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EFFECTIVENESS OF TERRESTRIAL PROTECTED AREAS IN REDUCING BIODIVERSITY AND HABITAT LOSS

Systematic Review

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Summary

Background

Protected areas cover up to 15.5% of the planet's land surface and are amongst the most important tool to maintain habitat integrity and species diversity.
Unfortunately, despite the increase in coverage, there is considerable debate over the extent to which protected areas deliver conservation outcomes in terms of species populations, habitat coverage, or habitat condition.

Ideally the success of protected areas should be measured in terms of whether they improve condition for biodiversity or habitats compared to a control scenario; often the state before their establishment or in comparable areas outside the protected area boundary. This requires an approach able to document a causal link between conservation actions (e.g. establishment of a protected areas or its management) and the observed outcomes (e.g. improved population trends for species or reduced habitat loss).

Objectives

The primary question of this review is 'Do terrestrial protected areas maintain natural species populations and prevent habitat loss?'

Methods

Multiple electronic databases, internet engines, and the websites of specialist organizations were searched to identify published and unpublished literature relevant to the review question.

Predefined inclusion criteria were applied to each article included in the review:

Subject population: Spatially referenced units of biodiversity and/or habitat

Intervention: Establishing a protected area.

Comparators: Inside/outside and before/after establishment of protected areas, and differences in interventions.

Outcome: Changes in species abundance or habitat extent or structure

Types of study: Studies describing a trend or spatial difference in populations, or habitat cover, relating to either management or governance of protected areas, were included. Studies without a counterfactual scenario were excluded. Studies where change in outcomes could not be attributed to PA effectiveness were excluded. All factors described by the studies to have influenced the observed changes besides PA effectiveness were recorded.

Main results

In total, 35 articles containing species population time-series and 51 articles covering habitat change were included in the review. All 86 articles linked the primary intervention (protection) and the observed changes in outcomes (populations or habitats) by either comparing inside to outside the PA or before and after their

establishment. However, because of the multitude of factors impacting changes in outcomes, we did not attempt to compare effect size across papers, instead recording for each study whether PAs had a) no impact, b) positive impact or c) negative impact on outcomes.

All articles were subdivided into studies based on the number of counterfactual scenarios presented, leading to 42 studies on population trends and 76 studies on habitat change. In the studies focusing on species 31 of the 42 studies reported that protected areas (PAs) were effective in protecting target species populations, when compared with a counterfactual scenario. For habitat change, 60 of 76 studies found that the rate of habitat loss was lower inside PAs when compared with a counterfactual scenario. However differences between study-design across studies as well as important regional and contextual differences (especially in the species studies) precludes us from going beyond vote counting of studies, which might bias results reporting to suggest predominantly positive or negative ones.

Conclusions

Implication for policy: For species populations, the low number of studies precludes strong policy recommendations, but we do see a need to make data from monitoring and management programs available, transparent, and standardized.

For habitat protection, the review shows that PAs are an important element of conservation strategies to preserve tropical forests, which was the only habitat for which there was substantial evidence. However, we need to move from a simple understanding of whether PAs are effective or not (which can be established using remote sensing studies) to why they are effective (i.e. how 'on the ground' actions influence PA effectiveness, requiring in-situ research), in order to guide PA managers and improve PA performance.

Implications for research: One of the most important conclusions from this review remains the call for systematic reporting and documentation of conservation projects, as well as the inclusion of pressures and responses in the study design of ecological experiments. This includes the need for an improved methodology for the studies of population trends, using BACI (before/after and control/intervention) design to ensure that observed changes can be linked to the human conservation interventions and thus increase our knowledge on what can be done to halt the loss of biodiversity.

Keywords

Effectiveness, Habitat change, Management, Population change, Protected area,

1. Background

Protected areas (PAs) cover up to 15.5% of the planet's land surface, depending on the definition chosen [1], exceeding the Convention on Biological Diversity (CBD) 2010 global target of 10%. They are perhaps amongst the most important tools to maintain habitat integrity and species diversity [2-9]. In addition to protecting biodiversity and habitats, protected areas are also increasingly recognized for their role in protecting ecosystem services such as carbon storage and sequestration, pollination, water, climate and soil stabilization, and various timber and non-timber products [10-15]. Politically, international conservation strategies implemented by both governments and Non-Governmental Organizations (NGOs) rely primarily on PAs to safeguard biological diversity, as was confirmed by the new 2020 increased protected area estate targets of the CBD CoP10 in Nagoya, Japan from 10% to 17%.

Despite the increase in coverage, there is considerable debate over the extent to which PAs deliver conservation outcomes in terms of species and habitat protection [2, 8, 16-22]. It has been suggested that many of the world's PAs exist only as 'paper parks' [23, 24], having no effective management on the ground, and are thus unlikely to deliver benefits for conservation [25, 26]. Whether PAs deliver conservation benefits for species and habitats is an essential question, for policy makers, planners, managers and conservation advocates [3, 9, 27-33].

Conservation success has traditionally been defined and evaluated in different ways, largely depending on the context and the available data. Studies on the effectiveness of PAs have examined the representativeness of PA networks in terms of their coverage of species diversity, endemism, or exposure to threats [34-37]. These gap analyses have been applied at global [36], continental [38], sub-regional [39], national [40, 41] and sub-national scales [42, 43]. Although PA gap analyses are valuable in planning conservation, and can inform the design of protected area networks, they do not examine whether these reserves effectively protect and preserve biodiversity. Indeed, whether the particular location of protected areas has any effect on the survival of animals and plants cannot be inferred from their existence alone, but must be tested by evaluating the effect of the protected area on a set of *a priori* defined criteria of conservation success. Thus the success of PAs depends on whether the condition of these is superior compared to a control scenario; either the state before their establishment or in comparable areas outside the protected area boundary. This requires an approach able to document a causal link between conservation actions (e.g. establishment of protected areas or management of these) and the observed outcomes (e.g. superior population trends for species or reduced habitat loss).

A lack of data has been the primary reason why it has been difficult to go beyond measuring the representativeness in biodiversity coverage of PA networks (e.g. [8]), or assessing reserve management initiatives inside PAs (e.g. [44]), to measuring the effectiveness of PAs in conserving biodiversity. This shift has also been influenced by discussions on how biodiversity outcomes might best be measured [45-48], and an increasing demand for more rigorous analysis to ensure reliable results [49-51].

In this review we examine the global evidence, to determine whether there is a relationship between the quality of terrestrial PAs and their effectiveness and the biological outcomes in those protected areas. Specifically we examine changes in a) habitat cover and b) species populations. We have not considered marine or freshwater protected areas in this assessment.

2. Objective of the Review

2.1 Primary question

Do protected areas help improve natural species populations and prevent habitat loss compared to a counter factual scenario?

Our primary focus was on studies that evaluate whether protected areas are effective in promoting a positive change in biological outcomes compared to if the protected areas had not been established. We included both comparisons of areas over time before and after protection was established, and comparisons of similar land areas inside and outside protected areas.

2.2. Secondary question

Which drivers and actions help determine PA effectiveness?

We did not *a priori* define "drivers" or "actions", but referred to those described in the individual papers accepted for the systematic review.

Table 1. PICO elements of the review question

Question/Element	Definition
Subject population	Spatially referenced units of biodiversity and/or habitat
Intervention	Establishing a protected area, including any type of management as defined in the individual study (e.g. staffing, budgets or activities)
Comparators	Inside/outside protected area comparison. Before after establishment of protected areas. Drivers and interventions, where described.
Outcome	Changes in species abundance or habitat extent or structure

3. Methods

The review was conducted following an a-priori protocol, which was peer reviewed and posted at http://www.environmentalevidence.org/SR10007.html

3.1 Search strategy

The effectiveness evaluation was divided into two separate searches reflecting the two distinct outcome variables *i)* species abundance and *ii)* habitat area/extent. A large number of English scientific bibliographic databases, search engines, expert sources and conservation organization websites were surveyed for the systematic review:

<u>Online databases and catalogues:</u>
BIOSIS citation index, Directory of Open Access Journals, Index to Theses Online, ISI Web of Knowledge, ProQuest, Science Direct, SCOPUS, SCRIS, World Environment Library, and Zoological records

<u>Specialist websites</u>
CIFOR, Conservation International, Conservationevidence.org, COPAC, FAO, Forestscience.info, IUCN, United Nations Development Programme, World Bank, World Conservation Monitoring Centre, Wildlife Conservation Society, and WWF,

<u>Internet search engines</u>
Google scholar

Besides English, the search was also conducted in Spanish and Danish, though only in ISI Web of Knowledge and Google scholar. The languages used for the search were selected based on the language skills amongst the review team.

Relevant terms were compiled from the referenced literature or derived directly from the questions addressed in the review (Table 2). The list of terms was subsequently reviewed by anonymous reviewers facilitated by the Collaboration for Environmental Evidence, as part of the systematic review procedure to ensure that important terms were not left out or redundant ones included [52]. Boolean nomenclatures were used when appropriate. For some search engines with limited search capability the number of search terms was reduced.

Table 2: English search terms used in the systematic review

Outcome	Protected Area	Management	Output
Biodiversity	"Indigenous people"	Monitor*	Effect*
Population*	"Community conser- ved area$"	Management	Effectiveness
Species		Governance	Outcome
Threaten*	Habitat$	Conserv*	Success
"Threatened species"	"National park$"		
"Red list*"	"Protected area$"		
Trend$	Reserve*		
Endanger*			
Increase*			
Decline*			

Danish search terms: naturforvaltning, biodiversitet, monitering, forvaltning, afskovning, skov, forvaltningseffektivitet, succes, arter, truede$arter, trend*, truede*, endemisk*, rødliste*, sammensætning, habitat, ødelæggelse, beskyttede$område*, beskyttede*, nationalpark, reservat*
Spanish search terms: Conservación, Biodiversidad, Seguimiento, Gestión, La deforestación, Bosque$, Selva$, Silvestre, Forestales, La degradación, Eficacia, La eficacia, Resultado$, Resulta$, Efect*, Éxito, Éxito, Un Éxito, *Especi*, specia, Las especies en amenaza, Tendencia$, Endémica$, composición, Lista$rojo, Amenaza*, En$ amenaza, Poner en peligro*, *Disminución, , Hábitat*, Destrucción, *Salida*, Gobernabilidad, Protegida$, Área$, Zona$, Nacional*, Parque$, Parqu$$naci$nal*,

Reserva$, Comunid*,*Conserv*, *Preserv*, PersonaIndgena*, área de conservation de la comunidade, áreas de conservation de las comunidades

Online databases and catalogues:
Articles were ordered by relevance, where this feature was available, and searches were restricted to papers within the databases' 'conservation' categories to increase the relevance of papers found. All articles were first assessed by title alone based on the PICO table. Papers accepted based on title were subsequently reviewed by abstract and finally full text.

Specialist websites
Library and report sections of the websites were located and reports assessed by title. Potentially relevant sources were downloaded and fully assessed.

Internet search engines
Different combinations of search terms (Table 2) were used so that all categories were represented in all searches. The first two hundred hits of all search combinations were assessed.

The search was first conducted using ISI Web of Knowledge, and results from other search engines, and specialist websites were subsequently added to the two lists of population time-series and habitat articles respectively. This insured that duplicates were removed throughout the search process. Articles that were evaluated to be outside the scope and question of the systematic review or did not follow the study inclusion criteria or quality assessment were removed from the list, as they were identified.

The final list of papers generated using the systematic search approach, was subsequently shared with an expert group of about 15 people from the IUCN joint taskforce on Biodiversity and Protected Areas. They were asked to contribute any papers or reports not included in the primary list based on their extensive knowledge of the subject area.

3.2 Study inclusion criteria

Predefined inclusion criteria were applied to each article included in the review:

Subject population: Spatially referenced units of biodiversity and/or habitat

Intervention: Establishing a protected area.

Comparators: Inside/outside and before/after establishment of protected areas, and differences in interventions.

Outcome: Changes in species abundance or habitat extent or structure

Types of study: Studies describing a trend or spatial difference in populations, or habitat cover, relating to either management or governance of protected areas, were included. Studies without a counterfactual scenario were excluded.

Studies describing a trend or spatial difference in populations, or habitat cover were included in the study. Studies without a counterfactual scenario, i.e. studies of population or habitat condition only inside PAs, rather than also in external areas, were excluded, unless these presented data on populations or habitat before and after implementation of conservation intervention.

PAs were not defined *a priori* using international standards [53], but instead the definitions were based on the information in the studies reviewed, i.e. we did not cross reference PA descriptions with IUCN criteria or the World Database of Protected Areas (WDPA) but accepted definitions presented in the articles.

Within the articles that met the search criteria, we extracted information on drivers, actions, and interventions reported to impact PA effectiveness, as well as information on possible biases, and ecological factors reported to contribute to the variation observed in the populations or habitat change (Figure 1).

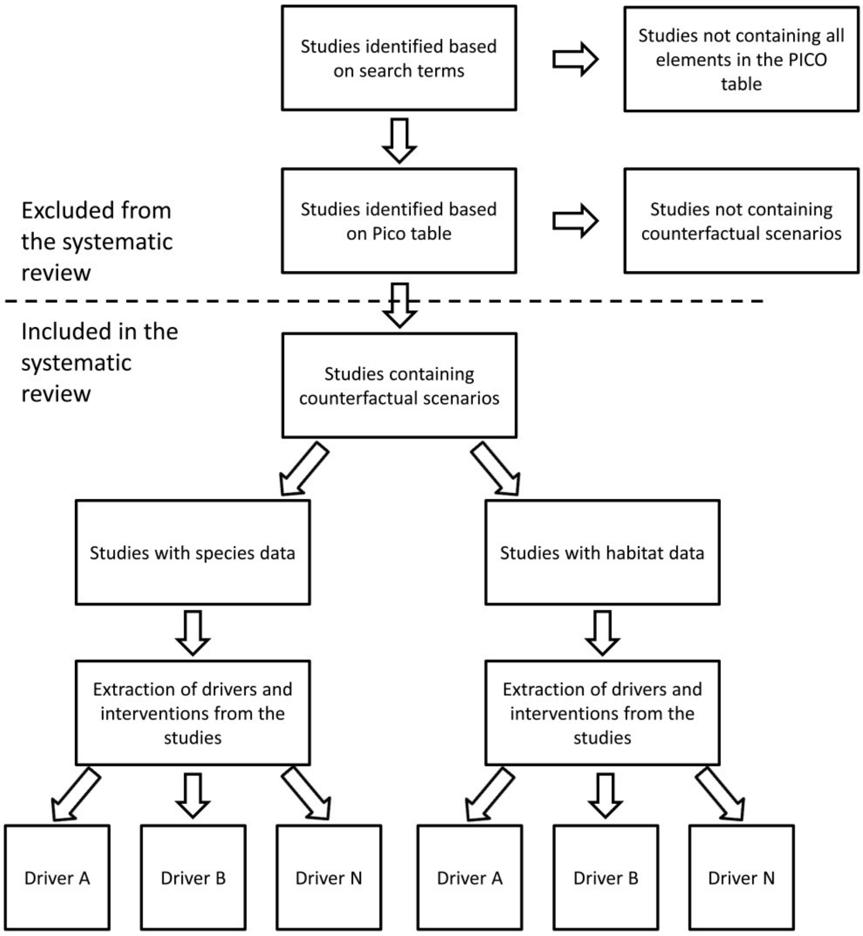

Figure 1. Flow chart of search strategy and extraction of information from articles identified through the searches.

A kappa analysis to evaluate the comparability of search results by the different reviewers [54] was conducted for habitat and biodiversity respectively on title and on abstract. After sorting using the relevance function in Web of Knowledge, the first 200 papers were included in the Kappa analysis, and reviewed by two independent reviewers. This was to evaluate to what extent the results found by the individual reviewers reflected a mutual understanding of the criteria for the search.

At full text, all included articles were first screened by one of the reviewers for *i)* link between intervention and population change, *ii)* PA information, *iii)* conservation objectives and *iv)* data, review or essay driven analyses. Articles that were selected by one or more of the reviewers based on the above criteria were subsequently evaluated by all authors. Only papers accepted by all reviewers were included in the review (see supplementary material for list of articles excluded at full text).

3.3 Study characterization & quality assessment

For papers where multiple PAs were examined against different counterfactuals, such that the paper 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 papers and are henceforth referred to as: "studies".

For all study we evaluated whether there were direct observations of population trends, indices or expert evaluations. All measures were included in the final review. For habitat the remote sensing product or the on-ground evaluation method was assessed. We also recorded whether comparisons were spatial (control/intervention) or temporal (before/after).

For all studies we collected information to assess the ability to link input and outcomes and to evaluate their ability to make quantitative or only qualitative evaluations of the effect of protection and secondarily interventions. Recorded characteristics included elements of the following:

- Country and geographical area of study
- Governance factors influencing protection
- Counterfactual scenarios (BACI)
- Reported confounding factors i.e. weather, diseases, predation and intraspecific competition
- Actions and management interventions aiming to improve effectiveness
- Contextual factors reported do reduce effectiveness
- Number of species used in the study-design
- Methods for data collection and type of analysis
- Predator-prey interactions

All of the above was used to critically appraise the included studies and evaluate to what extend results and conclusions were appropriate to support the statements of PA effectiveness as reported in the papers.

For population time-series studies we evaluated the quality of the connection made between interventions and outcomes, i.e. if the authors were able to experimentally link the change in intervention with change in population trends or whether they could only document effect/no effect. We further recorded the methodology used to estimate populations as well as recorded biases in population estimations and if methodology prevented linking interventions with outcomes to what extent this was the case.

For habitat studies we extracted information on habitat change inside and outside PAs, where this information was available. Where no quantitative data on habitat change were presented we evaluated the evidence of PA and management effectiveness, based on our evaluation of the qualitative difference between the protected and the control scenario. We also recorded the overall trend of change inside the PAs. For all studies statistically testing the effectiveness of PAs we extracted information on the model used to analyze the effectiveness of protection and to what extent the model included contextual factors as additional predictors of effectiveness.

For all studies we assessed the author's ability to attribute changes observed in outcomes measures to PA existence. Studies that were not able to include the effect of factors other than PA existence were also included, when the impact of the PA was causally linked to outcomes measures, even if not explaining all variation observed.

Where studies evaluated the same site, 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). PAs evaluated as part of a site level study will also have been evaluated as part of a global or regional study. In this case both studies were included, as results for one level could not be directly extracted to another. Thus, the results presented at different levels contribute different information on PA effectiveness

3.4 Data extraction and synthesis

For each source, the following data were extracted:

1. Location of the PA,
2. Study site "characteristics" (e.g. forest, grassland, etc.),
3. Intervention (e.g. type of PA),
4. Actions (e.g. management and governance measures)
5. Outcomes measures (e.g. deforestation, species populations and diversity),
6. Methodology (e.g. temporal and spatial as well as data-collection approach and types of analysis), and
7. Other effect modifiers (e.g. impact of weather/climate, disease outbreaks, and species interactions)

Although the question of whether PAs protect species populations is of critical importance in conservation, there exists no standard framework to report this. The extensive need for documentation and the large number of potential factors influencing population time-series reduced our ability to calculate the effect of interventions, even less to compare these between studies. For studies on changes in population time series we recorded whether there was a difference between trends inside and outside, or before and after interventions as well as the direction (+ / 0 / -). Thus where quantitative data were presented we evaluated differences between areas with interventions and without to obtain an effect measure of the interventions (measuring only the direction). Although we acknowledge that estimation of an explicit effect size is important, this was not attempted because no studies could report effects of protection independently of other factors, thus where data on inside/outside or before/after was presented the differences never only reflected the effect of protection. Based on the quality assessment, we therefore carefully evaluated whether the difference could be contributed to protection, and collected all relevant information contained in the sources on other factors believed to impact the measured outcome.

Where the impact of an action or driver within a PA (i.e. enforcement, management actions etc.) was not directly measured (i.e. through regression modeling), but the direction of the impact reported (i.e. increasing or decreasing effectiveness), the methods and conclusions in the papers were examined and evaluated to ensure that the reported effect of the action/driver was credible.

Due to the constraints outlined above, no quantitative meta-analysis of the studies was attempted and we present only a narrative synthesis in the form of tables, figures, and text.

For articles on habitat change, a large number of studies reported annual or total changes in habitat cover. We did not attempt to conduct a meta-analysis of habitat studies as a) there was high diversity in background condition influencing the specific studies (discussed previously and b) many studies presented an combined effectiveness measure for multiple protected areas, and therefore could not be compared with studies which presented effectiveness measures for single PAs. . Where information on drivers of habitat change was included in the analysis we recorded these. In studies not including drivers explicitly in any analysis, but otherwise documenting their impact, this was evaluated and recorded.

For all studies we recorded all factors that were documented or speculated to also affect the observed patterns in outcome variables. This was done by evaluating the methods, results and discussion section of the articles recording data collected or observation made in the studies. This could be everything from recording of precipitation or droughts to speculations on the importance of inter- or intraspecific completion amongst species.

4. Results

4.1. Search results

Literature searches were conducted from July-August 2010. Search results were recorded in an excel spread sheet as well as Endnote, and duplicates were removed as they were found. This method did not allow for subsequent evaluation of the contribution of each web source, though it could be established that the main search engine providing results was ISI Web of Knowledge (WoK). A post hoc test, searching for each article separately showed that all but one [112] could be found using only WoK. The Kappa analysis was restricted to the results from WoK.

The kappa analysis for papers on species trends in PAs showed a moderate similarity between searches of the two reviewers when based on paper titles alone (k = 0.51).

When the search included the papers' abstracts, the similarity was improved (k = 0.77).

A total of 97,737 articles were found using the search terms listed in the method section (Table 2). Restricting the search to the topic of 'Biodiversity and Conservation', as defined by WoK, reduced the number of articles considerably to 2,599. Following title assessment, less than 300 (ca. 10-12%) of the papers were evaluated based on their abstract and full text (see Appendices A & B for lists of those excluded at these stages).

We tested *a posteriori* the impact of restricting the search to only capture studies in the 'Biodiversity and Conservation' category of WoK by evaluating the first 200 papers without any restricting filters, sorted by 'Publication Date – newest to oldest' and 'Relevance' respectively. The 'publication date' search yielded five papers inspected by abstract, of which all were rejected and two were already contained in the Biodiversity and conservation search. Sorting the search result by 'relevance' yielded 36 papers which were inspected by abstract. Of these seven were already included in the review, 24 were already captured by the 'Biodiversity and Conservation' search, while five were rejected at the level of abstract. All together 395 unique sources were evaluated yielding no new papers.

The majority of papers reviewed were excluded at the title stage, because they fell far outside the scope and question of this review. The majority of articles excluded at the abstract and full text stages were articles on population time-series that only speculated on the effects of conservation actions, or suggesting their relevance for conservation, without any data or testing of these statements. These were primarily papers on population demography, ethnography, population studies only inside PAs, or without links to any PA.

The expert evaluation of the final list, facilitated through the IUNC SSC/WCPA taskforce on Biodiversity and Protected Areas did not contribute any additional articles that met the criteria for the review.

The peer-review and open consultation process of the manuscript yielded two new articles [60, 97], both published after the original search dates. The final number of papers included in the systematic review was 35 on population time series and 51 for habitat change.

4.2. Species trends

4.2.1. Number of papers and spread of data

We found only 35 articles on species population trends in PAs which met the search criteria (Table 5). A large number of the articles were excluded on the basis of lacking counterfactual data and containing only anecdotal evidence. Three articles on population trends covered more than one evaluation of PA effectiveness and four articles covered the same two sets of original data, yielding to a total of 42 studies across the 35 articles.

Of the 42 studies included, 35 examined five or less PAs and the remaining seven regional or national PA networks. In total, the reviewed studies covered 70 distinct PAs plus four studies with no information on the specific PAs included [55-60] (Figure 2).

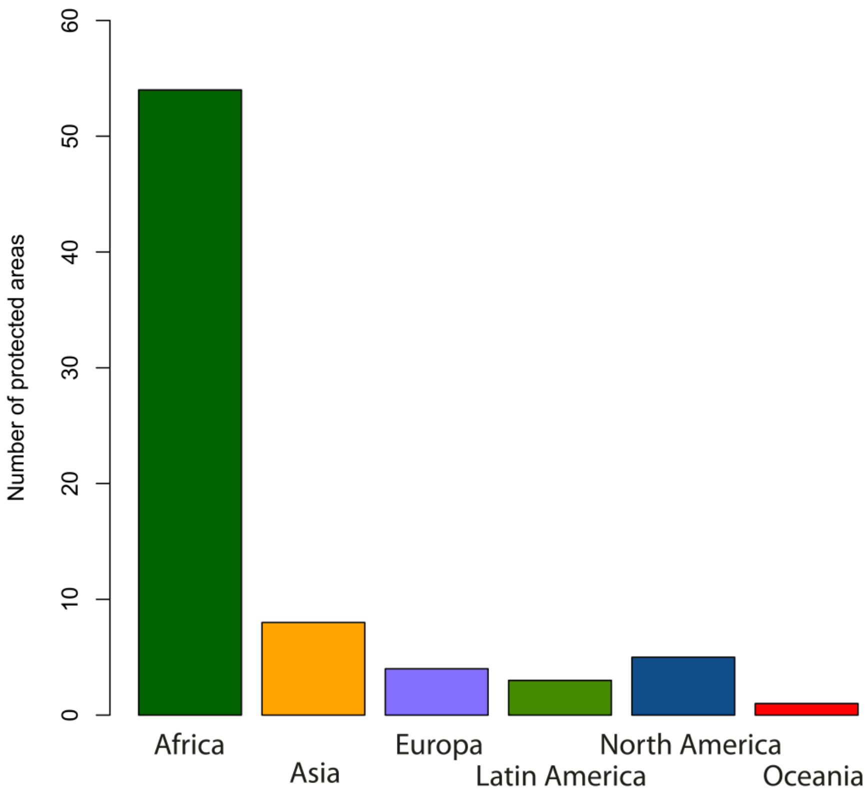

Figure 2. Number of protected areas by continent where PA effectiveness in conserving target species populations has been measured using appropriate counterfactuals (n=42 studies).

Most of the data (74%) came from PAs in tropical regions, with 24 studies from Africa, five from Asia and two from Latin America. North America (n=5) and Europe (n=5) represented 24% of the studies and Oceania (n=1) made up the last 2%.

Table 3. Overview of the 40 articles which measured PA effectiveness in conserving target species populations using appropriate counterfactuals

Continent	Total studies	Total effective	Mammals	Birds	Other taxa
Africa	24	18	22	1	1
Asia	5	4	4	1	0
Oceania	1	1	0	1	0
Europe	5	3	0	4	1
Latin America	2	2	2	0	0
North America	5	3	3	0	2
Total	42	31	31	7	4

The category "others" contains studies on insects and amphibians. "Effective" refers to the number of studies, where species population trends in reserves were positive compared to the counterfactual scenario, albeit overall trends might still be negative both under management and without.

Of the total of 42 studies, most studied mammals (74%), followed by birds (17%), insects (7%) and amphibians (2%). Thirty-seven of these studies, that contained species information, covered 233 different species from 456 populations. Two-hundred-twenty-six populations were mammals and 100 came from one study of bird populations in France [59] (Figure 3). In four studies we were not able to determine the species involved [58, 61-63].

Seventeen studies were single species, 20 studies were of assemblages of species (<50), and five were of multiple species (>50) or alternative measures of biodiversity.

The most common method for collection of population estimates were ground based methods; either spot counting for birds or transects for mammals (n=24), followed by aerial count (only used for mammals) (n=15), individual observations with radio-telemetry or capture-recapture (=3), camera trapping (n=2) or questionnaire and other methods (n=4). Six studies used more than one method, which explains why the total exceeds 42.

Thirty-eight of the 42 studies measured one or multiple 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, 16), food availability (n=10) or habitat properties (n=17). No studies were able to control for the effects of these variables when evaluating the effect of protection. However in all cases they were considered by the paper authors not to affect the overall direction of the results.

Fourteen studies considered the impact of protection on predator-prey interactions. Of these, seven did not report any interactions, four reported increases in both prey and predator species [64-67], one study reported increases in predator species and declines in prey species [68] where declines were still smaller compared to the counterfactual, and two studies reported populations declines within PAs which were greater compared to the counterfactual, possibly due to increased predation [62, 69].

In terms of the counterfactuals used, 15 used a Before/After counterfactual: three studies compared the same area before and after establishment of the PA, and twelve compared the same populations within a PA before and after implementation of management interventions (which we have grouped into 5 main categories). Twenty-seven used a Control/Intervention counterfactual: 16 compared populations from one or several PAs to populations with the PAs immediate surroundings, five compared trends in protected areas to non-protected land with similar characteristics but not adjoining the reserve, and six compared populations between PAs with varying legislation or management regulations (Table 6).

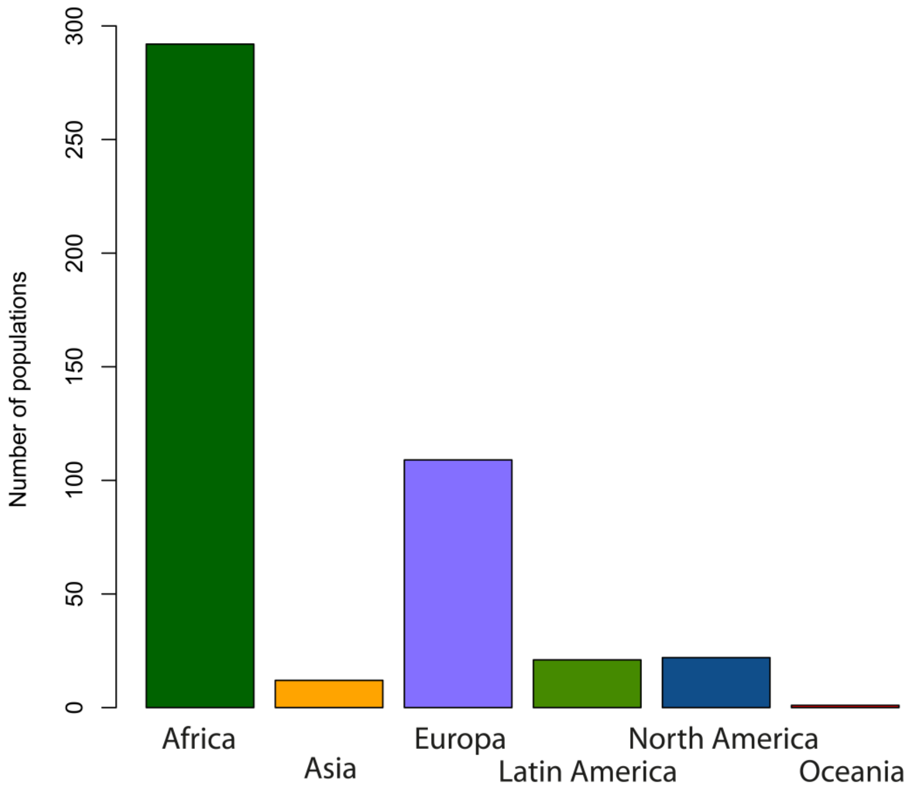

Figure 3. Total number of species included in studies of PA effectiveness, by continent.

4.2.2. Population trends

Narrative synthesis
Based on the critical appraisal of all studies accepted for the systematic review, we decided against a meta-analysis of the available data. Though all studies included were evaluated to be able to answer the simple question: did the protected area a) contribute positively to the observed temporal pattern in outcome variables, b) contribute negatively to the observed temporal pattern in outcome variables, or c) make no measurable contribution to the observed temporal pattern in outcome variables, the number of confounding factors which could influence the observed temporal pattern were in all cases estimated to be of possible significant importance, precluding measures of effect size and a meaningful quantitative comparison across studies. Thus we restricted ourselves to a narrative synthesis. However for all studies we recorded the factors reported to influence the observed temporal pattern.

The time periods for population trend measurements ranged from two years [70, 71] to 70 years [65]. The mean time series was 17 years and the median was 14.

Descriptions of all studies can be found in Table 5 and 6. In 16 of the 42 studies populations increased, while in 22 they decreased, compared to the first year of sampling. In three cases populations remained stable or no overall change could be determined between first and last year of sampling (Table 5).

In 31 of the 42 studies populations did better within PAs compared to non-PAs, or compared with the situation prior to PA designation/interventions. PAs were considered effective even if overall trends were negative inside PAs, so long as the rate of population decline within PAs was lower than in the control (outside PAs, or before PA designation). In five cases no effect of protection could be detected, and in six studies, a negative effect on population trends were observed inside PAs than compared to controls: In southern and central Spain five species of passerine birds declined, perhaps from increased predation, after management had reduced hunting pressure on natural predators [62, 66]. In Pilanesberg National Park, South Africa, the increased populations of lions (*Panthera leo*) following fencing of the reserve correlated with decreases in populations of blue wildebeest (*Connochaetus taurinus*) [69]. In Lassen Volcanic national park, California, USA, preservation of the area's natural values through fire reductions and suppression of cattle grazing was followed by a decline in Cascades frogs (*Rana cascadae*) apparently from the loss of open habitats through forest regrowth [72]; and similarly a decline in rare species of butterflies was observed in preserved Minnesota prairies following an increase in fire frequencies [58].

4.2.3. Management actions and attributes

Within those studies which matched the search criteria (42 studies which measure the effect of PAs on species populations, with appropriate counterfactuals) we then evaluated the studies to see whether PA effectiveness had been linked in the study to any specific PA management activity or PA characteristics.

We grouped the reported interventions in seven categories: *i)* PA size and infrastructure, *ii)* legislative and governmental regulations, *iii)* PA management plans *iv)* guards and anti-poaching, *v)* fencing, *vi)* threat reduction, and *vii)* targeted interventions for focus-species (Table 4). These categories were not based on *a priori* criteria but reflected management reported in the studies (Figure 4).

Table 4. Examples for each of the seven categories used to group management actions and attributes.

Category	Source	Description
Protected area size	Laidlaw, 2000	Study on increased path size of protected area network
Legislative and governmental regulations	Struhsaker et *al*., 2005	National regulations were tightened to protect endangered species.
Unspecified management intervention (management plans)	Pettorelli et *al*., 2010	Protected areas managed after management plans (MP) did better, but no details of the MP was disclosed
Specified management intervention (guards and anti-poaching)	Caro, 1999	Anti-poaching efforts inside park and increased guard presence
Specified management intervention (fencing)	Gough and Kerley, 2006	Reserve boundaries was fenced to protect elephant populations
Specified management intervention (species)	Catrey et al., 2009	Artificial nest sites were supplemented to facilitate increased breading success
Specified management intervention (Protected area)	Schlicht et al. , 2009	Regulation of vegetation inside reserved with initiation of fire

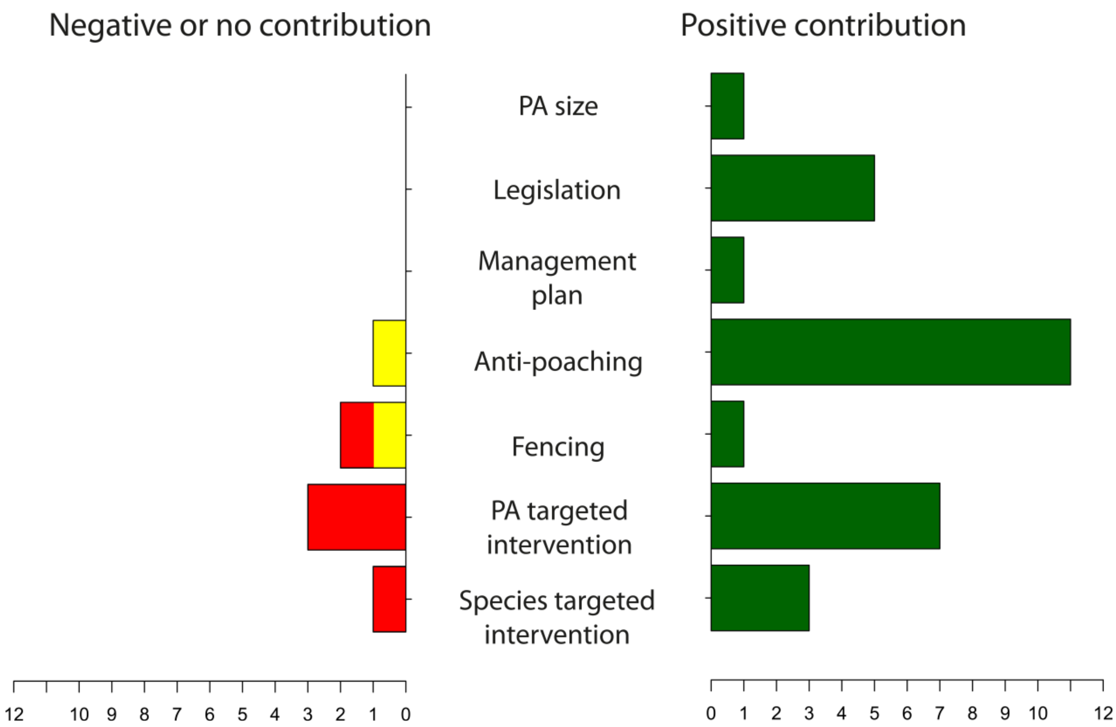

Figure 4. Reported management actions for population time-series studies. Number of studies is described on the x-axis. Green indicates reporting of positive results of interventions, orange that no difference was detected and red that the intervention was reported as negative compared to control scenario. The total number does not equal 42 as six studies reported more than one management intervention fitting the categories.

In three cases authors looked at the effect of habitat fragmentation or increasing the size of PAs [71, 73, 74]. Six studies investigated either multiple PAs with different legislative frameworks [63, 75], or the same PAs before and after new legislation targeted biodiversity conservation was implemented [57, 76-78] and all reported positive effects. The same was the case for studies implementing management plans [57, 79-81].

The most commonly reported management intervention was actions aimed at reducing poaching of which all were looking at responses in mammal populations with the majority (n=7) from African PAs. Eleven out of 12 studies reported improved biodiversity outcomes linked to these activities to reduce poaching.

One out of three studies found positive impacts of fencing [66, 69, 82] and one described negative effects through trophic displacement. In all studies looking at the effect of fencing, they only evaluated one protected area against the conditions outside.

In ten studies, conservation interventions were targeted at specific threats or challenges inside PAs, which covered management of grasslands, including burning [58] and grazing [56, 67, 72], predator and invasive species exclusion[62, 83], and involvement of NGOs [63]. In five cases management was targeted a specific (monitored) species, including provision of feeding and breeding sites [82, 84, 85], animal-vaccination programs [68], and one failed translocation [86].

4.3. Habitat Change

4.3.1. Number of papers and spread of data

We found 51 articles on the ability of PAs to maintain habitats. Within 13 of the 51 studies on habitat change there were multiple counterfactual scenarios, and when separated these yielded a total of 76 individual studies for further analysis. Of these studies 18 were from Africa, 16 from Asia, one from Europe, 35 from Latin America, one from North America (USA and Canada), two from Oceania, and four were global studies. All except three were from the tropics and all except the European study were on deforestation, though seven of these studies included other habitat types too (Figure 5).

Studies of habitat change were divided into four categories based on the studies' scale: *i*) single PAs (n=25), *ii*) PA networks (<50) (n=21), *iii*) larger PA networks (>50) (n=17), or *iv*) continental or global (n=13).

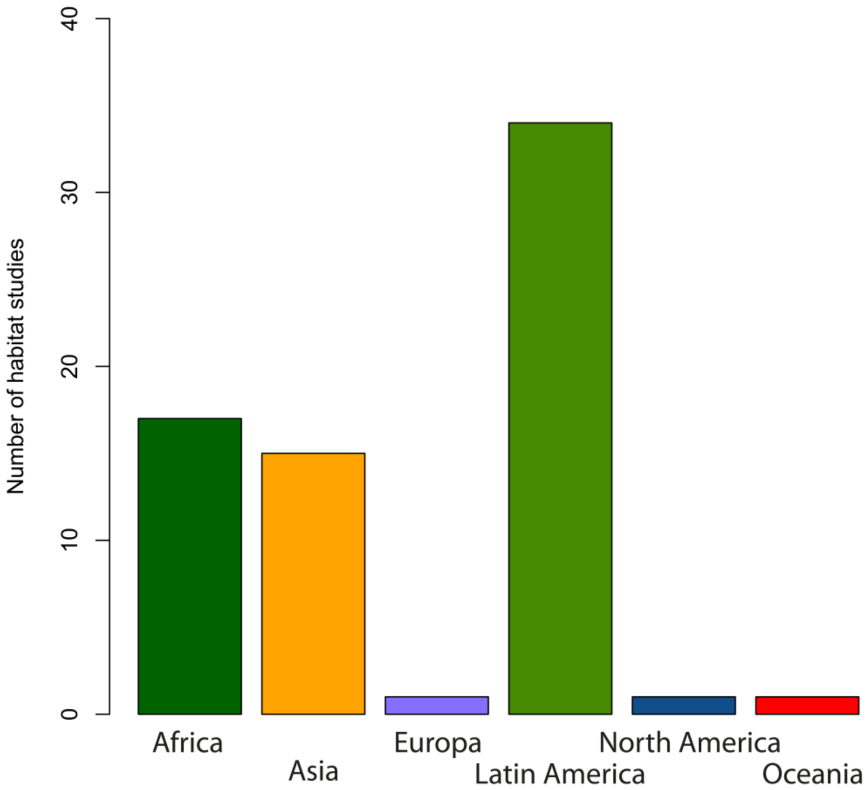

Figure 5. Geographical distribution of habitat change studies.

4.3.2 Estimates of habitat change

Narrative synthesis

Though most studies used a comparable measure of outcome (remote sensing products) we decided against a meta-analysis of the data, as a) the number of factors estimated to influence the observed temporal patterns was too many to make such comparisons meaningful and b) Many studies presented a combined effectiveness measure for multiple PAs, and therefore could not be compared with studies which presented effectiveness measures for single PAs. We therefore report a) the direction of effectiveness and b) the factors affecting the outcome, without making quantitative analysis of effect size. However, for all studies where it was possible we calculated the difference between the rates of change inside compared to the counterfactual scenario (Table 7). Comparing these rates across studies should be done with consideration of the confounding variables influencing these, differences in sample sizes, and methodologies. All factors which influence the values reported and which cannot be standardizes across studies.

Of the 76 studies that aimed to measure the effect of protection on forest cover (Table 8), 68 used satellite remote sensing techniques to obtain a Normalized Difference Vegetation Index (NDVI). Such studies are only reliable for changes in habitat cover visible from a satellite: usually forest clearing and regrowth and are not able to measure habitat degradation. Five studies used measures collected on the ground, either estimation of disturbance across plots, [45, 87] or interviews and questionnaires [4, 88], and three used aerial photos.

There was heterogeneity in PA effectiveness at regional, national and sub-national scales. In forty-one of the 60 studies, the data provided by the study allowed the calculation of the habitat loss ratio between the PAs and their counterfactual. Where PAs had lower habitat loss compared with the counterfactual (40 studies), ratios ranged from 1.25 [89] to 22.7 [90] times lower loss, with an mean of 5.4 (S.D.=4.9). For the eight studies where PAs had higher rates of habitat loss compared with the counterfactual, the difference ranged between 1.15 [91] to 3.97 [92] times higher loss. Differences between inside and outside were generally larger for Latin America (mean= 6.04, S.D.= 6.2) and Africa (mean= 4.67, S.D.= 4.0), compared to Asia (mean=2.40, S.D.= 1.5), suggesting that Latin American and African PAs are better at reducing deforestation within their borders (Table 7).

Several methodologies have been proposed to analyze observed habitat loss in forested areas, which partly reflect the development of tools and methods for analysis of deforestation patterns. We have divided the analysis into five types to measure the difference between deforestation patterns inside PAs and their surroundings: *i*) Inside-outside where PAs are compared to their immediate surroundings (buffer-analysis), *ii*) Matched inside-outside analysis (apple-to-apple comparison), where 'outside' pixels are selected to match inside characteristics such as distance to roads, human settlements, slope and elevation, *iii*) Regression analysis where NDVI values of different pixels of PAs are used as dependent variables modeled against different values of characteristics such as distance to roads, human settlements, slope, and elevation, *iv*) field observation on the ground, and *v*) interviews and questionnaires with local area managers and experts (Table 7).

The most common type of analysis found in the studies was buffer analysis, generally at a single or few sites (n=37), followed by regression analysis (n=23), matched inside-outside analysis (n=8), interviews and questionnaires (n=2), and on-ground observations (n=2). For one study the methods did not match the above categories [93] (see Table 8). While both regression and buffer analyses have been used throughout the period covered by the studies, "matching" [2] is a newer, computationally more sophisticated, and 'fairer' way to assess the impact of PAs on habitat trends, by more explicitly including the heterogeneity of protected and non-protected landscapes. Matching reduces the effect of non-protection modifiers by controlling for elements related to selection of sites or landscape level variables (such as remoteness) that may vary between sites independent of the effectiveness of management and protection. The same factors will often be included in regression analysis, but where matching documents the effect of PAs, by restricting comparison to sites of similar (matched) values, regression analysis treats the factors them as explanatory variables thus estimating their direct effect on protection effectiveness.

Inside-outside (buffer) analysis does not account for the impact of landscape-level variables, and so can overestimate the effect of protection as well as neglect the effect of leakage and landscape differences between inside and outside PAs, which in some cases account for much of the difference in deforestation rates observed between protected and non-protected land. To evaluate the overall performance of PAs when it comes to the rate of habitat change inside and outside PAs, matching analysis or regression analysis therefore perform better. However while matching and regression analysis incorporate effects that may influence habitat trends without being related to the protection, they are dependent on larger, more complicated data sets and modeling techniques compared with buffer analyses.

Studies using a buffer analysis reported higher levels of PA effectiveness than studies which used regression modeling or matching estimators (Table S4). This result shows the methods used to evaluate PA effectiveness can alter the apparent effect size.

4.3.3 Trends in habitat change

Of the 76 studies, 82% (n=62) show a reduced rate of habitat loss inside PAs. Eight studies found higher habitat loss inside PAs than outside, and five studies found no significant effect of protection compared to outside. The use of remote sensing data and large scale analysis results has the effect that even small differences between PAs and non-protected areas will appear significant. Thus no studies have reported no differences but in some studies the effects are small (Table 7)

As the contextual differences between the different studies related to remote sensing product, years recorded, method of analysis, geographical region, country level conditions and specific location of the PAs no quantitative meta-analysis was attempted.

The three global scale studies were restricted to habitat loss in the tropics, and all show overall loss inside PAs to be less than outside [94-96].One detailed global study using a buffer approach, found that, on average, PAs had lost 3.32% of forest cover while unprotected land had lost 8.65% over a period of 20 years [95]. Similarly, one study [94] found that deforestation rates of tropical forests inside PAs were about half those of non-protected forests. Moreover, a detailed study using matched inside-outside analysis [96] showed that 7.67% of the current global PA would have been deforested if it had never been protected; this was about half of the expected benefit of protection within reserves when compared to a non-matched analysis.

There was heterogeneity in PA effectiveness at regional, national and sub-national scales. In forty-three of the 63 studies, the data provided by the study allowed the calculation of the habitat loss ratio between the PAs and their counterfactual. Where

PAs had lower habitat loss compared with the counterfactual (40 studies), ratios ranged from 1.25 [89] to 22.7 [90] times lower loss, with an mean of 5.6 (S.D.=4.9). For the eight studies where PAs had higher rates of habitat loss compared with the counterfactual, the difference ranged between 1.15 [91] to 3.97 [92] times higher loss. Differences between inside and outside were generally larger for Latin America (mean= 6.04, S.D.= 6.2) and Africa (mean= 4.67, S.D.= 4.0), compared to Asia (mean=2.40, S.D.= 1.5), suggesting that Latin American and African PAs are better at reducing deforestation within their borders

Southeast Asian PAs have had the greatest regional loss of tropical forest [94, 95], with around 0.60×10^6 km^2 lost in a period of 20 years compared to 0.58×10^6 km^2 in Latin America [95]. However, protected forest in South and Central America suffered the greatest percentage loss in carbon stock compared to PAs in Africa, Asia and Oceania [94]. Using fire events as a proxy for success of protection, one study [97] showed that the reduction of fires inside PAs is greatest in Latin America and the Caribbean followed by Africa and Asia.

Of the 76 studies on forest, eight observed increased cover in some or all PAs, either from tree planting [98] or natural re-growth [4, 99-104]. Only six studies showed negligible or no forest loss inside PAs [105-110]. Twenty-two studies reporting annual loss indicated that there has been a loss of forest cover within PAs, ranging from 0.07% [111], to 3.17% [91] loss per year in the PAs concerned (mean 0.55% annual loss).

4.3.4 Types of protection

Three global studies examined deforestation rates between reserves under different IUCN reserve management categories. In tropical forests, reserves in IUCN categories I and II were better at mitigating deforestation than reserves in categories III-VI using an inside-outside approach, comparing pixels in protected and non-protected areas to estimate the differences between carbon loss in PAs and outside, as well as between categories of protection [94]. Similarly, stricter protection (IUCN categories I-IV) were found to be more successful than multiple-use reserves (IUCN categories V-VI) at reducing fire frequency, using a matching technique to control for factors other than protection [112]. However, one study [113], also using matching analysis found that the effect of IUCN categories was dependent on whether size was included in the analysis and that IUCN categories I and II only performed better because of their larger average size. All three studies were considered highly reliable and all use high quality remote sensing data: MODIS [94, 112] or GLC2000 and Globecover300 [113]. However only one [113] consider the effect of size of PAs, which they found to be a contributing factor to the greater effectiveness of areas under stricter protection using the IUCN guidelines.

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 studies found higher community reserve impact [114, 115] and five lower impact [45, 116-119].

In one of the global analyses the authors were able to evaluate the performance of indigenous PAs, which were 2.5-6 times more effective than other PAs in Latin America and the Caribbean, even taking into account the more remote and isolated locations of indigenous reserves [112]. Multiple-use reserves (IUCN categories V and VI) appeared to be more effective than stricter PAs (IUCN categories I-IV) by a factor of about 1.5 in mitigating fires. The same patterns of multiple-use reserves being more effective was mirrored in Asia, however stricter protection was found to be more effective in Africa [112] and several studies include only more strictly PAs (e.g. [95]). Similar results were found within the Chalkhul Biosphere Reserve in Mexico [115], in the Amazon rainforest [120], and in Panama [119], though in the latter, indigenous PAs were also more isolated, making it difficult to determine whether protection status or isolation is driving the difference.

Other types of local governance show similar patterns. In Guatemala and south-east Mexico, community conserved PAs were found to reduce deforestation better than other types of protection in areas of low risk, while both community managed PAs and traditional PAs in high threat zones failed to prevent deforestation compared to land outside reserves [114].

4.3.5 Factors causing habitat change in protected areas

Within those studies which matched the search criteria (57 studies which measure the effect of PAs on habitat, with appropriate counterfactuals) we then searched the studies to see whether PA effectiveness had been linked in the study to any specific PA management activity or PA characteristics.

We grouped factors reported to influence PA effectiveness into seven categories *i*) regulations and activities *ii)* slope of the landscape *iii*) elevation, *iv*) Isolation (distance to human settlements), *v)* land use change, *vi)* fire intensity, and *vii)* human population density. The categories were based on our evaluation of the types of explanatory variables used in the studies and ultimately stem from the available GIS layers used in the analyses (Figure 6). Thus these categories do not represent a complete list of factors speculated to influence the effectiveness of PAs. Studies relying on remote sensing products generally lack data on 'on the ground' interventions and are restricted to conclusions on information that exists on large scales and can be processed using GIS.

While isolation and human populations ultimately describe of the same pressure on PAs, they have subtle differences. We have therefore respected the distinctions used in the reviewed studies. Isolation is a measure of distance and as such does not concern itself with the size of settlements, whereas human population is a measure of human density thus takes density and size of settlement into account.

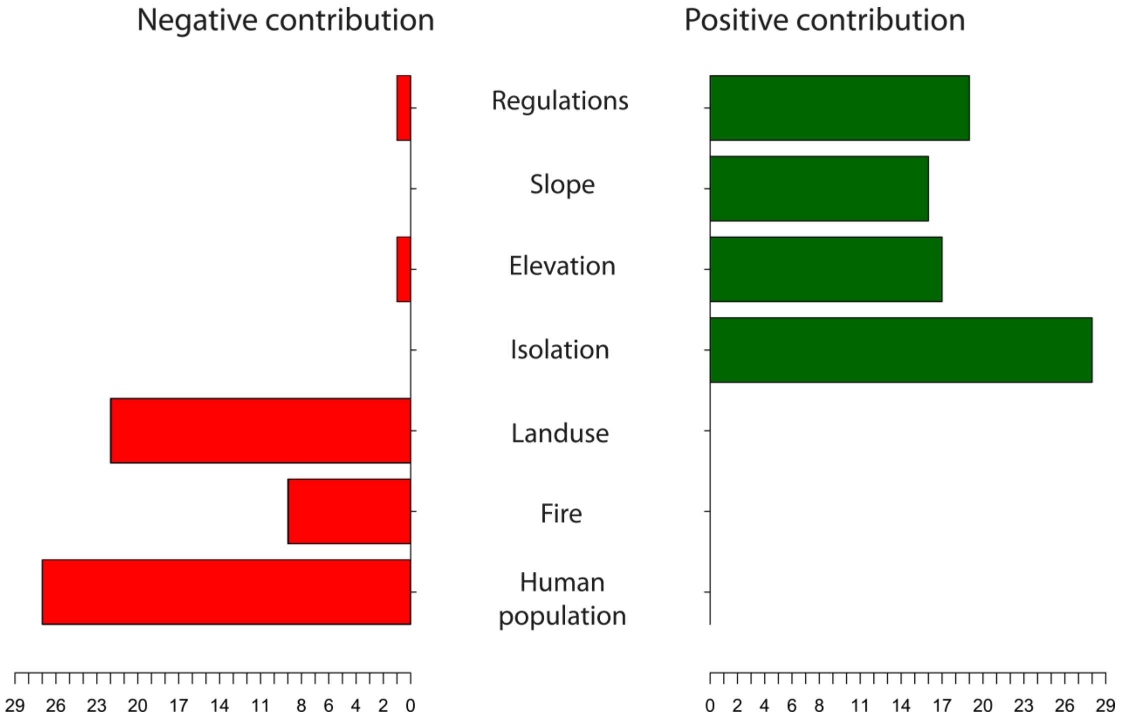

Figure 6. The number of studies where the above PA characteristics were found to have a positive (green) effect on habitat loss or negative (red) effect.

Twenty-seven studies identified increased human population density or encroachment of human settlements into the PAs as a main cause of deforestation. In 11 cases where human population density was included in the regression model it was found to be a significant predictor of deforestation. In all cases areas closer to human population centers or with higher human densities experienced higher deforestation rates than less populated areas (Table 8).

All studies examining the impact of isolation, and increased distance, from human population centers and cities (n=28) found a positive effect of remoteness on PA effectiveness in mitigating habitat changes. This was supported by a global analysis [113] as well as four previous meta-analyses (not included here) [50, 121-123] and seven additional studies [93, 101, 115, 124-127].

Seventeen out of 18 studies on elevation found a positive effect of higher elevations [2, 99, 101, 113, 115, 124, 126, 128, 129], while only one for five national parks in Guatemala found a negative correlation [125]. Sixteen studies found a positive correlation between less slope and deforestation, so that steep slopes reduced deforestation [2, 99, 110, 113, 119, 126, 129-131].

All studies were conducted using high quality and validated remote sensing products for the dependent variable of habitat change as well for drivers such as human population and topography.

Management interventions were included in 20 studies; including, management plans, tree planting, funding, NGO commitments. However compared to the direct measurements of effects of landscape properties and human pressure, all studies were only to contribute an either positive or negative effect of these. In eight studies, management plans were developed for the PA and in seven of these cases a positive effect on the reserve's ability to reduce deforestation was observed [45, 101, 124, 132-135]. In contrast, a study of Kerinci Seblat National Park in Indonesia found deforestation increased from 1.1% per year to 3% after the creation of a targeted conservation plan for halting the deforestation there [136]. In two studies, tree planting projects helped increase the forest cover of the PAs [98, 104]. Five studies examined increased funding and staffing and all found a decrease in deforestation [4, 88, 115, 137, 138].

A number of other factors were identified in single studies. For example, in Tanzania PAs with NGO presence and involvement had less deforestation than areas managed by park authorities alone [139]. In Celaque National Park, Honduras, deforestation decreased after NGOs started working with local communities on education on local conservation issues [110]. In Nicaragua increased deforestation rates were correlated with the end of the civil war, probably as a result of re-establishing timber harvesting [109].

We evaluated all interventions described for their contribution to the observed changed in habitat extent inside and outside reserves. Only interventions documented in the studies to affect rates of habitat loss or increase were included. As none of the factors described act independently, and as the type of analysis used in the studies were not based on isolation of individual factors, no effect size could be obtained.

5. Discussion

Understanding the effectiveness of PAs remains one of the most important challenges in conservation biology [140]. Here, we have evaluated attributes of PAs and their management on their ability to *i*) preserve biodiversity, measured as species population changes over time and *ii*) preserve habitat extent. The two measures of conservation outcomes are distinct both in terms of the methods used to gather data, and the scope and scale at which they can be evaluated. However both reflect important conservation outcomes and goals for PA management.

This review has found that there is insufficient evidence with which to determine whether PAs are effective in preserving species populations compared to if no protection existed. Although results generally are positive, the studies were few and we did not obtain a good measure of effect size, so the evidence is equivocal.

PAs are generally effective in preventing habitat change for forested PAs, but evidence is lacking for other habitats. For habitats there was a larger number of studies and far greater number of PAs included, in the analysis. The availability of standardized (grid-based) data sources at global to local scales, also allowed detailed statistical analyses to be conducted. This has permitted greater rigor and greater confidence in the conclusion that PAs do help reduce rates of deforestation, but there were too few studies of other biotope types for any general conclusion outside forests. However, disentangling the effect of protection from the effect of isolation and other geographical and social variables can be extremely complicated, and it appears that a bivariate approach (protected/not protected) will overestimate the effectiveness of interventions.

5.1. Reduced population declines

On a global scale, biodiversity is declining rapidly [141, 142], suggesting that even reduced rates of population decline might be considered a conservation success when compared to the likely outcome if no conservation actions had occurred. To study this, however, observation inside reserves need be viewed in context of their surroundings [49, 126]. The only large scale study of population changes of 83 African PAs found mammal population declines of around 50% in Eastern Africa and 85% in Western Africa, while Southern Africa saw increases of about 30% between 1970 and 2005 [143]. However, while these results might suggest the failure of Eastern and Western African PAs, case studies from reserves included in the larger analysis suggest that populations were already extirpated outside reserve boundaries [144] or suffered greater declines than within reserves [75, 145, 146]. Hence, the reserves should still be considered successful, compared to the dire situation in unprotected land.

The interplay between biotic and abiotic factors influencing population trends contributes to the complexity of the observed patterns and makes it difficult to create generic models, or a common methodology to examine the effectiveness of PAs in preserving biodiversity. Events such as droughts and floods also affect numbers, and these events are often not captured in the time series studies, even though they may explain large parts of the variation observed [68, 146-148]. For example, the decline of small mammals in Kakadu National Park in Australia was first attributed to drought events [149], but a reanalysis after a series of wet years failed to show expected increases, suggesting that additional factors contributed to the decline [150].

The reviewed studies focused largely on large African mammals. This bias in the literature might be explained by the direct monetary value of these animals and the dependency on nature based tourism in some African countries [151, 152]. The same parks are often under great pressure from poaching and bush meat hunting [153, 154], increasing the importance of effective management. At the same time, Africa remains the only continent to retain much of its original mammal fauna long past lost on other continents. Further, surveying large mammals in open savannah habitats can be done more easily from planes or cars with larger precision and over larger areas which could also affect the number of studies from these sites.

Sixty-nine percent of reviewed studies also reported specific management interventions within the PA. The most widely studied intervention was the use of activities to reduce poaching inside the reserves, where 11 out of 12 studies reported PA effectiveness. These initiatives are often directly related to staffing and thereby affect budgets, suggesting a need for adequate funds for effective management of this kind. In the few cases where management actions to exclude poaching activities had no effect, this was either because the efforts were deemed inadequate [155] or because of trophic displacement [67, 69].

Where management interventions were tailored to a specific target (such as population translocation or establishment of feeding areas), three out of four were considered successful, but the paucity and variety of the interventions precludes any general conclusion.

5.2. Habitat change

The evidence that deforestation and habitat degradation rates are greater outside PAs is convincing. Unfortunately, almost all analysis has been in tropical forests (all except [133]), so the validity of the results does not extend beyond that biome. For several other habitat types (including mangroves [5] and tall grass prairies [156]) a decline in overall extent has been documented, but this has not been linked to PAs coverage or effectiveness.

The narrow range of biotopes studied is largely because remote sensing methods struggle to resolve changes in non-forested habitats. Remote sensing best detects changes in habitat extent (forest / no forest), but is less effective in capturing seasonality or subtle changes [157], which can be of more importance in non-forested areas where a minor shift, not detectable by satellite, might fundamentally change the habitat.

The IUCN management categories would be expected to predict performance, as is suggested in two global studies [94, 112]. However, when the size of PAs is considered, results are less convincing [113], suggesting that the larger average size of PAs in IUCN categories I and II might be the real reason for their higher success. For all studies examining the effectiveness of indigenous protected lands, remoteness appears important, suggesting that in addition to governance and tenure, location and area are important to the success or failure of PAs [114].

Isolation from human populations has been shown to reduce deforestation and is an important predictor in all 35 studies analyzing its effect. Similarly higher elevation and slope of the PA reduces the likelihood of deforestation. Thus, as PAs are often located in remote mountain regions, their deforestation rates may reflect location rather than protection[158].

PAs in areas of greater threats and pressures generally experience higher absolute rates of habitat conversion. However, where appropriate resources are available and good management is applied, threats can be mitigated (see Figure 6).

Studies at different scales and across continents all suggest that PAs perform better than non-protected lands. However the drivers and conditions responsible for these observations vary, as does the actual effect of protection.

5.3. Review limitations

A major finding is that data requirements in order to causally link interventions to observed biological changes are challenging. In particular the data required is expensive, time-consuming and requires ongoing institutional support of some kind. As a result, full (or even partial) BACI design (before/after/control/impact) [159] is poorly applied in conservation science. In their systematic review of the effect of community managed forests Bowler et al. [160] faced the same challenge of finding studies where observed results inside community managed forests could be directly linked to the interventions and not to the prior condition of the area.

The use of data on species persistence, population trends or habitat change to evaluate effectiveness of PAs brings together two quite different sets of data and challenges. Whereas the use of remote sensing to document biotope change allows the measurement of effectiveness using similar terminology and methodology, this is not the case for species data. For the latter, the many different studies employing time-series data have made the compilation of relevant literature challenging. It is thus likely that we have missed relevant studies.

The majority of studies found that PAs are effective in reducing habitat loss and protecting biodiversity. The exceptions do not suggest any particular intervention, governance type, or region of the world that results in poor performance. However, neither the studies nor this review have been able to determine whether the lack of negative results is real, or because of a reporting bias in publication. Hence specifically for the species studies, this review risks a bias towards the, more interesting, positive results.

For population time-series the great variability in study design and objectives, prevented us from going beyond simple descriptive statistics (vote-counting), with no estimations of effect size, neither on a study-by-study level or cumulative across studies or interventions. Stochastic and cyclical population fluctuations further complicate our ability to evaluate the effect of management interventions beyond positive/no effect/negative. To address this we recorded the number of studies which measured other factors than management interventions. Thirty four out of 40 studies included information on factors other than just interventions and outcomes, but we could not estimate effect differences between these, because the impact of these factors on management interventions and outcomes was not explicitly tested by the studies.

Additionally, the methods we have used to evaluate these studies are only descriptive, restricting us to scoring whether studies delivered positive, negative or no effect. So, even where PA and/or management interventions appear to be effective, it is difficult to demonstrate whether these management interventions are *cost*-effective. While this has not been a major concern in the review, due to the focus on effectiveness in terms of biological measures, this can ultimately be the determining factor for the choice of interventions and thus in the success of delivering conservation outcomes. This further restricts the general validity or overall conclusions possible to extract across studies, as reducing results to vote counting introduced the risk of poor quality studies being given the same 'weight' as high quality studies thus potentially biasing the synthesis of results by their inclusion. However, as the selection criteria for the inclusion of studies has been very strict concerning the methodology applied to evaluate PA effectiveness, and the need for appropriate counterfactuals, the risk of low quality studies 'painting the picture' is significantly reduced. Thus the major restriction of vote counting remains that effect size is not considered.

There were some interesting findings about the sources of studies. All those for population trends, and all but one for habitat change that met the search criteria were from the peer-reviewed literature. Only one study was found from NGOs, intergovernmental, UN or governmental Agencies [112].

Although many countries, especially in the developed world, have excellent records of species population trends at various scales, these do not seem to have been used to compare trends in protected and unprotected areas; or the data do not exist in a format that allows such an analysis to be performed. In particular, species based conservation efforts are seldom restricted to PAs, with conservation agencies taking a holistic approach over the entire range of the species both inside and outside reserves. Protection and management of American endangered species [161], the declines in wild bees in USA [162], or the monitoring of birds in Australia [163] and Europe [164] are all examples of this. Thus, for many of these cases, even if data are available they may not be specific to protected and matched non-protected areas. Conversely, in less wealthy countries, conservation actions are often entirely restricted to protected or partially protected landscapes, in particular where compliance must be enforced.

The small number of studies on population trends has resulted in all analyses in this review being only descriptive, never amounting to true meta-analysis. As a result figures and tables are only able to aggregate information in logical categories without evaluation of effect sizes or comparison between management interventions. This is in part due to the specific nature of the questions in each of the reviewed studies, focusing only on the specific element they apply to particular situations. Compared to the population studies, studies on forest loss have been more successful in identifying generic pressure and response categories that can be measured in similar ways between studies.

6. Reviewers' conclusions

6.1. Implications for policy

For population time-series, the low number of studies found, precludes strong policy recommendations, but we do see a need to make data from monitoring and management programs available, transparent, and standardized.

In most cases anti-poaching initiatives within PAs were reported as effective, but even though poaching is a major threat to many animal populations, the high proportion of studies on this topic may not reflect the global threats to biodiversity, and as such might misguide conservation practitioners to focus interventions to illegal hunting and bush meat extraction.

For habitat protection the review suggests that PAs are an important element of conservation strategies to preserve tropical forests. However, establishing PAs without understanding the context in which they work might overestimate their role in preventing loss. With or without protection, remote and inaccessible areas loose less habitat cover than areas closer to human settlements and in flat and low lands. This does not imply that PAs should be located only remotely, where they might prevent all loss, or only close to cities where the difference between protected / non-protected is the greatest. However depending on whether the objective is to preserve pristine biodiversity hotspot regardless of the level of threat or to reduce the overall loss of habitat understanding the context in which protection works can influence decisions on where to allocate land for protected

Other factors such as local involvement and on ground management initiatives, where reported, decreased habitat loss. Conservation practitioners should thus move beyond simply studying the effectiveness of PAs to understanding the impacts of the governance structures and management regimes implemented within these PAs. This review points to local stakeholder engagement as a potentially effective conservation strategy.

One of the most important conclusions from this review remains the call for systematic reporting and documentation of conservation projects as well as the inclusion of pressures and responses in the study design of ecological experiments. Too many studies were rejected because they failed to link the observed changes in biodiversity or habitat with its possible drivers. Conservation projects need to *a priori* identify all possible factors expected to drive the observed changes, and include them in a manner that enables project evaluation to isolate the effect of interventions from those factors beyond the control of conservationists. This is further emphasized by the situation in many places where the need for effective protection is most dire. Here even populations declines can be considered a conservation success if the decline is less than without management. However without proper documentation and controlled conditions making this evaluation is not possible.

6.2. Implications for research

We have documented the need for an improved methodology for the studies of population trends, including full BACI (before/after and control/intervention) design to ensure that observed changes can be linked to the human conservation interventions and thus increase our knowledge on what can be done to halt the loss of biodiversity.

Compared to the small number of studies qualifying for this review there are vast amounts of research on population changes either inside or outside PAs. Further, information on management and environmental conditions are often available within reserves. PA managers usually have information on budget, staffing as well as the contextual element of the PAs. We therefore believe that more stringent evaluation of the effect of management and PAs is possible. This may be done retrospectively by adding a few key pieces of information, or in new studies including these factors from the outset.

We could identify no standard framework across the reviewed studies to evaluate the effectiveness of PAs in conserving animals using population time-series data. Further, no attempt had been made in any of the studies to disentangle the impacts of *i*) background condition (weather, climate, human population changes, infrastructure), *ii*) PA attributes (elevation, slope, size, habitat composition, age), and *iii*) management (guards, fencing, resources, hunting regulations). Thus, often studies are only able to speculate on the causality between input and outcomes. Further, the lack of a framework to evaluate the effectiveness in a standardized way limits the comparability between studies and thus the ability to synthesize across studies.

We see a need for such a framework to document formally the link between input and outcomes in PAs. This would include gathering data on all three of the above categories to ensure that observed changes could be related to conservation actions as well as natural processes.

This could enhance many existing studies in which time-series of abundance data are collected for more basic biological questions, but which potentially can be used to improve understanding of management-induced biodiversity responses as well. Initiatives to collate existing data on population time-series such as the Living Planet Index [165] already exist and need to be supported. However, collecting information on potentially causative factors in population studies within and outside of PAs is also important. All this would assist greatly with extending the findings of this review.

For habitat change, the lack of studies outside tropical forests is evident. This is partly related to remote sensing products not being able to capture discrete changes in habitats often related to non-forested areas. However, understanding the effect of protection outside tropical forests remains of critical interest to conservation science. Though this review has not been able shed light on this issue, it has confirmed an important knowledge gap that needs to be resolved.

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8. Potential Conflicts of Interest and sources of Support

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Table 5. 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., 2007	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	+

Source	Countries	Protected area	Monitoring period	Taxa	Counterfactual	BACI	Background trend	Effect of PA
Struhsaker et al., 2005	11 African countries	16 PAs	1966-2000	Biodiversity	PA compared to buffer	CI	N/A	+
Suarez et al., 1993	Spain	Las Amoladeras and Layna Paramos	1989	Aves	PA compared to similar habitat outside	CI	Decrease	-
Tambling and Du 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, 2009	Kenya	Tsavo NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western, 2009	Kenya	Mara NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western, 2009	Kenya	Amboseli NP	30 years	Mammals	PA compared to buffer	CI	Decrease	0
Western, 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 S6 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 S6) 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 6. Detailed data from the 42 studies evaluating PA effectiveness for species populations

Source	Protected area	Counterfactual	Outcome measure	Survey type of outcome	Improvement ratio	BACI	Predator prey conflicts	Reporting of other factors and biases	Species list
Adams et al., 2008	Gates of the Arctic national park and preserve	Implementation of regulation	Animals pr. area / Abundance	Radio telemetry	1/1	BA	Not reported	Disease, prey availability and migration of non-resident wolfs	Wolf
Balme et al., 2010	Phinda-Mkhuze Complex	PA compared to buffer	Animals pr. area / Abundance	Radio telemetry	1/1	CI	Not reported	Intra-specific competition and prey availability	Leopard
Bhattacharya, 1993	Kaziranga National Park	Introduction of staffing	Population estimate	ground count	1/1	BA	Not addressed	Not reported	Indian Rhio
Blake et al., 2007	6 protected areas	PA compared to buffer	occupancy time	ground transect	1/1	CI	Not addressed	Population density	Forest elephant
Brereton et al., 2008	Multiple	Establishment of PA	population estimate	Transect counts on ground	1/1	BA	Not addressed	Weather and grazing pressure	Chalkhill blue butterfly
Caro, 1999	Katavi national park	PA compared to buffer	Animals pr. area / Abundance	Aerial census, ground counts	7/8	CI	Not addressed	Food availability	Elephant, Hippopotamus, Giraffe, Buffalo, Eland, Roan, Sable, Zebra, Waterbuck, Greater kudu, Hartebeest, Topi, Bushpig, Warthog, Reedbuck, Impala, Bushbuck, Lion, Spotted hyanea, small carnivores, mongoose, Baboon, Vervet
Caro, 1999	Katavi national park	Game controlled area	Animals pr. area / Abundance	Aerial census, ground counts	15/?	CI	Not addressed	Food availability	Elephant, Hippopotamus, Giraffe, Buffalo, Eland, Roan, Sable, Zebra, Waterbuck, Greater kudu, Hartebeest, Topi, Bushpig, Warthog, Reedbuck, Impala, Bushbuck, Lion, Spotted hyanea, small carnivores, mongoose,

Caro, 1999	Katavi national park	Forest reserve	Animals pr. area / Abundance	Aerial census, ground counts	5/16	CI	Not addressed	Food availability	Baboon, Vervet Elephant, Hippopotamus, Giraffe, Buffalo, Eland, Roan, Sable, Zebra, Waterbuck, Greater kudu, Hartebeest, Topi, Bushpig, Warthog, Reedbuck, Impala, Bushbuck, Lion, Spotted hyanea, small carnivores, mongoose, Baboon, Vervet
Carrillo et al., 2000	Corcovado national park and Golfo Dulce forest reserve	Different levels of protection	Animals pr. area / Abundance	ground transect	N/A	CI	Both predators and prey increased	Isolation, weather and landuse	Common opossum, Nine-banded armadillo, Lesser anteater, Mantled howler monkey, Geoffroy's spider monkey, White-faced capuchin monkey, Central American squirrel monkey, White-nosed coati, Raccoon, Southern river otter, Ocelot, Margay, Jaguar, Puma, White-lipped peccary, Collared peccary, Red brocket deer, Central American tapir, Peca, and Central American agouti
Catry et al., 2009	Castro Verde special protection areas	Introduction of artificial nests	Population estimate	capture-recapture	1/1	CI	Not reported	Intra-specific competition, nest location and predation	Lesser kestrel
Devictor et al., 2007	All protected areas	National estimates outside PA	Density compared to trends	spot count	20/30	CI	Not addressed	Not reported	100 bird species, see orginal article
Eberhardt et al., 2007	Yellowstone national park	Implementation of regulation	Population estimate	Ground and aerial	2/2	BA	Wolf and elk both improved	Population structure and predators	Elf and Wolf

Fellers and Drost, 1993	Lassen Volcanic National Park	Establishment of management	Presence	count on locations	0/1	BA	Not addressed	Invasive species and habitat loss	Cascades frog
Gough and Kerley, 2006	Addo Elephant national park	Introduction of fence	Population estimate	ground count	1/1	BA	Not addressed	Population structure and weather	African elephant
Harrington et al., 1999	Kruger National Park	Closing of waterpoints	Animals pr. area / Abundance	Aerial census	1/1	BA	Not reported	Predators, inter-specific competition, weather, population structure, disease	Roan antelope
Herremans and Herremans-Tonnoeyr , 2000	Multiple	PA compared to buffer	Animals pr. area / Abundance	spot count	47/47	CI	Not addressed	Weather	47 raptor species
Hilborn et al. 2006	Serengeti national park	Implementation of regulation	Not reported	Not reported	3/3	BA	Not addressed	Not reported	Buffalo, Elephant and Black rhino
Ma et al., 2009	Yancheng biosphere reserve	Different zones of PA	Population estimate	ground count	1/1	CI	Not addressed	Habitat quality	Red-crowned crane
Mduma et al., 1999	Serengeti national park	Establishment of PA	Population estimate	Aerial and ground census	1/1	BA	Not reported	Population structure, weather, food availability, and predators	Wildebeest
Meijaard and Nijman, 2000	Pulau Kraget nature reserve	Translocation of population	Population estimate	ground count	0/1	BA	Not addressed	Not reported	Proboscis monkey
Metzger et al., 2010	Serengeti national park	Implementation of regulation	Population estimate	Aerial	1/1	BA	Not reported	Landscape properties, food availability, and predators	Buffalo
Ottichilo et al, 2000	Masai Mara national reserve	PA compared to buffer	Population estimate	aerial	12*	CI	Not addressed	Vegetation types	Buffalo, Eland, Elephant, Grant's gazelle, Thomson's gazelle, Giraffe, Impala, Kongoni, Ostrich, Topi, Warthog, and Waterbug
Pedrono et al., 2009	Yok Don, Cat Tien national parks, Ea So and Vinh Cuu nature reserves	None-protected land within species range	Area of occupancy	ground count and DNA	1/1	CI	Not addressed	Weather, and disease	Banteng
Pettorelli et al., 2010	Arusha NP, Kilimanjaro NP and FR, Mahale NP, Lake Manyara NP, Minziro FR, Ngorongoro Conservation Area, Serengeti NP, Tanga CF, Tarangire NP, Biharamulo-Burigi-Kimisi	Different levels of protection	Encounter rate	Camera trapping	23**	CI	Not addressed	Landscape properties	Aardwolf, African civet, African palm civet, Banded mongoose, Bat-eared fox, Black-backed jackal, Bushy-tailed mongoose, Clawless

	GR, Zoraninge FR,								otter, Caracal, Common genet, Dwarf mogoose, Honey badger, Large spotted genet, Leopard, Lion, Marsh mongoose, Serval, Side-stripped jackal, Slender mongoose, Spotted hyena, White-tailed mongoose, Wild cat, and Zorilla
Schlicht et al. , 2009	Multiple	Areas not managed with fire	Animals pr. area / Abundance	ground transect	-	CI	Not addressed	Landscape properties	Silver-bordered fritillary, Regal fritillary, Orange sukphur, Delaware skipper, Common rnglet, Great spangled fritillary, Nothern brown, Aphrodite fritillary, Long dash, Pearl crescent, Meadow fritillary, Melissa blue, Common wood-nymph, Clouded sulphur, Black Swallowtail, Dakota skipper, Poweshiek skipperling, and Monarch
Sergio et al., 2005	Doñana national park	Populations outside PA	Territories pr. area / Abundance	bird spotting and nest inventory	2/2	CI	Nest predator populations increased	Nest location, inter-specific competition and density of alternative prey	Black kite and Red kite
Sinclair et al., 2007	Serengeti national park	Implementation of regulation	Population estimate	Aerial	2/2	BA	Lion populations increased	Food, predation, habitat, disease, and weather	Buffalo and Wildebeest
Stoner et al., 2007	Burigi-Biharamulo national park	PA compared to buffer	Animals pr. area / Abundance	Aerial	20%	CI	Not addressed	Species traits, human density, feeding guilt, and weather	Buffalo, Eland, Elephant, Giraffe, Grant's Gazelle, Greater kudu, Hartebeest, Impala, Puku, Oryx, Reedbuck, Roan, Sable, Thomson's gazelle,

									Topi, Warthog, Waterbuck, Wildebeest, and Zebra
Stoner et al., 2007	Greater Ruaha national park	PA compared to buffer	Animals pr. area / Abundance	Aerial	25%	CI	Not addressed	Species traits, human density, feeding guilt, and weather	Buffalo, Eland, Elephant, Giraffe, Grant's Gazelle, Greater kudu, Hartebeest, Impala, Puku, Oryx, Reedbuck, Roan, Sable, Thomson's gazelle, Topi, Warthog, Waterbuck, Wildebeest, and Zebra
Stoner et al., 2007	Tarangire national park	PA compared to buffer	Animals pr. area / Abundance	Aerial	10%	CI	Not addressed	Species traits, human density, feeding guilt, and weather	Buffalo, Eland, Elephant, Giraffe, Grant's Gazelle, Greater kudu, Hartebeest, Impala, Puku, Oryx, Reedbuck, Roan, Sable, Thomson's gazelle, Topi, Warthog, Waterbuck, Wildebeest, and Zebra
Stoner et al., 2007	Selous-Mikumi national park	PA compared to buffer	Animals pr. area / Abundance	Aerial	5%	CI	Not addressed	Species traits, human density, feeding guilt, and weather	Buffalo, Eland, Elephant, Giraffe, Grant's Gazelle, Greater kudu, Hartebeest, Impala, Puku, Oryx, Reedbuck, Roan, Sable, Thomson's gazelle, Topi, Warthog, Waterbuck, Wildebeest, and Zebra
Stoner et al., 2007	Ugalla national park	PA compared to buffer	Animals pr. area / Abundance	Aerial	70%	CI	Not addressed	Species traits, human density, feeding guilt, and weather	Buffalo, Eland, Elephant, Giraffe, Grant's Gazelle, Greater kudu, Hartebeest, Impala, Puku, Oryx, Reedbuck, Roan, Sable, Thomson's gazelle, Topi, Warthog, Waterbuck, Wildebeest,

									and Zebra
Struhsaker et al., 2005	16 protected areas	PA compared to buffer	Status of fauna and flora	questionnaire	N/A	CI	Not reported	Isolation and species traits	Fauna and flora
Suarez et al., 1993	Las Amoladeras reserve and Layna Paramos	PA compared to similar habitat outside	Nest mortality	Ground observations	0/5	CI	Study populations possibly limited by predators inside PA	Predators	Dupont's lark, Black-bellied sandgrouse, Little bustard, and Stone curlew
Tambling and Du Toit, 2005	Pilanesburg national park	Introduction of fence	Population estimate	Aerial	1/2	BA	Predators increased as target species declined	Population and habitat structure, and weather	Lion and Wildebeest
Theberge et al., 2006	Algonquin provincial park	PA compared to buffer	Population estimate and annual loss to hunters	Radio telemetry	1/1	CI	Not addressed	Population structure	Wolf
Wegge et al, 2009	Bardia national Park	Establishment of PA	Animals pr. area / Abundance	Camera trapping	5/8	BA	Both predators and prey increased	Habitat heterogeneity, inter-specific competition, and prey density	Tiger, Leopard, Chital deer, Muntjac, Hog deer, Wild boar, Barasingha, and Nilgai
Western, 2009	Tsavo national park	PA compared to buffer	Population estimate	ground count	Not reported	CI	Not addressed	Weather and habitat	Elephant, buffalo, Burchell's zebra, giraffe, Wildebeest, Eland, Waterbuck, Warthog, Grant's gazelle, Thomson's gazelle, Impala, Lesser kudu, Oryx, Black rhino, Topi, and Hartebeest
Western, 2009	Mara national park	PA compared to buffer	Population estimate	ground count	Not reported	CI	Not addressed	Weather and habitat	Elephant, buffalo, Burchell's zebra, giraffe, Wildebeest, Eland, Waterbuck, Warthog, Grant's gazelle, Thomson's gazelle, Impala, Lesser

									kudu, Oryx, Black rhino, Topi, and Hartebeest
Western, 2009	Amboseli national park	PA compared to buffer	Population estimate	ground count	Not reported	CI	Not addressed	Weather and habitat	Elephant, buffalo, Burchell's zebra, giraffe, Wildebeest, Eland, Waterbuck, Warthog, Grant's gazelle, Thomson's gazelle, Impala, Lesser kudu, Oryx, Black rhino, Topi, and Hartebeest
Western, 2009	Meru national park	PA compared to buffer	Population estimate	ground count	Not reported	CI	Not addressed	Weather and habitat	Elephant, buffalo, Burchell's zebra, giraffe, Wildebeest, Eland, Waterbuck, Warthog, Grant's gazelle, Thomson's gazelle, Impala, Lesser kudu, Oryx, Black rhino, Topi, and Hartebeest
Whitehead et al., 2008	Fiordland national park	Managed section compared to unmanaged	Animals pr. area / Abundance	ground count	1/1	CI	Eradication of invasive predators	Population and habitat structure	Whio duck

Improvement ratio describes the number of species which improved compared to the counterfactual scenario

Table 7. Summary of the 76 studies evaluating PA effectiveness for habitat extent. Intervention describes whether the PA did better (+), worse (-) or whether no difference could be detected (0). "Change in PA" is the rate of change in the protected area while "Change in CFS" is the change in the counterfactual scenario to which the PA is compared. "Difference PA vs. CFS" is the calculated difference between PA and counterfactual. "Method for analysis" describes which method was used.

Source	Country	Protected area (PA)	Counterfactual scenario (CFS)	PA effect	Change in PA	Change in CFS	Change measure	Difference PA vs. CFS	Method for analysis
Abbot and Homewood, 1999	Malawi	Lake Malawi NP	PA compared to buffer	0	-0.06	-	Total	-	In-Out
Alados et al. 200	Spain	Cabo de Gata-Nijar	PA compared to buffer	+	-	-	-	-	Regression
Alo and Pontius, 2008	Ghana	Forest reserves	PA compared to buffer	-	-0.014	-0.005	Total	0.36	In-Out
Andam et al. 2008	Costa Rica	150 protected areas	PA compared to similar habitats outside	+	0.111	0	Difference	-	Matching
Armenteras et al. 2006	Columbia	Indigenous reserves	Reserve compared to buffer	+	1.5 times		Difference	1.5	Regression
Armenteras et al. 2006	Columbia	Guyana NP	PA compared to buffer	+	-0.00071	-0.0028	Annual	3.94	Regression
Armenteras et al. 2006	Columbia	Guyana NP	PA compared to indigenous reserves	+	5.8 times		Difference	5.8	Regression
Arroyo-Mora et al. 2005	Costa Rica	Chorotega region	PA compared to adjacent landscape	+	0.6363	0.2934	Total	0.44	In-Out
Bleher et al., 2006	Kenya	Kakamega	PA compared to forest reserve	+	-3.5	-32.3	Trees harvest pr. ha.	9.23	Ground
Bray et al. 2008	Mexico	11 PAs	PA compared to community managed area	-	-0.00043	-0.00024	Annual	0.56	In-Out + Reg
Bray et al. 2008	Guatemala	11 PAs	PA compared to community managed area	-	-0.00356	-0.00243	Annual	0.68	In-Out + Reg
Brower et al. 2002	Mexico	4 reserves	Region of the reserves	-	-0.02095	-0.01815	Annual	0.87	In-Out
Bruner et al. 2001	Global	93 protected areas	Protected not protected	+	-	-	-	-	Interview
Chatelain et al., 2010	Cote d'Ivoiry	Tai NP	PA compared to buffer	+	-0.0028	-0.0287	Annual	10.25	In-Out
Chowdhury 2006	Mexico	Calakmul BR	PA compared to buffer	+	-0.1303	-0.6198	Percent converted	4.76	Regression
Cropper et al. 2001	Thailand	Multiple	Wildlife sanctuaries compared to buffer	+	-0.0026	-0.0043	Probability of clearing	1.39	Regression
Cropper et al. 2001	Thailand	Multiple	PA compared to buffer	0	-0.0031	-0.0043	Probability of clearing	1.39	Regression
Curran et al. 2004	Indonesia	Gunung Palung NP	PA compared to buffer	+	-0.56	-0.7	Total	1.25	In-Out
Cushman and Wallin 2000	Russia	Sikhote-alinskiy BR	PA compared to buffer	+	-0.002	-0.007	Annual	3.5	In-Out
DeFries et al. 2005	Global	198 protected areas	PA compared to buffer	+	-0.0332	-0.0865	Total	2.61	In-Out
Ellis and Porter-Bolland	Mexico	Calakmul BR	PA compared to community	-	-0.00418	0.000003	Annual	0.001	Regression

2008			managed area						
Forrest et al. 2008	Bolivia	Madidi NP, Tierras Origen Tacana	PA compared to adjacent landscape	+	increase	decrease	Total	-	In-Out
Gaveau et al. 2007	Indonesia	Bukit Barisan Selatan NP	PA compared to Wildlife Sanctuary	+	-0.005	-0.0256	Annual	5.12	Regression
Gaveau et al., 2009	Indonesia	Multiple	PA compared to buffer	+	-0.28	-0.45	Total	1.61	In-Out
Gaveau et al., 2009	Indonesia	Multiple	PA compared to region	+	-0.28	-0.58	Total	2.07	In-Out
Hayes et al. 2002	Guatemala	5 NPs 4 BRs	PA compared to buffer	+	-0.0016	-0.0075	Annual	4.69	Regression
Ingram and Dawson, 2005	Madagascar	All protected areas	PA compared to similar habitats outside	0	-0.4055	-0.4051	Total	1.00	In-Out
Joppa and Pfaff 2011	Global	Global tropical forested PA's	PA compared to matched outside	+	0.07667		Effect of PA	-	Matching
Kinnaird et al. 2003	Indonesia	Bukit Barisan Selatan NP	PA compared to buffer	+	-0.02	Forest gone	Annual	4	Regression
Kiragu Mwangi et al., 2010	Kenya	36 IBAs	Protected compared to none-protected IBAs	+	-	-	-	-	Ground
Linkie et al., 2004	Indonesia	Kerinci Seblat NP	PA compared to buffer	+	-0.0028	-0.0096	Annual	3.43	Regression
Liu et al. 2001	China	Wolong	Establishment of PA and compared to buffer	-	1.15	0.29	Ratio between inside and outside	0.25	In-Out
Luque 2000	USA	New Jersey Pinelands	PA compared to buffer	+	decrease	larger decrease	Total	-	In-Out
Mapaure and Campbell, 2002	Zimbabwe	Sengwa	PA compared to similar habitats outside	-	-0.0158	-0.0104	Annual	0	In-Out
Mas 2005	Mexico	Calakmul BR	PA compared to matched outside	+	-0.003	-0.006	Annual	2	Regression
Mas 2005	Mexico	Calakmul BR	PA compared to buffer	+	-0.003	-0.013	Annual	4.33	Regression
Mendoza and Dirzo 1999	Mexico	Monte Azules BR	PA compared to adjacent landscape	+	-0.0014	-0.0279	Annual	19.93	Regression
Mertens et al. 2004	Bolivia	Amboro NP, Noel Kempff, Mercado NP, BR, the Rios Blanco and Negro WR	PA compared to adjacent landscape	+	decrease	larger decrease	Total	-	Regression
Messina et al. 2006	Ecuador	Cuyabeno Wildlife Production Reserve	PA compared to buffer	+	-0.0189	-0.2042	Total	10.80	In-Out
Mulley and Unruh, 2004	Uganda	Kibale NP	PA compared to buffer	+	-0.18	-0.82	Total	4.56	In-Out
Nagendra et al. 2008	Nepal	Chitwan NP and Parsa	PA compared to similar habitats outside	+	-0.137	-0.178	Total	1.30	In-Out
Nagendra et al. 2008	Nepal	Chitwan NP and Parsa	PA compared to buffer	+	-0.137	-0.244	Total	1.78	In-Out
Nelson and Chomitz, 2009	Africa	IUCN I-IV	PA compared to matched outside	+	0.0115		Difference in fire risk	-	Matching

Nelson and Chomitz, 2009	Asia	IUCN I-IV	PA compared to matched outside	+	0.0185		Difference in fire risk	-	Matching
Nelson and Chomitz, 2009	Latin America	IUCN I-IV	PA compared to matched outside	+	0.035		Difference in fire risk	-	Matching
Nelson and Chomitz, 2009	Africa	IUCN V-VI	PA compared to matched outside	+	0.03		Difference in fire risk	-	Matching
Nelson and Chomitz, 2009	Asia	IUCN V-VI	PA compared to matched outside	+	0.051		Difference in fire risk	-	Matching
Nelson and Chomitz, 2009	Latin America	IUCN V-VI	PA compared to matched outside	+	0.056		Difference in fire risk	-	Matching
Nelson et al. 2001	Panama	Darién NP	PA compared to matched outside	0	Same with protection as without		Probability of clearing	-	Regression
Nelson et al. 2001	Panama	Darién NP	Indigenous reserves compared to matched outside	+	Lower with protection than without		Probability of clearing	-	Regression
Nepstad et al. 2006	Brazil	10 Extractive reserves	Reserves compared to buffer	+	-0.0015	-0.0027	Annual	1.8	In-Out
Nepstad et al. 2006	Brazil	121 indigenous reserves	Indigenous reserves compared to buffer	+	-0.0018	-0.0146	Annual	8.11	In-Out
Nepstad et al. 2006	Brazil	18 National forest	National forests compared to buffer	+	-0.0008	-0.0079	Annual	9.88	In-Out
Nepstad et al. 2006	Brazil	33 PAs	PA compared to buffer	+	-0.0003	-0.0068	Annual	22.67	In-Out
Oestreicher et al. 2009	Panama	San Lorenzo, Soberani´a, Chagres, Altos de Campana	PA compared to buffer	+	-	-	-	-	Interview
Oliveira et al. 2007	Peru	all in the amazon region	PA compared to buffer	+	-0.0115	-0.0476	Total	4.14	In-Out
Pelkey et al., 2000	Tanzania	All GCA	GCA compared to entire country outside protection	-	1.53		Probability of clearing compared to outside	0.65	Regression
Pelkey et al., 2000	Tanzania	All FR	FR compared to entire country outside protection	0	0.91		Probability of clearing compared to outside	1.10	Regression
Pelkey et al., 2000	Tanzania	All NP	PA compared to entire country outside protection	+	0.62		Probability of clearing compared to outside	1.62	Regression
Sader et al. 2001	Guatemala	MBR	PA compared to buffer	+	-0.0013	-0.0159	Annual	12.23	In-Out
Sanchez-Azofeifa et al. 2002	Costa Rica	Corcovado NP	PA compared to buffer	+	0	-0.0113	Annual	-	In-Out
Sanchez-Azofeifa et al. 2003	Costa Rica	20 NPs	PA compared to buffer	+	-0.0054	-0.0083	Annual	1.54	In-Out
Sanchez-Azofeifa et al.	Costa Rica	4 Biosphere reserves	BR compared to buffer	+	-0.0029	-0.0083	Annual	2.86	In-Out

2003									
Scharlemann et al. 2010	The Afrotropic	All tropical forested PA's	PA compared to similar habitats outside	-	-0.31	-0.23	Total	0.73	In-Out
Scharlemann et al. 2010	Oceania	All tropical forested PA's	PA compared to similar habitats outside	+	-0.79	-2.93	Total	3.71	In-Out
Scharlemann et al. 2010	The Neotropic	All tropical forested PA's	PA compared to similar habitats outside	+	-0.67	-0.83	Total	1.25	In-Out
Scharlemann et al. 2010	Tropical Asia	All tropical forested PA's	PA compared to similar habitats outside	+	-1.33	-2.29	Total	1.72	In-Out
Shearman and Bryan 2011	Papua New Guinea	34 PAs	PA compared to similar habitats outside	+	-0.089	-0.24	Total	2.70	In-Out
Smith 2003	Nicaragua	Bosawas	PA compared to buffer	+	0	-	Total	-	In-Out
Songer et al. 2009	Burma	Chatthin	PA compared to buffer	+	-0.0045	-0.0186	Annual	4.13	In-Out
Southworth et al. 2004	Honduras	Celaque NP	PA compared to buffer	+	-0.0387	-0.2512	Total	6.49	In-Out
Tabor et al., 2010	Kenya	75 PAs	PA compared to similar habitats outside	+	-0.0001	-0.008	Annual	8	In-Out
Tabor et al., 2010	Kenya Tanzania	75 PAs	PA compared to similar habitats outside	+	-0.002	-0.008	Annual	8	In-Out
Tabor et al., 2010	Kenya Tanzania	30 KBAs	PA compared to similar habitats outside	+	-0.003	-0.008	Annual	8	In-Out
Tabor et al., 2010	Tanzania	2 AZEs	PA compared to similar habitats outside	+	-0.001	-0.008	Annual	8	In-Out
Tole 2002	Jamaica	Hellshire Hills	PA compared to buffer	+	-0.01	-0.15	Annual	15	In-Out

Table 8. Summary of the 76 studies evaluating PA effectiveness for habitat extent. Extension of table S4 including specific positive and negative drivers reported, methods used for data collection, habitat type and where reported IUCN categories for the PAs.

Source	PA (short)	IUCN	Counterfactual	Positive Drivers	Negative Drivers	Data type	habitat
Abbot and Homewood, 1999	Lake Malawi NP	II	PA compared to buffer		Fuel wood collection	Aerial	Forest
Alados et al. 200	Cabo de Gata-Nijar	V	PA compared to buffer	Increased slope, elevation, reduced soil quality	human settlement	Aerial	Forest
Alo and Pontius, 2008	Forest reserves	-	PA compared to buffer		Logging outside the reserve and agricultural conversation outside.	Remote sensing	Forest
Andam et al. 2008	150 protected areas	-	PA compared to similar habitats outside	Isolation, elevation, increased slope	Human populations density	Remote sensing	Forest
Armenteras et al. 2006	Indigenous reserves	-	Reserve compared to buffer	Isolation, Size	Human population density, economic conditions, cattle grazing, rivers and roads	Remote sensing	Forest
Armenteras et al. 2006	Guyana NP	-	PA compared to buffer	Isolation, Size	Human population density, economic conditions, cattle grazing, rivers and roads	Remote sensing	Forest
Armenteras et al. 2006	Guyana NP	-	PA compared to indigenous reserves	Isolation, Size	Human population density, economic conditions, cattle grazing, rivers and roads	Remote sensing	Forest
Arroyo-Mora et al. 2005	Chorotega region	-	PA compared to adjacent landscape	Governmental management, reduced cattle prices	Cattle grazing, logging	Remote and Aerial sensing	Forest
Bleher et al., 2006	Kakamega	-, II	PA compared to forest reserve	Management for wildlife. National reserve > forest reserve	Logging	Ground	Forest
Bray et al. 2008	11 PAs	-	PA compared to community managed area	Remoteness	Human population density and distance to previous forest area	remote sensing	Forest
Bray et al. 2008	11 PAs	-	PA compared to community managed area	Remoteness	Human population density and distance to previous forest area	remote sensing	Forest
Brower et al. 2002	4 reserves	-	Region of the reserves		Logging, agricultural encroachment * before and after establishment	Remote sensing	Forest
Bruner et al. 2001	93 protected areas	-	Protected not protected	Number of guards, level of deterrent, fencing and compensation programs		Ground	Forest
Chatelain et al., 2010	Tai NP	II	PA compared to buffer		Human population density and encroachment	Remote and Aerial sensing	Forest
Chowdhury 2006	Calakmul BR	VI	PA compared to buffer	Management plan, community involvement, Elevation	distance to roads, settlements and previously forested areas	Remote sensing	Multiple
Cropper et al. 2001	Multiple	-	Wildlife sanctuaries compared to buffer		Human population density, roads	Remote sensing	Forest
Cropper et al. 2001	Multiple	-	PA compared to buffer		Human population density, roads	Remote sensing	Forest
Curran et al. 2004	Gunung Palung NP	II	PA compared to buffer		Logging by timer concessions	Remote sensing	Forest
Cushman and Wallin 2000	Sikhote-alinskiy BR	Ia	PA compared to buffer		Fires and human infrastructure	Remote sensing	Forest
DeFries et al. 2005	198 protected areas	I and II	PA compared to buffer		Encroachment	Remote sensing	Forest
Ellis and Porter-Bolland 2008	Calakmul BR	VI	PA compared to community managed area	community managed > protected area, external funding (GEF), Elevation	Distance to roads, settlements	Remote sensing	Forest
Forrest et al. 2008	Madidi NP, Tierras	II, -,	PA compared to adjacent landscape	Elevation, Natural resource protection	Human settlements, roads	Remote sensing	Forest

	Origen Tacana	-		laws			
Gaveau et al. 2007	Bukit Barisan Selatan NP	II	PA compared to Wildlife Sanctuary	Increased slope, elevation	Logging, roads, PA edge	Remote sensing	Forest
Gaveau et al., 2009	Multiple	-	PA compared to buffer	National Park >> Nature Reserve and Wildlife Sanctuary. Law enforcement, Staffing, anti-logging campaigns and eviction of rural communities	Human populations density	Remote sensing	Forest
Gaveau et al., 2009	Multiple	-	PA compared to region	National Park >> Nature Reserve and Wildlife Sanctuary. Law enforcement, Staffing, anti-logging campaigns and eviction of rural communities	Human populations density	Remote sensing	Forest
Hayes et al. 2002	5 NPs 4 BRs	-	PA compared to buffer		Elevation, roads and human infrastructure	Remote sensing	Forest
Ingram and Dawson, 2005	All protected areas	-	PA compared to similar habitats outside		Logging and fires (for agricultural expansions)	Remote sensing	Forest
Joppa and Pfaff 2011	Global tropical forested PA's	-	PA compared to matched outside	Isolation, elevation, increased slope IUCN category I and II were effective depending on method	Human population density, roads, rivers	remote sensing	Multiple
Kinnaird et al. 2003	Bukit Barisan Selatan NP	II	PA compared to buffer	Increased slope	conversation to agriculture	Remote sensing	Forest
Kiragu Mwangi et al., 2010	36 IBAs	-	Protected compared to none-protected IBAs	Management planning, implementation of management actions	species specific threat	Ground	Multiple
Linkie et al., 2004	Kerinci Seblat NP	II	PA compared to buffer	Gauds, Integrated Conservation and development project	Logging concessions, road constructions	Remote sensing	Forest
Liu et al. 2001	Wolong	V	Establishment of PA and compared to buffer			Ground	Forest
Luque 2000	New Jersey Pinelands	V	PA compared to buffer	Management plan	Urban encroachment	Remote sensing	Multiple
Mapaure and Campbell, 2002	Sengwa	-	PA compared to similar habitats outside	Regulation of Elephant populations and fires	Large elephant populations	Aerial	Forest
Mas 2005	Calakmul BR	VI	PA compared to matched outside	Elevation and increased slope	Human population density, roads *higher number outside in none-matched	Remote sensing	Forest
Mas 2005	Calakmul BR	VI	PA compared to buffer	Elevation and increased slope	Human population density, roads *higher number outside in none-matched	Remote sensing	Forest
Mendoza and Dirzo 1999	Monte Azules BR	VI	PA compared to adjacent landscape	Wildlife sanctuaries (-0.26%) > protected areas (-0.31%)	Human population density	Remote sensing	Forest
Mertens et al. 2004	Amboro NP, Noel Kempff, Mercado NP, BR, the Rios Blanco and Negro WR	-	PA compared to adjacent landscape	Isolation	Human settlements, roads, favorable agricultural conditions	Remote sensing	Forest
Messina et al. 2006	Cuyabeno Wildlife Production Reserve	VI	PA compared to buffer		human population density, poverty, urban expansion	Remote sensing	Forest
Mulley and Unruh, 2004	Kibale NP	II	PA compared to buffer	management plan, tea growing outside PA	Human encroachment	Remote and Aerial sensing	Forest
Nagendra et al. 2008	Chitwan NP and Parsa	II,IV	PA compared to similar habitats outside	Isolation	Grazing and fuel wood extraction	Remote sensing	Forest

Nagendra et al. 2008	Chitwan NP and Parsa	II,IV	PA compared to buffer	Isolation	Grazing and fuel wood extraction	Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN I-IV	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN I-IV	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN I-IV	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN V-VI	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN V-VI	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson and Chomitz, 2009	IUCN V-VI	-	PA compared to matched outside	Indigenous land and multi-use protected areas		Remote sensing	Forest
Nelson et al. 2001	Darién NP	II	PA compared to matched outside	Slope and isolation		Remote and Aerial sensing	Forest
Nelson et al. 2001	Darién NP	-	Indigenous reserves compared to matched outside	Slope and isolation		Remote and Aerial sensing	Forest
Nepstad et al. 2006	10 Extractive reserves	-	Reserves compared to buffer	Land tenure to indigenous people. Stricter protection		Remote sensing	Forest
Nepstad et al. 2006	121 indigenous reserves	-	Indigenous reserves compared to buffer	Land tenure to indigenous people. Stricter protection	Fires	Remote sensing	Forest
Nepstad et al. 2006	18 National forest	-	National forests compared to buffer	Land tenure to indigenous people. Stricter protection	Fires	Remote sensing	Forest
Nepstad et al. 2006	33 PAs	-	PA compared to buffer	Land tenure to indigenous people. Stricter protection		Remote sensing	Forest
Oestreicher et al. 2009	San Lorenzo, Soberani´a, Chagres, Altos de Campana	-	PA compared to buffer	Guard numbers, funds and NGO involvement	Agricultural expansion and logging concessions	Remote sensing and interviews	Forest
Oliveira et al. 2007	all in the amazon region	-	PA compared to buffer	protected areas > Indigenous lands		Remote sensing	Forest
Pelkey et al., 2000	All GCA	-	GCA compared to entire country outside protection	Management under national duristiction, guard patrols	Sub-national management duristiction	Remote sensing	Multiple
Pelkey et al., 2000	All FR	-	FR compared to entire country outside protection	Management under national Jurisdiction, guard patrols	Sub-national management	Remote sensing	Multiple
Pelkey et al., 2000	All NP	-	PA compared to entire country outside protection	Management under national jurisdiction, guard patrols	Sub-national management	Remote sensing	Multiple
Sader et al. 2001	MBR	-	PA compared to buffer	Isolation	Human settlement, roads and rivers	Remote sensing	Forest
Sanchez-Azofeifa et al. 2002	Corcovado NP	II	PA compared to buffer			Remote sensing	Forest
Sanchez-Azofeifa et al. 2003	20 NPs	-	PA compared to buffer	Isolation	logging for agriculture	Remote sensing	Forest
Sanchez-Azofeifa et al. 2003	4 Biosphere reserves	-	BR compared to buffer	Isolation	logging for agriculture	Remote sensing	Forest
Scharlemann et al. 2010	Tropical forested PA's	-	PA compared to similar habitats outside	Stricter protection IUCN I-II > IUCN III-VI and no IUCN category		Remote sensing	Forest

Scharlemann et al. 2010	Tropical forested PA's	-	PA compared to similar habitats outside	Stricter protection IUCN I-II > IUCN III-VI and no IUCN category		Remote sensing	Forest
Scharlemann et al. 2010	Tropical forested PA's	-	PA compared to similar habitats outside	Stricter protection IUCN I-II > IUCN III-VI and no IUCN category		Remote sensing	Forest
Scharlemann et al. 2010	Tropical forested PA's	-	PA compared to similar habitats outside	Stricter protection IUCN I-II > IUCN III-VI and no IUCN category		Remote sensing	Forest
Shearman and Bryan 2011	34 PAs	-	PA compared to similar habitats outside	Isolation, elevation, increased slope	Human population density	Remote sensing	Forest
Smith 2003	Bosawas	VI	PA compared to buffer	Buffers	End of civil war.	Remote sensing	Multiple
Songer et al. 2009	Chatthin	III	PA compared to buffer	Staff and research program	Logging	Remote sensing	Forest
Southworth et al. 2004	Celaque NP	II	PA compared to buffer	Increased slope, NGO initiatives	Agricultural expansion, increased coffee prices	Remote sensing	Forest
Tabor et al., 2010	75 PAs	-	PA compared to similar habitats outside			Remote sensing	Forest
Tabor et al., 2010	75 PAs	-	PA compared to similar habitats outside			Remote sensing	Forest
Tabor et al., 2010	30 KBAs	-	PA compared to similar habitats outside			Remote sensing	Forest
Tabor et al., 2010	2 AZEs	-	PA compared to similar habitats outside			Remote sensing	Forest
Tole 2002	Hellshire Hills	-	PA compared to buffer		Subsistence encroachment, human settlements, Edge effect	Ground	Forest