Running dry: Freshwater biodiversity, protected areas and climate change

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Abstract. Freshwater biodiversity is in significant decline and existing conservation strategies have not stemmed the loss to date. The damage is due to growing threats from traditional pressures and now the direct impacts of climate change, as well as from human responses to climate change. A suite of tools is required to address these threats, and one of these -- protected areas -- has been underutilized and poorly applied to freshwater conservation. We outline how the effectiveness of investments in maintaining and improving the resilience of freshwater systems within protected area systems for conserving freshwater biodiversity can be enhanced. Measures for better protected area network design and management, and for restoration of connectivity required to build resilience are summarized. Strategies for aiding societal adaptation to climate change through protected area establishment in a river basin context are also proposed. We conclude with a call to ensure that climate change mitigation and adaptation policies better integrate conservation objectives to avoid more serious impacts on freshwater biodiversity.

Key words. freshwater, wetlands, biodiversity, protected areas, climate change, resilience, adaptation, mitigation, conservation planning, connectivity, environmental flows.

STATUS AND THREATS

STATE OF FRESHWATER BIODIVERSITY

Freshwater habitats cover little of the earth's surface – by some accounts 0.8% (Millennium Ecosystem Assessment (MEA) 2005a) – and support high species diversity per unit area. Freshwaters in most regions have been poorly studied, yet ~6% of the world's species have been described from them (Dudgeon *et al*. 2006). The MEA summarizes extensive losses of wetlands globally and describes freshwater ecosystems as being over-used, under represented in protected areas (PAs), and having the highest portion of species threatened with extinction (MEA 2005b). Primary direct drivers of degradation and loss include infrastructure development, land conversion, water withdrawal, pollution, over-harvesting and overexploitation, the introduction of invasive alien species, and global climate change (MEA 2005a).

The prospects for reducing continued losses of freshwater biodiversity are dim. For instance, one of the top threats to those river basins with the greatest richness in freshwater fish species is hydropower development since they tend to be those with the greatest untapped hydropower potential (compare IUCN *et al*. 2003 and International Journal of Hydropower and Dams (IJHD) 2002). The 2015 Millennium Development Goals seek to halve poverty by, in part, extending water supplies and energy to the poor, and by expanding agricultural production (United Nations General Assembly (UNGA) 2000), including through dam construction and other infrastructure developments. If poorly implemented, these agreements may further exacerbate impacts from climate change and further facilitate the decline in freshwater ecosystems. Yet governments have also agreed by 2010 to "significantly reduce the rate of loss of biological diversity" (UN 2002). If this commitment is to be achieved then freshwater biodiversity must be a focus of urgent action.

Today, PAs are still the primary tool for conserving terrestrial and marine biodiversity. Following a new definition proposed to the IUCN's World Commission on Protected Areas (WCPA), we consider a protected area to be "a clearly defined geographical space, recognized, dedicated and managed to achieve the long-term conservation of nature, associated ecosystem services and cultural values" (IUCN 2008). Despite their prominence, there is evidence that PAs have failed to meet their potential for conserving freshwater biodiversity, largely due to ineffective design and management (Abell *et al.* 2007). This paper assesses what the added challenges posed by climate change will be to conserving freshwater biodiversity, what role PAs should play in addressing these challenges, and how they can be improved to be part of larger climate change resilience and adaptation strategies.

We define adaptation as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (Intergovernmental Panel on Climate Change (IPCC) 2008:221). Resilience is "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self organization, and the capacity to adapt to stress and change" (IPCC 2008:233-234) and is a subset of adaptation that represents less change from the *status quo* compared to other adaptation options.

FRESHWATER BIODIVERSITY IN PROTECTED AREAS

Understanding the nexus of freshwater biodiversity, PAs, and climate change adaptation is complicated by a lack of data on the extent to which freshwater biodiversity is currently conserved by PAs. The MEA (2005a) overlaid spatial data from the World Database on Protected Areas (WDPA; Chape *et al*. 2003) with data describing the distribution of freshwater systems and concluded that 12% of the world's inland waters are in PAs. However, GIS data have insufficient resolution to adequately define the global extent of freshwater ecosystems, especially for seasonal wetlands and smaller streams. Existing institutions fail to adequately measure representation of freshwater systems in PAs. Ramsar notes the presence but not the area of each wetland type in its sites (Ramsar 2006).The WDPA records the extent of marine and terrestrial biomes in PAs but the only freshwater category is "lake systems", with 1.54% coverage (Chape *et al.* 2003:28). At best, existing data suggest that freshwaters have not been intentionally excluded from PA designations (Abell *et al*. 2007).

Further, we cannot accurately say to what degree PAs around the world are *effectively* conserving freshwater ecosystems.

Effectiveness issues relate principally to PA siting, design, and management. Whether or not PAs are managed explicitly for freshwater conservation, there is evidence that freshwaters within PAs receive some protection simply by having portions of their catchments maintained in natural land cover (Driver *et al*. 2005). A well-known example is the protection of the Catskill and Delaware watersheds to improve the quality of New York City's drinking water (Dudley and Stolton 2003:86-89). However, most freshwater systems and their catchments extend beyond PAs, and threats from upslope, upstream, and even downstream can be propagated via hydrologic pathways to the 'protected' freshwaters (Abell *et al*. 2002:9, 26). The flow regime for running water systems and the hydroperiod for standing water systems are typically the variables that drive maintenance of those systems (Poff *et al*. 1997; Williams 2006). Changes to the hydropattern of so-called protected freshwater systems as a result of external water withdrawals, dams, channelization, land cover conversion, and other modifications are therefore of serious concern (Jackson 2006).

Even well-sited PAs may fail to reach their full potential for freshwater conservation due to management shortcomings. Many of the world's conservation reserves have been afflicted with activities detrimental to freshwater systems, whose terrestrial equivalents – such as large-scale hunting, mining or logging – are not tolerated. In one well-known early example, in 1913 a reservoir was constructed in the US's Yosemite National Park (National Park Service (NPS) 2008). South Africa's Kruger National Park, where around half the species depend on aquatic and riparian habitats, has suffered from water infrastructure developed upstream, within, and downstream of the park (H. Biggs, SANParks, correspondence 10 May 2008; du Toit *et al*. 2003). Other widespread impacts to freshwaters within PAs include stocking of exotic fish species and fishing of native species (eg. Department of Conservation and Environment (DCE) 1992).

In the past, PAs have often contributed little to maintaining the resilience of freshwater ecosystems within their boundaries, and better management is required regardless of climate change. Yet we also believe that they are a logical place to invest in maintaining resilience in the face of climate change due to the legal protections they may be afforded from some impacts, the resources allocated to their management, the potentially more intact status of their freshwater ecosystems, and the community support they may receive.

DIRECT THREATS TO FRESHWATER BIODIVERSITY FROM CLIMATE CHANGE

Water is part of the climate system and is one of the most vulnerable parts of this system to climate change. As the Earth warms, a host of changes to freshwater ecosystems are occurring. With warming, freshwaters experience: higher evaporations rates; changes in quantity and forms of precipitation, leading in some cases to dramatically altered hydrologic regimes most readily seen as more severe or more frequent floods and droughts; altered thermal regimes with changes in seasonal timing (such as spring onset and winter freeze patterns); altered water chemistry; and increased vulnerability to salination due to sea level rise and drawing down of aquifers. There are also changes in the Earth's cryosphere, where two-thirds of the world's fresh water is held (Shiklomanov 1993). Climate change-induced melting of glaciers, other permanent ice, and snow is resulting in further changes in the timing, quantity and temperature of river flows. The potential acidification of aquatic systems, similar to that seen in marine ecosystems, remains largely unexplored. Second order impacts include reduced water quality due to pulses of nutrients and contaminants, fostered by more intense rainfall events. Other impacts include oxidized soils from drought conditions (such as sulphuric acid generated in the lower reaches of Australia's Murray River from 2007), pulses of contaminant melt from glaciers (Blais *et al.* 2001), increased use of chemicals in response to climate change, and greater erosion and siltation.

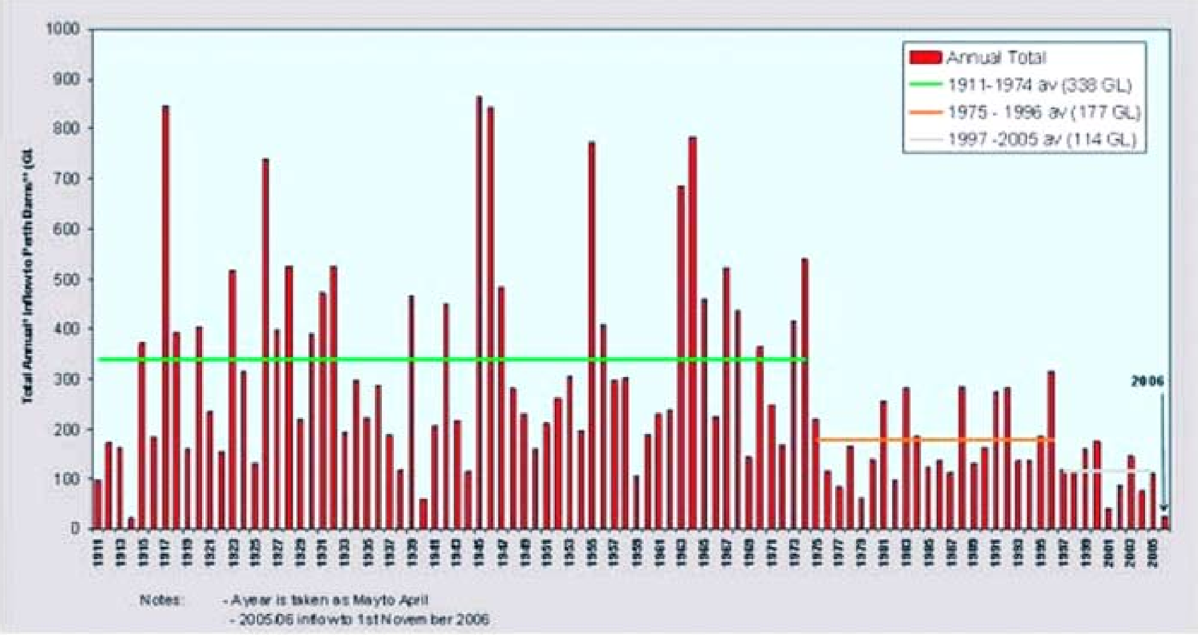

Figure 1.Southern Australia is particularly vulnerable to climate change as global warming draws rain-bearing cold pressure systems south of the mainland and into the Southern Ocean in winter. Since the 1980's it has been predicted that southern Australia may suffer reduced precipitation due to climate change. From the 1975, for example, inflows into Perth's reservoirs fell in two 'step changes' from an average 338 Gigalitres (Gl) per year to 114 Gl from 1997. Stepwise reductions to dam inflows, Perth, Western Australia. Source: WA Water Corporation.

Historical and new non-climate stressors will compound the adverse effects of climate change, further reducing ecosystem resilience. Eutrophication and contaminant issues will be exacerbated by climate change as the multiple stresses of elevated nutrients and increasing temperature lead to reduced dissolved oxygen; altered thermal patterns in rivers and stratification in lakes; increased metabolic rates causing greater contaminant sensitivity; and reduced toxicity thresholds as compounds become more toxic at lower concentrations due to paired thermal stress or climate-induced chemical changes.

Already climate change impacts are affecting freshwater biodiversity (Parmesan 2006). Fish and fisheries are perhaps the best studied systems with regard to vulnerability to climate change (Poff *et al.* 2002; Ficke *et al*. 2007), with changes to upstream migrations (Daufresne and Boet 2007), stocks and productivity (Casselman 2002), species diversity (Jackson and Mandrak 2002), and aquatic community composition (Carveth *et al*. 2006). Some amphibian declines have been in part attributed to climate change (Pounds *et al.* 2006). Shifts in invertebrate community structure and composition have already been seen and are expected to continue (Durance and Ormerod 2007, Raddum and Fjellheim 2002). Changes in the abundance of freshwater primary production due to increasing water temperatures have begun to affect entire aquatic food webs (Wrona *et al.* 2006). These are only a small subset of examples of the effects of climate change on freshwater ecosystems and their biodiversity (IPCC 2008).

THREATS FROM POLICY RESPONSES TO CLIMATE CHANGE

In addition to these direct impacts from climate change, policies that governments and societies adopt to reduce socio-economic risks related to climate change have a great potential to extensively affect freshwater biodiversity both within and outside of PAs. Types of adaptation measures (IPCC 2008) – or maladaptation measures if considered from the perspective of freshwater ecosystems – include addressing water shortages and flood control using infrastructure to store and divert more water. Climate change mitigation policies to increase production of low carbon energy such as hydropower and biofuels (IPCC 2008) are likely to impact freshwater ecosystems even more in the future. Production of many crops for biofuels could intensify water use (IPCC 2008), leaving little water for biodiversity conservation in some countries (de Fraiture *et al*. 2008), as well as increasing conversion of riparian lands and the discharge of pollutants. For example, China has adopted a comprehensive national climate change program. While proposing measures to integrate sectoral policies and protect ecosystems, the program also commits to raising the portion of energy produced by hydropower and biofuels, and managing water through "rational exploitation*",* new infrastructure, and speeding up construction of the South-to-North Water Diversion (Chinese Government 2007:25-50). The three canal systems of the Water Diversion will supply water from the Yangtze River to areas up to 1,800 km away in north China (US Embassy in China 2003) and will change the hydrologic regimes of all affected systems. Here and elsewhere, those seeking to conserve freshwater biodiversity both within and outside PAs must not only consider the direct impacts of climate change and non-climate pressures but also the additional impacts of the climate change policies of governments.

REDUCING IMPACTS BY ENHANCING RESILIENCE

The very nature of climate change means that all systems are changing in their fundamental physical nature, and therefore we can no longer protect or restore to a past state. Rather, we need to think about what makes systems functional, useful, or valuable. This concept has been well developed in regard to coral reef systems. For example, coral reef protected area managers think in terms of maintaining a functional or sustainable coral system and preventing a state change to an algal-dominated system. This means they work to identify and exploit those factors that make:

- sites less likely to experience adverse climate pressure (e.g. refugia, heterogeneity, resilient populations);
- a system less likely to respond adversely to a climate change pressure, and;
- system recovery from an adverse response to a climate pressure more likely;
- (Marshall and Schuttenberg 2006);

In general, climate adaptation strategies for biodiversity conservation first require assessment of the problem, the vulnerabilities and the opportunities for action. The required actions can be categorized as:

- protecting adequate and appropriate space and connectivity;
- reducing non-climate stresses;
- employing active adaptive management to start testing strategies now, and;
- using vulnerable systems and the challenge of resilience-building to encourage action to slow the rate and extent of climate change (Hansen *et al*. 2003).

PA's can play a role in all four of these adaptation components, but the lens of climate change needs to be applied explicitly. Without climate-informed management within and beyond PA boundaries, many PAs will not be able to contribute to freshwater conservation because of broader contextual impacts. Shifting spatial and temporal precipitation patterns will require reconsideration of which (wet)lands to protect to ensure catchment functionality, as well as consideration of when to allow extractive water use and how much. Changes in precipitation patterns will likely affect patterns of anthropogenic activities within PA catchments, such as agricultural practices and associated water use. A reduction in acceptable levels of pollutants to avoid shifts to undesirable states will require better policies and management. Even without the onus of climate change we have not adequately managed over-use of water resources. For example, in the western United States, maintaining adequate flows to support fish populations is often directly at odds with agricultural and municipal interests (Committee on Endangered and Threatened Fishes in the Klamath River Basin, National Research Council (CETFKRB NRC) 2004), with a greater challenge during drought years.

MURRAY–DARLING BASIN

The impacts from the combination of non-climate pressures, climate change, and climate change policies, and the potential to build resilience to these pressures, is well illustrated by the problems in maintaining aquatic connectivity and adequate environmental flows in the Murray–Darling basin, which covers a seventh of Australia. PAs in the basin, including 15 Ramsar sites, encompass extensive freshwater ecosystems. On average there are 25,000 Gigalitres per year (Gl pa) of inflows in the basin and, if none were diverted, 48% would be discharged into the estuary (Kirby *et al*. 2006). However, water diversions, of which 95% are for irrigated agriculture, are severely degrading aquatic habitats (Kirby *et al*. 2006:6-8), including those within major PAs. Of the inflows, 44% is lost to evaporation and transpiration, 44% is diverted for agriculture and other human uses, and only 12% now reaches the estuary (Kirby *et a*l. 2006:9). A 2006 risk assessment of inflows over 20 years concludes that climate change could potentially reduce inflows by 5% in 20 years, and that additional impacts from adaptations and biological responses to climate change such as greater use of groundwater, bushfire-induced forest regrowth, more on-farm dams, forest establishment, and re-use of irrigation tail waters could result in a total reduction of between 10 and 23% of annual inflows (van Dijk *et al*. 2006:1, 26).

Two conclusions can be drawn from this assessment: i) the combined environmental impact of these risks to water resources is secondary compared to the diversion of nearly half the water for human uses, and ii) poor water management (eg. of groundwater) and mal-adaptations that did not consider resulting reductions in inflows (on-farm dams, afforestation and tail water re-use) may reduce inflows as much as the direct impact of climate change. Even with this scale of reduction in inflows from the assessed risks, if measures promised by governments are well implemented, including reducing water diversions and increasing environmental flows, then some parts of the Murray-Darling's freshwater biota may be conserved (eg. Murray-Darling Basin Ministerial Council (MDBMC) 2003, Wong 2008).

Other Murray-Darling models based on observational studies suggest a more significant reduction in inflows from climate change. Cai and Cowan (2008) conclude that with every 1˚C rise in average temperature, evaporation reduces inflows by 15%, and they model a 55% reduction in inflows from reduced precipitation and increased evaporation with a 2˚C temperature rise by 2060. This magnitude of inflow reduction would exceed thresholds for the survival of substantial elements of the freshwater biota. Doolan (2007) models a similar scenario for the Barmah Forest Ramsar site on the Murray River, where flood return intervals would become too infrequent for many species to persist. Biota that may be conserved *in situ* in the face of moderate climate change with better adaptation policies are unlikely to survive in the longer term with more severe impacts.

Governments identified six Murray-Darling "icon sites" – major wetlands (five of which are Ramsar sites) that are the focus of conservation efforts to avoid desiccation of a range of freshwater ecosystems (Murray-Darling Basin Commission (MDBC) 2008). In 2002 an expert panel recommended options to "deliver a healthy working river", including generating up to 4,000 additional Gl pa for environmental flows through decreasing the volume allocated for diversion (Jones *et al.* 2002). Governments made a "first step decision" in 2003 to reallocate a mere 500 Gl pa to sustain a specific portion of each wetland type and icon site, ranging between 20 and 80% of their original areas, and with a "low-moderate" probability of delivering a healthy river (MDBMC 2003). This decision is being revised in 2008 with significantly higher reallocation to the environment to increase functionality, partly to compensate for the reductions in inflows forecast from climate change (Wong 2008). The Victorian Government (2008) is now finalizing an adaptation policy covering much of this area that emphasizes conservation of valued elements of freshwater biodiversity through better catchment management, water allocation, ecological connectivity using riparian corridors, and enhancing reserves.

The Ovens River is one example of practical freshwater resilience-building using designation and better management of PAs. This river is one of only two substantially unregulated tributaries remaining in the Murray-Darling basin, and thus is important for conserving riverine biodiversity. Protected under the Victorian *Heritage Rivers Act* as a Heritage River Area, most natural resource extraction, including water resource developments, is prohibited along the 227 km river in a riparian corridor that is up to 400 m wide (Victorian Government 1992). New riverine PAs are also planned (VEAC 2008). Biodiversity is likely to cope better in the Ovens compared to other tributaries in the basin, as there are no dispersal barriers; a protection and restoration program prioritizes the riparian corridor; the river flows from south to north with a large altitudinal gradient; and its upper catchment is protected in the Alpine National Park.

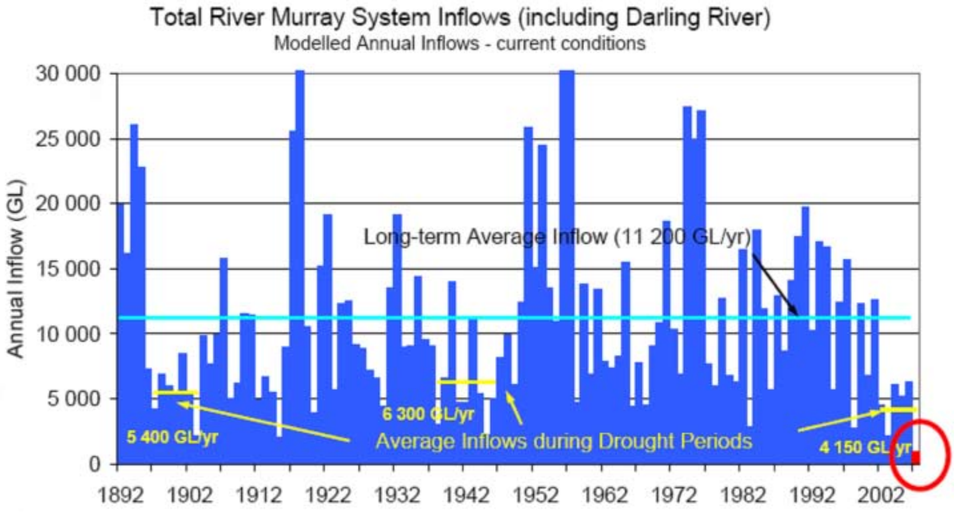

Figure 2. The Murray–Darling basin covers a seventh of the continent's landmass in Australia's south-east. The low levels of rainfall in the current "drought" in southern Australia (now ascribed by government agencies in part to climate change) are not unprecedented, but the inflows into the river systems are at an historical low (see graph below) that many fear represents the type of inflow reduction experienced in Western Australia. It is likely that the combination of greater evapotranspiration with higher temperatures and inflow intercepting land uses has dramatically reduced runoff.

River Murray system inflows. Source: Murray Darling Basin Commission.

Many freshwater systems would benefit from further investment in PAs. If the local effects of climate change are limited (because the site contains thermal refugia, for example), then freshwater biodiversity may be conserved *in situ* by building ecosystem resilience. If effects are more extensive, then responses may require greater investment in approaches like removing barriers to species movement, species translocation, and securing environmental flows. Environmental flows are a portion of the original flow regime of a river that should continue to flow down it and onto its floodplains in order to maintain specified, valued features of the ecosystem (Tharme 2003). For PAs to be effective, these responses must be applied both within and outside of them. Options for using current water infrastructure to attenuate climate change impacts are worth investigation. Reverse use of thermal pollution mitigation devices at dam outlets to maintain naturally cooler waters downstream of dams in the face of higher temperatures is a promising option, albeit one that requires consistently good management of dams to succeed. No manner of investment in conservation strategies may build or maintain sufficient resilience for some other systems in the face of continued climate change. Examples include high elevation, high latitude, or east-west flowing rivers, most lentic systems, and many ephemeral systems.

Consistent with the measures proposed by the Convention on Biological Diversity (CBD 2007) and the Victorian Government (2008), it should become standard practice to use designation and management approaches to increase the resilience of PAs to:

- take advantage of and support innate resistance to climate change of more intact habitats;
- maximize the existing investment in PAs and benefits of active management of PAs for conservation;
- use the many measures required to build resilience of PAs in the absence of climate change, like restoring connectivity, for better climate change adaptation;
- buy time to institute other adaptation and abatement strategies, including stabilizing atmospheric greenhouse gas concentrations.

These measures apply equally to freshwaters as to other realms. PAs must now be thought of as a piece of a larger adaptation strategy, rather than as a stand-alone intervention. Ultimately, however, limiting the rate and extent of climate change is critical to protection of freshwater biodiversity.

OPPORTUNITIES TO IMPROVE ADAPTATION

Developing effective climate change adaptation strategies for freshwaters requires holistic planning. Due to human water use and biodiversity needs, those wishing to protect freshwater ecosystems in the face of climate change need to engage in a process where all user concerns are integrated (eg. Postel and Richter 2003). Adaptation for anthropogenic needs that does not address key needs for ecosystem integrity will further damage freshwater ecosystems and potentially restrict or omit the possibility of long-term sustainable use of freshwater ecosystems. Adaptation strategies for conserving freshwater biodiversity through the designation and management of PAs could include:

Conserving ecosystems that are the source of water supplies

Designation of river catchments and groundwater recharge zones as PAs can help sustain water supplies. Already 33 of the world's 105 largest cities rely on PAs for a significant part of their water supplies and this could be enhanced with additional PAs (Dudley and Stolton 2003:4). While upstream river systems can be conserved with this approach, it may be at the cost of adequate flows downstream due to diversions for human uses.

"Restoring" freshwater habitats to reduce impacts of natural disaster

A greater frequency of large floods is forecast in many regions due to climate change (IPCC 2008). Many countries are restoring floodplains' capacity to attenuate peak floods, enabling the establishment of reserves for lowland freshwater habitats. In China, for example, reconnection of floodplains around Dongting Lake has reduced flood risk, improved residents' livelihoods, and provided considerable conservation benefits (Pittock *et al.* 2006). Reopening the Gerlderse Poort floodplain on the Rhine River in the Netherlands to create a 2,500 ha nature reserve will help increase the safe flood discharge at the cities of Arnhem and Nijmegen from 15,000 m3/s before 2006, to 16,000 m3/s in 2015, and 16,500 m3/s in 2100, and locally the peak flow will be lowered by 9 cm (Bekhuis *et al.* 2005, V&W *et al.* 2006, J. Bekhuis, Stichting Ark, correspondence, 27 March 2008). This "nature development" will not recreate a past habitat but will provide ecosystem services, including abated flood risks; valuable habitat for a range of biota; and more natural ecological functions including improved opportunities for species dispersal.

Enhancing water services through riparian reserves

Some of the predicted impacts of climate change may be reduced by protection and restoration of riparian corridors to reduce pollution of watercourses, sustain fisheries, control temperatures through shading, and provide woody debris and allochthonous materials to freshwater systems (Vannote *et al.* 1980). A number of rivers are designated as new types of linear PAs (WWF 2006:30-33), including Wild and Scenic Rivers in the USA, Heritage Rivers in Canada, Heritage Rivers of Victoria (such as the Ovens River example in this paper) and Wild Rivers of Queensland in Australia, and four rivers under the European Union Natura 2000 network in Sweden (A. Forslund, WWF Sweden, correspondence, 9 April 2008). Riparian reserves will be important beyond the small number of protected rivers in these geographies, and many countries already have legislation for broad protection of riparian zones (Moore and Bull 2004). This legislation is irregularly enforced but could provide the basis for protection of habitats that are essential both for freshwater and terrestrial species and water services for human communities.

Managing water demand to ensure adequate water allocations

In areas where water demand exceeds supply, adjustments to water allocations, including for adaptation to climate change, are an opportunity to ensure that PAs have environmental flows. This can be achieved through such measures as reallocation from consumptive uses, more efficient water use, reduced transmission losses, recycling of wastewater, and capping water extraction (eg. IPCC 2008). Australia's *National Water Initiative* (National Water Commission (NWC) 2008) and South Africa's *environmental reserve* (Department of Water Affairs & Forestry (DWAF) undated) are two national programs for systematically allocating environmental flows, although implementation has been slow.

Harnessing current political and resource commitments

The world's governments have made many commitments to conserve freshwater biodiversity in representative and well-managed PAs, pledges that should be used to accelerate climate change adaptation through protecting adequate spaces and connectivity, reducing non-climate stresses, and practicing adaptive management. Member countries of the Ramsar Convention on Wetlands have agreed to designate sites representing the diversity of inland and coastal wetlands, and have a target for 2010 of at least 2,500 sites covering 250 million hectares (Ramsar 2006, Pittock *et al.* 2006). The CBD has also adopted programs that include rectifying the under-representation of inland water ecosystems in PAs (CBD 2004a:1.1.3 & 2004b). The CBD's targets are to conserve at least 10% of inland water ecosystems by area under integrated river or lake basin management, and 275 million hectares of wetlands in representative PAs, by 2010 (CBD 2006:Annex IV). Additional consideration should be given to assessing the length and representation in protected areas of linear systems such as rivers.

Many people question whether governments are serious about implementing these commitments. Under Ramsar many countries, like China, have adopted and are implementing strategies for representative wetland reserves (State Forestry Administration (SFA) 2002:42). Outside Ramsar there is less evidence of systematic conservation of freshwater ecosystems. Australian governments, for instance, have had programs to establish representative terrestrial and marine PAs from 1992 but have failed to implement parallel commitments for freshwaters (Nevill 2007). More positively, South Africa has embarked on a National Freshwater Ecosystem Priority Areas Project to identify a national network of freshwater conservation areas (M. Driver, SANBI, pers. comm. 27 March 2008). By taking their pledges seriously, more governments could enhance their PA programs to improve resilience to climate change.

Climate-informed implementation of these PA commitments can be improved for freshwaters by:

- selecting for new reserves the most favorable geographies for climate resilience and managing these and existing PAs better for freshwater dynamics, as has been done in some marine systems (eg. Green *et al.* 2007);
- adopting the *Freshwater Ecoregions of the World* (Abell *et al.* 2008) regionalization as course planning regions for freshwater biodiversity conservation and developing detailed ecoregional or landscape/catchment-scale conservation plans to ensure the representation of the full range of freshwater habitat types in PAs (Abell *et al.* 2002; Hansen *et al.* 2003; Higgins 2003; Theime *et al.* 2007; and Sowa *et al.* 2007);
- ensuring adequate connectivity among existing and new PAs, and also other areas that will act as climate refugia;
- improving collaboration among conventions, which is strong between Ramsar and the CBD (CBD and Ramsar 2007), yet appears insubstantial with the Framework Convention on Climate Change (UNFCCC; Ramsar 2002; UNFCCC 2008a);
- coordinating the national plans required under each multilateral convention, especially the UNFCCC, CBD, and Ramsar (UNFCCC 2008b; Ramsar 1999; CBD 2008), to maximize conservation and help avoid maladaptation.

Figure 3. The Coorong Ramsar site (#5AU025; 140,500 ha), the Murray's estuary, and many other wetlands are increasingly desiccated. The Coorong estuary is divided in two by a barrage system to prevent upstream sea water intrusion. The upstream portion of the Coorong is now 0.5 metres below sea level and would require around two years of average river flows to refill; 3A, Coorong lake bed at Meningie West before (May 2006); 3B, after (March 2008). Copyright: K Strother; 3C, Dry lake bed in the Coorong at Milang, May 2008. Copyright B Gunn.

Applying protected area design and management principles

Freshwater habitats most able to respond to climate change effects or act as refugia should be selected for new PA designations wherever possible. These may include systems with a north–south orientation and those with large altitudinal gradients that may facilitate dispersal of aquatic species to suitable refugia. Relatively intact freshwaters should be more resilient than equivalent degraded systems, and are more appropriate targets for PAs. The ideal PAs for freshwaters will encompass a whole catchment (Peres and Terborgh 1995; Saunders *et al*. 2002), preferably of a free-flowing river, but such opportunities are rare. The next-best design option is inclusion of PAs within an integrated catchment framework, with the PAs forming the nuclei around which the framework is built (Gilman *et al*. 2004). Areas whose conservation would be essential to maintaining the viability and resilience of those PAs – such as riparian zones, upstream headwaters, or migratory pathways – would be identified and incorporated into additional PAs, buffer zones, or other managed areas. Finally, an integrated river basin management plan would support the PAs as well as meet human needs (eg. Gilman *et al*. 2004). One conceptualization of such a framework is offered by Abell *et al*. (2007), which, while not prepared with climate adaptation in mind, elaborates on design principles that will help maintain functionality and build resilience. There are a number of similar methods (eg. Abell 2002; Higgins 2003) and examples (eg. Theime *et al.* 2007; Sowa *et al.* 2007) of broad-scale freshwater planning that embrace the idea of prioritizing parts of river basins to establish a representative network of PAs, maintaining adequate connectivity and flows, and supported by integrated river basin management. However these were developed in the context of a largely stationary hydrological environment and now need revision to better provide for climate change adaptation, such as by better targeting potential refugia (eg. Hansen *et al.* 2003).

Figure 4. Exposed wetlands sediments high in sulphates are oxidizing, producing sulphuric acid. Around 3,000 hectares of the Coorong lake bed is affected, and as the damage spreads up the Murray River valley, up to a quarter of other wetlands are impacted. At Bottle Bend lagoon near Mildura, for example, the water is now ph 1.6; 4A, Acidified lagoon, Bottle Bend NSW, February 2008. Copyright Murray Wetlands Working Group. See: http://www.mwwg.org.au/bottlebend.php; 4B, Dead red gum floodplain forests and salinized and acidified creek, Bottle Bend NSW, April 2007. Copyright Murray Wetlands Working Group; 4C**,** Acidified and salinized lagoon, Psyche Bend, Victoria, 2008. Copyright Murray Darling Freshwater Research Centre.

Although there are limits to what PA design can achieve in terms of climate change adaptation, enhancing PA management can help to reduce non-climate stresses and enable adaptive management. Every PA encompassing or linked to freshwater systems should have climate change and freshwater considerations in its management plan (Abell *et al*. 2007). The WCPA Inland Waters Taskforce recommends that freshwater management within existing PAs should include restoring connectivity of streams, such as by removing barriers and reconnecting rivers with floodplains; prohibiting exotic fish stocking and over-fishing; protecting native flora, particularly in riparian zones; and protecting water quality (WCPA 2008). In most cases PAs will be effective freshwater conservation tools only with allocation of environmental flows and integrated river basin management.

CONCLUSION

Freshwater biodiversity is in decline and its conservation has not been advanced in PAs to a great extent because of the lack of attention to the needs of freshwater biodiversity. Governments have yet to achieve the aspirations they have set for freshwater biodiversity conservation. The cumulative and growing impacts of non-climate pressures on freshwaters, the direct impacts of climate change, and maladaptation to climate change all heighten the threat to freshwater biodiversity.

A range of responses, including more effective networks of PAs, is required. We contend that building resilience for freshwater ecosystems through further, climate-informed protected area designations and management in an ecoregional context is a sound investment. Resilience-building measures may permit the dispersal of some biota to refugia and buy time for these systems to be restored or managed more appropriately to support biodiversity in light of climate change impacts. Further work is needed on the scientific, ethical, legal and financial implications of adaptation options, if freshwater biota are to survive greater warming.

Designations of PAs to sustain key water services for people and nature may be the most effective incentives for governments and societies to act to enhance PAs for conservation of freshwater biota. Lastly, while freshwater managers are working to address climate change in their planning, it will be equally necessary for governments and other organizations to consider freshwater resources and conservation in setting climate change policies to avoid maladaptation.

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Using species distribution models to effectively conserve biodiversity into the future

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Abstract. Canadian biodiversity is especially high in temperate southern regions, where human-dominated land uses are both intensive and widespread. As a result, endangered species are also disproportionately concentrated in these areas. Climate change presents a new threat across most of Canada, including areas of intensive human land use, which creates conditions for substantial shifts in species composition and potential losses of many rare species. Protected areas is one adaptation strategy but, in Canada, parks suffer from severe limitations in their distribution, size, and because they have static boundaries. Land use changes around several protected areas in Canada are leading increasingly to their effective isolation, a trend we demonstrate using high resolution satellite data. Little published research has yet addressed this issue in the Canadian context, although some models now forecast ecological changes in the next century. Adaptation to global change impacts will necessitate refocusing conservation strategies beyond the boundaries of protected areas to include broader landscape perspectives. Necessary responses to these challenges include validated models predicting future biotic responses to global change, expanded biodiversity monitoring across Canada, improvements to the patchwork of federal and provincial legislation protecting species, and preemptive conservation strategies that recognize impending transitions to unprecedented environmental conditions.

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INTRODUCTION

Global changes, such as climate change or land use conversion, threaten elements of the world's biodiversity. While habitat loss impacts on species have long been at least qualitatively obvious, it is only relatively recently that strong evidence emerged outlining that anthropogenic climate changes are now affecting species (reviewed in Kerr and Kharouba 2007). In the past century, for instance, species' phenological timing for critical biological processes, like flowering period, have begun to occur earlier in the year (Walther *et al*. 2002; Root *et al*. 2003; Root and Hughes 2005), and many species appear to be tracking toward the poles (Parmesan *et al*. 1999; Hill *et al*. 2002; Parmesan and Yohe 2003; Hickling *et al*. 2006; Hitch and Leberg 2007) and to higher elevations (Konvicka *et al*. 2003; Wilson *et al*. 2005; Hickling *et al*. 2006). Habitat losses to agriculture and urbanization, the primary causes of species endangerment in the U.S. and Canada (Dobson *et al*. 1997; Kerr and Cihlar 2003; Kerr and Cihlar 2004; Kerr and Deguise 2004), have during the same period, generated potentially insurmountable barriers to species migration (Dennis and Shreeve 1991; Collingham and Huntley 2000; Hill *et al*. 2001). The expansion of many butterfly species' ranges already appears to be lagging behind current climates due to lack of habitat availability (Hill *et al*. 1999; Parmesan *et al*. 1999; Warren *et al*. 2001). The interaction of climate and land use change alone is expected to commit 15-37% of the world's species to extinction by 2050 (Thomas *et al*. 2004). Canada's biodiversity is similarly threatened (Kerr and Deguise 2004): the latest research suggests that global changes have caused widespread shifts in the distribution of Canadian butterfly species (White and Kerr 2006).

With significant climate changes predicted for the future (IPCC 2007), successful conservation strategies and reasoned policy directives that incorporate a range of possible species responses are critical. Global changes are likely to force many species to shift beyond the boundaries of existing protected areas, threatening the effectiveness of traditional conservation strategies. Accurate predictions of climate and land use impacts on species distributions are a prerequisite for any successful conservation plan. In this article, we review the impacts of recent global changes on species' distributions in Canada, and the role of protected areas and species distribution modeling in the context of a rapidly changing environment. We highlight the imperative to focus conservation efforts beyond the boundaries of static reserves and suggest implications for policy and conservation management in Canada.

THE CONTEXT: GLOBAL CHANGE ACROSS CANADA IN THE 20TH CENTURY

Recent global changes have created a unique pattern in Canada: land use changes have been focused in southern Canada, whereas climate changes have been in mountainous areas and northern latitudes (Kerr and Cihlar 2003; White and Kerr 2006). Agriculture is heavily concentrated in the prairie region, southern British Columbia, and southern Ontario and Québec (Kerr and Cihlar 2003). Land use intensity has increased dramatically since World War II through the introduction and widespread application of pesticides (Freemark and Boutin 1995; Benton *et al*. 2002). Similarly, human population density is also highest in these areas (Figure 1) and has increased substantially over the last century (White and Kerr 2006), leading to increased habitat loss to agriculture.

In addition to extensive and intensive land use changes, temperature and precipitation have also changed across Canada over the last century. Most areas have experienced warmer temperatures, although temperatures have actually decreased in some regions, such as Northern Ontario and in some parts of Northern Quebec (Lemmen *et al*. 2008). Changes in Canada have been more substantial than in other countries, given its northern location. Moreover, temperatures are expected to continue to rise over the next century, especially in the north (IPCC 2007). Future climate change scenarios also predict increased glacial melt and flooding in the west, melting of the ice caps in the Arctic, increased drought episodes in central Canada and a rise in sea levels in the Atlantic (Lemmen *et al*. 2008).Canada also holds a significant portion of the world's boreal forest, which is expected to be more affected by climate change than either temperate or