Research Brief

Is there a role for freshwater protected areas in the conservation of migratory fish?

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Abstract

Migratory fish have been declining in number as a result of numerous processes including hydropower development, pollution, invasive species, and climate change. Migratory fish are important ecosystem components, and yet there are many gaps in our knowledge of migratory fish life history and their relationship with hydrological processes. Consequently, few mechanisms are available to promote their conservation. An emergent tool is the Freshwater Protected Area (FPA), a zone of restricted use and access within freshwater systems analogous to terrestrial or marine protected areas that aim to conserve constituent resources. These protected areas are often criticized for their inability to control pollution inputs and their tendency to be implemented only as components of terrestrial parks, meaning that they traditionally do not reflect the importance of aquatic systems or promote connectivity. This paper reassesses FPAs in the context of migratory fish conservation and addresses a variety of obstacles inhibiting FPAs from being suitable for protecting migratory fishes. Developing FPAs that encompass critical life-stage habitat for migratory species, such as spawning and nursery areas, migratory corridors, and feeding zones, is essential for ensuring ample interconnected habitat for migratory fishes to thrive and ecological and evolutionary processes to occur.

Key words: connectivity, conservation, diadromy, freshwater fish, migration, potamodromy, protected areas

Introduction

Health of freshwater systems has been declining in recent years as a result of habitat loss, pollution, species invasions, and other factors (Dudgeon et al. 2006). This state of decline is reflected by the increasing number of imperiled freshwater taxa, whose populations have been reduced by an average of 76% since the 1970s (World Wildlife Fund 2014). Migratory freshwater fishes are at particular risk; they are almost twice as likely to become endangered compared to nonmigratory fishes (4% risk of endangerment for nonmigratory fish species vs. 7.2% risk for migratory fish species; Reid 2002, 2004).

Migration, exhibited by many taxonomic groups, is most simply defined as predictable and/or synchronized movement of many individuals in a population between discrete sites that provide distinctly different environments (Lucas and Baras 2001). Among ~35 000 described species of fish, 874 species are presently known to exhibit migratory behaviour, although this number is likely an underestimate due to a lack of life history knowledge (Flecker et al. 2010, Cooke et al. 2012). Moreover, the number does not reflect the high relative significance of migratory fishes to the functioning of their resident ecosystem (Holmlund and Hammer 1999). For example, migratory fishes are an important vehicle for transfer of nutrient subsidies among sites, which can have significant impacts on recipient ecosystems (Bryan et al. 2013, Childress et al. 2014).

On land and in the marine environment, reserves and protected areas are considered essential for biodiversity conservation efforts (Soulé and Terborgh 1999). Freshwater protected areas (FPAs) were developed as an analogous initiative founded on the same conservation principles. Although FPAs were conceived with the intention of preserving freshwater aquatic resources in general, their

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potential use for conservation of freshwater migratory fish species deserves special attention; Crofts (2004) specifically described the protection of migratory species by protected areas as an emerging priority for conservation managers.

What are freshwater protected areas?

FPAs are included in the International Union for the Conservation of Nature (IUCN) concept of "protected areas" as "clearly defined geographical space, recognised, dedicated, and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (IUCN 2008). Within this definition, FPAs can belong to one of 7 usage-based categories ranging from a "strict nature reserve" to "a protected area in which natural resources are sustainably used" (Box 1). FPAs are therefore categorized according to the amount and type of activity permitted within the area, with leeway for a variety of activities to occur within the preserve (IUCN 2008). Many terrestrial protected areas encompass freshwaters, and many such freshwaters have been retroactively designated as FPAs, although it has been argued that such retroactive designations produce "paper parks" and serve more to inflate statistics than to act as a conservation mechanism (Saunders et al. 2002, Abell et al. 2007).

To date, little consideration has been given to the types of freshwaters that are protected because protected areas have not often been designated according to hydrological processes or relative importance of constituent species (Suski and Cooke 2007). As a result, decreased connectivity, potential introduction or proliferation of invasive species, and upstream point-sources of pollution are often unaddressed within the current FPA framework (Saunders et al. 2002, Pittock et al. 2008). Because freshwater catchments often cross institutional boundaries, their effective protection may require collaboration of political, social, and jurisdictional systems, further constraining broad-scale conservation efforts. These drawbacks have resulted in a perceived failure of FPAs as a conservation tool for aquatic systems (Abell et al. 2007); however, FPAs may benefit from a more goal-oriented mandate, one of which should be to protect migratory fishes in freshwater.

Protection of freshwater migratory fishes in FPAs

In a 2011 review of the status of migratory fish, the Convention of Migratory Species offered 5 suggestions for improving the study of migratory species: developing baseline information on current and historical abundances, improving knowledge of migratory fish ecology, addressing problems created by damming, reducing habitat degradation (including pollution), and initiating transboundary monitoring and management programs (Hogan 2011). Similarly, Cooke et al. (2012) offered a list of 10 factors limiting successful conservation of endangered riverine species, 3 of which were particularly relevant to migratory fish, including a lack of knowledge of natural history, a lack of knowledge of migratory behaviours and the amount of connectivity required to facilitate these behaviours, and the often understudied relationship between conservation and the human dimension. Here, we combine these factors to describe the potential role of FPAs in the conservation of freshwater migratory fish using 3 main categories: life history, connectivity, and human dimensions.

Box 1. The IUCN has various definitions of protected areas worldwide. Highly restricted protected areas are considered to be Category I parks, whereas more liberal restrictions may be considered Category VI parks along the continuum.

IUCN Protected Area Categories (Adapted from IUCN 2008)
Category Ia: Strict Nature Reserve. Human access is strictly controlled with the aim of conserving biodiversity and/or protecting landscape/seascape features.
Category Ib: Wilderness Area. Generally applied to areas with low to no anthropogenic impact. Human access is limited to preserve the natural condition.
Category II: National Park. Applied to large areas to preserve large-scale ecosystem processes and features. Human activity is permitted under regulatory guidance. May contain areas of strict protection resembling Categories 1a, 1b.
Category III: National Monument or Feature. Applied to specific locations that represent a natural or culturally significant feature or monument to preserve its state. Human traffic is regulated, but generally high volume.
Category IV: Habitat/Species Management Area. Applies to localized areas protected to promote restoration, conservation or maintenance of specific species or habitats. Human traffic is generally uncontrolled.
Category V: Protected Landscape/Seascape. Applies to areas of land and sea with distinct scenic and cultural features where traditional land-use has played a role in maintaining system integrity. Maintenance of current human use is a goal of this category.
Category VI: Protected Area with Sustainable Use of Resources. Applies generally to large, natural areas with the aim of maintaining sustainable natural resource use and low-level industrial use. Human traffic is usually uncontrolled. "No-take" zones are recommended.

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Life history

Effectively implementing FPAs requires an understanding of the life history and habitat needs of freshwater migratory fish (Cooke et al. 2012). Generally, there are 3 different categories of migratory fishes that may frequent freshwaters: anadromous, catadromous, and potamodromous species; each of these uses freshwater habitat differently, and none can be effectively managed with a single strategy (Fig. 1). Understanding life history of constituent species provides insight into which habitats are particularly important to protect, such as spawning habitat or productive feeding zones (Rosenfeld and Hatfield 2006). Although migratory fishes inevitably transition among habitats within riverine systems at different life stages, they likely spend the majority of their time in discrete, definable habitats that should be considered important in conservation contexts.

FPAs must focus on maintaining source populations of important migratory species to ensure that the population will persist. This entails protecting spawning areas and spawning time periods, nursery areas where juveniles can mature and disperse from (Rosenfeld and Hatfield 2006), and associated riparian areas (Richardson et al. 2010). While FPAs do not protect fish against natural variability in size and recruitment success, these same variations are influenced by numerous factors, internal and external to the aquatic system, including stressors arising from human use and impact of these systems, such as commercial exploitation or heavy recreational use. FPAs can serve to support recruitment by reducing or removing such stressors.

Connectivity

The relationship between species distribution and connectivity of system components is believed to be crucial to the maintenance of biological processes in freshwater (Lapointe et al. 2014). Catchment-scale protection is the most effective means for protecting migratory fishes and freshwater communities (Stefansson and Rosenberg 2006), but such large-scale protection is not always feasible and may not even be appropriate for managing varied habitat types and different user groups (Saunders et al. 2002). Numerous alternatives to catchment-based management have been proposed, notably multiple-use modules (MUMs) and protection networks (Fig. 2). MUMs are an alternative to catchment-scale protection that reduces activities adjacent to FPAs by restricting land use on neighbouring territories and selectively protecting the most critical habitats (Saunders et al. 2002). Keith (2000) suggested that protected areas should adopt a "network" component that focuses on areas that are strategically significant to fishes, such as spawning and nursery areas. The suitability of these alternatives will depend on system-specific dynamics, such as the impact of dams on movement and the number and type of user groups in the system.

Reductions in lateral (connections between aquatic systems and wetlands and floodplains) and longitudinal (connections between tributaries and main river stems) connectivity affect riverine assemblages and can disconnect habitats that are important at different life history stages of migratory fishes (Pelicice and Agostinho 2008, Cooke et al. 2012). In Brazil, installation of a dam lacking a fishway on the Doce River resulted in the loss of 4 species upstream of the dam, including the commercially important robalo (*Centropomus undecimalis*; Godinho and Kynard 2009). In areas where fishways have been installed to bypass barriers to longitudinal connectivity, passage success is not guaranteed. For example, the Pak Mun dam fishway on the Mun River, Thailand, was found to discourage passage of gravid females of all species studied (Roberts 2001).

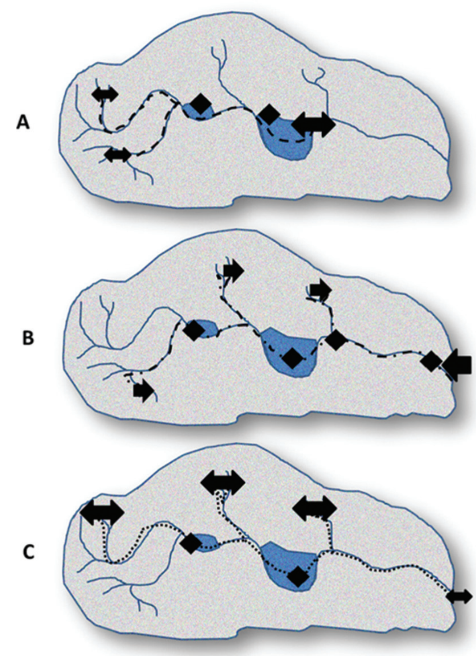

Fig. 1. A theoretical catchment illustrating the challenges associated with establishing FPAs in a single region where different migratory strategies occur. Iteroparity is illustrated using bidirectional arrows, and semelparity is illustrated with unidirectional arrows. Regions likely to be significant to early life stages (e.g., eggs, larvae, fry) have smaller arrows, while those significant to adult life stages are represented by large arrows. Midlife stages and areas of congregation for feeding or other behaviours are indicated by diamonds. Catchment A depicts a theoretical lifetime distribution of an iteroparous potamodromous species, catchment B a semelparous anadromous species, and catchment C an iteroparous catamodromous species. In such a theoretical catchment, FPAs could be established in any or all of these key areas (arrows, diamonds) on a seasonal or year-round basis to facilitate the management of multiple species with different migratory behaviours that occur at different times and life stages in a single system.

While some species may effectively transition to new spawning and foraging sites when preferred habitats become unavailable, many will never successfully navigate obstacles or find suitable alternative habitat and may ultimately become extirpated (Paukert and Galat 2010). Further, construction of fishways may improve connectivity for select species, but passage success is often different among species (Cooke and Hinch 2013). As such, it is difficult to create fishways that are effective at the community level. Fishway designs have begun incorporating natural substrates to improve community-level passage with some success (see Haro et al. 2008, Cooke and Hinch 2013, and Steffensen et al. 2013 for potential sources of bias in estimating passage efficiency), but more research is needed to evaluate passage efficiency at the community level.

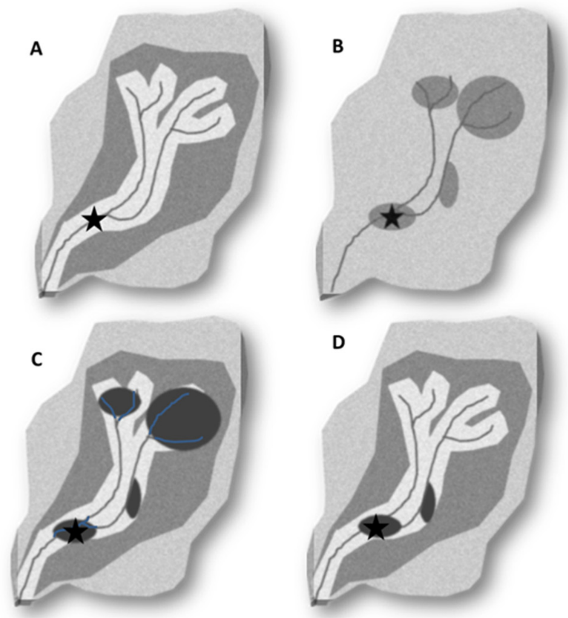

Fig. 2. A theoretical catchment bordered in medium grey and containing a hydropower dam (star) in which different management options are modelled. Catchment A describes the multiple-use module concept, where increased protection and limited activities (such as recreational use) occur within the riparian zone boundary (light grey) with increasing activities (such as light commercial or industrial use) permitted at increasing distances from the protected area (dark grey and medium grey respectively), as described in Saunders et al. (2002). Catchment B shows the same theoretical catchment utilizing the network approach, where increased protection is afforded to key life history zones and sensitive zones such as areas of facilitated passage (i.e., a fishway), floodplains, and tributary spawning areas marked by medium grey circles. Finally, catchments C and D demonstrate the potential for combining both concepts in multiple time frames, with catchment C representing increased protection, such as by prohibiting recreational fishing in seasons where key life history activities (i.e., spawning) are taking place. Catchment D represents the same catchment in seasons where prohibited activities may be allowed in certain areas.

Effectively designed FPAs may support connectivity by reducing the impacts of stressors in habitats that support connectivity. For example, establishing FPAs at sites where fishways occur may allow migrants to make and recover from passage attempts without the added disruption of anthropogenic activities in the immediate area. Other options include designing protected areas that contain fish passage structures, such as pool-and-run stream diversions, at sites where fishways do not currently exist. FPAs may be a useful tool for protecting remaining connections among wetlands, floodplains, and river stems, particularly in systems where such lateral connectivity has been reduced.

Human dimensions

One of the criticisms levelled against FPAs has been the breadth of activities permitted within them (Pittock et al. 2008). Yet, studies of successful establishment of marine protected areas (MPAs) demonstrate that community support for such conservation endeavours is essential to their success (e.g., Jentoft et al. 2012). Naiman (2013) suggested that the next phase of freshwater conservation is the integration of conservation and restoration efforts with the values and needs of the local social system. This underscores the importance of human dimensions in the utility of FPAs as a conservation implement for freshwater migratory fish.

Support for river protection and rehabilitation seems to be on the rise (but see Cooke et al. 2013, which questions that assertion) but is occurring concomitantly with increases in agricultural withdrawal, pollution inputs, invasive species introductions, and habitat loss, all of which place additional strain on these systems (Naiman 2013). The need to solicit social support for FPAs that protect against such degradation may be particularly important in local communities where point-sources of pollution, such as industrial inputs, may be tied to local employment and economies.

The nature of activities permitted to occur within the borders of an FPA is also important to consider. For example, recreational angling has been beneficial for promoting conservation of some endangered freshwater migratory species, such as mahseer (*Tor* spp.) in India (Pinder and Raghavan 2013) and taimen (*Hucho taimen*) in Mongolia (Jensen et al. 2009). Conversely, when access to activities such as angling was limited or removed, support for conservation initiatives tended to decrease (Danylchuk and Cooke 2011). This highlights the importance of balancing freshwater activities with the goals of FPAs to ensure their sustainability, which requires species-specific and often population-specific studies to evaluate viability.

Instituting FPAs to conserve freshwater migratory species will require numerous collaborations to be

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successful. Primarily, there must be a genuine benefit to local communities derived from the conservation of the target species, which may occur through direct (e.g., increased tourist activity results in increased community-level expenditures), or indirect (e.g., decreased localized industrial pollution inputs increases local crop yields) means. To avoid social conflict resulting from decreased access, these benefits must be both adequately compensated and communicated at the community level (bottom-up support) and must receive legislative and enforcement support from appropriate levels of government (top-down support; Bower et al. 2014).

Conclusions

A central question arising from this discussion is: where can we institute FPAs that would effectively protect migratory fish? The suitability of using FPAs as a conservation tool for migratory species will depend on many factors, each of which will have attributes specific to the species and freshwater system in question. The availability of knowledge surrounding the natural history of species targeted for conservation, the physical attributes of the freshwater system (e.g., hydrological processes, lateral and longitudinal connectivity, constituent habitat quality), and the nature and significance of human activities taking place in areas proposed for protection will be essential considerations for deciding if and where to institute FPAs. Based on these considerations, we offer the following suggestions:

1. Planning stages for FPAs should consider the natural history of migratory species in freshwater systems, including identification of migratory species and essential habitats supporting migratory behaviours (e.g., holding areas, habitats more likely to generate fallback behaviours or negatively impact migration success). While we acknowledge that in many cases research identifying these essential habitats may be lacking, generating more information about life histories of local migratory fishes will be directly linked to the effective establishment of FPAs for conserving migratory species.
2. In systems where multiple migratory species inhabit the same areas, planners should strive to locate FPAs in areas most likely to support the conservation of a maximum number of species (Fig. 2). This location would be determined, again, by considering the migration behaviours and habitat use of these species and prioritizing areas of overlap. For example, if certain tributary streams are more likely to support spawning habitat for multiple migratory species than others, these tributaries would be more suitable locations for FPAs, whether instituted on a seasonal or year-round basis.
3. Planners should consider connectivity at multiple scales when attempting to locate an FPA. Priority should be given to areas where FPAs can be used to support connectivity and migratory behaviours by reducing anthropogenic activity (e.g., at fishways). Consideration should also be given to the potential for connectivity to negatively impact effectiveness of FPAs. For example, it would be inadvisable to locate an FPA immediately downstream of a pollution source in a well-connected system.
4. Stakeholders and community members should be included at all stages of planning for FPAs. Careful consideration should be given to the socioeconomic impacts of limiting certain activities in the proposed area. These impacts should be used to inform the chosen FPA type (i.e., what activities to limit; Box 1), placement, and timeline (i.e., whether to institute a year-round or seasonal FPA).

We believe that FPAs designed to conserve migratory fish can support limited extractive (i.e., subsistence fishing) and nonextractive human activities, provided such activities are supported by appropriate regulations to achieve a balance between protection and access. Moreover, this balance must be maintained over time and in accordance with changing needs brought on by dynamic environmental and socioeconomic conditions. It cannot be overemphasized that the viability of such activities must be supported by local or population-specific scientific evaluations with human dimension research and stakeholder engagement (across jurisdictions to reflect migratory range of a given species) on a case-by-case basis to achieve conservation goals and ultimately ensure the success of a FPA for migratory fish protection.

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References

Abell R, Allan JD, Lehner B. 2007. Unlocking the potential of protected areas for freshwater. Biol Conserv. 134:48–63.

Bower SD, Nguyen VM, Danylchuk AJ, Beard TD Jr, Cooke SJ. 2014. Inter-sectoral conflict and recreational fisheries of the developing world: opportunities and challenges for co-operation. In: McConney P, Medeiros R, Pena M, editors. Enhancing stewardship in small-scale fisheries: practices and perspectives. Barbados (West Indies): University of the West Indies, Cave Hill Campus, Too Big To Ignore (TBTI) and Centre for Resource Management and Environmental Studies. CERMES Technical Report No. 73.

Bryan HM, Dairmont CT, Paquet PC, Wynne-Edwards KE, Smits JEG. 2013. Stress and reproductive hormones in grizzly bears reflect nutritional benefits and social consequences of a salmon foraging niche. PLOS One. 8(11):e80537. doi: 10.1371/journal.pone.0080537

Childress ES, Allan DJ, McIntyre PB. 2014. Nutrient subsidies from iteroparous fish migrations can enhance stream productivity. Ecosystems 17(3). doi: 10.1007/s10021-013-9739-z

Cooke SJ, Hinch SG. 2013. Improving the reliability of fishway attraction and passage efficiency estimates to inform fishway engineering, science, and practice. Ecol Eng. 58:123–132.

Cooke SJ, Lapointe NWR, Martins EG, Thiem JD, Raby GD, Taylor MK, Beard TD Jr, Cowx IG. 2013. Failure to engage the public in issues related to inland fishes and fisheries: strategies for building public and political will to promote meaningful conservation. J Fish Biol. 83(4):997–1018.

Cooke SJ, Paukert C, Hogan Z. 2012. Endangered river fish: factors hindering conservation and restoration. Endanger Species Res. 17:179–191.

Crofts R. 2004. Linking protected areas to the wider world: a review of approaches. J Environ Policy Plann. 6(2):143–156.

Danylchuk AJ, Cooke SJ. 2011. Engaging the recreational angling community to implement and manage aquatic protected areas. Cons Biol. 25(3):458–464.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Naiman RJ, Prieu-Richard AH, Soto D, Stiassny MLJ, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol Rev. 81(2):163–182.

Flecker AS, McIntyre PB, Moore JW, Anderson JT, Taylor BW, Hall RO Jr. 2010. Migratory fishes as material and process subsidies in riverine ecosystems. Am Fish Soc Symp. 73:559–592.

Godinho A, Kynard B. 2009. Migratory fishes of Brazil: life history and fish passage needs. River Res Appl. 25:702–712.

Haro A, Franklin A, Castro-Santos T, Noreika J. 2008. Design and evaluation of nature-like fishways for passage of Northeastern diadromous fishes. Final Report. Prepared for Turner Falls (MA): NOAA National Marine Fisheries Service Office of Habitat Conservation.

Hogan Z. 2011. Review of freshwater migratory fish. Convention on migratory species. Tenth Meeting of the Conference of the Parties. Bergen (Norway), November 2011. 37 p.

Holmlund CM, Hammer M. 1999. Ecosystem services generated by fish populations. Ecol Econ. 29(2):253–268.

[IUCN] International Union for the Conservation of Nature. 2008. Defining protected areas: an international conference in Almeria, Spain. Dudley N, Stolton S, editors. Gland, Switzerland. 220 p.

Jensen OP, Gilroy DJ, Hogan Z, Allen BC, Hrabik TR, Weidel BC, Chandra S, Vander Zanden MJ. 2009. Evaluating recreational fisheries for an endangered species: a case study of taimen, *Hucho taimen*, in Mongolia. Can J Fish Aquat Sci. 66:1707–1718.

Jentoft S, Pascuel-Fernandez JJ, De La Cruz Modino R, Gonzalez-Ramallal M, Chuenpagdee R. 2012. What stakeholders think about marine protected areas: case studies from Spain. Hum Ecol. 40:185–197.

Keith P. 2000. The part played by protected areas in the conservation of threatened French freshwater fish. Biol Conserv. 92:265–273.

Lapointe NWR, Cooke SJ, Imhof JG, Boisclair D, Casselman JM, Curry RA, Langer OE, McLaughlin RL, Minns CK, Post JR, et al. 2014. Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. Environ Rev. 22:1–25.

Lucas MC, Baras E. 2001. Migration of freshwater fishes. Oxford (UK): Blackwell Scientific Publications.

Naiman R. 2013. Socio-ecological complexity and the restoration of river ecosystems. Inland Waters. 3:391–410.

Paukert CP, Galat D. 2010. Large warm water rivers. Inland fisheries management in North America, 3rd ed. Bethesda (MD): American Fisheries Society. p. 699–730.

Pelicice FM, Agostinho AA. 2008. Fish-passage facilities as ecological traps in large neotropical rivers. Cons Biol. 22(1):180–188.

Pinder AC, Raghavan R. 2013. Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. Curr Sci India. 104(11):1472–1475.

Pittock J, Hansen LJ, Abell R. 2008. Running dry: freshwater biodiversity, protected areas and climate change. Biodiversity. 9(3–4):30–38.

Reid K. 2002. Global register of migratory species. German Federal Agency for Nature Conservation. Project 808 05 081.

Reid K. 2004. Global register of migratory species - from global to regional scales. Final Report, German Federal Agency for Nature Conservation. Project 808 05 081.

Richardson JS, Taylor E, Schluter D, Pearson M, Hatfield T. 2010. Do riparian zones qualify as critical habitat for endangered freshwater fishes? Can J Fish Aquat Sci. 67(7):1197–1204.

Roberts TR. 2001. On the river of no returns: Thailand's Pak Mun Dam and its fish ladder. Natural History Bulletin of the Siam Society. 49(2):189–230.

Rosenfeld JS, Hatfield T. 2006. Information needs for assessing critical habitat of freshwater fish. Can J Fish Aquat Sci. 63(3):683–698.

Saunders DL, Meeuwig JJ, Vincent ACJ. 2002. Freshwater protected areas: strategies for Conservation. Cons Biol. 16(1):30–41.

Soulé M, Terborgh J. 1999. Continental conservation: scientific foundations of regional reserve networks. Washington (DC): Island Press. 227 p.

Stefansson G, Rosenberg AA. 2006. Designing marine protected areas for migrating fish stocks. J Fish Biol. 69:66–78.

Steffensen SM, Thiem JD, Stamplecoskie KM, Binder TR, Hatry C, Langlois-Anderson N, Cooke SJ. 2013. Biological effectiveness of an inexpensive nature-like fishway for passage of warmwater fish in a small Ontario stream. Ecol Freshw Fish. 22:374–383.

Suski CD, Cooke SJ. 2007. Conservation of aquatic resources through the use of freshwater protected areas: opportunities and challenges. Biodivers Conserv. 16:2015–2029.

World Wildlife Fund. 2014. Living Planet Report. McLellan R, Iyengar L, Jeffries B, Oerlemans N, editors. Gland (Switzerland): WWF International.

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