aims of both water development and biodiversity conservation. Moreover, its broad acceptance as a means of managing this key resource in a sustainable manner provides the basis for adoption in a range of development and conservation contexts. But for all its appeal, IWRM presupposes levels of integration and information flow, and consistent foundations of decision making, that make it particularly challenging to implement.[44,45] In many rural settings in the developing world, IWRM requires a high level of coordinated planning and formal stakeholder input that simply are nonexistent. Areas that harbor natural and sociocultural diversity add further complications, as heterogeneous settings often require very different approaches to implement IWRM.[26,45] Technical requirements of thorough integration—e.g., surface and subsurface, agricultural and natural, water use and waste treatment, government and private sector—often are difficult to incorporate in particular project settings.[42] Finally, some have criticized IWRM for not accommodating sufficient development,[46] for not including enough environmental considerations and equity,[17] and for having insufficient definition and guidelines to promote true integrated management.[47]

When water development and biodiversity conservation opportunities cooccur, coordination is both desirable and necessary. However, in many settings a less refined, less systematic form of coordination often is more feasible. One might present this as development of joint awareness and accommodation for the sake of practicality and mutual benefit. The development project that is aware of local conservation activities can avoid actions that undermine those activities, and possibly introduce steps that serve to conserve aquatic and terrestrial habitat that benefit its own goals through maintaining water sources. The conservation project that recognizes local efforts to improve the human condition can take steps to locate development restrictions solely in areas that specifically need them, and possibly provide conditions that improve water resources used by local people. The desire to avoid conflicting actions, and the need to consider trade-offs of different water management strategies, both are extremely important and ultimately have their roots in IWRM. Less formal coordination of water-related activities is much less demanding than IWRM, generally embodying only a slight reorientation of secondary project goals and concerns such that water development accommodates selected considerations of biodiversity conservation, and *vice versa*, while maintaining the primary focus of each (Figure 3). Development and conservation organizations have begun to coalesce around the theme of WASH and freshwater ecosystem management, agreeing to a "Joint Statement on Water, Sanitation and Hygiene (WASH) and Freshwater Ecosystem Conservation" to promote integrated approaches.[48] Guidelines for implementing these ideas provide a means of synchronizing development and conservation activities in places where project coordination and structured, integrated programs are difficult to develop.[49]

Conscious efforts to coordinate water use for people and nature have been occurring in some form for decades. There have been noteworthy success stories, including impressive cost-savings from incorporating watershed maintenance to help meet urban water demands in a range of cities, including New York City, USA; Quito, Ecuador; and Bogota, Colombia.[50] Compilations of IWRM case studies in a range of geographic and problem settings indicate broad adoption and general success of such projects,[27,51,52] though lack of adequate data and a need for longer periods of observation often limit the strength of project evaluations. Efforts that are focused specifically on coordinating water development and biodiversity conservation are more recent and fewer in number, though examples do exist. In the Morogoro Region of central Tanzania, a project to provide safe drinking water to villages also incorporates upland habitat protection. Overall, this project shows early indications of success, along with the potential for long-term impacts on both fronts.[53] In Ethiopia, work with local governments and community organizations has helped to restore eroded landscapes through natural resource management interventions that include terracing, check dams, stone bunds, and hillside microbasins for collecting rainfall runoff. In combination with multiple uses of water for WASH, irrigation, and small crop production enterprises, these conservation efforts have led to improved quality of surface water as well as a dramatic increase in agricultural productivity in five Ethiopian *woredas* (districts), which now experience two crop harvests annually instead of the previous single harvest.[54] In the Intibuca Region of Honduras, efforts have focused on organizing local committees to oversee water use and watershed protection and management. Between 2009 and 2012, the population in this region with access to improved water supply increased 50%, protected water production zones were legally established that help maintain aquatic habitat and water quality, and local communities became effective managers of water resources.[55] In Nairobi, Kenya, large users of water contribute to the Upper Tana Water Fund that helps to support environmental conservation in upstream villages along the Tana River.[48] Improved erosion control benefits rural communities while reducing water treatment costs in Nairobi. Payments into a water trust fund by sugarcane producers in the East Cauca Valley of Colombia support reforestation as well as education and training, crop planting, and the construction of water and sanitation facilities in upland villages.[56] This fund has conserved more than 120,000 hectares of the watershed, improving conditions in local communities and for a variety of species while helping to maintain a reliable supply of water for sugarcane production. With the passage of time, more projects integrating water development and environmental concerns will provide a stronger sense

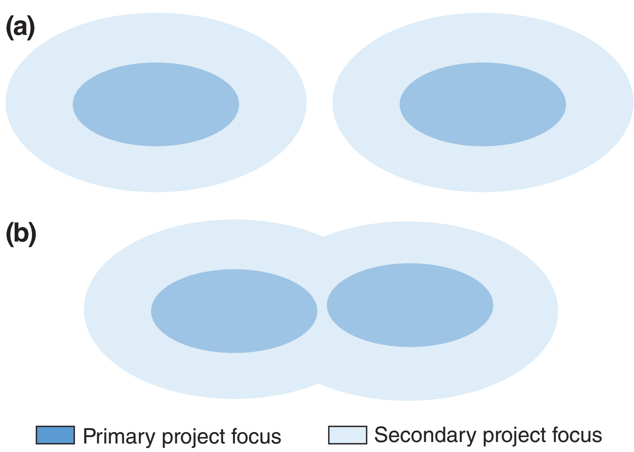

FIGURE 3 | Conceptual diagram showing independent water development and biodiversity conservation projects (a) and projects that become partially integrated in the interest of seeking separate solutions that consider impacts on the other area of engagement (b).

of their potential, as well as possible shortcomings that inevitably emerge in challenging project settings.

CONCLUSION

The realities for water provisioning and freshwater biodiversity conservation, particularly in less-developed countries, reveal a desperate need for success in both areas. With growing human population and demand bound to place further pressure on water, maintaining quantity and quality of this essential resource will only become more difficult in coming decades.[57] In many settings—certainly the tropics, where much of the world's biological diversity exists amid considerable human poverty—development needs occur in close proximity to conservation challenges. Development can have negative impacts on biodiversity conservation; indeed, habitat degradation and loss, the introduction of invasive species, and pollution often are by-products of development as well as the main drivers of biodiversity decline. Biodiversity conservation, in turn, can have an adverse effect on development, possibly restricting development activities in important areas where the potential to improve the human condition might be greatest. And yet both types of actions have what appear to be enormous potential to profit from coordination that meets the goals of one while benefitting, or at least not undermining, the other.

Of course as in most attempts to coordinate two or more different activities, success is easier said than done. Complications include competing goals, for as much as mutual benefits exist the ultimate aims of development and conservation often are different. Beyond such inherent problems, the challenge of coordinating such activities can be great in places where projects are small and where the potential for defining mutual goals, exchanging information, and assessing and monitoring projects all are quite challenging. We propose IWRM as a logical means of coordinating development and conservation in settings that will accommodate it, a broadly accepted idea but also often a difficult solution to implement. Less formal coordination, in turn, based on projects committed to maintaining awareness about efforts in other water-related activities, and to exchanging information among these activities as a basis of avoiding actions that may compromise their achievements, may provide greater promise of success in settings where IWRM is impractical. Development efforts have great potential to undermine biodiversity conservation; however, they can benefit through environmental maintenance that helps guarantee long-term supply of water of sufficient quality and quantity. Conservation efforts have great potential to constrain development; however, often they can incorporate human use that supports attempts to improve the human condition while maintaining sufficient amounts of habitat and ecosystem function. Coordinating efforts may provide not only the foundation for long-term success in both areas, but possibly the sole chance for long-term success in a world forced to accommodate enormous demands for increasingly limited resources.

NOTE

[a] Because global data on human development are available at a national level, they lack the geographic precision of species data that likely would reveal greater cooccurrence with the latter. This is particularly the case in rural localities that normally have greater development needs as well as larger numbers of species. The general concentration of species in the tropics, and the similar concentration of human need, establishes a broad pattern of cooccurrence likely made stronger were more geographically precise data available.

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