

Terrestrial Protected Areas: Threats and Solutions

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Abstract: *We provide an overview of the principal threats to land based protected areas and then discuss measures by which protected areas can continue to be effective at conserving biodiversity this century.*

INTRODUCTION

A protected area (PA) is defined as “an area of land and/or sea especially dedicated to protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means” (IUCN 1994). The IUCN divides PAs into six management categories ranging from strict nature reserves to those that allow sustainable use of natural resources (Table 1) (IUCN 1994). From a biological standpoint, the effectiveness of PAs as a conservation tool depends on its ability to incorporate biodiversity (e.g., Rodrigues and others 2004) and to buffer plant and animal populations against anthropogenic forces (e.g., Bruner and others 2001; Hayes 2006) and most appraisals generally suggest that PAs are successful in their goal of biodiversity conservation when compared to areas with no formal protection. Nonetheless, plant and animal populations inside PAs are not immune to anthropogenic forces. Here we review a selection of contemporary threats to terrestrial PAs in all IUCN categories and provide some ideas as to how PAs can cope with anthropogenic pressures in the future. Our purpose is not to provide an exhaustive list of threats to PAs (see Worboys et al 2005; Chape and others 2008) but instead to offer an up-to-date assessment of threats and how they can be addressed.

GLOBAL THREATS

Climate Change

By the end of the 21st century, average global temperatures are expected to increase by 1.1 to 6.4°C (NRC 2010). Many species have already exhibited range shifts

Table 1. IUCN Protected Area Categories (IUCN 1994, adapted from Chape and others 2005), with percentages out of total PAs, including non-categorized PAs.

Category	Description	Percent by Number	Percent by Area
Category Ia	strict nature reserve: PA managed mainly for science	4.9	5.4
Category Ib	wilderness area: PA managed mainly for wilderness protection	1.2	3.3
Category II	national park: PA managed mainly for ecosystem protection and recreation	3.5	23.1
Category III	natural monument: PA managed mainly for conservation of specific natural features	17.3	1.4
Category IV	habitat/species management area: PA managed mainly for conservation through management intervention	24	15.5
Category V	protected landscape/seascape: PA managed mainly for landscape/seascape conservation and recreation	7.4	12.4
Category VI	managed resource PA: PA managed mainly for the sustainable use of natural ecosystems	3.7	22.1

in response to climate change (Root and others 2003), moving between 6.1 and 16.9 km per decade (Parmesan and Yohe 2003). Altitudinal shifts in species distributions have also been documented within PAs, with species showing average range shifts from 6.1 m (Parmesan and Yohe 2003) to 11 m (Chen and others 2011) up altitudinal gradients per decade. Increasing temperatures may also affect species interactions through changes in phenology or temporal mismatches, where one trophic level or taxonomic group shows more plasticity in timing of key events than others (e.g., Visser and others 1998).

Due to differences in response rates to climate change, species in PAs may lose or gain prey, predators, pollinators, or competitors leading to changes in interspecific interactions and formation of novel (non-analog) communities (Huntley 1991). However, our understanding remains largely theoretical at present, as there is a great degree of uncertainty regarding ecosystem and biotic responses to climate change.

EXTERNAL THREATS

Isolation and Fragmentation

Degradation of habitat between PAs results in loss of connectivity between PAs, whereas fragmentation of PAs reduces their effective size. Many parks and reserves were originally carved out of much larger wilderness areas, and as a result, the available habitat for animals and plants found within these areas extended well beyond their borders. However, in recent decades PAs have become increasingly isolated due to degradation of surrounding habitat. For example, nearly 70 percent of the lands surrounding PAs in tropical forests experienced habitat loss or degradation in the past 20 years (DeFries and others 2005). Fragmentation of PAs has arisen not only from direct habitat destruction and conversion to agriculture but also from construction of

roads and fences and hunting both inside and outside reserves (Newmark 2008). Fragmentation of habitat can lower genetic diversity of constituent populations, slow population growth rates, reduce trophic chain length of communities living in PAs, alter species interactions, and ultimately decrease biodiversity (Fahrig 2003, Rudnick and others 2012).

Effects of isolation and fragmentation on species are idiosyncratic and difficult to predict. Even within the carnivore guild, isolation can have dissimilar effects on different species. For example, isolation of PAs in the northern Rocky Mountain region of the USA had a greater impact on grizzly bears (*Ursus arctos*) than on wolves (*Canis lupus*) (Carroll and others 2004).

Human Population Pressure

In many areas, human populations are growing quickly near reserve borders (Zommers and MacDonald 2012). Population growth near PA borders may be a result of migrants being “pushed” into areas near reserves due to lack of resources elsewhere, especially arable land for farming (“frontier engulfment”). Where agricultural expansion is a primary driver of population growth near PA borders, growth will likely continue so long as agriculture is the primary economic opportunity for local people. Alternatively, people may move to these areas because they are attracted to features of the PA, such as job opportunities in ecotourism, clean water, or the very resources that are being protected. Whatever the cause of population growth, increasing population pressure at reserve borders may exacerbate PA isolation and other threats to PAs.

PADDD

Protected area downgrading, downsizing, and degazettement (PADDD) is a constant threat to PAs even as the global area covered by reserves continues to increase. Downgrading refers to a reduction in legal restrictions on human activities in PAs, downsizing to a reduction in reserve area, and degazettement to a loss of legal protection for an entire PA (Mascia and Pailler 2011). PADDD usually occurs for the extraction of resources for human needs. In the United States, demand for recreation in PAs may lead to increased public pressure and justification of PADDD. Some conservationists see PADDD as a positive conservation strategy because funds can be reallocated from poorly performing PAs, but there are many risks. If conservation embraces PADDD, it may be easier for PAs to be downgraded or degazetted for resource extraction without any corresponding conservation benefit.

INTERNAL THREATS

Deforestation

Protected areas are generally successful at reducing deforestation within their borders but deforestation remains a major concern in many regions and will likely pose an increasingly large threat to PAs. A meta-analysis of 49 locations from 22 countries showed that the majority of PAs had significantly lower levels of deforestation than non-PAs, but their effectiveness varied globally (Nagendra 2008). Deforestation in PAs occurs through extractive activities such as logging, fuelwood collection and charcoal production. Secondary and regenerating forests that have undergone extraction activities have consistently lower levels of biodiversity than primary forests (Gibson and others 2011). Proximate factors (such as agriculture, wood extraction) and

ultimate factors (such as economics and national policies) both drive deforestation in PAs; they are complex and often site or region specific (Geist and Lambin 2002).

Wildlife Exploitation

Legal and illegal exploitation of wildlife occurs both outside and inside PAs and is a major driver of species declines globally. Wildlife offtake is driven by demand for medicine, luxury items (e.g., pets and fashion), trophy hunting, and food, resulting in a huge international trade (Smith and others 2009). Increased global wealth has driven an upsurge in wildlife exploitation for both medicine and luxury items. An estimated 80 percent of the world's people depend on traditional medicine (WWF 1993) most of which comes from plants (Engler and Parry-Jones 2007). Between 2000 and 2005, more than 6.7 million live birds, 7.9 million live reptiles and over 30 million reptile skins were traded globally (Engler and Parry-Jones 2007). Trophy hunting, another form of luxury-driven wildlife exploitation, is a valuable industry for many countries but it can have negative effects on wildlife populations in PAs when quotas are set unsustainably high (Lindsey and others 2007). Bushmeat consumption occurs on a vast scale. For example, the extraction of mammal bushmeat from the Congo Basin is a staggering 4.9 billion kg/year while 150 million kg are extracted from the Amazon (Fa and others 2002).

Each type of extraction can lead to negative consequences for species and ecosystems within PAs. Large-bodied animal species are particularly vulnerable because they have wide-ranging behavior, a low rate of reproduction, and are specifically targeted by hunters (Wilkie and others 2011). Removal of top predators negatively affects ecosystems by creating trophic cascades and reducing the length of the food chain (Estes and others 2011), while the removal of ecosystem engineers, such as elephants (*Loxodonta africana*), alters vegetation structure (Wilkie and others 2011). Many animal species are important seed dispersers or predators, and offtake can affect plant regeneration by decreasing seed dispersal, germination, and seed size of some plant species (Peres and Palacios 2007, Wright and others 2007, Galetti and others 2013).

Invasive Species

Most PAs have at least one documented invasive species (90 percent of PAs surveyed; De Poorter 2007). As anthropogenic disturbance increases inside and outside PAs, the spread and establishment of invasive species within PAs will become an increasing threat. Increased predation is a common result of introduced animal species in PAs. For example, the introduced Burmese python (*Python bivittatus*) has led to a dramatic decline in frequency of observations of raccoons (*Procyon lotor*), and opossums (*Didelphis virginiana*), and a complete disappearance of once common rabbits (*Sylvilagus* spp.) in the Florida Everglades NP (Dorcas and others 2012). Conversely, introduced prey can also have negative impacts on their predators. In Kakadu NP in northern Australia, the poisonous invasive cane toad (*Bufo marinus*) colonized the entire reserve within two years, leading to the rapid decline of the quoll (*Dasyurus hallucatus*), a native carnivorous marsupial (Woinarski and others 2010).

Introduced parasites and disease can also have detrimental effects on native populations inside and outside PAs. Avian malaria and avian poxvirus were introduced to Hawaii in 1826, and it is believed that these diseases led to the extinction of at least 13 birds species (Sodhi and others 2011). Invasive species can also lead to the decline of native species in PAs through

competition (Gurevitch and Padilla 2004). In Yellowstone NP and surrounding areas, the invasive plant *Linaria vulgaris* has dramatically reduced the cover of native plants (Pauchard and others 2003). Competition has also been documented between animals in PAs, as seen in the decline of giant Galapagos tortoises (*Chelonoidis nigra*) due to the presence of non-native goats (*Capra hircus*) on Alcedo Volcano island in Galapagos NP (Márquez and others 2012).

The ability of PAs to buffer against invasive species is limited because waterways, roads, and in-park disturbances (natural and human) allow invasive plants to spread more easily (Foxcroft and others 2011). Recreation can also contribute to the spread of invasive plants within PAs (Pickering and others 2011), as can the expansion of invaders' potential ranges due to climate change (Hulme 2006). As global temperatures and human population increases, invasive species will become an increasingly large problem for PAs.

Livestock-Wildlife Conflict

Livestock grazing has been implicated in environmental degradation, water shortages, and forage scarcity in and around PAs (Voeten and Prins 1999). And incursions of livestock into reserves are common. A study of 93 PAs by Bruner and colleagues (2001) found that over 40 percent of parks were ineffective at mitigating the impacts of grazing. Livestock negatively affects wildlife within PAs, with numerous studies documenting a negative relationship between livestock density and wildlife density.

Competition between wild herbivores and livestock is context-dependent. For example, wild ungulates and cattle compete for food during the dry season when resources are scarce but can enhance each other's diet quality during the wet season when resources are high (Odadi and others 2011). Livestock may even provide unexpected benefits to PAs by promoting seed dispersal (Brown and Archer 1989) and increasing plant diversity (Hickman and others 2004). In Guanacaste NP, native herbivorous seed dispersers are all extinct, but park officials have been able to use livestock to disperse seeds and restore native plant communities (Janzen 1982). Thus, the effects of livestock in PAs need not always be negative.

Fire

Fire is a powerful ecological disturbance that shapes ecosystem structure and can maintain biodiversity. Fire activity can also dramatically alter habitat structure and affect nutrient and particle content of soil, water, and air. The threat of fire in PAs is a result of human-imposed deviations from natural fire regimes and can be divided into two situations. In the first, fire is uncommon in nature. But human influences have artificially elevated the frequency of fires. For example, in the Brazilian Amazon, fires occurred in at least 20 percent of reserves in most years, with more fires in dry years, near roads, and in forests with a high level of human impact (Adeney and others 2009). In the second situation fire is naturally common. For example, subtropical and temperate forests, grasslands, and shrublands are fire-adapted. Here the question of fire in PAs is an issue of maintaining regular fire in that ecosystem. Human activities including fire suppression and livestock grazing have reduced fire intervals in fire-adapted ecosystems worldwide over the past century leading to fuel buildup and woody species recruitment. Climate change and invasive species have increased susceptibility to fire in recent years, promoting severe fires in regions where fuel load has built up due to

suppression policies (Bowman and others 2011). Severe fires in National Forests and other PAs in the U.S. Northwest are a risk for endangered species, such as the northern spotted owl (*Strix occidentalis caurina*) (Spies and others 2006). Implementing fire-friendly policies can be difficult when people live near PA boundaries, and prioritizing fire in the landscape can be at odds with species-focused approaches such as the U.S. Endangered Species Act that may prohibit popular ecosystem management techniques like prescribed burning (Quinn-Davidson and Varner 2012).

Hydrology

Decreasing water availability will have large impacts on PAs during this century. Alteration of hydrologic processes is often the result of anthropogenic demands for water, and with human populations expected to swell to over 9 billion by 2050, worldwide water demand will increase (UNEP 2010). Compounding the problem, water use over the last century has grown at twice the rate of population increase. Declines in water availability increase mortality of native plant and animal species and can have profound impacts on ecosystem services such as animal- or water-mediated seed dispersal (Konar and others 2013). Massive die-offs due to water shortages have been documented for a wide range of taxonomic groups in PAs, including migrating birds in Klamath NP (AP 2012) and mammals in South Africa's Kalahari Gemsbok NP (Knight 1995). In addition, many PAs act as dry-season water sources for wildlife (Western 1982).

Analysis of a century of hydrologic records from 31 North American rivers revealed flow declines for 67 percent; these rivers provide water for a large number of North American PAs (Rood and others 2005). The decrease in flow results from a combination of urbanization, irrigation, damming, and reduced snow pack due to climate change (Leppi and others 2012). Already, reductions in snow pack as a result of warming have led to decreases in seasonal water availability for PAs throughout the western USA (Hamlet and others 2005).

Mining

Legal and illegal mining around PAs, as well as accidental mining spills, pollute water sources, destroy habitat, and threaten biodiversity. Indeed artisanal and small-scale mining (mineral extraction characterized by low levels of mechanization and high labor intensity) occurs in or around 96 of 147 PAs evaluated (Villegas and others 2012). Drainage and tailings from mining activities can contaminate watersheds with lethal levels of chemicals such as arsenic, mercury, and lead. In the Coto Donana, a protected estuarine marsh ecosystem in Spain, the accidental upstream release of 5 million cubic meters of acid waste from the processing of pyrite ore led to severe declines in fish, invertebrate, and bird species (Pain and others 1998).

Drilling

Increased reliance on fossil fuels has sparked unprecedented levels of oil and gas exploration and extraction (Osti and others 2011). Demand for oil and gas is predicted to increase in coming decades (McDonald and others 2009) driving increased exploration in and around PAs. For example, in the federally owned section of the Arctic National Wildlife Refuge in Alaska, USA, there are approximately 7.69 billion barrels of recoverable oil, an amount roughly equal

to US oil consumption for 2007 (Kotchen and Burger 2012), and the possibility of opening this region for oil exploration has been intensely debated (Baldwin 2005, Snyder 2008). More than a quarter of the 911 UNESCO World Heritage sites worldwide are thought to be under threat from oil and gas extraction, with the Arabian Oryx Sanctuary in Oman being the first site in history to be delisted from the World Heritage list due to a significant reduction in size for oil and gas extraction (Osti and others 2011). In North America fossil fuel extraction activities disrupt migration patterns of caribou (*Rangifer tarandus*) and mule deer (*Odocoileus hemionus*; Hebblewhite 2011) and have led to significant population declines of the greater sage grouse (*Centrocercus urophasianus*; Naugle and others 2011). Many potential impacts of fossil fuel extraction on PAs have yet to be realized since oil and gas concessions within PAs have yet to be exploited. Opening these concessions will lead to increased CO₂ emissions, deforestation, habitat degradation, and biodiversity loss (Finer and others 2010).

Recreation

Protected areas worldwide are used for recreational activities and there has been a substantial rise in non-consumptive wildlife recreation and nature-based tourism over the last four decades (Tisdell and Wilson 2012). Recreation in PAs can result in damage to the local environment and its wildlife. For example, on federally protected lands in the USA, recreation is the second largest danger to threatened and endangered species (Losos and others 1995). Creation of roads, trails and facilities leads to direct habitat destruction and to altered hydrologic processes, increased erosion and damage to tree roots (Pickering and Hill 2007). Trampling by hikers, bicycles, cross-country skiers, ORVs, and horses causes soil compaction and can result in decreased plant diversity and density (e.g., Torn and others 2009; Marzano and Dandy 2012). Trail proliferation in PAs degrades habitat beyond the anticipated boundaries of human impact (Farrell and Marion 2001).

Recreational activities can also negatively affect animals in PAs by causing direct mortality (e.g., collisions with ORVs), altering animal behavior (Buckley 2004), or introducing diseases (e.g., human-primate disease transmission; Wallis and Lee 1999). Even quiet, non-consumptive recreational activities that seem to have low impact can have detrimental effects on wildlife populations. For example, wildlife viewing reduces foraging efficiency in birds and causes higher nest predation or abandonment of young (Boyle and Samson 1985). On the other hand, revenue generated by tourism in PAs contributes to the conservation of wildlife (Buckley 2012, Steven and others 2013). Nature-based tourism can also be vital for the establishment and management of PAs. For example, tourism is the primary source of revenue for South African NPs and assists in funding the expansion of PAs and conservation projects (SANParks 2012).

Interactions

Although we have discussed particular threats to PAs, these threats are connected through a web of interactions. Climate change will not only shift species distributions but will increase fire frequencies (Bowman and others 2009), provide opportunities for invasive species establishment (Hulme 2006), and cause more frequent droughts in some areas (Pittock and others 2008), thereby affecting park hydrology and necessitating greater use of PA resources by local people. In turn, deforestation can exacerbate climate change and make remaining forest edges

more susceptible to fire (Bowman and Murphy 2010). Population growth at PA borders will likely speed PA isolation via nearby agricultural land conversion (Zommers and MacDonald 2012) leading to livestock-wildlife conflict. Population pressure may also increase wildlife and timber extraction. Tourists visiting PAs for recreation may introduce or spread invasive species (Pickering and others 2011) and so on.

SOLUTIONS

More Protected Areas

Although the number of PAs is increasing, many species and habitats remain unprotected. To take just a single example, the distribution of PAs in Africa overlaps poorly with distributions of endangered birds (Beresford and others 2011). To meet conservation needs of hitherto unprotected habitats and species, large NGOs and researchers have devised several plans as to where to focus conservation effort. These include Conservation International's 25 biodiversity hotspots (Myers and others 2000); the World Wide Fund for Nature (WWF) "Global 200" ecoregions (Olson and Dinerstein 2002); 24 wilderness areas (Mittermeier and others 2003); and the Wildlife Conservation Society (WCS) "Last of the Wild" initiative (Sanderson and others 2002). Other conservation organizations take a more species or taxon-specific approach. Bird Life International has spearheaded Important Bird Areas (IBAs) as a way to conserve habitat for threatened, migrating, or congregating birds. Several PAs have been created in the name of charismatic flagship species (Andelman and Fagan 2000). While some argue that the use of flagship species may detract from the protection of other species (Simberloff 1998), use of charismatic species can raise significantly higher revenue than less well known species (White and others 1997). The relative effectiveness of these and other conservation strategies remains largely untested.

Enlargement

Large PAs are better buffered from anthropogenic influences around their edges (e.g., fire), can sometimes fully encompass migratory routes, may provide sufficient area for population viability (especially for large predators), can serve to protect entire watersheds and ecosystem processes, are likely to fare better in the face of climate change, and are easier and less expensive to protect and maintain on a per hectare basis than smaller reserves (Peres 2005). Given the benefits of large reserves, enlargement of existing PAs is a credible solution to counter impending threats. Unfortunately, less than 0.05 percent of all PAs qualify as "very large PAs"—those reserves with an area of 25,000 km² or more—these account for only 26 percent of global PA coverage -while over 70 percent cover less than 10 km² in area (Cantú-Salazar and Gaston 2010).

Reserve size is frequently a political decision. For example, large PAs are often established along international boundaries as transboundary conservation areas. But in some cases PA designation can be influenced by species minimum area requirements (Woodroffe and Ginsberg 1998, Gurd and others 2001).

Buffer Zones

Buffer zones are areas around PAs designed to insulate them from the negative impacts of anthropogenic activities occurring immediately outside but also support low impact land-use wherein people can sustainably extract resources or even practice agriculture (UNESCO 1974, Noss 1983). From a biological standpoint, buffer zones increase the effective size of a PA and limit high-impact land and water use nearby, both of which are growing problems. For example, intermediate to large-sized buffers are predicted to decrease illegal extraction within the PA core (Robinson and others 2013) and can help prevent destruction of forest immediately bordering PAs that otherwise might form abrupt forest edges to PA borders (DeFries and others 2005). Furthermore, buffer zones can help protect wide-ranging carnivores that move outside reserves (Balme and others 2010).

Despite the recognized importance of buffer zones, only general guidelines exist for their development and management (Robinson and others 2013) and current understanding of the dynamics of anthropogenic pressures at park boundaries is still weak (Shafer 1999). Indeed, in certain areas, land-use is more intense in buffer zones around PAs than in areas further away for reasons that are unclear (Naughton-Treves and others 2005). Nevertheless, buffer zones remain an important protection strategy for achieving both conservation and socioeconomic goals: helping to protect biodiversity within PAs while providing access for local people to utilize resources at PA boundaries.

Corridors

Corridors between PAs are vital for wildlife population viability because such linkages allow species to disperse between PAs, maintain genetic variability within populations, rescue populations from local extinction, facilitate species' range shifts due to global climate change, and provide more area for species requiring large home ranges (Rudnick and others 2012). A review of empirical evidence notes that animals do use corridors and the ensuing connectivity can increase overall population viability (Beier and Noss 1998). Corridors can increase species movement between patches by 50 percent compared to patches unconnected by corridors, although corridor effectiveness of course differs among taxa, with linkages being more important for non-avian vertebrates and plants (Gilbert-Norton and others 2010).

Linking existing PAs may be an important tool for mitigating the threat of climate change (Heller and Zavaleta 2009). By allowing species to shift their distributions to climatically favorable areas, corridors increase the probability of long-term population viability (Krosby and others 2010). As a cautionary note, while corridors can be effective in connecting habitat patches and species that reside within them, they can potentially transmit disease, fire, and invasive species (Simberloff and others 1992). Nonetheless, corridors are being increasingly viewed as vital to the future success of PAs and numerous linkages between reserves are being planned and implemented globally (Jones and others 2009).

Translocations

As anthropogenic pressures continue to lead to local extinctions of populations within PAs, translocation of individuals may be necessary to maintain sufficiently large, viable metapopulations

of threatened and endangered species. Translocation, the purposeful movement of organisms by humans from one area to another, can be dichotomized into reintroduction and assisted colonization (Ricciardi and Simberloff 2009). Reintroduction involves the release of species into ranges where they historically occurred. For example, wolves were successfully reintroduced into Yellowstone NP in the mid-1990s and now have a viable population (Smith and others 2003).

Assisted colonization, the movement of species into areas not part of their historic range, is much discussed as a solution to helping species change latitudes in response to rapid climate change and to assist them crossing fragmented landscapes (Hoegh-Guldberg and others 2008). For example, *Torreya taxifolia*, a conifer endemic to Florida, has been planted throughout North Carolina in an attempt to save its dwindling populations (McLachlan and others 2007). Some have argued that relocated species have the potential to become invasive in their new habitats and may drive out native species or disrupt ecosystems (Ricciardi and Simberloff 2009). Others argue that this risk can be managed with nuanced evaluations of past species invasions (Sax and others 2009), and that inaction is an equally insidious threat (Schwartz and others 2009). If assisted colonization is adopted as a conservation strategy, PAs will be crucial in protecting newly established populations against further anthropogenic impacts.

Management

Addressing many of the direct and indirect threats to PAs will depend on the effectiveness of PA planning and management (Knight and others 2013). For example, stopping illegal extraction requires law enforcement and negotiating with local communities; tackling invasive species requires prevention and removal techniques; and managing fire may require suppression or prescribed burning. The success of these activities depends on a clear management policy based on research and monitoring, effective communication, sufficient funding, and competent staff.

PAs are established for many reasons (Chape and others 2008), and any successful management framework should begin by clearly identifying those goals and establishing priorities that will allow the PA to succeed in the face of numerous direct and indirect threats. A reserve established to protect an endangered species may limit disturbance, whereas an ecosystem management approach may introduce natural disturbance as part of management activity. An extractive reserve must prioritize the resource in question while considering impacts of extraction on the ecosystem as a whole. A popular and effective framework for conservation in all PA types is adaptive management, which emphasizes ongoing adjustment of policy based on frequent monitoring of biodiversity. That said, considerable proactive and precautionary ecological and sociological management decisions will be needed to counteract the growing effects of climate change (Millar and others 2007, Heller and Zavaleta 2009).

Perhaps the most controversial issue in PA management is who should manage and how local communities should be involved in the process. Over the past few decades, community based conservation (CBC) schemes and integrated conservation and development projects (ICDPs) that involve the participation or compensation of local people (bottom-up management) became popular in response to sociopolitical injustices related to a century of strict protectionism (top-down management). Community involvement and compensation can further conservation goals by increasing local support for conservation and reducing activities such as wildlife and timber extraction from reserves. Enthusiasm for such approaches has waned, however, as some CBCs

and ICDPs have failed to produce win-win solutions to stem biodiversity decline and poverty that they promised (McShane and others 2011). Some conservationists are now advocating a return to the “fences and fines” approach, suggesting that it is the best way to protect biodiversity despite sometimes being politically unpopular (Adams and Hutton 2007).

Though community involvement has most often been identified with utilization and protectionism with preservation, the means and ends of management need not co-vary (Borgerhoff Mulder and Coppolillo 2005). In many cases, hybrid approaches that combine elements of community participation with preservationist goals may be best. For example, strict reserves may be managed or co-managed by communities, or have strong conservation education and outreach programs while tightly limiting resource extraction within the reserve.

CONCLUSION

There is abundant evidence that PAs are effective at conserving species and landscapes globally. However, reserves are still vulnerable to many human activities that they aimed to prevent at the time of establishment, and they are now facing new threats which were formerly unanticipated. We began our review with climate change, a broad threat that is starting to affect PAs around the world. Next, we discussed threats that act on PAs at and beyond their borders, such as increasing isolation and human population growth. Then we examined threats acting inside reserves such as deforestation, wildlife exploitation, invasive species, grazing, fire, changing hydrology, mining, drilling and recreation. It is clear that many of these threats act synergistically. In the last part of the review we discussed ways that some of these threats can be ameliorated. Where possible, the creation of additional PAs can address many of these issues, but enlarging, buffering and connecting existing reserves will also be very important. Furthermore, nations need to invest in effective monitoring and management of their current PA network. While there is no single approach to addressing the current and future threats to PAs, conservation solutions are available and future challenges to terrestrial PAs can be overcome.

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