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Unlocking the potential of protected areas for freshwaters

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ABSTRACT

Declining trends in the integrity of freshwater systems demand exploration of all possible conservation solutions. Freshwater protected areas have received little attention, despite the prominence of protected areas as conservation interventions for terrestrial and more recently marine features. We argue that a dialogue on freshwater protected areas has been neglected both because few models of good protected area design exist, and because traditional notions of protected areas translate imperfectly to the freshwater realm. Partly as a result of this conceptual disconnect, freshwaters have been largely ignored in protected area accounting schemes, even though a number of existing freshwater conservation strategies could qualify according to general protected area definitions. Rather than impose terrestrially-motivated ideas about protected areas onto freshwaters, we propose new vocabulary – *freshwater focal area*, *critical management zone*, and *catchment management zone* – that can be used in conjunction with IUCN protected area categories and that recognize the special ecological dynamics of freshwaters, and in particular the critical role of fluvial processes. These terms, which attempt to diffuse concerns about locking away essential ecosystem goods and services, move us toward consideration of protected areas *for* freshwaters. This conceptual shift, which acknowledges that freshwater conservation may occur remotely from freshwater features, opens the door for improved integration of freshwater, terrestrial, and marine concerns in protected area design and management.

1. Introduction

Mounting evidence showing that freshwater systems and the species they support are among the most imperiled worldwide (Ricciardi and Rasmussen, 1999; Jenkins, 2003; Revenga and Kura, 2003; Revenga et al., 2005) has resulted in calls for redoubled efforts to reverse declining trends (Shumway, 1999; Abell, 2002; Dudgeon, 2003; Dudgeon et al., 2006). How to effect that positive change is far from obvious. A number of strategies are available for conserving freshwater systems, encompassing everything from macro-scale integrated catchment management to micro-scale restoration of individual habitats (Cowx, 2002; Saunders et al., 2002). Data are usually lacking to evaluate the long-term effectiveness of different strategies (WWF, 2004), but the downward trend of freshwater biodiversity measures suggests that the conservation and management communities should explore all reasonable interventions. Despite considerable progress in identifying threats, including habitat fragmentation (Nilsson et al., 2005), habitat loss (Revenga et al., 2000), flow alterations (Poff et al., 1997), overfishing (Allan et al., 2005), and non-native species (Harrison and Stiassny, 1999), scientific debate on

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how best to protect freshwater ecosystems and their species has barely begun.

One category of conservation practices, long common for terrestrial systems and rapidly gaining attention and recognition in the marine realm, is protected areas (PAs). For freshwater systems, PAs have largely been a footnote in the scientific literature. A database search (Web of Science®, conducted 14 March 2006) found a scant eleven papers relating to freshwater protected areas, versus several hundred for marine. This paper explores why freshwater PAs have received little attention, examines whether this is warranted, and suggests ways that the concept of PAs might be redefined and made more relevant for freshwater systems.

The topic of freshwater PAs is timely. Intact freshwater systems are becoming increasingly rare around the world and will require protection before they fall victim to a range of threats (Meybeck, 2004; Nilsson et al., 2005). About 90% of freshwater species listed as critically endangered, endangered, or vulnerable on the 2004 IUCN Red List are threatened by human-induced habitat loss or degradation (IUCN, 2004), and 71% of freshwater fish extinctions are attributable at least in part to habitat alteration (Harrison and Stiassny, 1999). A smaller fraction of freshwater fish are at risk due to over-harvest, but this includes some of the largest and most vulnerable species (Allan et al., 2005). PAs would in principle protect against or mitigate these place-specific threats, and in special cases could proactively prevent others like pollution and the invasion of exotic aquatic species, the latter being the second most common cause of freshwater fish extinctions (Harrison and Stiassny, 1999) (Table 1).

Conserving freshwater biodiversity for its own sake has limited support throughout much of the world (Dudgeon, 2000; Wishart et al., 2000), but even a purely utilitarian perspective argues for protecting freshwaters. Growing evidence shows the market and non-market economic values to human communities of maintaining functionally intact freshwater systems (Emerton and Bos, 2004; Pattanayak, 2004), and the costs over large geographic areas that can result from impaired systems (Holmlund and Hammer, 1999). Protection will almost always be more economical than restoration (Chen, 2001). For the continental United States alone, Bernhardt et al. (2005) estimate that at least $14–15 billion was spent on restoration of streams and rivers between 1990 and 2003, or about $1 billion/year. If conservation of functionally intact freshwater ecosystems is in the best long-term interest of the global community, then it is due time that conversations about managing freshwater systems begin to include thoughtful debate about when and how PAs can be an effective strategy.

Table 1 – Threats to freshwater ecosystems and the possibility of prevention by PAs

Threat to freshwater ecosystems	Description/cause	Origin: local	Origin: catchment	Origin: extra-catchment	Place-based solution for proactive protection?
Direct habitat alteration	Degradation and loss	X	X		Local-to-catchment management
	Fragmentation by dams and inhospitable habitat segments	X			Protected rivers or river reaches
Flow alteration	Alteration by dams	X	X		Protected rivers or river reaches
	Alteration by land-use change		X		Catchment management
	Alteration by water abstraction	X	X		Abstraction prohibited or managed for priority systems
Overharvest	Commercial, subsistence, recreational, poaching	X	X		Fishery reserves
Contaminants	Agricultural runoff (nutrients, sediments, pesticides)		X		Catchment management
	Toxic chemicals including metals, organic compounds, endocrine disruptors	X	X		Catchment management; local prohibitions against point-source discharges
	Acidification due to atmospheric deposition and mining			X	None
Invasive species	Altered species interactions and habitat conditions resulting from accidental and purposeful introductions	X	X		Preventing introductions to systems with natural or constructed barriers to invasion
Climate change	Results in changes to hydrologic cycle and adjacent vegetation, affects species ranges and system productivity			X	None (except maintaining dispersal opportunities and thermal refugia)

In nearly all cases where both local and catchment origins are listed, local stresses are transferred downstream to become catchment impacts elsewhere. (Information drawn from Brinson and Malvarez (2002), Bronmark and Hansson (2002), Malmqvist and Rundle (2002), and Tockner and Stanford (2002).)

2. Background: protected areas and their accounting

Protected areas in their many forms have been the core element of conservation efforts for well over a century and have been variously called reserves, parks, preserves, and refuges, among hundreds of other terms (Phillips, 2004). IUCN's standard definition of a PA – 'An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means' – focuses on ends rather than means, with the ends formalized as objectives that encompass both biodiversity and natural resource conservation (IUCN, 1994). The definition's wide reach on objectives has underpinned controversies about what constitutes 'true' PAs and how people fit into them (Terborgh, 2004; Andrade, 2005; Hutton et al., 2005; Terborgh, 2005). Despite ongoing debates, PAs have remained central strategies for biodiversity conservation (IUCN, 2003), particularly for terrestrial habitats and species.

Over the past two decades, there has also been a surge of attention for marine protected areas (MPAs), born from studies evaluating overfishing impacts and spurred by a National Center for Ecological Analysis (NCEAS) working group synthesis (Lubchenco et al., 2003; Norse et al., 2003). The dialogue about MPAs has quickly matured enough to have engendered a healthy discussion about the promise and effectiveness of such areas for both biodiversity conservation and fisheries management (Norse et al., 2003; Hilborn et al., 2004). As of 2005, MPAs had a total extent of about 2.2 million km^2 (WWF Global Programme, 2005). This number represents only 0.6% of the marine environment, though the percentage would be higher for coastal areas alone. Numerous new areas are currently proposed, including in South Africa, the Solomon Islands, Australia, Hawaii, and Canada.

Similar data for freshwaters are variable, largely because there are no adequate accounting systems. The World Database on Protected Areas (WDPA) subsumes freshwaters under Udvardy's (1975) 'terrestrial' biomes. Of these biomes, though, one is 'lakes.' In 2003, the WDPA catalogued lake PAs covering 7989 km^2, or 1.54% of the world's total extent of lakes, comprising less than 0.05% of all terrestrial PAs (Chape et al., 2003). Although these figures are hardly impressive, many PAs classified under other terrestrial biomes undoubtedly contain rivers and additional lakes as well. Yet, as we argue below, freshwaters within many PAs receive inadequate protection. In general, the structure of the WDPA is indicative of where freshwaters sit within most conversations about PAs: they are buried within terrestrial accounting sheets and rarely recognized as their own special case.

A more optimistic accounting comes from The Millennium Ecosystem Assessment, which provides a figure of 12% protection for inland waters (Millennium Ecosystem Assessment, 2005). This value, generated by overlaying protected area polygons with inland waters categories of the Digital Chart of the World, unfortunately tells us little about actual freshwater protection. About 12% of the earth's non-marine surface occurs within protected areas, suggesting only that inland waters have not been intentionally excluded from such areas.

Ramsar Sites – also called Wetlands of International Importance – are the closest equivalent to a global set of freshwater PAs, but they also offer limited insight into the true extent of freshwater protection. According to the Ramsar Sites database (accessed February 2006), the area of Ramsar Sites whose dominant wetland type is natural inland wetland cover totals 468 424 km^2. Because Ramsar Sites may contain a wide variety of terrestrial, freshwater, and marine habitats, translating this number to a global extent of freshwater habitats encompassed in PAs is not possible. Designation of Ramsar Sites and plans for conservation of their 'ecological character' and 'wise use' do not require the formal designation of PAs under national law, though about 75% of these inland water sites receive national protection in whole or part (Ramsar Convention on Wetlands, 2004). Like other protected areas, management varies widely (Georges and Cottingham, 2002). The only two global review publications devoted to freshwater PAs, Saunders et al. (2002) and Crivelli (2002), include no substantive discussion of Ramsar Sites, suggesting that their potential as important tools for freshwater biodiversity protection has yet to be fully realized.

The scarcity of freshwater PAs, and of data to describe those that exist, has not gone unnoticed. Formal outputs from the third IUCN World Conservation Congress, the fifth World Parks Congress, and the seventh Meeting of the Conference of the Parties to the Convention on Biological Diversity call for the establishment of representative systems of inland waters PAs, and several independent authors have also called for the creation of freshwater PAs, both for specific critical habitats and more generally (Moyle and Sato, 1991; Sedell et al., 1994; Rahr et al., 1998; Platt and Thorbjarnarson, 2000; Impson et al., 2002; Nevill and Phillips, 2004; Filipe et al., 2004; Abellán et al., 2005; Cooke et al., 2005; Fitzsimons and Robertson, 2005; Kreb and Budiono, 2005).

3. Freshwater protected areas: why not?

The many recommendations for the establishment of freshwater PAs have failed to set a broad dialogue in motion. We suggest that a lack of positive examples, the unique position of freshwaters within landscapes, and the difficult application of PA categories to freshwaters have together acted as barriers to the maturation of the conceptual framework of freshwater PAs.

3.1. *Perceived failures of existing freshwater protected areas*

Assessments of existing PAs are quick to turn up failures in terms of conferring protection to freshwater features, largely because most such areas were not designed or managed explicitly toward this end (Pringle, 2001; Cowx, 2002; Georges and Cottingham, 2002; Collares-Pereira and Cowx, 2004). Maitland and Lyle (1992) found that Great Britain's National Nature Reserves fortuitously included populations of most native fish species despite not having been designed for this purpose; however, many of the species most in need of protection lacked adequate PA coverage. Similarly, Impson et al. (2002) analyzed national parks and nature reserves of South Africa's Cape Floral Kingdom and concluded that, although this set of PAs contained populations of most indigenous fish species, actual protection was seriously impaired because the species' ranges extended largely outside the areas or invasive alien species were present within them. Keith (2000) found that PAs in France also did a poor job of conserving fish species of special concern, with all mainland national parks located in higher altitude areas while most imperiled species occurred downstream; furthermore, restocking of exotic fish species was common in these parks, increasing the risk to native fauna. Crivelli (2002) recounts additional examples of aquatic habitats protected specifically to conserve endangered fish species while simultaneously allowing fishing and fish stocking. Similarly, Knapp and Matthews (2000) document the decline of an endangered frog in certain California PAs as the result of intentional fish introductions.

Fish have received the most attention in analyses of protection gaps, though there is some evidence that aquatic invertebrates and freshwater-dependent mammals are similarly underrepresented by existing PA networks (Lawler et al., 2003; Revenga and Kura, 2003; Yip et al., 2004). The medium to long-distance longitudinal movements between habitats of many fish species make them particularly challenging taxa to conserve through place-based strategies (Schlosser and Angermeier, 1995; Fausch et al., 2002), with problems compounded for long-lived species exposed to different combinations of threats over time. But these facts should not invalidate the use of freshwater PAs for fish or for other freshwater species and their habitats (Filipe et al., 2004; Nevill, 2005). Even the protection of particularly vulnerable or critical habitats would provide benefits over no protection at all (Baird, 2006).

Gap analyses of aquatic habitats, while rare, have revealed insufficient protections. Nel et al. (2004) have found that over 90% of South Africa's main rivers fall outside PAs, and an additional 5% serve as PA boundaries and so are also considered unprotected. A gap assessment of aquatic habitats in a portion of the southwest Amazon basin similarly found that lowland rivers and streams were especially poorly represented in PAs when 'boundary' rivers were counted as unprotected (Thieme et al., in review). Worldwide, rivers are viewed as PA markers, rather than as habitats requiring dedicated protection themselves.

Nearly all of the above-cited authors recommend improvements to PA design and management, suggesting that PAs are not by definition a poor conservation strategy for freshwaters. In fact, Williams (1991), in his review of preserves and reserves designed explicitly to protect native fishes of the western United States, concludes that most areas evaluated were relatively successful, though success was lower for those larger freshwater systems that were more permeable to invasion by exotics. Exotics, then, as well as fishing and poor siting and design, have been common problems for freshwater species conservation within PAs.

We argue that freshwater PAs cannot be discounted based on past history because PAs designed explicitly for freshwater biodiversity hardly exist outside the Ramsar framework. Yet, because freshwaters are subject to any and all impacts originating in their catchments, the types of problems described above raise the question of whether 'freshwater protected area' is an oxymoron. Here we define a 'catchment' as the land and embedded streams, lakes, and wetlands from which water runs off to supply a particular location in a freshwater system. There is general consensus that comprehensive conservation of freshwaters requires a whole-catchment approach, but also that people live virtually everywhere and cannot and should not be excluded in most cases from the water resource (Crivelli, 2002; Saunders et al., 2002; Dudgeon et al., 2006). We suggest that these very real issues do not invalidate the concept and potential utility of freshwater PAs. Below we address the relationship of PAs to whole-catchment management and then examine the kinds of human uses that might be permitted, restricted, or prohibited through a freshwater PA designation.

3.2. Challenges of exogenous threats and whole-catchment management

Freshwaters within PAs are especially vulnerable to exogenous threats. Aquatic ecosystems within France's National Nature Reserve of Camargue have been contaminated by chemicals transported to the reserve via drainage and irrigation ditches originating in the catchment (Roche et al., 2002). Similarly, Spain's Doñana National Park was devastated by a massive acid waste spill outside the wetland PA (Pain et al., 1998). Barendregt et al. (1995) describe the decline of ecological integrity of the Netherland's Naadermeer nature reserve as a result of external threats, principally altered hydrologic flows into the wetland. Canada's Banff National Park, which was originally established as a tourist destination, has suffered not only from fish introductions but also from multiple flow modification structures and serious pollution, both occurring within the park boundaries (Schindler, 2000). Driver et al. (2005) noted that South Africa's flagship park, Kruger, cuts across the region's major rivers and thereby offers only partial protection to all of them.

Good land management makes a difference. Driver et al. (2005) found that river ecosystems showed significant recovery within PAs. Mancini et al.'s (2005) findings for central Italy's PAs reinforce this point; they found that biotic integrity was positively correlated with good land management within PAs, whereas the effect of PA size was insignificant. All things equal, larger PAs most likely are better for freshwaters than smaller PAs as they should include a larger portion of the upstream catchment and a greater extent, diversity, and redundancy of freshwater habitats, but design and management may be equally if not more important than size alone (Moyle and Yoshiyama, 1994; Pringle, 2001).

The examples of the Doñana, Camargue, Naadermeer, and other 'protected' freshwater systems affected by activities and accidents outside PA boundaries emphasize the high permeability of freshwater PAs. These same characteristics apply to marine systems; both are boundary systems affected by activities within (e.g., fishing, point-source discharges) and without (Table 2). One could argue that terrestrial systems suffer similarly from exogenous threats yet many conversations about terrestrial PAs focus more on the permeability of park boundaries to people than to biophysical processes (Peres and Terborgh, 1995; Pringle, 2001).

Marine conservation scientists, having long considered connections between and among locations and the influence

Table 2 – Comparisons among freshwater, terrestrial and marine ecosystems from the perspective of PAs to protect individual species and biodiversity

Key system characteristics	Terrestrial	Marine	Freshwater
Extent of protected area	11.5%	<1%	Unknown
Focal features	Commonly emphasize individual species and inclusive biodiversity	Protection of fish from over-harvest; invertebrates, other vertebrates and all biodiversity elements may be included	Protection of system types may take precedence where biodiversity inventories and flagship species are lacking; vertebrates, especially in wetlands; protection against over-harvest is less common
Prioritization process	Commonly set priorities and ensure representativeness using models based on spatially explicit data for vegetation and well-studied animal groups	Spatially explicit biodiversity data often lacking, greater reliance on population, recruitment and catch data	Spatially explicit biodiversity data often lacking, some use of population data, frequent reliance on species-habitat associations to develop spatially explicit habitat mapping
Connectedness	Tend to be 'closed' re movement of energy. Population connectedness relies mainly on discrete corridors and adjacency	Highly 'open' re movement of energy, materials. Population connectedness determined by currents and patterns of dispersal, not static	Variably open to upstream–downstream, land–water, and groundwater–surface water transfers of energy, materials. Springs, unconnected wetlands, and many lakes likely fall at the closed end of this spectrum, rivers are strongly influenced by longitudinal connectivity
Population processes	Relatively closed systems, dispersal and recruitment mainly at local scales	Open systems. Early life stages often disperse great distances, recruitment can be decoupled from parental populations	Intermediate. Most recruitment is local but many taxa are sufficiently mobile that population processes occur at the meso-scale and migratory species connect disparate habitats over great distances
Scale of protection	Emphasizes the protection of species and habitat within PA boundaries	Emphasizes sustainable populations, including harvestable surplus beyond boundaries	More similar to terrestrial PAs, although migratory fish and waterfowl and other wide-ranging taxa (e.g., dolphins) require an expanded scale; some freshwater harvest zones similar to small MPAs
Access and ownership	Strongly influenced by land ownership and administration; most on public land; oversight by one or few entities	Ownership boundaries usually less distinct; managed by boundaries and harvest regulations; frequently transnational	Small springs and wetlands may be protected through land ownership; large catchments raise complex access and ownership issues; often subject to multiple, overlapping jurisdictions and many levels of governance

Characterization of terrestrial and marine ecosystems based on Carr et al. (2003) and Chape et al. (2003), and of freshwater ecosystems based on literature reviewed in the text. Freshwater (FW) systems include lakes, wetlands, springs and rivers of all sizes; however, in this comparison, rivers and wetlands receive primary emphasis.

of outside factors within the ocean, have recently begun to emphasize how land and coastal marine ecosystems are connected. In reference to coastal marine systems, Stoms et al. (2005) have described how remote but connected ecosystems can act as 'promoters' of PA conditions, for example as sites of spawning and recruitment; or as 'demoters,' such as when rivers transport sediments or pollutants to coastal waters. These same ideas have equal currency for freshwaters, suggesting real benefits from an improved dialogue between marine and freshwater conservationists.

The issue of exogenous threats leads to the generally-accepted conclusion that full protection of a given freshwater system requires conserving both its entire upstream catchment as well as the downstream habitats of focal species (Cowx, 2002; Saunders et al., 2002), though even catchment-wide protection may be compromised by extra-catchment threats like acid precipitation and climate change. In the case of a headwater or small endorheic system with highly resident species, the upstream component of this requirement might be met relatively easily, though an individual small PA could still be highly vulnerable to natural disturbance (Frissell, 1997). At the other extreme, the area of concern for a downstream system supporting migratory species with estuarine or marine life stages could theoretically include the entire catchment of a major river as well as portions of the marine realm – the 'ridges to reefs' concept.

An obvious problem with this basic conservation tenet of catchment protection is that, worldwide, few intact large catchments remain (Nilsson et al., 2005). Lower reaches of larger rivers, deltas, and estuaries tend to be particularly disturbed (Pringle, 2001; Buijse et al., 2002; Kennish, 2002; Stein et al., 2002). Even in the least inhabited places, any human settlements will likely be concentrated along freshwater margins, as water is a non-substitutable resource. Managing entire large catchments in their pristine states is for most practical purposes no longer an option. Existing opportunities to protect intact small catchments, such as along some undeveloped coasts, deserve urgent attention.

Realizing that catchments today encompass multiple stakeholder groups competing with each other and aquatic species for limited resources, many freshwater planners and managers have embraced the concept of integrated river basin management (also called watershed management or integrated catchment management) as a strategy for balancing these various interests. Integrated river basin management (IRBM) can be broadly defined as "the process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems" (Jones et al., 2003). IRBM is in effect a specific form of ecosystem-based management, which has also been broadly advocated for marine fisheries conservation (Pikitch et al., 2004).

Protected areas and integrated catchment management are complementary, and multiple observers have suggested that the latter should be the organizing principle of freshwater conservation, with PAs serving as a component strategy. Crivelli (2002) cites several authors who note the necessity of catchment-wide policies applied outside of PAs to achieve true freshwater conservation. Recommendation 31 from the fifth World Parks Congress notes that the establishment of PAs "is best undertaken through the processes of integrated river basin or watershed management" (IUCN and WCPA, 2004). Similarly, Goal 1.2 of the Convention on Biological Diversity's Recommendation VIII/2 is "To establish and maintain comprehensive, adequate and representative systems of protected inland water ecosystems within the framework of integrated catchment/watershed/river basin management" (Convention on Biological Diversity, 2003). Yet despite these recommendations from the scientific and policy arenas, PAs have at best represented a small part in IRBM plans (Gilman et al., 2004). Below we explore how definitions and perceptions of 'protection' might be hampering the creation of freshwater PAs within catchment management efforts.

3.3. *Protected area categories and freshwaters: an imperfect fit*

Protected areas vary in their restrictions, prohibitions, and management levels. IUCN recognizes six PA management categories, based on an area's management objective (IUCN, 1994). Categories V and VI explicitly include human use, and some conservation biologists have argued that these 'soft' PAs should be excluded from the PA categorization, or at least

Table 3 – Assignment of protected areas to IUCN protected area categories

	IUCN categories[a]							
	Ia	Ib	II	III	IV	V	VI	Unassigned
% of WDPA[b]	5	1.3	3.2	19.6	25.8	7.9	3.7	33.5
% of MPA[b]	9.5	1.7	17.1	3.7	31.8	13.2	5.4	17.6
Proposed freshwater protection areas								
Freshwater target zone	xxxxxx	xxxxxx		xxxxxx	xxxxxx			
Critical management zone			xxxxxx	xxxxxx	xxxxxx	xxxxxx		
Integrated management zone						xxxxxx	xxxxxx	
Real-world freshwater examples								
Freshwaters within terrestrial parks			xxxxxx					
Ramsar sites			xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	
Heritage/wild rivers			xxxxxx			xxxxxx		
Inland fishery reserves							xxxxxx	
Riparian buffers					xxxxxx			

Assignment of real-world freshwater examples is based on the authors' interpretation and represents most but not all occurrences.
Ia Strict nature reserve, managed mainly for science.
Ib Managed mainly for wilderness protection.
II National park, managed for ecosystem protection and recreation.
III Natural monument, managed for conservation of specific natural features.
IV Habitat/species management area, conservation through management intervention.
V Protected landscape/seascape managed for conservation and recreation.
VI Managed resource protected area, for sustainable use of natural systems.
a IUCN categories.
b Taken from Wells and Day (2004).

clearly defined within reporting systems (Terborgh, 2004; Locke and Dearden, 2005). There are good reasons to highlight the differences between those PAs designated and designed primarily for biodiversity conservation (categories I–IV), and those intended to accommodate greater human use (categories V and VI). However, the segregation of PAs into either 'strict' or 'other' categories is problematic for freshwaters, because strict protection of freshwaters is nearly impossible outside wilderness areas. This division also ignores the important role that category V and VI areas can play in maintaining ecosystem processes in downstream category I–IV areas.

Freshwater PAs like Ramsar Sites have rarely been categorized according to the IUCN framework, though Ramsar's members have resolved to do this more systematically (Ramsar Resolution IX.22). That effort may meet with challenges similar to those encountered in recent attempts to fit MPAs into single IUCN categories (Wells and Day, 2004). As an example, Wells and Day (2004) map eight different management zone types of the Great Barrier Reef Marine Park against four IUCN categories. Despite the complexity of such exercises, those authors argue for the use of IUCN categories with MPAs as a way of facilitating consistent analyses and comparisons. We advocate a similar approach here (Table 3).

MPA theory and practice may have particular applicability to freshwater systems, reflecting similarities between freshwater and marine environments that derive largely from the literal and figurative fluidity and thus the openness of both systems (Table 2). A recognition of the need to protect adjacent coastal lands in the service of marine conservation (Convention on Biodiversity, 2002) echoes freshwater conservation requirements for terrestrial interventions. However, as we argue below, PAs for freshwaters may need to take this concept further, with protections distant as well as adjacent to focal freshwater features.

4. Freshwater protected areas: stretching definitions and accounting tools

Spatially defined freshwater protections do exist, yet they often stretch traditional PA notions. Below we explore the fit with PAs of three freshwater conservation strategies: heritage or wild rivers, inland fishery reserves, and riparian buffer zones. We then consider the challenges of incorporating these types of PAs into established PA accounting systems.

4.1. *Heritage or wild rivers*

Heritage or wild rivers provide a good illustration of traditional PA ideas bent to fit the freshwater environment, though the number of real-world examples is small. National legislation with a primary focus on river protection currently exists only in the United States; Canada has a non-statutory national program, and provincial programs exist elsewhere such as in Australia (Kingsford et al., 2005). Theoretically, most of the rivers protected through these programs might fit within IUCN Category II – areas managed mainly for ecosystem protection and restoration.

The United States' wild and scenic rivers, which can be designated either for their biological integrity or for cultural or scenic values, may encompass entire rivers but normally cover only sections. Within a designated river, all federally-assisted development activities that could compromise water quality or quantity are prohibited; federal lands within a buffer along the river, recommended to extend 0.25 miles (0.4 km) beyond the bank (Haubert, 1998), are also managed. In principle, these prescriptions mean that designated sections will remain free-flowing, though in practice state-funded projects and activities on private lands could interfere with this goal. Activities outside the protected corridor are untouched by the legislation, leaving open the risk of threats originating in the upstream catchment or downstream. As well, fishing and certain other activities within the river are permitted (Public Law 90-542).

Canada's heritage rivers system is a voluntary, community-driven program that neither universally prohibits nor mandates activities. However, rivers designated specifically for natural values may not be impounded, or have impoundments outside their boundaries that would affect their key elements or ecosystem features (Canadian Heritage Rivers Board Secretariat, 2001). Canada's designations may result in fewer restrictions and less permanence than in the US case, though the community-initiated and supported aspects of the Canadian system create strong constituencies that bring their own benefits.

Some provincial legislation elsewhere is also notable. For instance, in Australia, the Victorian Heritage Rivers Act identifies 'natural catchment areas' for protection in addition to heritage rivers (Government of Victoria, 1992). Within natural catchment areas, the clearing of indigenous flora, the harvesting of timber, the establishment of plantations, mining, and most mineral exploration are prohibited. Victoria's legislation is considered exceptional by river protection advocates (Nevill, 2001).

4.2. *Inland fishery reserves*

Inland fishery reserves, also called harvest reserves, provide an example of freshwater PAs with direct counterparts in the marine realm. A fishery reserve is 'a spatially defined area of water managed by a specified set of technical regulations intended to sustain or increase the potential fish yield available from existing, natural fish stocks for the benefit of fishers' (Hoggarth et al., 1999). Inland fishery reserves may be permanent or seasonal and may be relocated over time (Ruffino, 2001). Within a PA all fishing might be prohibited, certain types and amounts of gear or storage equipment might be regulated, or access by particular types of fishers might be controlled (e.g., no commercial fishers) (de Castro and McGrath, 2003). Many existing fishery reserves are experiments in cooperative management (co-management), in which responsibility for managing the fishery is shared by resource users and governing bodies (Nielsen et al., 2004).

Fishery reserves are intended primarily to provide a refuge in which focal species populations can grow and be sustained, with spillover or export enhancing fisheries outside the reserves (Demartini, 1993). Many inland fishery reserves have been established for species with limited dispersal distances, with the benefit primarily to local fishing communities (DFID Fisheries Management Science Programme et al., 2000). There are also examples of protection of upland spawning areas and other critical habitats for migratory species, with benefits intended to accrue to fishers throughout a catchment (Koeshendrajana and Hoggarth, 1998; Agostinho and Gomes, 2001). Like marine reserves, inland fishery reserves have rarely attempted to address threats originating outside their boundaries, though in some cases coastal, floodplain, and riparian protections have been incorporated (Agostinho and Gomes, 2001; Ruffino, 2001). Encouraging but largely preliminary results from inland fishery reserves come from the Amazon (Schuyt, 2005) and Mekong (Baird, 2000; Baird and Flaherty, 2005).

Unlike in the marine realm, the freshwater conservation community has placed little emphasis on the use of inland fishery reserves as a biodiversity protection strategy (Saunders et al., 2002). Nonetheless, many existing and proposed inland fishery reserves include biodiversity objectives (Koeshendrajana and Hoggarth, 1998; de Lima, 1999; Navodaru et al., 2001; Thompson et al., 2003), and there is evidence that sustainable management of focal fishery species, which are often large predators, can be important for broader ecosystem functioning (Allan et al., 2005). And, because fishing regulations within reserves are often non-specific, benefits should accrue in those cases to both focal and non-focal species alike. However, lack of an explicit conservation goal technically disqualifies most inland fishery reserves as PAs within the IUCN framework. This is also an issue for no-take zones within marine fishery management areas (Wells and Day, 2004). The potential for marine and inland fishery reserves to be defined by shifting boundaries and restrictions in both space and time presents further challenges to traditional notions of what PAs can and should be (Wells and Day, 2004).

4.3. Riparian buffer zones

Riparian buffer zones provide a final freshwater example of non-traditional PAs. These managed or 'reserved' stream- or lakeside lands are a widely accepted tool for protecting freshwaters from nonpoint source pollution, for providing and protecting habitat, for contributing allochthonous organic matter and habitat-forming wood to channels, and for displacing harmful activities away from the stream (Gregory et al., 1991; Saunders et al., 2002). Prescriptions for buffer dimensions, cover types, and permissible activities are typically determined based on stream and landscape conditions. Restricted land uses can include logging, grazing, and crop production, among others.

Many nations and provinces have promulgated guidelines for riparian protection, often linked to forestry practices. Moore and Bull (2004) describe five types of forestry codes designed to protect fish and fish habitat in freshwater and nearshore environments, ranging from purely voluntary recommendations to legislative codes requiring compliance. The authors document codes from every region of the world, including a particularly high number of Asian countries. While many such codes are currently unenforced, either by choice or necessity, the existence of such guidelines demonstrates the potential for 'riparian reserves' as an important class of freshwater PA (Sedell et al., 1994).

The conservation goals of riparian reserves vary. Riparian reserves have sometimes been designated to protect the specific and often distinctive terrestrial biodiversity features of a given riparian area (Fenger, 1996; Sabo et al., 2005). A number of PAs around the world have also been designed to conserve floodplain biota. For example, 12 Ramsar Sites are named for floodplains, and waterbirds and wetland plants figure prominently in the sites' descriptions (Ramsar Sites database, accessed September 2005).

Most riparian buffers are established to protect aquatic habitat or more generally the freshwater resource, and these cases can create conceptual challenges to accepting them as types of protected areas. These more generic riparian buffers are geographically non-specific – for example, they may be required along all streams of a certain size across an entire province or country – whereas traditional PAs are virtually always associated with discrete *named* places. Moreover, designated riparian buffer zones are often on private lands and are rarely permanent in nature, even where their establishment is legislated and enforced. When riparian buffers are designated specifically to protect aquatic species or habitats, the focal biodiversity features are in the adjacent or downstream aquatic system, rather than in the buffer itself. Finally, there are limits to the protections riparian buffers can provide, especially if the upstream catchment is highly modified (Roy et al., 2006). Despite this complexity, riparian zones are considered among the most strategic areas to protect to maintain freshwater ecosystem integrity and should be included in PA discourse (Benstead et al., 2003; Decamps et al., 2004).

4.4. Neglected accounting and conceptual disconnects

We offer several reasons why riparian buffer zones, fishery reserves, and protected rivers, among other freshwater conservation strategies, are typically omitted from global PA calculations and conversations. These reasons grade from logistical to conceptual. One logistical explanation is that many of the systems under protection are essentially linear, whereas most PA accounting systems are designed only to capture area. For example, the wild and scenic rivers and heritage rivers programs each measure their sites in terms of river length, yet there is only an area field in the WDPA, and for these protected rivers that entry is '0 ha'. The WDPA is more than a list; it is also a map, used for gap assessments and other analyses. Reducing a river reach up to 1375 km long (the longest of the protected rivers) to a point on a map has real implications for how linear freshwater systems are included in PA discourse and planning (Canada Heritage Rivers Board, 2004).

Ramsar Sites are a better fit with the WDPA, as the Ramsar accounting system is in hectares, and every Ramsar Site has an area measurement. Non-linear lakes and other lentic systems are the dominant wetland type in about 80% of all inland Ramsar Sites (comprising 73% of the total area gazetted), whereas rivers, streams, and springs are the dominant wetland type in only about 20% of cases, comprising 27% of the total area (Ramsar database, accessed February 2006). No Ramsar Sites are currently defined solely by river channels, though there is a proposal for a 140 km-long reach of the

Ganga in India to conserve dolphins (J. Pittock, personal communication).

For aforementioned reasons, most riparian buffer zones are omitted from PA accounting. However, at least in those cases where they are both legislated and enforced – in principle in China and Russia, and in parts of Australia, the United States, and Canada (Moore and Bull, 2004) – beginning the process of counting these systems as protected at some level might be feasible. Even knowing only about official intent is preferable to knowing nothing, and the inclusion of 'paper parks' within global databases might argue for consideration of these legislated buffers as well.

Fishery reserves share with riparian buffers the characteristics of often being impermanent and not legislated. Where fishery reserves are legislated, they are counted. For example, Brazil's Mamirauá, a Ramsar Site and sustainable development area covering 1124000 ha of flooded forest and associated water bodies in the Amazon, is often cited as an example of successful community-based management of focal aquatic species (L. Castello, personal communication). However, most inland fishery reserves are community-derived and enforced, and so they remain invisible to the larger conservation community.

These disconnects raise the question of whether freshwater protections *should* always be forced into the terrestrial mold. In addition to a degree of nonconformity to traditional ideas about fencing in conservation features, what these different freshwater strategies have in common is a focus on conserving *processes*, both biotic and abiotic. With these examples in mind, we propose a new vocabulary for discussing freshwater PAs that allows for the full range of protections to be expressed without compromising basic freshwater conservation principles, like maintenance of connectivity and natural hydrologic processes (Pringle, 2001; Baron et al., 2002; Silk and Ciruna, 2004).

5. A new vocabulary

The three-part vocabulary that we introduce here has two intentions. The first is to diffuse tensions surrounding the term 'freshwater protected area'. Despite the range of IUCN PA categories, there is nonetheless a perception that PAs equal total exclusion (Crivelli, 2002). For example, the US National Park Service, describing Wild and Scenic Rivers, is careful to point out that '... designation as a wild and scenic river does not 'lock it up'. The idea behind the National System is not to halt use of a river ... Uses compatible with the management goals of a particular river are allowed; change is expected to happen' (US National Park Service, 2005). Most authors writing about conserving freshwaters through place-based strategies have eschewed mention of PAs and have coined their own terms, such as habitat management areas and aquatic diversity management areas (Moyle and Yoshiyama, 1994; Murray-Darling Basin Ministerial Council, 2003). These authors have also shared our second intention – to communicate the difference between fencing in a focal freshwater feature (freshwater protected area) and conserving a focal freshwater feature through place-based interventions that may or may not have a one-to-one geographic correspondence to that feature (freshwater *protection* area). Here we take the idea of a *freshwater protection area* and divide it into three terms that express, simply, the complexity of conserving freshwater systems through place-based strategies.

First, we propose the term *freshwater focal area* to describe the location of a specific freshwater feature requiring protection (Fig. 1(a)). Examples might include richness or endemism hotspots, spawning or nursery areas for a focal species, or perhaps the entire habitat of a range-restricted species or assemblage. Known by a variety of other names, proposed freshwater focal areas are relatively common. In one example from the literature, Kreb and Budiono (2005) identify three river-tributary confluences in Indonesia critical to the protection of the Irrawaddy river dolphin, *Orcaella brevirostris*. The European Union's Habitats Directive (Council Directive 92/43/EEC), which requires the protection of 'Special Areas of Conservation' within the Natura 2000 network, has resulted in the identification of numerous freshwater sites. Management interventions might or might not occur directly in a freshwater focal area, but when they did occur they would likely be fairly restrictive, to prevent direct disturbance to the feature of concern. In the dolphin example, proposed restrictions include setting speed limits for boats, excluding large coal-carrying ships and employing smaller barges or transport over land, and regulating or excluding gill-nets used and the location, season, and manner of setting (Kreb and Budiono, 2005). Freshwater focal areas would not by definition be small or localized; for instance, an unfragmented river might be managed along its length as a rare example of a functionally connected system.

Next, we suggest the term *critical management zone* to describe those places whose management is essential to maintaining functionality of a focal area (Fig. 1(b)). Restrictions would be tailored to the specific function of the zone and likely would not exclude all uses. For example, a wetland area essential for regulating downstream water flows might be identified as a critical management zone for a drought-prone freshwater focal area, and construction in or draining of the wetland might be prohibited. Or, the length of a river constituting the migration corridor of one or more focal freshwater species might be a critical management zone between two focal areas – separated spawning and nursery areas, for example – and that critical management zone might be designated free of instream barriers (Filipe et al., 2004). Use restrictions for critical management zones might also be temporal, designed to coincide with time-specific events like seasonal spawning migrations. Riparian zones along and perhaps directly upstream of freshwater focal areas could also be examples of critical management zones.

Finally, we propose the term *catchment management zone* to describe the entire upstream catchment of a critical management zone (Fig. 1(c)). In addition to surface catchments, these zones might also be designated to protect the groundwatersheds of subterranean focal areas (Pringle, 2001). Within a catchment management zone, basic catchment management principles would be applied (Naiman, 1992). Best practices might include maintaining riparian buffers of appropriate widths along all streams, restricting activities on steep slopes, treating all wastewater to established standards, and restricting the use of pesticides and fertilizers. A catchment

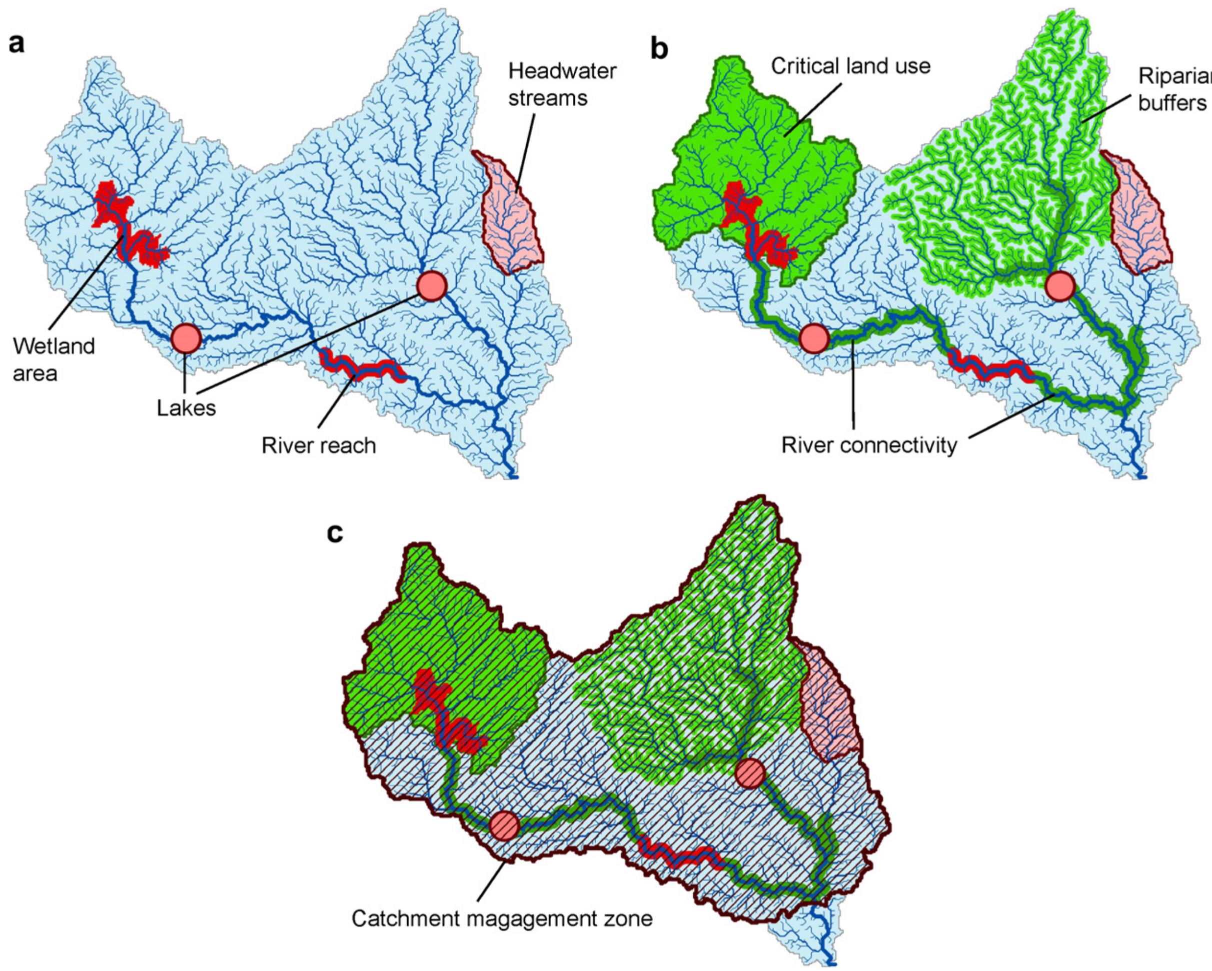

Fig. 1 – Schematics of proposed freshwater protected area zones. (a) Freshwater focal areas, such as particular river reaches, lakes, headwater streams, or wetlands supporting focal species, populations, or communities. (b) Critical management zones, like river reaches connecting key habitats or upstream riparian areas, whose integrity will be essential to the function of freshwater focal areas. (c) A catchment management zone, covering the entire catchment upstream of the most downstream freshwater focal area or critical management zone, and within which integrated catchment management principles would be applied.

management zone might also include prohibitions against the introduction of exotic species, particularly for catchments where exotics were absent, with restrictions extending downstream as far as the first natural or man-made barrier to upstream movement. Catchment management zones might technically count as multiple-use PAs, but the term has the benefit of emphasizing a whole-catchment perspective without suggesting that activities across an entire catchment should be exceedingly restricted. In addition to supporting biodiversity conservation, these areas would also contribute to the maintenance of ecosystem services; PAs created to protect water-related services have a long history and include areas like New York State's Adirondack Park, comprising a mix of over 23500 km^2 of public and private lands (Adirondack Park Agency, 2003).

This terminology integrates basic tools of conservation biology, such as corridors and buffer zones, with broadly accepted catchment management ideas. Zoning is common in conservation planning, and for freshwaters the idea has been recommended by the Ramsar Convention (Ramsar Resolution VIII.14) and formalized in Article 7.3 of the European Union's Water Framework Directive (The European Parliament and the Council of the European Union, 2000). Frissell's (1997) concept of 'critical contributing areas' is a foundation for our critical management zones. And, with focal freshwater areas we acknowledge the core importance of 'hard' PAs within a catchment management approach; certain freshwaters do deserve and require greater use restrictions if we are going to stem the decline of freshwater biodiversity.

Adopting a hierarchical protection strategy that embeds freshwater focal areas and critical management zones within catchment management zones may be a second-best solution to the increasingly unattainable goal of protecting pristine catchments from headwaters to mouth. In such a hierarchical framework, conservation strategies would be explicitly and spatially defined and could themselves be subsumed within an IRBM approach that might emphasize additional strategies for maintaining sustainable water supplies and other catchment services. Levels of protection might be added sequentially, beginning with focal areas and moving outward in scale, particularly as new information became available regarding ecosystem processes and threat pathways. This hierarchy should be flexible enough to accommodate restoration projects or the conservation of intact elements within otherwise degraded systems.

The actual terminology that we have proposed is ultimately unimportant compared to the need to modify current perceptions of PAs in the context of freshwater systems. We have suggested a new vocabulary that focuses on PAs *for* freshwaters, as opposed to mere freshwater protected areas, a term that raises a host of concerns. We hope that taking freshwater PAs out of the water and onto the land, and potentially even as far as the ocean, will open up new possibilities for integrating freshwater and terrestrial, and freshwater and marine, conservation interventions.

6. Future directions in planning and management

The effective design and management of freshwater protection areas will require that the most innovative ideas in conservation biology, freshwater ecology and biology, landscape planning, hydrology, environmental economics, and other social sciences be brought together. Combining these disciplines may also begin to bridge the sometimes artificial divide between freshwater, terrestrial, and marine planning, particularly when hydrologic processes are recognized as central to planning and management.

6.1. *Integrated protected areas*

We have argued that PAs designed to achieve freshwater conservation goals will in many cases extend beyond the aquatic systems of interest to encompass some or all of the contributing catchment, and even downstream areas as well. Critical management zones delineated to include portions of the upland landscape crucial to maintaining hydrologic, nutrient, sediment, wood, or other regimes might in effect be terrestrial PAs. If an upland critical management zone were also a priority for conserving terrestrial biodiversity features, it would be a true integrated PA. Decision-makers seeking to meet quantitative targets for protecting forests or other terrestrial biomes, such as through the World Bank/WWF Forest Alliance or the CBD's 2010 Biodiversity Target, could magnify the effectiveness of new PAs by strategically locating them to maximize benefits to freshwater systems (CBD Decision VII/30) (WWF and The World Bank, 2005).

There are additional opportunities for integrating freshwater considerations into the design of 'terrestrial' PAs. One of the most straightforward is the delineation of PAs to coincide with catchment boundaries, as opposed to using rivers themselves to mark PAs (Peres and Terborgh, 1995). Whole or nearly-whole catchment PAs, designed originally to protect terrestrial biodiversity features, do exist. For example, the Central Suriname Nature Reserve, encompassing more than 1.6 million forested hectares, provides incidental protection for the entire catchment of the pristine upper Coppename River (UNEP-WCMC, 2000). Even in the absence of freshwater-specific management prescriptions, strict protection of all native land cover within whole-catchment protected areas should confer benefits to freshwater systems (Gergel et al., 2002). Whole-catchment protection will be particularly important for poorly-studied freshwater systems where vast data gaps obviate defining focal areas.

Taking hydrologic processes into account will benefit both freshwater and terrestrial biodiversity. As Pringle (2001) has documented, many of the world's best known PAs are at risk because their design and management have failed to account for hydrologic processes and hydrologically-mediated threats. New hydrographic datasets and tools make it possible for PA planners and managers working virtually anywhere to map the surface watersheds in which their PAs sit along with associated stream networks, and even coarse hydrologic models can provide useful information about key processes (Lehner et al., 2006).

Adoption of some additional basic management guidelines might also lead to marked benefits for freshwaters within terrestrially-defined PAs. These guidelines would include carefully siting access roads to minimize sedimentation and instream barriers; removing existing small instream impoundments, where possible; and preventing or carefully regulating fishing and other species removals or introductions. Additionally, downstream threats like planned dams should be evaluated and addressed, where necessary. When the interior freshwater systems of a PA are better protected, both aquatic species and the many 'terrestrial' taxa that often rely on riparian and floodplain habitats should benefit (Dudgeon et al., 2006).

Integrated protected areas need not stop at a river's mouth (Stoms et al., 2005). For instance, a combined terrestrial–freshwater–marine PA might be built around meeting the linked goals of maintaining water quality in freshwater and marine systems by protecting both critical management zones and catchment management zones on the terrestrial landscape. Some examples already exist; for instance, Australia's Kakadu National Park encompasses virtually the entire catchment of the South Alligator River and extends out to include estuarine and mangrove habitats, among others (UNEP-WCMC, 2002).

6.2. *Evaluating and improving design and management*

We presently have no satisfactory way of evaluating the extent to which the vast majority of existing PAs actually conserve the freshwater systems within them, whether or not they were defined to protect freshwater biodiversity. In only a few cases do we have sufficient pre-establishment baseline data to evaluate trends, though comparative studies of biotic communities within and outside PAs can be informative (Driver et al., 2005; Mancini et al., 2005). Monitoring systems should be put in place immediately, even if assessments must be based in the near term on biodiversity surrogates like landscape indicators (Gergel et al., 2002). We cannot begin to fill gaps in protection until we know, even to some level of approximation, what those gaps actually are.

Perhaps most important, we urgently need increased research into identifying which lands will be most critical for protecting focal freshwater systems, the configuration of those lands to each other and to freshwaters, and the amount of land required for protection (Abell, 2002). Many freshwater ecosystems, and especially rivers, are vulnerable to threats from coupled but distant ecosystems, and so addressing remote threats, while a common issue for all PAs, may play an especially large role in freshwater protection efforts.

The answers to these questions will not come from biologists alone. Data gaps aside, biologists are well-equipped to identify freshwater focal areas based on species distributions and habitat requirements. Once we take freshwater PA design and management out of the water and onto the landscape, though, teams of physical and biological scientists will need to collaborate to fit the pieces of their disciplinary knowledge together. This will be facilitated by promising recent advances such as the geomorphic classification of river types, which, once mapped, provide a powerful framework for comparing like with like and targeting conservation and management decisions across entire large catchments (Brierley and Fryirs, 2005). New decision-making frameworks are being developed by hydrologists and others concerned with ensuring ecologically sustainable flows while satisfying human needs (Postel and Richter, 2003), and these approaches explicitly bring land-based stakeholders to the table to discuss river management. Recent cross-disciplinary, catchment-wide planning efforts include the Woods Hole Research Center's Amazon scenarios project and the Willamette alternative futures analysis (Baker et al., 2004). To our knowledge, however, no research collaborations have explicitly addressed integrated PA design.

7. Conclusion

Given the global crisis facing freshwater systems and their biodiversity, it is time that the conservation community reassessed the potential value of PAs to the conservation of these features. Although PAs cannot be the sole strategy for tackling freshwater conservation challenges and should instead be one part of a broad catchment management approach, we offer the view that PAs can and in some cases perhaps should play much larger and more central roles in catchment management plans. The first step will most often be identifying those focal freshwater features requiring protection, and then building comprehensive plans outward.

When we broaden our conception of PAs to encompass a range of management options, we see that many examples of freshwater PAs already exist, but they often bear different names. Highlighting the inclusiveness of the PA concept is not a semantic trick to include all freshwater management activities under the PA umbrella. Rather, we emphasize that PAs *must* be conceived of and defined broadly when freshwaters are concerned, but that existing IUCN categories in most cases provide a suitable framework.

We have introduced a new vocabulary in an attempt to provide a platform for discussing freshwater PAs that is free from older, more restrictive notions about what those areas can be. Once it is acceptable to consider PAs as a core part of integrated catchment management, we can then focus on designing those areas as efficiently and strategically as possible, preferably in a coordinated attempt to achieve terrestrial and marine goals simultaneously. Freshwater planners and managers can borrow the best of what terrestrial and marine conservation biology have to offer regarding PAs, add a freshwater perspective, and in return offer back innovative, integrated ideas with the potential to take all biodiversity conservation forward.

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