Biological Conservation 161 (2013) 230–238

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Systematic review

Effectiveness of terrestrial protected areas in reducing habitat loss and population declines

Jonas Geldmann [a,*], Megan Barnes [b,c], Lauren Coad [d], Ian D. Craigie [e], Marc Hockings [b], Neil D. Burgess [a,f]

[a] Center for Macroecology, Evolution and Climate, Department of Biology, University of Copenhagen, Denmark
[b] School of Geography, Planning and Environmental Management, University of Queensland, Australia
[c] Environmental Decisions Group, Australia
[d] Environmental Change Institute, School of Geography, University of Oxford, Oxford OX1 3QY, United Kingdom
[e] ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia
[f] UNEP, World Conservation Monitoring Centre, Cambridge, United Kingdom

ARTICLE INFO

Article history:
Received 27 June 2012
Received in revised form 24 February 2013
Accepted 27 February 2013
Available online 3 May 2013

Keywords:
Effectiveness
Habitat loss
Management
Population trend
Protected area
Systematic review

ABSTRACT

Protected Areas (PAs) are a critical tool for maintaining habitat integrity and species diversity, and now cover more than 12.7% of the planet's land surface area. However, there is considerable debate on the extent to which PAs deliver conservation outcomes in terms of habitat and species protection. A systematic review approach is applied to investigate the evidence from peer reviewed and grey literature on the effectiveness of PAs focusing on two outcomes: (a) habitat cover and (b) species populations. We only include studies that causally link conservation inputs to outcomes against appropriate counterfactuals. From 2599 publications we found 76 studies from 51 papers that evaluated impacts on habitat cover, and 42 studies from 35 papers on species populations. Three conclusions emerged: first, there is good evidence that PAs have conserved forest habitat; second, evidence remains inconclusive that PAs have been effective at maintaining species populations, although more positive than negative results are reported in the literature; third, causal connections between management inputs and conservation outcomes in PAs are rarely evaluated in the literature. Overall, available evidence suggests that PAs deliver positive outcomes, but there remains a limited evidence base, and weak understanding of the conditions under which PAs succeed or fail to deliver conservation outcomes.

1. Introduction

Protected Areas (PAs) have long been regarded as an important tool for maintaining habitat integrity and species diversity (Brooks et al., 2004; Butchart et al., 2010; Coad et al., 2008; Rodrigues et al., 2004), covering more than 12.7% of the planet's land surface (Bertzky et al., 2012). However, there is considerable debate on the extent to which PAs deliver conservation outcomes in terms of habitat and species protection (Brooks et al., 2006; Ferraro and Simpson, 2002; Meir et al., 2004). It has been suggested that many of the world's PAs exist only as 'paper parks' (Dudley and Stolton, 1999), lacking effective management capacity, and unlikely to deliver effective conservation (Joppa et al., 2008).

PAs are often treated as a single conservation strategy. However, in reality they are established for a variety of reasons, with very different objectives and criteria for success. PAs have been set up for the conservation of ecosystems and their constituent species (Dudley, 2008), protection of specific threatened species (Liu et al., 2001), ecosystem services (Campos and Nepstad, 2006), or for cultural and social reasons (Coad et al., 2008). Understanding the conditions under which PAs deliver conservation benefits for habitats and species is essential for policy makers, managers and conservation advocates (Brooks et al., 2004; Kleiman et al., 2000; Margules and Pressey, 2000).

The success of PAs has generally been evaluated using measures such as the representativeness of PA networks in terms of their species diversity, or coverage of endemic and threatened species (Rodrigues et al., 2004), assuming that PAs provide effective protection once established. Alternatively, by investigating management 'inputs' – e.g. whether PAs have management plans, boundaries, staffing, and other management systems and processes (Jachmann, 2008), assuming that increased levels of management equates to successful protection. However, these analyses are not able to describe how conditions inside PAs change over time (Craigie et al., 2010), or evaluate the effectiveness of protection, by combining measures of inputs and measures of outcomes in a temporal framework; thus measuring how biodiversity outcomes change over time in relation to protection or implementation of management actions.

The objective of this paper is to use a 'systematic review' methodology (Pullin and Knight, 2009) to review the evidence that PAs

---

* Corresponding author. Tel.: +45 3523 1230; fax: +45 3532 2128.
E-mail address: jgeldmann@bio.ku.dk (J. Geldmann).

0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.02.018

deliver a positive change in two conservation outcomes: (a) habitat cover and (b) species populations, i.e. the ability of PAs to maintain or improve native habitat integrity, or native species populations, over time respectively. We further consider the impact of different PA management interventions, or characteristics, where measured, on biodiversity outcomes.

2. Methods

2.1. Search strategy

To locate relevant literature, we searched 14 databases, eight specialist sources and 13 websites in English (Table S1). We identified a list of relevant search terms and used Boolean operators and multi term searches (Table S2). Anonymous reviewers appraised the list of relevant search terms and the search strategy. The search was conducted between July and August 2010, covering all publications available up to that point. For a full description of the search strategy, search-terms, and inclusion criteria see Geldmann et al. (2012).

2.2. Study inclusion criteria

Two main criteria were used to determine study inclusion. First, we reviewed whether the publication assessed conservation interventions and biodiversity outcomes. We only included publications that measured the effectiveness of PAs targeting biodiversity conservation of native habitats/species. We excluded publications that looked at changes in alien species, or species not expected to improve with successful protection.

Second, we only included publications that used suitable counterfactuals (controls), following the BACI (before/after or control/intervention) framework. Counterfactuals were defined as: (a) before vs. after: e.g. PA establishment/implementation or PA management intervention, or (b) control vs. intervention: e.g. PAs compared to their immediate surroundings or to non-protected areas with similar characteristics.

2.3. Study characterization and quality assessment

For publications where multiple PAs were examined against different counterfactuals, such that the publication contained more than one examination of PA effectiveness, we divided these based on the type of counterfactual. All summaries and estimations of impact are based on this subdivision of results from publications that are henceforth referred to as: "studies".

For each study we first extracted detailed information on biodiversity outcome variables. This included information on the methods used to measure habitat or species population change (i.e. remote sensing, transect surveys, etc.), the rates of change, and the units of measurement. For studies that did not report the rate of change, we noted the given direction of change (improving/no effect/declining) compared to the counterfactual. For all studies of species populations we also estimated the fraction of species that did better inside the PA compared to the counterfactual, and also noted any reported trophic impacts (such as population changes due to predator–prey dynamics).

Second, we extracted information on PA management interventions and characteristics, as well as external drivers of habitat or species change. We recorded either the given effect size of the variable, or where this was not given, noted the direction of change (improving/no effect/declining) compared to the counterfactual. The management interventions and PA characteristics identified were then grouped into categories (with separate categories for habitat and species) that were defined post hoc (details of categories are provided in Tables S3 and S4).

Third, we extracted information on other biological and geographical variables, and study biases. These effects had not been measured using appropriate counterfactuals, but were mentioned in the publications as having potentially affected biodiversity outcomes.

zWhere multiple publications evaluated the same site using the same data, sites were only included once to avoid double counting. However, for habitat studies, PA effectiveness was evaluated at different scales (i.e. globally, regionally, nationally or site-level). In this case both studies were included, as results for one level is not simply part of the result of another. Thus, the results presented at different levels contribute different information on PA effectiveness.

3. Results

Of the 2599 publications selected through the systematic search strategy, we found 51 publications on habitat cover and 35 publications on species population trends that fulfilled the inclusion criteria.

Within 13 of the 51 habitat change publications there were multiple counterfactual scenarios. When separated these yielded a total of 76 studies. Three population trend publications covered more than one evaluation of PA effectiveness, yielding 42 studies in total across the 35 publications. Detailed descriptions of the data extracted from individual studies are presented for habitats (Tables S5 and S6) and populations (Tables 1 and S7).

3.1. Protecting habitats

Of the 76 studies on the effectiveness of PAs in retaining habitat cover, four were global, 35 evaluated regional, national or subnational networks of PAs, and 34 evaluated five or fewer PAs. There was a strong bias in study location; 35 were from Latin America, 18 from Africa, 16 from Asia, two from Oceania, and one each from Europe, and North America. There was also a strong bias in habitat focus. Sixty-eight of the 76 studies (89%) investigated changes in forest cover only, 67 (88%) of which were for tropical forest. The remaining eight evaluated multiple land-use types of which all but one (Alodos et al., 2004) included forests.

To determine changes in habitat cover, 63 studies (83%) used satellite remote sensing techniques, three used aerial photos, and five used a combination of both. The remaining five used in situ data collection, either estimation of disturbance across plots (Bleher et al., 2006; Liu et al., 2001; Tole, 2002), or interviews and questionnaires (Bruner et al., 2001; Mwangi et al., 2010). To analyze PA effectiveness in protecting habitat, 36 of the 76 studies used buffer analyses (comparing changes in habitat cover inside PAs to a surrounding buffer), 21 compared to similar areas outside the PAs, and 10 used matching estimator methods (Table S5).

Sixty-two of the 76 studies of habitat change (82%) found habitat loss to be higher outside PAs than inside, nine studies found habitat loss to be higher inside PAs than outside, and five could not detect an effect of protection (Tables 2 and S5). The three global studies were generally in agreement, finding that PAs were effective in reducing habitat loss. DeFries et al. (2005) compared PAs to their buffer, and found rates of habitat loss for 198 PAs to be 2.6 times lower inside compared to outside. Scharlemann et al. (2010) found that PAs lost about half as much carbon as forest outside PAs globally (ca. 2 times lower than outside PAs), and the loss in Oceania, the Neotropics, and in Tropical Asia to be higher outside PAs than inside. Joppa and Pfaff (2011), found that rates of habitat loss in PAs were 1.08 times lower than the counterfactual.

In 52 of the 76 studies the results reported, we were able to calculate the ratio of the habitat change in the PA compared to their counterfactual (Table S5). Where PAs had lower habitat loss com-

Table 1
Detailed data from the 42 studies evaluating PA effectiveness for species populations.

Source	Countries	Protected area	Monitoring period	Taxa	Counterfactual	BACI	Background trend	Effect of PA
Adams et al. (2008)	USA	Arctic NP	1986–1992	Mammals	Implementation of regulation	BA	Stable	+
Balme et al. (2010)	South Africa	Phinda–Mkhuze	2002–2007	Mammals	PA compared to buffer	CI	Increase	+
Bhattacharya (1993)	India	Kaziranga NP	1908–1991	Mammals	Introduction of staffing	BA	Increase	+
Blake et al. (2008)	Congo	6 PAs	2003–2005	Mammals	PA compared to buffer	CI	Increase	+
Brereton et al. (2008)	England	Multiple	1981–2000	Insecta	Establishment of PA	BA	Increase	+
Caro (1999)	Tanzania	Katavi NP	1995–1996	Mammals	PA compared to buffer	CI	Increase	+
Caro (1999)	Tanzania	Katavi NP	1995–1996	Mammals	Game controlled area	CI	Increase	+
Caro (1999)	Tanzania	Katavi NP	1995–1996	Mammals	Forest reserve	CI	Increase	+
Carrillo et al. (2000)	Costa Rica	Corcovado NP and Golfo Dulce FR	1990–1994	Mammals	Different levels of protection	CI	Stable	+
Catry et al. (2009)	Portugal	Castro Verde	1996–2007	Aves	Introduction of artificial nests	CI	Increase	+
Devictor et al. (2007)	France	All protected areas	1989–2003	Aves	National estimates outside PA	CI	Increase	+
Eberhardt et al. (2007)	USA	Yellowstone NP	70 years	Mammals	Implementation of regulation	BA	Increase	+
Fellers and Drost (1993)	USA	Lassen Volcanic NP	1978–1991	Amphibian	Establishment of management	BA	Decrease	–
Gough and Kerley (2006)	South Africa	Addo Elephant NP	1931–2002	Mammals	Introduction of fence	BA	Increase	+
Harrington et al. (1999)	South Africa	Kruger NP	1977–1993	Mammals	Closing of waterpoints	BA	Decrease	+
Herremans and Herremans-Tonnoeyr (2000)	Botswana	Multiple	1991–1995	Aves	PA compared to buffer	CI	Increase	+
Hilborn et al. (2006)	Tanzania	Serengeti NP	1955–2005	Mammals	Implementation of regulation	BA	Decrease	+
Ma et al. (2009)	China	Yancheng	1982–2003	Aves	Different zones of PA	CI	Decrease	+
Mduma et al. (1999)	Kenya, Tanzania	Serengeti NP	1958–1998	Mammals	Establishment of PA	BA	Increase	+
Meijaard and Nijman (2000)	Indonesia	Pulau Kraget	1997	Mammals	Translocation of population	BA	Decrease	-
Metzger et al. (2010)	Tanzania	Serengeti NP	1970–2008	Mammals	Implementation of regulation	BA	Decrease	+
Ottichilo et al. (2000)	Kenya	Masai Mara	1977–1997	Mammals	PA compared to buffer	CI	Decrease	0
Pedrono et al. (2009)	Vietnam	Yok Don, Cat Tien, Ea So, and Vinh Cuu	1990–2005	Mammals	Non-protected land within species range	CI	Decrease	+
Pettorelli et al. (2010)	Tanzania	5 NPs, 3FR and 3 other PAs	2004–2007	Mammals	Different levels of protection	CI	Increase	+
Schlicht et al. (2009)	USA	Multiple	1988–1996	Insecta	Areas not managed with fire	CI	Decrease	–
Sergio et al. (2005)	Spain	Doñana NP	1989–2001	Aves	Populations outside PA	CI	Stable	0
Sinclair et al. (2007)	Tanzania	Serengeti NP	1955–2005	Mammals	Implementation of regulation	BA	Decrease	+
Stoner et al. (2007)	Tanzania	Burigi-Biharamulo NP	1980s–2000s	Mammals	PA compared to buffer	CI	Decrease	+
Stoner et al. (2007)	Tanzania	Greater Ruaha NP	1980s–2000s	Mammals	PA compared to buffer	CI	Decrease	+
Stoner et al. (2007)	Tanzania	Tarangire NP	1980s–2000s	Mammals	PA compared to buffer	CI	Decrease	+
Stoner et al. (2007)	Tanzania	Selous-Mikumi NP	1980s–2000s	Mammals	PA compared to buffer	CI	Decrease	+
Stoner et al. (2007)	Tanzania	Ugalla NP	1980s–2000s	Mammals	PA compared to buffer	CI	Decrease	+
Struhsaker et al. (2005)	11 African countries	16 PAs	1966–2000	Biodiversity	PA compared to buffer	CI	N/A	+
Suárez et al. (1993)	Spain	Las Amoladeras and Layna Paramos	1989	Aves	PA compared to similar habitat outside	CI	Decrease	–
Tambling and Toit (2005)	South Africa	Pilanesburg NP	1995–2001	Mammals	Introduction of fence	BA	Decrease	–
Theberge et al. (2006)	Canada	Algonquin	1988–1999	Mammals	PA compared to buffer	CI	Decrease	+
Wegge et al. (2009)	Nepal	Bardia NP	22 years	Mammals	Establishment of PA	BA	Increase	+
Western et al. (2009)	Kenya	Tsavo NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western et al. (2009)	Kenya	Mara NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western et al. (2009)	Kenya	Amboseli NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western et al. (2009)	Kenya	Meru NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Whitehead et al. (2008)	New Zealand	Fiordland NP	2000–2006	Aves	Managed section compared to unmanaged	CI	Increase	+

Key: NP = National Park, FR = forest reserve, PA = protected area, BA = before/after, CI = control/intervention. See Table S7 for further information on the individual studies. Counterfactual defines the comparator which the PA was evaluated against and BACI whether the comparison was before/after or control/intervention. Background trend defines the overall direction of the majority of the populations (see ratio in Table S7) which can be decreasing even in successful PAs. Effect of PA describes whether protection was better than counterfactual (+) worse than counterfactual (–), or no difference could be detected (0).

Table 2
Effectiveness of terrestrial protected areas in reducing habitat loss and population declines.

Region	Counterfactual			Impact					Habitat	
	Buffer	Regional	Matched	Positive	Negative	No effect	% Positive	Mean difference	Forest	Multiple
Africa	4	11	2	11	4	3	61%	4.7	14	4
Asia	10	3	2	14	1	1	88%	2.4	16	0
Europe	1	0	0	1	0	0	100%	–	1	0
Latin America	19	7	5	30	4	1	86%	6.0	33	2
North America	1	0	0	1	0	0	100%	–	0	1
Oceania	0	2	0	2	0	0	100%	–	2	0
Global	1	2	1	4	0	0	100%	–	2	1
Summary	36	24	10	62	9	5	82%	–	68	8

pared with the counterfactual (43 studies), ratios ranged from 1.25 (Curran et al., 2004) to 22.7 (Nepstad et al., 2006) times lower loss, with an mean of 5.4 (S.D. = 4.9). For the nine studies where PAs had higher rates of habitat loss compared with the counterfactual, the difference ranged between 1.15 (Brower et al., 2002) and 3.97 (Liu et al., 2001) times higher loss. Differences between inside and outside were generally larger for Latin America and Africa, compared to Asia, suggesting that Latin American and African PAs are better at reducing deforestation within their borders (Table 2).

Studies using a buffer analysis reported higher levels of PA effectiveness (mean = 5.2, S.D. = 5.0) than studies which used regression modeling (mean = 4.2, S.D. = 5.4). For studies using matching estimators only one reported a PA/counterfactual ratio, finding 2 times more deforestation outside PAs compared to inside (Mas, 2005). Similarly, Joppa and Pfaff (2011) comparing the results of matching estimators and buffer analyses, also found rates of habitat loss in PAs to be smaller using matching. Such results show that methods used to evaluate PA effectiveness can alter the apparent effect size.

Three global studies examined deforestation rates between reserves under different IUCN reserve management categories (Joppa and Pfaff, 2011; Nelson and Chomitz, 2009; Scharlemann et al., 2010), all finding that PA effectiveness increased with IUCN categories that infer stricter protection. However, Joppa and Pfaff (2011) showed this effect to be partly explained by the larger size of category I and II reserves. All seven studies investigating the effectiveness of indigenous protected lands found positive impacts compared to non-protected areas. In the eight studies that compared indigenous or community managed reserves with state managed PAs, three found community reserves to perform better (Bray et al., 2008; Ellis and Porter-Bolland, 2008) and five found them to perform worse (Armenteras et al., 2006; Bleher et al., 2006; Gaveau et al., 2007; Nelson et al., 2001; Nepstad et al., 2006).

Twenty studies included the effect of PA management; ranging from implementation of management plans and staff numbers, to involvement of local NGOs. None of the studies could estimate the explicit effect of management. Of the 20 studies, eight calculated the difference between inside and outside, showing 2.4 (S.D. = 1.5) times lower deforestation inside PA boundaries.

2Where studies used regression modeling to control for the effect of exogenous biological and geographical variables on habitat loss, the effect of these variables was often reported. Remote areas of higher or steeper terrain were generally reported to suffer less habitat loss (Joppa and Pfaff, 2011). Areas with high human population densities, located in areas with high demand for land, or with high fire frequency were reported more frequently to suffer greater habitat loss (Fig. 1A).

3.2. Protecting species populations

The relative impact of protection and management was positive in 31 of the 42 studies; in 12 of these, species populations still exhibited declined under protection, but less than in the counterfactual. Relative performance was worse with protection than without in five studies, and six studies found no effect of protection (Table 1 Individual study details, Table 3 Summary data).

The largest number of PAs included in any of the 42 studies was 16, spread across 11 African countries (Struhsaker et al., 2005). Seven of the 42 studies were at regional or national scale, and 35 (83%) were of five or less PAs. Like habitat studies, population studies also exhibited geographic bias with 57% from Africa, as well as a taxonomic bias with 74% studying mammals (Table 3). Thirty-four of the 42 studies measured changes in species population abundance, three measured changes in occurrence, and five used other measures such as spot counts, questionnaires, or nest mortality (Table S6).

Counterfactuals varied across studies. Fifteen of the 42 used a before/after (BA) counterfactual: Three of those compared the same area before and after establishment of the PA, and the other 12 compared the same populations within a PA before and after the implementation of specific management actions. The remaining 27 of the 42 population studies used a control/intervention (CI) counterfactual: 16 of those compared populations from one or several PAs to populations with the PAs immediate surroundings, five compared trends in PAs to non-protected land with similar characteristics but not adjoining the reserve, and six compared populations between PAs with varying legislation or management (Table 1).

In addition to the effect of protection per se, species populations in all studies were also affected by specific management actions (Table S6). Consequently, the impacts of protection and individual management actions are confounded. In addition, impacts of management and protection were evaluated using a range of dissimilar methods. It is therefore inappropriate and uninformative to calculate effect sizes. Instead, we report direction of change (improving/no effect/declining) compared to the counterfactual, as this was the only measure of success which could be justifiably compared between studies (Table 1).

The most commonly reported management actions were those aimed at reducing poaching (12 of 42 studies). Eleven of the 12 studies reported improved biodiversity outcomes linked to management actions, though of variable magnitude (Fig. 1B). Species were typically mammals and six of the studies examined large African herbivores. In Serengeti NP, reestablishment of anti-poaching efforts resulted in a shift from large declines in buffalo populations to increasing population in a short time period (Metzger et al., 2010). Similarly, elk populations in Yellowstone exhibited large population increases following anti-poaching regulations. In Costa Rica mammals in less strictly guarded reserves were 6–28% the relative density of that in reserves with strict anti-poaching regulation (Carrillo et al., 2000). More subtly, in Vietnam banteng populations (*Bos javanicus birmanicus*) declined only slightly more slowly when guard numbers increased (Pedrono et al., 2009). Three studies examined the use of fences. One noted stable roan antelope (*Hippotragus equinus*) populations compared to decreases outside fencing (Harrington et al., 1999) and a second noted no difference with bird populations remaining stable before and after fencing (Sergio et al., 2005). The third showed negative changes, with ca.

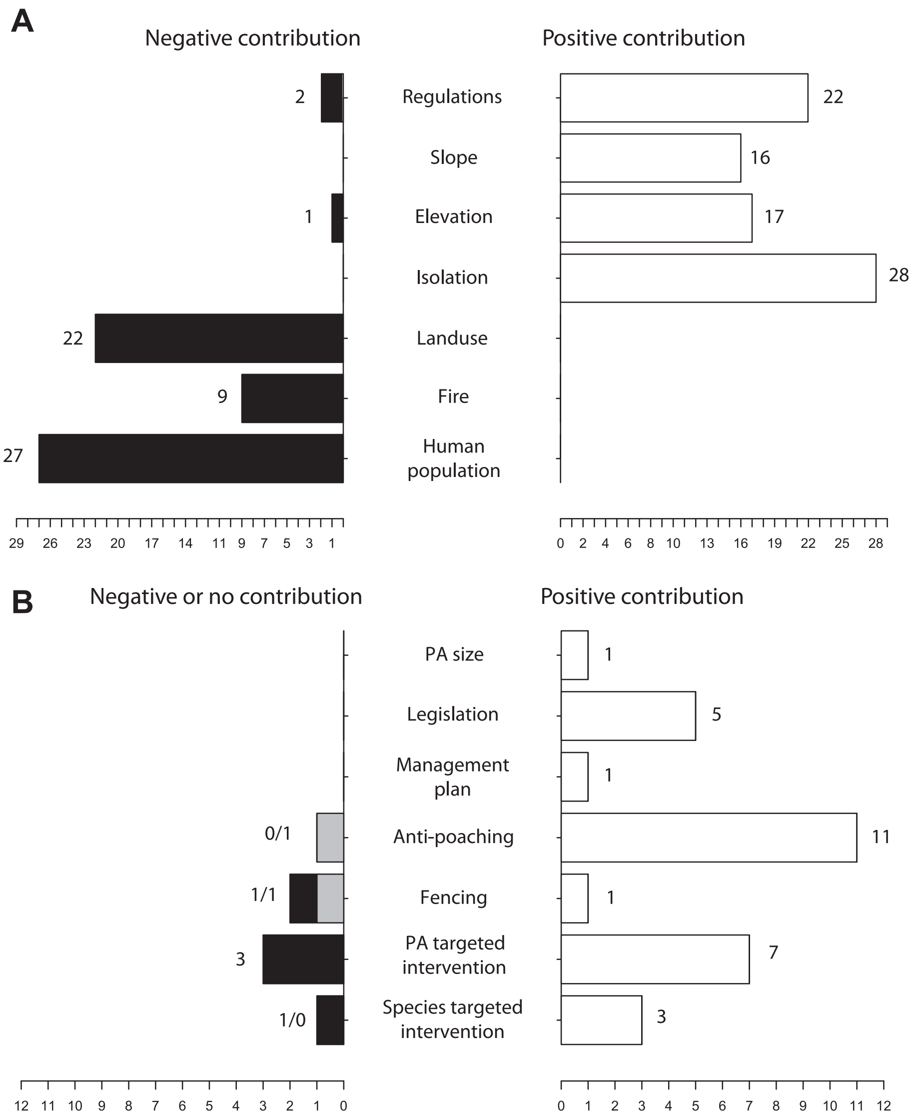

Fig. 1. Effects of drivers and management interventions of (A) habitat change and (B) species population change. The *x*-axis represents the number of studies including specific drivers or interventions. To the right of the center line are studies where drivers and interventions contributed positively to the effectiveness of PAs and to the left are studies where drivers or interventions had no effect (grey) or contributed negatively (black) to PA effectiveness. "No effect" is lumped with negative contributions to reflect the aim of the review to identify which drivers and interventions that could improve PA effectiveness. Total scores exceed the number studies, as some studies reported multiple driver and interventions. For habitat studies (1A) the figure includes 67 studies: 33 inside–outside, 22 regression, eight matching, two ground based, and two using questionnaires. For population time series (1B) the figure includes 35 studies: 13 of those compared populations from one or several PAs to populations with the PAs immediate surroundings, 12 compared the same populations within a PA before and after the implementation of specific management actions, five compared populations between PAs with varying legislation or management, three compared trends in PAs to non-protected land with similar characteristics, two examined the same area before and after establishment of the PA.

Table 3
Summary results derived from analysis of 42 studies of the impact of protected areas on species populations.

Region	Counterfactual				Impact			Taxa		
	Buffer	PA establ.	Strictness of protection	Intervention	Positive	Negative	No effect	Mammals	Birds	Other
Africa	14	1	3	6	18	1	5	22	1	1
Asia	1	1	1	2	4	1	0	4	1	0
Europe	3	1	0	1	3	1	1	0	4	1
Latin America	1	0	1	0	2	0	0	2	0	0
North America	2	0	0	3	3	2	0	3	0	2
Oceania	0	0	1	0	1	0	0	0	1	0
Summary	21	3	6	12	31	5	6	31	7	4

50% declines in wildebeest (*Connochaetus taurinus*) populations after fencing, while lion (*Panthera leo*) populations increased to an estimated three times their natural carrying capacity (Tambling and Toit, 2005).

Ten studies evaluated specific conservation interventions designed to target threats or challenges in the PA (Fig. 1B). Types of actions include: Burning (Schlicht et al., 2009), grazing (Fellers and Drost, 1993; Herremans and Herremans-Tonnoeyr, 2000;

Wegge et al., 2009), predator and invasive species exclusion (Suárez et al., 1993; Whitehead et al., 2008), and involvement of NGOs (Struhsaker et al., 2005). In four cases management was targeted at specific species, including provision of feeding and breeding sites for lesser kestrel (*Falco naumanni*) (Catry et al., 2009) and red-crowned crane (*Grus japonensis*) (Ma et al., 2009), animal-vaccination programs for buffalo and wildebeest (Sinclair et al., 2007), and a failed translocation of proboscis monkeys (*Nasalis larvatus*) (Meijaard and Nijman, 2000).

Thirty-eight of the 42 studies measured one or more additional variables that might be influencing population trends, such as impact of diseases ($n = 4$), weather ($n = 18$), inter and intraspecific competition ($n = 3$ and $n = 16$), food availability ($n = 10$) or habitat properties ($n = 17$) (Table S6). No studies were able to control for the impact of these variables when evaluating the effect of protection, but in all cases the authors indicated they were unlikely to have affected the overall direction of the results.

Fourteen studies considered the impact of predator–prey interactions on population under protection. Of these, seven did not report any effect of protection on interactions, four reported increases in both prey and predator species (Carrillo et al., 2000; Eberhardt et al., 2007; Sergio et al., 2005; Wegge et al., 2009), one reported increases in predator species and declines in prey species (Sinclair et al., 2007) (although declines were smaller compared to the counterfactual), and two studies reported population declines within PAs greater than the counterfactual, possibly due to increased predation (Suárez et al., 1993; Tambling and Toit, 2005).

4. Discussion

This review highlights the limited availability of evidence on the impact of PAs on habitats and fauna. Further, and more alarmingly, there is very little quantitative understanding of how, and under what conditions various PA management interventions improve PA effectiveness.

Analysis of 76 studies across local, regional, and global scales indicates that PAs experience lower rates of habitat loss than areas that are not protected. However, the majority of habitat studies suggest that the effect size of protection is small: PAs may be reducing the rate of decline compared to counterfactuals, but where external threats are high PAs are still experiencing dramatic habitat losses within their borders.

For species populations, the effect of protection is unclear and that this review found only 35 publications with appropriate counterfactuals highlights the lack of sufficient evaluation in PA management. The 42 studies compiled lend some support for PAs being effective, but are not unanimous. This highlights the importance of monitoring in PA management and decision-making – without monitoring we cannot manage effectively (Stem et al., 2005). The majority of publications do show at least some positive impact of protection, but poor sample size, and bias in geography and taxonomy make generalization unwise. Investment in anti-poaching appears to be very effective; however given the limited sample, it is impossible to tell whether publication bias has resulted in only positive or complex outcomes being reported, biasing this conclusion.

Habitat studies generally use remote sensed data, and can generate huge sample sizes across the planet. Unfortunately sufficient accuracy and resolution is primarily limited to forests. Habitat studies have therefore been able to statistically correlate patterns of habitat loss with various exogenous drivers (e.g. Mas, 2005; Mertens et al., 2004), However, few studies have gone beyond spatial layers to study the more subtle impacts of governance structure or management interventions on the ground (Oestreicher et al., 2009). Due to the relatively low cost of using remote sensed data, habitat change is often used as a proxy for overall PA performance. However, remote sensing generally precludes the estimation of changes in degradation and quality, and thus risks overestimating the value of remaining habitat (Redford, 1992; Wilkie et al., 2011). Quantification of the relationship between habitat and other outcomes in PAs would be valuable.

The use of remote sensed data also means that most studies of habitat change are able to estimate some measure of relative impact by comparing the rate of change inside PAs to a counterfactual. However, although such estimates are valid for individual studies, care should be taken when comparing between studies. Further, multiple studies from the same publication are potentially not independent from one another. The overall summary statistics (e.g. number of studies reporting positive or negative outcomes) thus need to be interpreted carefully. As demonstrated by Joppa and Pfaff (2010) the counterfactual chosen (such as buffer analyses vs. matching estimators), and to what extent models control for biases in PA placement (i.e. isolation and topology) greatly influences estimates of the relative impacts of protection. Studies control for potential confounding effects to varying degrees, and this influences the resulting impact ratio. In addition, sample size varies widely between studies, and was often not described sufficiently well to weight in quantitative comparison.

Conversely, in species abundance studies, which require long-term field monitoring inside and outside of PAs, 29 of the 42 studies included measures of endogenous drivers (i.e. staffing, fencing or management plans), but studies generally lacked the coverage required to draw generic and robust conclusions. Further, a large number of natural ecological processes also influence population changes, which makes quantifying the precise effect of protection difficult due to substantial background variance. Events such as droughts and floods, diseases and inter-specific competition affect population numbers, and these events are usually not controlled for in time-series studies (Owen-Smith et al., 2005; Sinclair et al., 2007; Western et al., 2009).

Unfortunately, collection of population time-series data is costly (in time, money and human capacity) It is therefore not surprising that studies are skewed towards 'charismatic' species, and PAs where conservation has a high and direct monetary value (Balmford et al., 2009). While cost is a major factor influencing the implementation of population monitoring, and PA financing generally does not extend to monitoring outside PAs, nor do management agencies usually have the desire, will or capacity to undertake such activities within constrained budgets. Further, many species found within PAs are extirpated outside park boundaries (Metzger et al., 2010), or have migratory ranges extending outside PA boundaries (Thirgood et al., 2004), making even the identification of unprotected control populations challenging.

For the majority of species population studies identified in this review, PA aims were broad, and management objectives were to protect native ecosystems and their constituent species. Less than 12% of studies investigated single-species management interventions. However the importance of broad site-level management even for single-species conservation has been highlighted by several studies (Forrest et al., 2012; Liu et al., 2001; Palomares et al., 2000) and site-level interventions constitute the majority (80%) of suggested interventions for the conservation of threatened species (McCarthy et al., 2012). The effectiveness of PAs is likely to vary with how appropriately specific conservation interventions are tailored to individual species.

4.1. Moving forward

The Convention on Biological Diversity's Aichi target 11 calls for 17% of terrestrial land surface area to be protected and effectively and equitably managed by 2020. Even if the coverage goal is achieved, effective and equitable management is unlikely without site-level monitoring and adaptation. Conservation scientists and practitioners can improve understanding of PA based conservation by: (a) adopting a more experimental approach for the implementation of conservation activities; emphasizing the causal link between interventions and the outcomes being measured and (b) promoting sharing and publication of data in a standardized format, thus facilitating the use and collation of data from across studies.

Most of the 2599 studies considered for this review did not follow a BACI design. BACI design is being increasingly demanded by conservation scientists (Ferraro, 2009; Joppa and Pfaff, 2010), but is still rarely implemented. For too long, past practice and theory have been used to guide decision making in conservation, and in particular in PA decision making. Existing initiatives to collate data on population time-series such as the Living Planet database (Loh et al., 2005) facilitate the 'scaling-up' of multiple small-scale studies by making data freely available in standardized format. Similarly, more recent efforts are underway to collate data on PA management (Leverington et al., 2010) which will aid further analyses of PA effectiveness. Conservation journals could facilitate these efforts by adopting routine policies for data reporting and sharing following publication, and/or ensuring that existing data policies are consistently followed by researchers; currently only 9% of the raw data from high impact publications are made available online (Alsheikh-Ali et al., 2011).

Recent studies illustrate the potential for meta-analyses to identify patterns in population changes: amongst regions of Africa (Craigie et al., 2010), differences in species recovery correlated with increased management activity across Australia (Taylor et al., 2011), or correlation between species persistence inside West African PAs and management resources (Tranquilli et al., 2012). Studies such as these, which go beyond case-based results, help bridge the gap between conservation practitioners working on the ground and the policy processes, setting the stage for further investments and engagement in biodiversity conservation. As studies increasingly document dramatic declines in habitat extent and biodiversity, both inside and outside PAs, the conservation community needs to move beyond asking 'what works' to 'when' and 'why'. This will require further effort to measure reserve effectiveness, and the linkages between input and management measures, and species and habitat outcomes. The continuing reliance on PAs as instruments for the protection of biodiversity means that testing how and why they are effective is of critical importance to conservation science.

Acknowledgements

We thank Professor A. Pullin and the Collaboration for Environmental Evidence for handling the systematic review, and the five reviewers, especially Dr. D. Dawson for invaluable feedback on the original manuscript. We also thank the three anonymous reviewers of this manuscript for valuable contributions and suggestions.

We thank the Danish National Research Foundation for financial support. We also thank the IUCN SSC/WCPA Joint Task-Force on Biodiversity and Protected Areas, UNEP–WCMC, WWF, and the University of Queensland for financial and institutional support.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.02.018.

References

Adams, L.G., Stephenson, R.O., Dale, B.W., Ahgook, R.T., Demma, D.J., 2008. Population dynamics and harvest characteristics of wolves in the Central Brooks Range. Alaska. Wildlife. Monogr. 170, 1–25.

Alodos, C.L., Pueyo, Y., Barrantes, O., Escós, J., Giner, L., Robles, A.B., 2004. Variations in landscape patterns and vegetation cover between 1957 and 1994 in a semiarid Mediterranean ecosystem. Landscape Ecol. 19, 543–559.

Alsheikh-Ali, A.A., Qureshi, W., Al-Mallah, M.H., Ioannidis, J.P.A., 2011. Public availability of published research data in high-impact journals. PLoS One 6, e24357.

Armenteras, D., Rudas, G., Rodriguez, N., Sua, S., Romero, M., 2006. Patterns and causes of deforestation in the Colombian Amazon. Ecol. Indic. 6, 353–368.

Balme, G.A., Slotow, R., Hunter, L.T.B., 2010. Edge effects and the impact of non-protected areas in carnivore conservation: leopards in the Phinda-Mkhuze Complex, South Africa. Anim. Conserv. 13, 315–323.

Balmford, A., Beresford, J., Green, J., Naidoo, R., Walpole, M., Manica, A., 2009. A global perspective on trends in nature-based tourism. PLoS Biol. 7, e1000144.

Bertzky, B., Corrigan, C., Kemsey, J., Kenney, S., Ravilious, C., Besancon, C., Burgess, N.D., 2012. Protected planet report: tracking progress towards global targets for protected areas. IUCN and UNEP-WCMC, Gland, Switzerland and Cambridge, UK.

Bhattacharya, A., 1993. The status of the Kaziranga Rhino population. Tiger Papers 1, 1–6.

Blake, S., Deem, S.L., Strindberg, S., Maisels, F., Momont, L., Isia, I.-B., Douglas-Hamilton, I., Karesh, W.B., Kock, M.D., 2008. Roadless wilderness area determines forest Elephant movements in the Congo Basin. PLoS One 3, e3546.

Bleher, B., Uster, D., Bergsdorf, T., 2006. Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. Biodivers. Conserv. 15, 1159–1177.

Bray, D.B., Duran, E., Ramos, V.H., Mas, J.-F., Velazquez, A., McNab, R., Barry, D., Radachowsky, J., 2008. Tropical deforestation, community forests, and protected areas in the Maya forest. Ecol. Soc. 13, 56.

Brereton, T.M., Warren, M.S., Roy, D.B., Stewart, K., 2008. The changing status of the Chalkhill Blue butterfly Polyommatus coridon in the UK: the impacts of conservation policies and environmental factors. J. Insect Conserv. 12, 629–638.

Brooks, T.M., Bakarr, M.I., Boucher, T., Da Fonseca, G.A.B., Hilton-Taylor, C., Hoekstra, J.M., Moritz, T., Olivier, S., Parrish, J., Pressey, R.L., Rodrigues, A.S.L., Sechrest, W., Stattersfield, A., Strahm, W., Stuart, S.N., 2004. Coverage provided by the global protected-area system: is it enough? Bioscience 54, 1081–1091.

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L., 2006. Global biodiversity conservation priorities. Science 313, 58–61.

Brower, L.P., Castilleja, G., Peralta, A., Lopez-Garcia, J., Bojorquez-Tapia, L., Diaz, S., Melgarejo, D., Missrie, M., 2002. Quantitative changes in forest quality in a principal overwintering area of the monarch butterfly in Mexico, 1971–1999. Conserv. Biol. 16, 346–359.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291, 125–128.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vie, J.C., Watson, R., 2010. Global biodiversity: indicators of recent declines. Science 328, 1164–1168.

Campos, M.T., Nepstad, D.C., 2006. Smallholders, the Amazon's new conservationists. Conserv. Biol. 20, 1553–1556.

Caro, T.M., 1999. Densities of mammals in partially protected areas: the Katavi ecosystem of western Tanzania. J. Appl. Ecol. 36, 205–217.

Carrillo, E., Wong, G., Cuaron, A.D., 2000. Monitoring mammal populations in Costa Rican protected areas under different hunting restrictions. Conserv. Biol. 14, 1580–1591.

Catry, I., Alcazar, R., Franco, A.M.A., Sutherland, W.J., 2009. Identifying the effectiveness and constraints of conservation interventions: a case study of the endangered lesser kestrel. Biol. Conserv. 142, 2782–2791.

Coad, L., Burgess, N.D., Fish, L., Ravillious, C., Corrigan, C., Pavese, H., Granziera, A., Besançon, C., 2008. Progress towards the convention on biological diversity terrestrial 2010 and marine 2012 targets for protected area coverage. Parks 17, 35–42.

Craigie, I.D., Baillie, J.E.M., Balmford, A., Carbone, C., Collen, B., Green, R.E., Hutton, J.M., 2010. Large mammal population declines in Africa's protected areas. Biol. Conserv. 143, 2221–2228.

Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., 2004. Lowland forest loss in protected areas of Indonesian Borneo. Science 303, 1000–1003.

DeFries, R., Hansen, A., Newton, A.C., Hansen, M.C., 2005. Increasing islolation of protected areas in tropical forests over the past twenty years. Ecol. Appl. 15, 19–26.

Devictor, V., Godet, L., Julliard, R., Couvet, D., Jiguet, F., 2007. Can common species benefit from protected areas? Biol. Conserv. 139, 29–36.

Dudley, N., 2008. Guidelines for Applying Protected Area Management Categories. International Union for Conservation of Nature, Gland, Switzerland.

Dudley, N., Stolton, S., 1999. Conversion of "Paper Parks" to Effective Management – Developing a Target. IUCN, WWF, WCPA.

Eberhardt, L.L., White, P.J., Garrott, R.A., Houston, D.B., 2007. A seventy-year history of trends in Yellowstone's northern elk herd. J. Wildlife Manag. 71, 594–602.

Ellis, E.A., Porter-Bolland, L., 2008. Is community-based forest management more effective than protected areas?: a comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico. For. Ecol. Manage. 256, 1971–1983.

Fellers, G.M., Drost, C.A., 1993. Disappearance of the cascades frog *Rana cascadae* at the southern end of its range, California, USA. Biol. Conserv. 65, 177–181.

Ferraro, P.J., 2009. Counterfactual thinking and impact evaluation in environmental policy. New Dir. Eval. 2009, 75–84.

Ferraro, P.J., Simpson, R.D., 2002. The cost-effectiveness of conservation payments. Land Econ. 78, 339–353.

Forrest, J.L., Wikramanayake, E., Shrestha, R., Areendran, G., Gyeltshen, K., Maheshwari, A., Mazumdar, S., Naidoo, R., Thapa, G.J., Thapa, K., 2012. Conservation and climate change: assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. Biol. Conserv. 150, 129–135.

Gaveau, D.L.A., Wandono, H., Setiabudi, F., 2007. Three decades of deforestation in southwest Sumatra: have protected areas halted forest loss and logging, and promoted re-growth? Biol. Conserv. 134, 495–504.

Geldmann, J., Barnes, M., Coad, L., Craigie, I.N., Hockings, M., Burgess, N., 2013. Effectiveness of terrestrial protected areas in reducing biodiversity and habitat loss. CEE 10-007, Collaboration for Environmental Evidence. Available from: <http://www.environmentalevidence.org/ SR10007.html>.

Gough, K.F., Kerley, G.I.H., 2006. Demography and population dynamics in the elephants Loxodonta africana of Addo Elephant National Park, South Africa: is there evidence of density dependent regulation? Oryx 40, 434–441.

Harrington, R., Owen-Smith, N., Viljoen, P.C., Biggs, H.C., Mason, D.R., Funston, P., 1999. Establishing the causes of the roan antelope decline in the Kruger National Park, South Africa. Biol. Conserv. 90, 69–78.

Herremans, M., Herremans-Tonnoeyr, D., 2000. Land use and the conservation status of raptors in Botswana. Biol. Conserv. 94, 31–41.

Hilborn, R., Arcese, P., Borner, M., Hando, J., Hopcraft, G., Loibooki, M., Mduma, S., Sinclair, A.R.E., 2006. Effective enforcement in a conservation area. Science 314, 1266.

Jachmann, H., 2008. Monitoring law-enforcement performance in nine protected areas in Ghana. Biol. Conserv. 141, 89–99.

Joppa, L., Pfaff, A., 2010. Reassessing the forest impacts of protection. The challenge of nonrandom location and a corrective method. Ann. N.Y. Acad. Sci. 1185, 135–149.

Joppa, L.N., Loarie, S.R., Pimm, S.L., 2008. On the protection of protected areas. Proc. Nat. Acad. Sci. 105, 6673–6678.

Joppa, L.N., Pfaff, A., 2011. Global protected area impacts. Proc. R. Soc. B – Biol. Sci. 278, 1633–1638.

Kleiman, D.G., Reading, R.P., Miller, B.J., Clark, T.W., Scott, M., Robinson, J., Wallace, R.L., Cabin, R.J., Felleman, F., 2000. Improving the evaluation of conservation programs. Conserv. Biol. 14, 356–365.

Leverington, F., Costa, K.L., Pavese, H., Lisle, A., Hockings, M., 2010. A global analysis of protected area management effectiveness. Environ. Manage. 46, 685–698.

Liu, J., Linderman, M., Ouyang, Z., An, L., Yang, J., Zhang, H., 2001. Ecological degradation in protected areas: the case of Wolong Nature Reserve for Giant Pandas. Science 292, 98–101.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V., Randers, J., 2005. The living planet index: using species population time series to track trends in biodiversity. Philos. Trans. R. Soc. B: Biol. Sci. 360, 289–295.

Ma, Z.J., Li, B., Li, W.J., Han, N.Y., Chen, J.K., Watkinson, A.R., 2009. Conflicts between biodiversity conservation and development in a biosphere reserve. J. Appl. Ecol. 46, 527–535.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

Mas, J.-F., 2005. Assessing protected area effectiveness using surrounding (buffer) areas environmentally similar to the target area. Environ. Monit. Assess. 105, 69–80.

McCarthy, D.P., Donald, P.F., Scharlemann, J.P.W., Buchanan, G.M., Balmford, A., Green, J.M.H., Bennun, L.A., Burgess, N.D., Fishpool, L.D.C., Garnett, S.T., Leonard, D.L., Maloney, R.F., Morling, P., Schaefer, H.M., Symes, A., Wiedenfeld, D.A., Butchart, S.H.M., 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338, 946–949.

Mduma, S.A.R., Sinclair, A.R.E., Hilborn, R., 1999. Food regulates the Serengeti Wildebeest: a 40-year record. J. Anim. Ecol. 68, 1101–1122.

Meijaard, E., Nijman, V., 2000. The local extinction of the proboscis monkey *Nasalis larvatus* in Pulau Kaget Nature Reserve, Indonesia. Oryx 34, 66–70.

Meir, E., Andelman, S., Possingham, H.P., 2004. Does conservation planning matter in a dynamic and uncertain world? Ecol. Lett. 7, 615–622.

Mertens, B., Kaimowitz, D., Puntodewo, A., Vanclay, J., Mendez, P., 2004. Modeling deforestation at distinct geographic scales and time periods in Santa Cruz, Bolivia. Int. Reg. Sci. Rev. 27, 271–296.

Metzger, K., Sinclair, A., Hilborn, R., Hopcraft, J., Mduma, S., 2010. Evaluating the protection of wildlife in parks: the case of African buffalo in Serengeti. Biodivers. Conserv. 19, 3431–3444.

Mwangi, M.A.K., Butchart, S.H.M., Munyekenye, F.B., Bennun, L.A., Evans, M.I., Fishpool, L.D.C., Kanyanya, E., Madindou, I., Machekele, J., Matiku, P., Mulwa, R., Ngari, A., Siele, J., Stattersfield, A.J., 2010. Tracking trends in key sites for biodiversity: a case study using Important Bird Areas in Kenya. Bird Conserv. Int. 20, 215–230.

Nelson, A., Chomitz, K.M., 2009. Protected Area Effectiveness in Reducing Tropical Deforestation. A Global Analysis of the Impact of Protection Status, The World Bank, Washington DC.

Nelson, G.C., Harris, V., Stone, S.W., 2001. Deforestation, land use, and property rights: empirical evidence from Darién, Panama. Land Econ. 77, 187–205.

Nepstad, D., Schwartzman, S., Bamberger, B., Santilli, M., Ray, D., Schlesinger, P., Lefebvre, P., Alencar, A., Prinz, E., Fiske, G., Rolla, A., 2006. Inhibition of Amazon deforestation and fire by parks and indigenous lands. Conserv. Biol. 20, 65–73.

Oestreicher, J.S., Benessaiah, K., Ruiz-Jaen, M.C., Sloan, S., Turner, K., Pelletier, J., Guay, B., Clark, K.E., Roche, D.G., Meiners, M., Potvin, C., 2009. Avoiding deforestation in Panamanian protected areas: an analysis of protection effectiveness and implications for reducing emissions from deforestation and forest degradation. Global Environ. Change 19, 279–291.

Ottichilo, W.K., De, L.J., Skidmore, A.K., Prins, H.H.T., Said, M.Y., 2000. Population trends of large nonmigratory wild herbivores and livestock in the Masai Mara ecosystem, Kenya, between 1977 and 1997. Afr. J.Ecol. 38, 202–216.

Owen-Smith, N., Mason, D.R., Ogutu, J.O., 2005. Correlates of survival rates for 10 African ungulate populations: density, rainfall and predation. J. Anim. Ecol. 74, 774–788.

Palomares, F., Delibes, M., Ferreras, P., Fedriani, J.M., Calzada, J., Revilla, E., 2000. Iberian lynx in a fragmented landscape: predispersal, dispersal, and postdispersal habitats. Conserv. Biol. 14, 809–818.

Pedrono, M., Ha, M.T., Chouteau, P., Vallejo, F., 2009. Status and distribution of the Endangered banteng *Bos javanicus birmanicus* in Vietnam: a conservation tragedy. Oryx 43, 618–625.

Pettorelli, N., Lobora, A.L., Msuha, M.J., Foley, C., Durant, S.M., 2010. Carnivore biodiversity in Tanzania: revealing the distribution patterns of secretive mammals using camera traps. Anim. Conserv. 13, 131–139.

Pullin, A.S., Knight, T.M., 2009. Doing more good than harm - Building an evidence-base for conservation and environmental management. Biol. Conserv. 142, 931–934.

Redford, K.H., 1992. The Empty forest. Bioscience 42, 412–422.

Rodrigues, A.S.L., Akcakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., Da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004. Global gap analysis: priority regions for expanding the global protected-area network. Bioscience 54, 1092–1100.

Scharlemann, J.P.W., Kapos, V., Campbell, A., Lysenko, I., Burgess, N.D., Hansen, M.C., Gibbs, H.K., Dickson, B., Miles, L., 2010. Securing tropical forest carbon: the contribution of protected areas to REDD. Oryx 44, 352–357.

Schlicht, D., Swengel, A., Swengel, S., 2009. Meta-analysis of survey data to assess trends of prairie butterflies in Minnesota, USA during 1979–2005. J. Insect Conserv. 13, 429–447.

Sergio, F., Blas, J., Forero, M., Fernandez, N., Donazar, J.A., Hiraldo, F., 2005. Preservation of wide-ranging top predators by site-protection: black and red kites in Donana National Park. Biol. Conserv. 125, 11–21.

Sinclair, A.R.E., Mduma, S.A.R., Hopcraft, J.G.C., Fryxell, J.M., Hilborn, R., Thirgood, S., 2007. Long-term ecosystem dynamics in the Serengeti: Lessons for conservation. Conserv. Biol. 21, 580–590.

Stem, Margoluis, R., Salafsky, N., Brown, M., 2005. Monitoring and evaluation in conservation: a review of trends and approaches. Conserv. Biol. 19, 295–309.

Stoner, C., Caro, T., Mduma, S., Mlingwa, C., Sabuni, G., Borner, M., 2007. Assessment of effectiveness of protection strategies in Tanzania based on a decade of survey data for large herbivores. Conserv. Biol. 21, 635–646.

Struhsaker, T.T., Struhsaker, P.J., Siex, K.S., 2005. Conserving Africa's rain forests: problems in protected areas and possible solutions. Biol. Conserv. 123, 45–54.

Suárez, F., Yanes, M., Herranz, J., Manrique, J., 1993. Nature-reserves and the conservation of Iberian shrubsteppe passerines – the paradox of nest predation. Biol. Conserv. 64, 77–81.

Tambling, C.J., Toit, J.T.D., 2005. Modelling Wildebeest Population Dynamics: implications of predation and harvesting in a closed system. J. Appl. Ecol. 42, 431–441.

Taylor, M., Sattler, P., Evans, M., Fuller, R., Watson, J., Possingham, H., 2011. What works for threatened species recovery? an empirical evaluation for Australia. Biodivers. Conserv. 20, 767–777.

Theberge, J.B., Theberge, M.T., Vucetich, J.A., Paquet, P.C., 2006. Pitfalls of applying adaptive management to a wolf population in Algonquin Provincial Park. Ontario. Environ. Manage. 37, 451–460.

Thirgood, S., Mosser, A., Tham, S., Hopcraft, G., Mwangomo, E., 2004. Can parks protect migratory ungulates? the case of the Serengeti wildebeest. Anim. Conserv. 7, 113–120.

Tole, L., 2002. Habitat loss and anthropogenic disturbance in Jamaica's Hellshire Hills area. Biodivers. Conserv. 11, 575–598.

Tranquilli, S., Abedi-Lartey, M., Amsini, F., Arranz, L., Asamoah, A., Babafemi, O., Barakabuye, N., Campbell, G., Chancellor, R., Davenport, T.R.B., Dunn, A., Dupain, J., Ellis, C., Etoga, G., Furuichi, T., Gatti, S., Ghiurghi, A., Greengrass, E., Hashimoto, C., Hart, J., Herbinger, I., Hicks, T.C., Holbech, L.H., Huijbregts, B., Imong, I., Kumpel, N., Maisels, F., Marshall, P., Nixon, S., Normand, E., Nziguyimpa, L., Nzooh-Dogmo, Z., Okon, D.T., Plumptre, A., Rundus, A., Sunderland-Groves, J., Todd, A., Warren, Y., Mundry, R., Boesch, C., Kuehl, H., 2012. Lack of conservation effort rapidly increases African great ape extinction risk. Conserv. Lett. 5, 48–55.

Wegge, P., Odden, M., Pokharel, C.P., Storaas, T., 2009. Predator-prey relationships and responses of ungulates and their predators to the establishment of protected areas: a case study of tigers, leopards and their prey in Bardia National Park, Nepal. Biol. Conserv. 142, 189–202.

Western, D., Russell, S., Cuthill, I., 2009. The status of wildlife in protected areas compared to non-protected areas of Kenya. PLoS One 4, e6140.

Whitehead, A.L., Edge, K.A., Smart, A.F., Hill, G.S., Willans, M.J., 2008. Large scale predator control improves the productivity of a rare New Zealand riverine duck. Biol. Conserv. 141, 2784–2794.

Wilkie, D.S., Bennett, E.L., Peres, C.A., Cunningham, A.A., 2011. The empty forest revisited. Ann. N.Y. Acad. Sci. 1223, 120–128.