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Collaboration for Environmental Evidence

Systematic Review No. *10-007*

WORKING TITLE:

*EFFECTIVENESS OF TERRESTRIAL PROTECTED AREAS IN
MAINTAINING BIODIVERSITY AND REDUCING HABITAT LOSS*

Draft Review

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Cover Sheet

Title	<i>Effectiveness of terrestrial protected areas in maintaining biodiversity and reducing habitat loss</i>
Systematic review	N^o. 10-007
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1. Background

Protected areas 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 the most important tool available to conservationists and other stakeholders 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].

Protected area coverage is one of the only global conservation targets achieved under the CBD. Unfortunately, despite the increase in coverage, there is considerable debate over the extent to which protected areas deliver conservation outcomes in terms of species and habitat protection [2, 8, 16-22]. It has been suggested that many of the world's protected areas 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 protected areas are delivering conservation benefits for species and habitats is an essential research question, for policy makers, planners, managers and conservation advocates [3, 9, 27-33]. Politically, international conservation strategies implemented by both governments and NGOs rely primarily on protected areas to safeguard biological diversity as was confirmed by the new 2020 increased protected area estate targets of the CBD CoP10 in Nagoya, Japan.

Conservation success has traditionally been defined and evaluated in different ways, largely depending on the context and the available data. Early studies on the effectiveness of protected areas looked at the representativeness of protected area networks in terms of their coverage of species diversity, endemism, or threat [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 protected area gap analyses are valuable in the planning phase of conservation, and can be used to inform the design of protected area networks, they do not provide information on the ability of these reserves to effectively protect and preserve biodiversity. They are not real examples of conservation success, as they are not able to document a causal link between conservation actions/input (e.g. establishment of protected areas or management of these) and the observed outcomes (e.g. improved population trends for species or reduced habitat loss). Whether the existence of protected areas in a particular location has any effect on the survival of animals and plants inside its boundaries cannot be inferred from its 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.

A lack of available data has been the primary reason why it has been difficult for conservation scientists to shift from measuring representativeness of the biodiversity within protected area networks (e.g. [8]) or assessing the broad effectiveness of reserve management (e.g. [44]), to measuring the effectiveness of protected areas at conserving biodiversity values. Combined with a lack of consensus on how these biodiversity outcomes might best be measured [45-48], as well as an increasing demand for more rigorous analysis to ensure reliable results [49-51], has made the shift difficult. Thus complicating the transition from analyses of spatial differences

95 between protected and non-protected land to temporal analyses of how biodiversity
96 values of protected areas change after establishment, or with improved management.

97
98 In this review we examine the available evidence to determine whether there is a
99 relationship between the quality, or effectiveness, of terrestrial protected area
100 management; and the biological outcomes in those protected areas. Specifically we
101 examine changes in a) habitat cover and b) species populations. We have not
102 considered marine or freshwater protected areas in this assessment. We also discuss
103 how the core question of whether enhanced biological outcomes result from better
104 managed protected areas might be more fully answered within the context of the
105 newly formed IUCN SSC/WCPA Task Force on Biodiversity and Protected Areas.

106

107

108 **2. Objective of the Review**

109

110 **2.1 Primary question**

111 What evidence exists to link conservation actions and activities to conservation
112 outcomes in terms of maintained species populations or prevented forest habitat loss
113 in terrestrial reserves?

114

115 Our focus will be on studies with data that evaluate whether protected areas are
116 effective. We either use comparison of biological outcomes (population estimates or
117 forest cover) inside and outside the protected area, or measured impacts of specific
118 management interventions, governance regimes, or other properties of protected areas
119 that are under the control of protected area managers.

120

121 Population/Changing value: Temporal biodiversity or habitat trend measures

122 Input data: Any type of management as defined in the individual study.

123 Comparator 1: Inside/outside protected area comparison*

124 Comparator 2: Attributes of protected area**

125 Comparator 3: Management input of protected area***

126 Outcome: Positive effects on species abundance or habitat maintenance and
127 persistence.

128

129 * Within reserve and outside reserve comparison of reserves matched by habitat types.

130

131 ** Protected area characteristics (e.g. IUCN category, age, spatial characteristics,
132 proximity to roads and urban areas, altitude, slope, habitat, nation/region and
133 background rate of deforestation and degradation, and human activities) influence
134 protected area effectiveness in conserving biodiversity

135

136 *** Elements of management input such as staffing, budget, management plan,
137 community outreach programme, and as defined in studies identified by the
138 systematic review search.

139

140

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142

143

144 **3. Methods**

145

146 **3.1 Literature search strategy**

147

148 The search was divided into two parts, one focusing on the effectiveness of protected
149 areas in terms of species population changes and the other on habitat changes.

150

151 A number of relevant terms and descriptive words were compiled from the referenced
152 literature and derived directly from the questions addressed in the review (Table 1).
153 Boolean nomenclatures ‘*’= all letters will be allowed after the *, were used when
154 appropriate and Boolean‘\$’ where only one letter changes are relevant. After running
155 several initial searches using a more restrictive and more inclusive number of search
156 terms the following list was created. For some search engines with limited search
157 capability the number of search terms was reduced.

158

159 Table 1: English search terms used in the systematic review

Biodiversity	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*			

160

161 To locate relevant literature, we searched 14 databases, 8 specialist sources and 13
162 websites in English (Table 2) and extended the search to Spanish and Danish for the
163 major search tools.

164

165 Table 2: Sources used in the search

Scientific sources	Specialist sources	Websites
ISI Web of Knowledge	World Environment Library http://www.nzdl.org/fast-cgi-bin/library?a=p&p=about&c=en	Google/Yahoo/chrome
BIOSIS citation index	Forestscience.info http://www.forestscience.info/	Google scholar
Zoological records	Tropical forest conservation and development database http://forestry.lib.umn.edu/bib/trps.html	IUCN website
ASFA	Conservationevidence.org	WWF website
SCRIS	UN-REDD Web Platform http://unfccc.int/methods_science/redd/items/4531.php	FAO website
Science Direct	FAO online catalogue: http://www4.fao.org/faobib/	UNEP website
Directory of Open Access Journals	World Environment Library http://www.nzdl.org/fast-cgi-bin/library?a=p&p=about&c=en	CIFOR website
Index to Theses Online	Forestscience.info http://www.forestscience.info/	Woods Hole research centre
CAB abstracts	Tropical forest conservation and development database http://forestry.lib.umn.edu/bib/trps.html	Conservation International
COPAC	Conservationevidence.org	WCS
University of Oxford		World Bank

166 Articles were ordered by relevance and searches were restricted to papers within the
167 bibliographic search engines conservation categories to increase the relevance of
168 papers found.

169
170 An unfiltered list of papers retrieved using the systematic search technique was sent to
171 an expert group of about 10-15 people from the IUCN taskforce for Biodiversity and
172 Protected Areas, primarily researchers, to try and locate possible papers and other
173 published material that had been missed. Although the majority of papers included
174 here were found using the systematic review search criteria, papers from other sources
175 have been added throughout the review process.

176
177 **Danish:** naturforvaltning, biodiversitet, monitoring, forvaltning, afskovning, skov,
178 forvaltningseffektivitet, succes, arter, truede\$arter, trend*, truede*, endemisk*,
179 rødliste*, sammensætning, fugl\$, pattedyr\$, padde\$, krybdyr, plante\$ habitat,
180 ødelæggelse, beskyttede\$område*, beskyttede*, nationalpark, reservat*

181 **Spanish:** Conservación, Biodiversidad, Seguimiento, Gestión, La deforestación,
182 Bosque\$, Selva\$, Silvestre, Forestales, La degradación, Eficacia, La eficacia,
183 Resultado\$, Resulta\$, Efect*, Éxito, Éxito, Un Éxito, *Especi*, specia, Las especies
184 en amenaza, Tendencia\$, Endémica\$, composición, Lista\$rojo, Amenaza*, En\$
185 amenaza, Poner en peligro*, *Disminución, Ave\$, Mamífero\$, Anfibio\$, Reptil*,
186 Planta\$, Hábitat*, Destrucción, *Salida*, Gobernabilidad, Protegida\$, Área\$, Zona\$,
187 Nacional*, Parque\$, Parqu\$\$naci\$nal*, Reserva\$, Comunid*, *Conserv*, *Preserv*,
188 Persona\$Ind\$gena*, área de conservation de la comunidade, áreas de conservation de
189 las comunidades

190

191

192 3.2 Study inclusion criteria

193

194 Studies describing a temporal or spatial change in populations, or habitat cover,
195 relating to either direct management interventions or governance measures in
196 protected areas were included in the study. Studies without a counterfactual, i.e.
197 studies that only examine population or habitat condition inside protected areas, rather
198 than examining temporal trends or comparing changes to external areas, were
199 excluded.

200

201 Protected areas were not defined *a priori* using international standards (Dudley et al.
202 2008), but instead the definitions were based on the information provided in the
203 studies reviewed. We made no attempt to cross check the protected areas in these
204 reviewed studies against standard lists of protected areas, such as those maintained by
205 the World Database of Protected Areas that is managed by UNEP-WCMC and IUCN
206 (see www.protectedplanet.net).

207

208 Management interventions and governance regimes were defined as anything
209 additional to the protection *per se* (i.e. gazettal).

210

211

212 3.3 Study quality assessment

213

214 All studies, reports and papers assessed in the systematic review were first screened
215 by one reviewer for *i*) subject comparability; *ii*) types of questions being proposed; *iii*)
216 data, review or essay driven analyses, and *iv*) quality of the methodology and type of
217 data. A kappa analysis was conducted for habitat and biodiversity respectively on the
218 level of title and abstract separately. After sorting by relevance, the 200 first papers
219 were reviewed by two independent reviewers. All papers included in the final report
220 were evaluated by all reviewers.

221

222 3.4 Data extraction strategy

223

224 For each source, data was extracted on:

225

- 226 1. Location of the protected area
- 227 2. Study site characteristics (e.g. forest, grassland, etc.)
- 228 3. Intervention (e.g. type of protected area)
- 229 4. Measures (e.g. deforestation, species populations and diversity),
- 230 5. Methodology (e.g. temporal and spatial comparisons - buffer analyses,
231 time-series),
- 232 6. Outcomes (e.g. deforestation rate, changes in species population over
233 time/space),

234

235

236 4. Results

237

238

239

4.1. Search results

240 The main search engine providing results was ISI Web of Knowledge. While other
241 search engines contributed a few papers, the search statistics and analysis were
242 restricted to the results from the ISI Web of Knowledge.

243

244 A total of 97,737 papers were found for the categories 1) biodiversity, 2) protected
245 area, 3) management and 4) outcome. Restricting the search to the Web of Knowledge
246 defined topic of 'Biodiversity and Conservation' reduced the number of papers to
247 22,599.

248

249 The kappa analysis for the search for papers on species trends in protected areas
250 showed a moderate similarity between searches of the two reviewers when based on
251 paper titles alone ($k = 0.51$). When the search included the papers abstract, the
252 similarity was improved ($k = 0.77$).

253

254

255 4.2. Species trends

256

257 4.2.1. Number of papers and spread of data

258

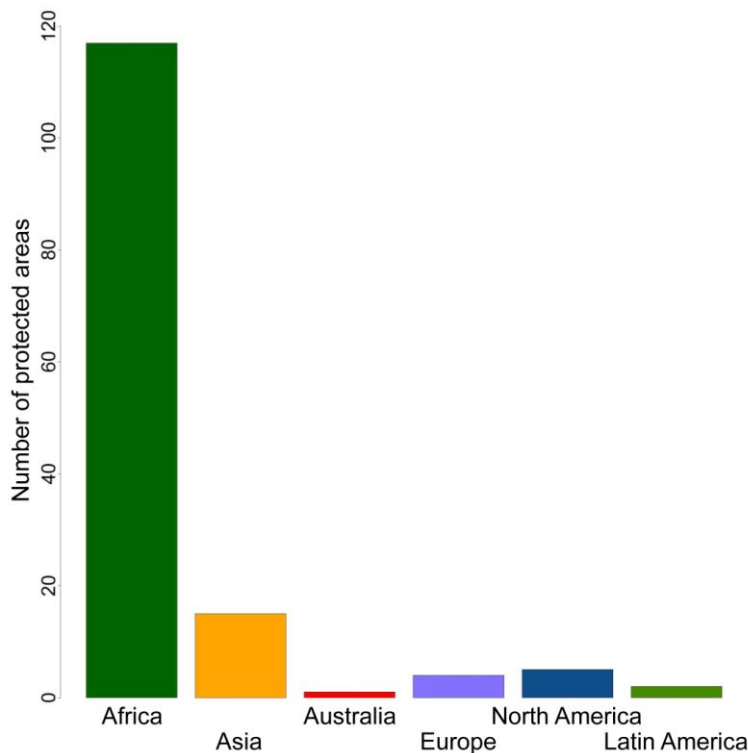
259 We found 39 papers reporting the impacts of protected areas on species population
260 trends, which also contained information on the management interventions undertaken
261 within those protected areas. The link between effective management and biodiversity

262 outcomes is the core question of our review, hence our focus only on papers that
 263 address that issue.

264

265 Of the 39 papers, 22 examined single protected areas studies, 12 considered national
 266 protected area networks (< 50 protected areas) in the same country, and 4 were from
 267 multiple protected areas across national boundaries. In total the reviewed studies
 268 covered 135 distinct protected areas plus four studies with no information on the
 269 specific protected areas included [52-55] (Figure 1).

270



271

272 Figure 1. Total number of protected areas by continent (for population time-series studies
 273 only)

274

275 Most of the data (73%) came from protected areas in tropical regions, there were 18
 276 studies from Africa, eight from Asia and three from Latin America. North America
 277 (n=5) and Europe (n=5) had 25% of the studies and Australia (n=1) made up the last
 278 3%. One study on Rhinos covered both Africa and Asia which explains the total of 40
 279 for the geographic coverage [53] (Figure 2 and Table 3).

280

281 Table 3. Overview of the 25 papers linking management inputs and the effectiveness of protected areas,
 282 divided by continent.

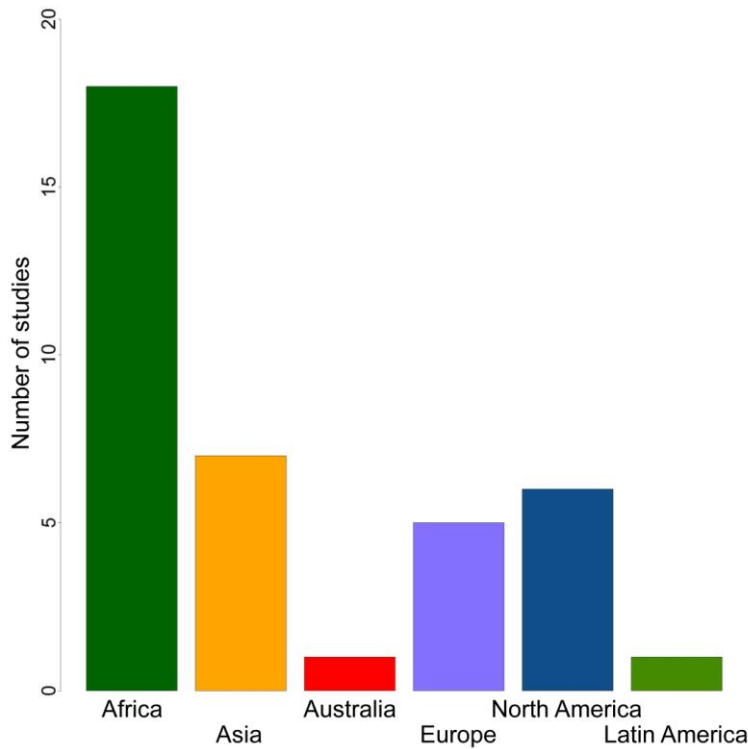
Continent	Total papers	Total Positive	Mammals Positive	Birds Positive	Other taxa Positive
Africa	18	14	12	1	1
Asia	8	5	4	1	0
Australia	1	1	0	1	0
Europe	5	3	0	2	1
Latin America	3	3	2	0	1
North America	5	3	3	0	0
Total	40	29	21	5	3

283

284 Sums may exceed total number of studies in cases were more than one taxa has been used in one study.

285

The category "others" contain studies on insects and amphibians.



286
 287 Figure 2. Geographical distribution of population time-series studies by continent.
 288

289 The reviewed studies covered 266 different species from 358 populations of which
 290 226 were mammals and 100 came from one study of bird populations in France [52]
 291 (Figure 3). In four studies it was not possible to determine the species involved [56-
 292 59]. Most studies looked at mammals (68%), followed by birds (20%), insects (7%),
 293 amphibians (2%) and overall biodiversity (2%). Half of all studies were of large
 294 mammals in African savannah parks.

295
 296 20 studies were of 1-2 species, 16 studies were of assemblages of species (<50), and 6
 297 were of multiple species (>50) or alternative measures of biodiversity.

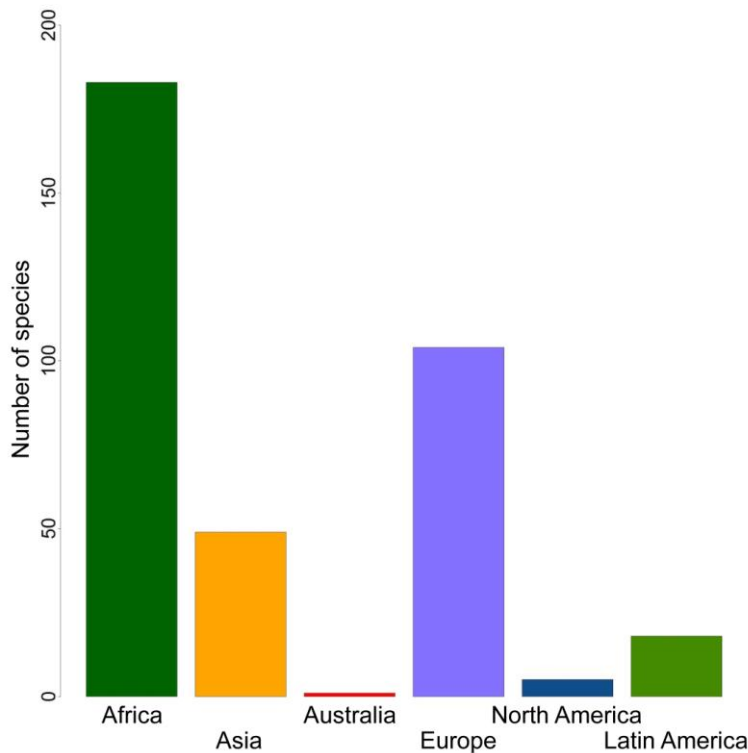


Figure 3. Total number of species by continent

4.2.2. Population trends

The time periods for population trend measurements ranged from two years [60, 61] to 70 years [62]. The mean time series for data included was 17 years and the median was 14.

In 15 of the 39 studies (38%) population sizes were reported to have increased over the study period, while in 17 studies (44%) decreases were reported. In four cases populations remained stable and in three cases the overall change was not possible to determine (Table 4). In none of the studies was there a like for like comparison of species trends in protected areas with similar, nearby or statistically matched areas that differed only in their protection status.

Of the sample of 39 papers, 29 showed a positive impact on species population trends following management interventions, five showed no effect, and five cases showed negative impacts. Some examples include: Five species of passerine birds in southern and central Spain declined due to increased predation after management had reduced hunting pressure on natural predators [58, 63]; In Pilanesberg National Park, South Africa, the increased populations of lions (*Panthera leo*) following fencing of the reserve lead to decreases in populations of blue wildebeest (*Connochaetus taurinus*) [64]; In Lassen Volcanic national park, California, USA management plans for the preservation of the area's natural values through fire reductions and suppression of cattle grazing lead to a decline in Cascades frogs (*Rana cascadae*) due to the loss of open habitats through forest regrowth [65]; A decline in rare species of butterflies was seen in preserved Minnesota prairies following an increase in fire frequencies [57].

329 **4.2.3. Management actions and attributes**

330

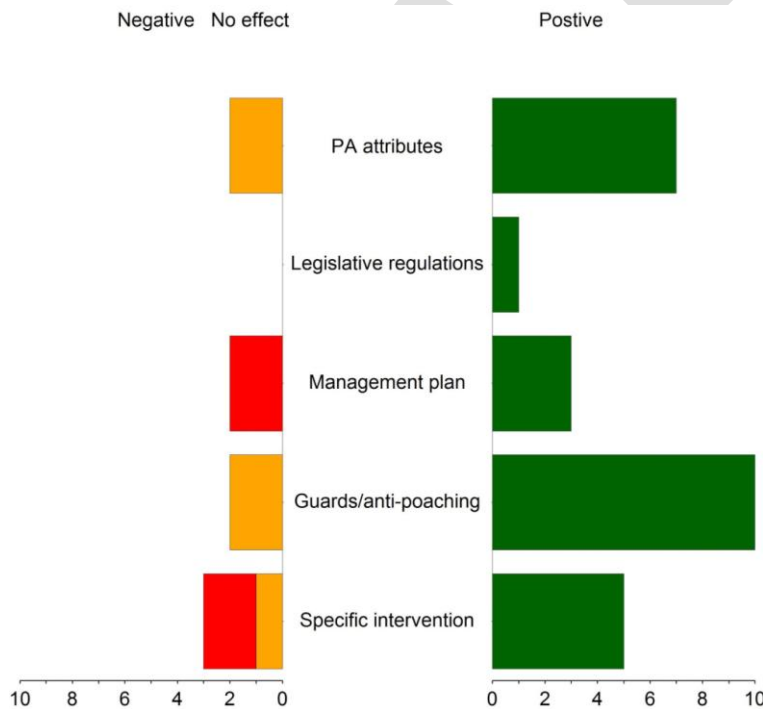
331 Based on the different types of management and interventions described in the papers
332 reviewed, we have grouped them into six categories: *i*) Protected Area attributes, *ii*)
333 legislative and governmental regulations, *iii*) Management plans, *iv*) Guards and anti-
334 poaching, and *v*) Targeted management interventions (Figure 4).

335

336 No standardized methodology exists to evaluate the effectiveness of protected areas in
337 conserving mammal diversity using population time-series data from different studies,
338 and no attempt has been made in any of the papers studied to disentangle the impacts
339 of *i*) background condition (weather, climate, human population changes,
340 infrastructure), *ii*) protected area attributes (elevation, slope, protected area size,
341 fragmentation, age of protected area), and *iii*) management impacts (guards, fencing,
342 resources, management plans, hunting regulations).

343 This often results in studies being able to only speculate on the causality between
344 input and outcomes without presenting clear evidence for the direct role of
345 conservation interventions. In cases where one or several of the above factors are
346 excluded, only minor changes in the experimental setup would be needed to improve
347 the design. A standardized methodology and common framework could improve this
348 for future studies.

349



350

351 Figure 4. Effects of management actions for population time-series studies. Green indicates
352 positive effect, orange that management made no difference and red that the intervention had
353 a negative effect.

354

355 The most frequently reported type of intervention was regulation of hunting or anti-
356 poaching actives (n=16), often linked to the presence of guards and ground patrols. In
357 Africa six cases from Ghana [66] and Tanzania [67-71] showed that populations of
358 between 20-28 species of large herbivores declined less within reserves with strictly
359 enforced anti-poaching policies than outside reserves, and in one case population

360 declines inside the protected area increased after patrolling ceased [67]. In Katavi
361 National Park, Tanzania [68] and in eight protected areas in Ghana [66] populations
362 increased following the enhancement of anti-poaching activities. This was also true
363 for populations of rhinoceros in Africa and Asia [53] and for nine mammal species in
364 Bardia national park, Nepal [72]. In Vietnam the rate of Banteng (*Bos javanicus*)
365 population declines slowed with anti-poaching activities but populations continued to
366 decline within the park as poaching was not completely eliminated [73].

367

368 A stricter legal framework was found to have a positive effect on biodiversity in 16
369 protected areas across 11 African countries, based on a questionnaire study of area
370 managers [59]. Stoner et al. [74] showed that populations in more strictly protected
371 reserves did better than those in less strictly protected areas, although populations in
372 all reserves declined over the 20 year study period. Five studies comparing
373 populations inside and outside protected areas all found reserves to be more effective
374 than external land-uses [52, 56, 75-77]. Other examples include increased density of
375 leopards (*Panthera pardus*) towards the core of the protected areas [78] and in
376 Botswana the same was the case for birds [54]. Moreover, in the Serengeti National
377 Park in Tanzania, populations of wildebeest increased hugely after the reserve was
378 established [79], though this case has been debated because of other confounding
379 factors [80].

380

381 Targeted management interventions were described in nine studies and found to be
382 effective in six of these. Fencing was found to be effective for elephants populations
383 (*Loxodonta africana*) in Addo Elephant National Park, South Africa [81]. In three
384 successful cases provision of artificial feeding sites [82] reductions of invasive
385 predators [83], and establishment of artificial nesting sites [84] had a positive effect
386 on bird populations.

387

388

389 **4.3. Habitat Change**

390

391

392 **4.3.1. Number of papers and spread of data**

393

394 We found 59 papers on the ability of protected areas to maintain habitat and reduce
395 deforestation. Of these 12 were from Africa, 11 from Asia (including Oceania), two
396 from Europe, 25 from Latin America, one from North America, and eight were global
397 studies. Except for three studies, all were from the tropics and except for the two
398 European studies all were on deforestation (Figure 5).

399

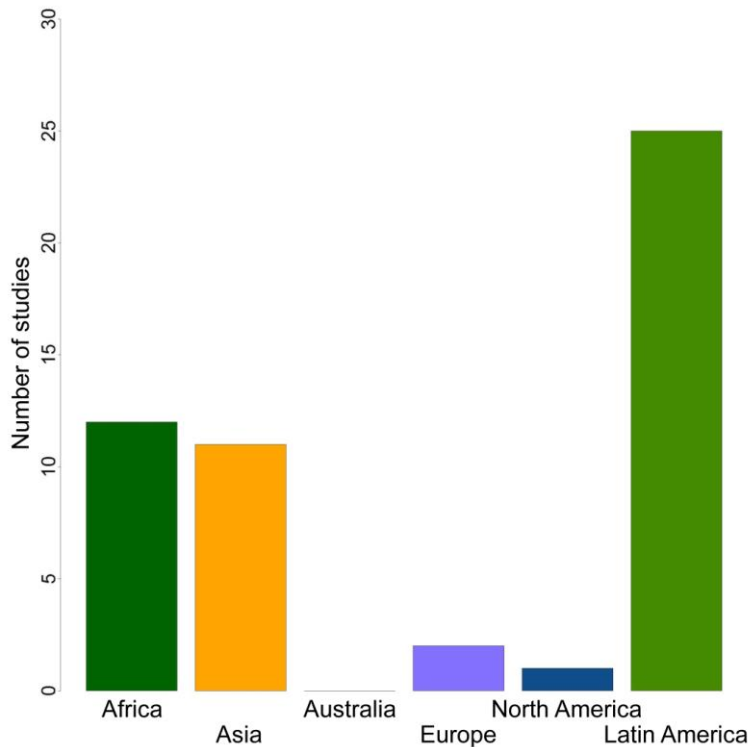


Figure 5. Geographical distribution of habitat change studies divided by continent.

Studies of habitat change were divided into four different groups based on the studies scale: *i*) single or small samples of protected areas, *ii*) total national coverage of protected areas, *iii*) total coverage of specific type of protected areas, or *iv*) global. Thirty-three studies examined one or a few protected areas in a restricted area or region, while 20 looked at either regional networks, or what type of protected area. Eight studies assessed global coverage, the latter ranging from 93 protected areas [4] to 5,787 protected areas [85] which also including 4 meta-analyses or reviews [50, 86-88].

4.3.2 Estimates of habitat change

Of the 59 studies that aimed to measure the effect of protection on forest cover, 53 used remote sensing techniques looking at Normalized Difference Vegetation Index (NDVI) measures from an array of satellite products. These remote sensing studies are only reliable for studies of distinct changes in forest cover visible from satellite usually forest clearing and regrowth or fragmentation and are not able to measure forest degradation where forest cover is not affected. Three papers used measures collected on the ground, either estimations of disturbance between plots, [45] or interviews and questionnaires [4, 89]. Three papers were meta analyses of deforestation [50, 86, 87].

Several methodologies have been proposed to analyze observed deforestation rates, which partly reflect the development of tools and methods for analysis of deforestation patterns. We have divided the analysis into six distinct types to measure the difference between deforestation patterns inside protected areas and their surroundings: *i*) Inside-outside (buffer-analysis) where protected areas are compared to their immediate surroundings, *ii*) Matched inside-outside analysis (apple-to-apple

431 comparison), where ‘outside’ pixels are selected to match inside characteristics such
432 as distance to roads, human settlements, slope, elevation, *iii*) Regression analysis
433 where NDVI values of different pixels of protected areas are used as dependent
434 variables modeled against different values of characteristics such as distance to roads,
435 human settlements, slope, and elevation, *iv*) field observation on the ground, *v*)
436 interviews and questionnaires with local area managers and experts, and *vi*) meta-
437 analysis of previous studies.

438

439 The most common type of analyses found in the papers was a comparison of the
440 extent of habitat change inside protected areas with their immediate surroundings,
441 generally at a single or small number of sites (n=30), followed by regression analysis
442 (n=17), matched inside-outside analysis (n=3), meta-analysis (n=4), interviews and
443 questionnaires (n=2), and on-ground observations (n=1). For two studies the methods
444 were not described (see Table 5). While both regression analyses and inside-outside
445 buffer analyses have been conducted throughout the period covered by the papers,
446 “matching” [2] represents a newer, computationally more sophisticated, and ‘fairer’
447 way to assess the impact of protected areas on habitat trends.

448

449

450 **4.3.3 Overall effectiveness on habitat change**

451

452 When deforestation inside protected areas is compared with unprotected forest lands,
453 the majority of studies (82%) show a reduced rate of habitat loss inside protected
454 areas (Table 5). Only three studies [90-92] found degradation or deforestation rates
455 inside protected areas to be higher than those outside (Table 5).

456

457 Five studies have assessed the effect of protected areas on a global scale and all show
458 overall habitat loss inside protected areas to be less than outside [4, 85, 93-95], but
459 all are restricted to deforestation in tropical regions.

460

461 One detailed global study comparing deforestation inside and in the immediate
462 surroundings of protected areas, found that on average protected areas had lost 3.32%
463 of forest cover while unprotected land had lost 8.65% over a period of 20 years [93].
464 Similarly, Scharlemann et al. [85] found that deforestation rates of tropical forests
465 inside protected areas were about half that of non-protected forests. In the most
466 sophisticated analysis so far undertaken, Joppa and Pfaff [94] were able to
467 numerically evaluate the added value of protected areas using matched inside-outside
468 analysis, showing that some 7.67% of the current global protected area estate would
469 have been deforested if it had never been protected. This was about half of the
470 expected benefit of protection within reserves when compared to a non-matched
471 analysis approach.

472

473 Studies also show that Southeast Asian protected areas have experienced the greatest
474 regional loss of tropical forest inside protected areas [85, 96], with around 0.60×10^6
475 km^2 lost in a period of 20 years compared to $0.58 \times 10^6 \text{ km}^2$ in Latin America [96].
476 However, protected areas in South and Central America suffered the greatest
477 percentages loss in carbon stock compared to protected areas in Africa, Asia and
478 Oceania [85]. Using fire events as a proxy for success of protection Nelson and
479 Chomitz [97] showed that the reduction of fires inside protected areas is greatest in
480 Latin America and the Caribbean followed by Africa and Asia.

481

482 Of 59 studies, eight observed increased forest cover in some or all protected areas,
483 either from tree planting [98] or through natural regrowth [4, 99-104]. Only six
484 studies showed negligible or no loss inside protected areas [105-110]. Twenty-two
485 studies reporting annual loss indicated that there has been a loss of forest cover within
486 protected areas, ranging from 0.07% [111], to 3.17% [91] loss per year in the
487 protected areas concerned (mean -0.55% annual loss).

488

489

490 *4.3.4 Types of protection*

491

492 Three global studies looked at differences in deforestation rates between reserves
493 under different IUCN reserve management categories. In tropical forests,
494 Scharlemann et al. [85] found that reserves in IUCN categories I and II were better at
495 mitigating deforestation than reserves in categories III-VI. Similarly, stricter
496 protection (IUCN categories I-IV) were found to be more successful than multiple-use
497 reserves (IUCN categories V-VI) at reducing fire frequency across geographical
498 regions [95]. However, Joppa and Pfaff [94] found that the effect of IUCN categories
499 was dependent on whether size was included in the analysis, so that IUCN categories I
500 and II only performed better because of their larger average size.

501

502 Seven studies of protected areas networks, all from Latin America, analyzed the effect
503 on rates of forest loss of areas managed by, or under the land tenure of, indigenous
504 people [101, 111-116]. Indigenous reserves are in all cases performing better than no
505 protection, but in one study using frequency of fires as a proxy for deforestation,
506 results were less clear [95].

507

508 In a more detailed analysis of fire patterns of within tropical forests, indigenous
509 reserves performed 2.5-6 times better than protected areas in Latin America and the
510 Caribbean, even taking in to account the more remote and isolated locations of
511 indigenous reserves [95]. Multiple-use reserves (IUCN categories V-VI) appeared to
512 be more effective than stricter protected areas (IUCN categories I-IV) by a factor of
513 about 1.5 in mitigating fires. The same patterns of multiple-use reserves being more
514 effective was mirrored in Asia, however stricter protection was found to be more
515 effective in Africa [95] and several studies only include more strictly protected areas
516 (e.g. [96]).

517

518 At a local scale, within the Chalkhul Biosphere Reserve in Mexico, indigenous
519 protected areas were found to be more effective at stopping forest clearing than other
520 protected areas [113]. Indigenous protected areas were also found to be more effective
521 across the Amazon rainforest [116] and in Panama [114], though indigenous protected
522 areas were also more isolated in the latter, making it difficult to determine whether
523 protection status or isolation is driving the difference in changes.

524

525 Other types of local governance show similar patterns. In Guatemala and south east
526 Mexico, community conserved reserves were found to reduce deforestation better than
527 other types of protection in areas of low risk, while both community managed
528 reserves and traditional protected areas in high threat zones failed to prevent
529 deforestation compared to outside reserves [117].

530

531 In three cases the indigenous reserves did not perform as well as other types of
 532 protected areas. In the Guyana Shield region, Columbia, indigenous reserves were
 533 found to be effective compared to outside reserves, but less effective than national
 534 parks [111, 112]. And while other types of protected areas in Panama experienced
 535 forest re-growth inside their boundaries, indigenous reserves were only able to reduce
 536 deforestation compared to outside [101].

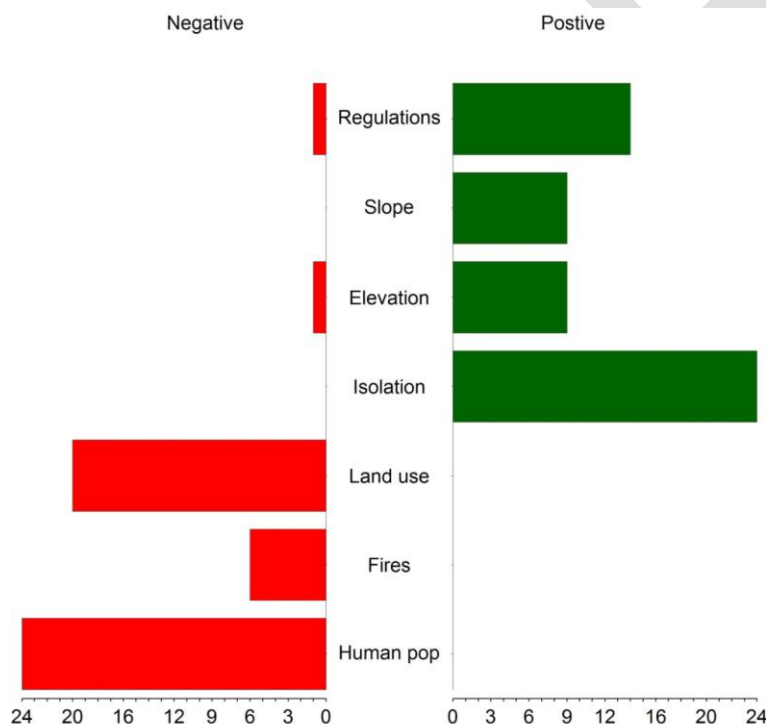
537
 538

539 **4.3.5 Factors causing of habitat change in protected areas**

540

541 We grouped factors reported to influence positive or negative habitat change within
 542 protected areas into four categories, considered to be distinct in their effect on
 543 protected area effectiveness and corresponded to the types of influences reported in
 544 the studies *i*) Human populations and urban extent *ii*) impact of and distance to human
 545 landscape modifications (roads, cities, dams) *iii*) factors intrinsic factors to the site
 546 (elevation, slope, soil quality, climate variables), and *iv*) management actions
 547 (regulations, guards, fencing). The categories were based on the types of explanatory
 548 variables used in the papers ultimately stemming from the available GIS layers used
 549 in the analyses (Figure 6).

550



551

552 Figure 6. Number of studies where the above drivers and spatial characteristics were found to
 553 have a positive (green) effect on habitat loss or negative (red) effect.

554

555 Twenty-four studies identify increased human population numbers or encroachment
 556 of human settlements into the protected areas as a main cause of deforestation within
 557 the reserve. For example, in Taï National Park in Côte d'Ivoire where the greater
 558 deforestation was correlated with an increased immigration to adjacent areas and
 559 increasing cash crop prices over a period of 30 years [105]. Moreover, in the area
 560 around Madidi national park, Bolivia, deforestation was found to be greater closer to
 561 roads with higher human population density [101].

562

563 In 11 cases where human population increase was included in the regression model
564 used to evaluate the effect of protection on rates of forest loss, it was found to be a
565 significant factor. In all cases areas closer to human population centers or with higher
566 human densities experienced higher deforestation rates than less populated areas
567 (Table 5).

568

569 All studies looking at the impact of isolation and increased distance from human
570 populations centers and cities (n=24) found a positive effect of protected areas located
571 in more remote locations. This was supported by a global analysis [94] as well as four
572 previous meta-analyses [50, 86-88] and seven additional papers in which closer
573 proximity to human infrastructure and roads were negatively correlated with
574 deforestation rates [101, 113, 118-122].

575

576 Nine out of ten studies testing the effect of protected areas and elevation found a
577 positive effect of protected areas in higher elevations [2, 94, 99, 101, 113, 118, 120,
578 123, 124], while only one found a negative correlation for five national parks in
579 Guatemala [119]. Nine studies found a positive correlation between decreasing slope
580 and deforestation, so that increased slopes reduced deforestation [2, 94, 99, 110, 114,
581 120, 124-126].

582

583 In seven of these studies management plans were developed for the protected area and
584 in all cases had a positive effect on the reserves ability to reduce deforestation [45,
585 101, 118, 127-130]. In two cases tree planting projects helped increase the forest
586 cover of the protected areas [98, 104]. In contrast to the above, one study from
587 Kerinci Seblat National Park in Indonesia experienced increased deforestation rates
588 from 1.1% per year to 3% after the creation of a targeted conservation plan for halting
589 the deforestation inside the protected area [131].

590

591 Five studies were able to evaluate the effect of increased funding and staffing in the
592 protected areas and all found a decrease in deforestation with increased funding and
593 staffing [4, 89, 113, 132, 133].

594

595 A number of other factors affecting change in forest cover within protected areas were
596 identified in single studies. For example, a study of protected areas in Tanzania
597 documents a positive influence of NGO presence and initiatives in and around
598 protected areas: reserves with involvement of conservation organizations had less
599 deforestation than areas managed by park authorities alone [134]. In Celaque National
600 Park, Honduras, deforestation decreased after NGOs started working together with
601 local communities in educational initiatives [110]. In one study from Nicaragua
602 increased deforestation rates were correlated with the end of the civil war, probably as
603 a result of re-establishing timber harvesting [109].

604

605

606 **5. Discussion**

607

608 Understanding the effectiveness of protected areas remains one of the most important
609 challenges in conservation biology [135]. Here we have evaluated the effectiveness of
610 protected areas on their ability to *i*) preserve biodiversity, measured as species
611 population changes over time and *ii*) preserve habitat extent and structure. The two

612 measures of conservation outcomes are distinct both in terms of the methods used to
613 gather data, and the scope and scale at which they can be evaluated.

614

615 This review has documented that the evidence for protected areas being effective in
616 terms of preserving species populations over time, remains limited. Although results
617 are generally positive, we do not claim that our results show conclusive evidence of
618 the positive impact of protected areas on species trends,. To formally answer the
619 question on whether species populations and trends are better within protected areas
620 than outside would require a larger sample of studies. Three-hundred-fifty-eight
621 populations of 266 species across 137 protected areas were examined in studies
622 linking species abundance over time and protected area effectiveness. Our results also
623 indicate that management interventions within protected areas tend to lead to an
624 improved status for target species, but there can often be negative consequences for
625 non-target species, and the impact of management interventions on overall
626 biodiversity values is hard to assess from the available literature.

627

628 For habitat loss, the larger number of studies and far greater number of protected areas
629 included, as well as the standardized (grid-based) data sources available at global
630 scale, allow for detailed statistical analyses. This has permitted far greater rigor in the
631 analyses undertaken and much greater confidence in the conclusion that protected
632 areas do, all other factors considered, help reduce rates of deforestation. Moreover, it
633 is also fairly clear that management interventions within forest protected areas can
634 have a positive influence on the conservation impact of the protected area. Overall, we
635 have confidence in the general conclusion that protected areas are effective in
636 reducing rates of deforestation and probably the loss of other habitats as well.
637 However disentangling the effect of protection from the effect of isolation, local
638 livelihoods, or the commercial value of the land being protected can be extremely
639 complicated in both instances.

640

641

642 **5.1. *Population declines***

643

644 On a global scale, biodiversity is declining at a rapid rate [136, 137], suggesting that
645 even reduced rates of population decline might be considered a conservation success
646 when compared to the likely outcome if no conservation actions had occurred. Thus
647 the need to understand the possible counterfactual scenarios for populations and
648 protected areas is shown to be increasingly important as observation inside reserves
649 need be viewed in context of their surroundings [49, 120]. In the only large scale
650 study of population changes of 83 African protected areas declines of around 50% in
651 Eastern Africa and 85% in Western Africa were observed, while Southern African
652 reserves saw increases of about 30% between 1970-2005 [138]. But while these
653 results might suggest the failure of Eastern and Western African protected areas, case
654 studies from reserves included in the larger analysis suggest that populations were
655 already extirpated outside reserve boundaries [139] or suffered greater declines than
656 within reserves [74, 75, 140]. Hence the reserves could still be considered successful,
657 compared to the situation in unprotected land, although a broad scale analysis to
658 support this conclusion, does not exist.

659

660 The interplay between biotic and abiotic factors influencing species trends contribute
661 to the complexity of the observed patterns and complicates setting up generic models

662 and a common methodology to examine the effectiveness of protected areas in
663 preserving biodiversity. Events such as droughts and floods also impact the changing
664 number of animals, and these events are often not captured in the time series studies,
665 even though they may explain large parts of the variation observed [71, 140-142]. For
666 example, the decline of small mammals in Kakadu National Park in Australia was
667 first attributed to drought events [143], but a reanalysis after a series of wet years
668 failed to show expected increases, suggesting that additional factors contributed to the
669 decline [144].

670

671 There is an uneven distribution of taxonomic groups towards large African mammals,
672 which might be explained by the direct monetary value of these animals and the
673 dependency of nature based tourism in some African countries, where the large
674 savanna parks are instrumental in drawing in safari tourists [145, 146]. The same
675 parks are often under great pressure from poaching and bush meat hunting [147, 148],
676 increasing the importance of effective management. At the same time, Africa remains
677 the only continent to retain much of its original mammal fauna long past lost on other
678 continents. Further, surveying large mammals in open savannah habitats can be done
679 more easily from planes or cars with larger precision and over larger areas which
680 could also affect the number of studies from these sites.

681

682 In the majority of studies reviewed, management actions have improved the
683 effectiveness of protected areas compared to the control scenario. The most widely
684 described type of intervention was the use of patrols and other activities to reduce
685 poaching inside the reserves. These initiatives are often directly related to staff size
686 and thereby exert a very direct impact on budgets suggesting the need for adequate
687 funds for the effective management of protected areas. In the few cases where
688 management actions to exclude poaching activities failed or had no effect, this was
689 either because the efforts were deemed inadequate [67] or because of trophic
690 displacement [64]. In the latter, illegal hunting was primarily directed towards
691 predators where a reduced pressure on lions increased the predatory rates on
692 herbivores. A similar situation was observed in Bardia national park, Nepal where
693 increased tiger populations were speculated to negatively affect rare prey species [72].

694

695 The studies included in the review did not allow for an evaluation of the correlation
696 between the available resources and the added effectiveness, due of the different
697 contexts in which patrols, fencing and guards are being used. However, examples
698 from Tanzania [67, 70], Ghana [66] and Thailand [73] showed that increased presence
699 of patrols decreased the poaching activities suggesting that a positive relationship
700 between staffing and the effectiveness of protected areas does exist.

701

702 Where management interventions were tailored a specific target, these were in most
703 cases successful, but less informative for providing general evidence of effectiveness.
704 These could be examples of food provisioning [82] and artificial nesting sites [84]
705 which led to increases in populations numbers as did the implementation of
706 management plans [55, 59, 83, 149]. However, the low number of studies and the
707 specific situations in which they were conducted does not allow for overall
708 conclusions. Disentangling natural variation from long term species trends, and
709 identifying causal relationships attributable to protected areas and specific
710 management actions remains a challenge.

711

712 In a small number of studies, protected areas failed despite conservation efforts. The
713 collapse of the cascade frog population in California or the decline of rare butterflies
714 in Minnesota are examples of management strategies that use grazing [65] and fire
715 [57], but failed in protecting frog populations or rare butterfly populations
716 respectively.

717

718

719

5.2. *Habitat change*

720

721 Based on the studies reviewed, the evidence that deforestation and habitat degradation
722 are proceeding more rapidly outside protected areas is convincing. Unfortunately,
723 land-use change analysis has been applied almost exclusively in tropical forests (all
724 except [128]), so the validity of the results does not extend much beyond that biome.
725 For several other habitat types (including mangroves [5] and tall grass prairies [150])
726 a decline in overall extent has been documented, but this has not been linked to
727 protected area coverage or effectiveness.

728

729 The narrow range of habitats studied in the reviewed papers is largely because remote
730 sensing methods struggle to accurately resolve changes in non-forested habitats.
731 Remote sensing best detects changes in habitat extent (forest / no forest), but is less
732 effective in capturing seasonality or subtle changes [151], which can be of more
733 importance in non-forested habitat where a minor habitat shift not detectable by
734 satellite might fundamentally change the area for the species living there.

735

736 The question of how management actions following the establishment of the protected
737 areas improve conservation conditions and outcomes remains important and is only
738 answered to a limited extent by the reviewed literature. Compared to two
739 questionnaire-based studies [4, 59] of biodiversity and habitat loss, the data used in
740 most analyses does not encapsulate many other factors believed to determine the
741 effectiveness of protected areas. Area specific attributes, such as the presence of
742 guards, fencing around the protected area is left out because this data is not available
743 for large-scale analysis. As well as community engagement and involvement, which
744 has often been shown to have a positive impact on the condition of forest as well as
745 forest cover [152-154], are impossible to capture using remote sensing to analyze the
746 effectiveness of reserves.

747

748 Within the protected area community, there is a general perception that protected
749 areas under stricter IUCN management categories should perform better than areas
750 under less strict IUCN categories, which has been confirmed in two global studies
751 [85, 95]. However when the size of protected areas are considered in analysis, results
752 are less convincing [94], suggesting that the larger average size of protected areas in
753 IUCN categories I and II might be the real reason for their higher success. The
754 importance of size and location in delivering successful outcomes has been found in
755 all studies examining the effectiveness of indigenous lands, suggesting that besides
756 governance and tenure, the location and area intrinsic attributes play a large role in the
757 success or failure of protected areas. One study of indigenous lands found that the
758 effectiveness of these areas was only determined by their isolated location far from
759 the threats and pressures of human settlement [117].

760

761 To account for the importance of location and the fact that not only protection status
762 determines the deforestation rate inside and outside reserves, two primary types of
763 analyses have been used: regression modeling and matching. The factors used in
764 regression models and matching analysis share three common traits: *i*) they are all
765 spatial data layers of acceptable resolution, quality and coverage compared to the
766 deforestation data from remote sensing available and *ii*) all of them do to some extent
767 relate to the pressure from a growing human population in and around protected areas,
768 or *iii*) they contain topographical and location specific information.

769

770 Greater isolation from human populations has been shown to improve reserves' ability
771 to reduce deforestation and is an important predictor in all studies analyzing its effect.
772 Similarly higher elevation and slope of the protected area reduces the likelihood of
773 deforestation. Thus as protected areas are often located in remote mountain regions
774 the predicted deforestation rate before protection is lower than a randomly selected
775 area in the same region [155].

776

777 The studies reviewed on different scales and across continents all suggest that
778 protected areas perform better than none-protected lands. However the drivers and
779 conditions responsible for these observations vary as does the actual effect of
780 protection. At the same time the types of analysis used largely depend on remote
781 sensing products making capturing of activities and management inside the protected
782 areas more challenging.

783

784

785 **5.3. Review limitations**

786

787 The use of data on either species persistence/population trends or habitat change to
788 evaluate effectiveness of protected areas brings together two quite different sets of
789 data and analysis challenges. Whereas the use of remote sensing data to assess habitat
790 change allows the measurement of protected area effectiveness using similar
791 terminology and methodology, this is not the case for biodiversity data. For the latter,
792 the many different research aims for collecting trend-data have made the compilation
793 of relevant literature challenging. It is likely that we have missed relevant studies
794 containing population time-series, due to the lack a common methodology and
795 established understanding of how to evaluate this question within protected areas.
796 While many studies contain population time-series, most of these do not contain data
797 required to evaluate the contribution of management to that trend, and hence could not
798 be used in this review. In these cases conservation measures can only be speculated to
799 have an impact, since there is no experimental testing to confirm their validity [156-
800 158]. We suspect that the much of the necessary information will often be available
801 with local protected area managers and efforts to ensure the collection and
802 dissemination of these data could be a valuable contribution.

803

804 Further the data requirement to evaluate the effect of management, and causally link
805 interventions to the observed biological changes the data requirements are extremely
806 challenging. A full BACI design (before/after/control/impact) is difficult for
807 researchers to meet and is often outside the scope of governmental agencies or NGOs,
808 since the collection of the required data is expensive and time consuming. In their
809 review of the effect of community managed forests Bowler et al. [154] faced the same
810 challenge of finding studies where observed results inside community managed

811 forests could be directly linked to the interventions and not to the prior condition of
812 the area.

813

814 It is striking that for this review all studies for populations trends (and all but one for
815 habitat change) identified that met the search criteria on measuring effectiveness of
816 protected areas at conserving populations of species or habitat area were from the
817 peer-reviewed literature. Only one report with analysis of this issue was found from
818 NGOs, intergovernmental, UN or governmental Agencies [95]. Another striking issue
819 was that although many countries, especially in the developed world, have excellent
820 records of species population trends at various scales, these have not been used in
821 studies that measure the effectiveness of protected areas compared with areas outside
822 reserves. In many of these countries conservation efforts are seldom restricted to
823 protected areas, with conservation agencies taking a holistic approach over the entire
824 range of the species both inside and outside reserves. Protection and management of
825 American endangered species [159], the declines in wild bees in USA [160], or the
826 monitoring of birds in Australia [161] and Europe [162] are all examples of this. In
827 the latter, authors showed a positive effect of Natura 2000 areas, by comparing eastern
828 and western Europe, but using trends both inside and outside reserves. Thus, for many
829 of these cases, even if data is available it might not be for specific protected areas.

830

831 In this review the majority of studies do show that protected areas are effective in
832 reducing habitat loss and protecting biodiversity. For the studies that do not support
833 these findings there seems to be no specific management intervention, governance
834 type, or region of the world that results in poor protected area performance. However
835 neither the studies nor this review have been able to determine whether the lack of
836 negative results is real, or because there may be a reporting bias in studies that are
837 published. Hence this type of review will be prone to type I errors. Similarly, the
838 methods used to evaluate these studies have been very descriptive, and at best a kind
839 of scoring approach of whether studies delivered positive, negative or no effect. So
840 even where management is shown to be effective, it is difficult to demonstrate
841 whether this effectiveness matches the resources invested in the project and therefore
842 whether the described management interventions are indeed cost-effective. While this
843 has not been a major concern in the review this can ultimately be the determining
844 factor for the implementation of different management strategies and thus in the
845 success of delivering conservation outcomes.

846

847 Compared to the small number of studies included in this review there are vast
848 amounts of research being conducted on population changes inside and outside
849 protected areas. Further, information on management and environmental conditions
850 are often available in the reserves. We therefore believe that the possibility for more
851 stringent evaluations of the effect of management and protected areas is possible.
852 Here existing literature including all but a few key pieces of information can be used
853 if the missing data can be subsequently collected, and new research programs should
854 aim to include a wider set of factors affecting populations changes to allow for
855 evaluation of conservation success.

856 We therefore see a need to set up a framework where conservation science can
857 formally document the link between input and outcomes in protected areas. This could
858 potentially help include many studies conducted today in which times series of
859 abundance data is collected for more basic biological questions, but which potentially
860 can be used to improve understanding of management-induced biodiversity responses

861 as well. Initiatives to collate existing data on population time-series such as the Living
862 Planet Index [163] already exist and need to be supported. However, collecting
863 information on potentially causative conservation measures in population studies of
864 biodiversity within and outside of protected areas is also important. Such a process
865 would hopefully increase the available evidence of whether conservation efforts have
866 been successful in halting the loss of biodiversity and habitats, and could also provide
867 further insights on which mechanisms are contributing to the success of conservation
868 on a global as well as on a project scale.

869
870

871 **6. Reviewers' conclusions**

872

873 This review has sought to compile studies that have examined the effectiveness of
874 protected areas in delivering conservation outcomes through management actions and
875 interventions.

876

877 The studies reviewed provide some evidence that protected areas are effective in
878 protecting species populations over time, and considerable evidence that protected
879 areas have been effective at reducing the loss of habitat. However the results do not
880 provide concrete proof of the effectiveness of protected areas for species
881 conservation, nor the effectiveness of specific management activities. Remote sensing
882 data has primarily been used to evaluate whether protected areas are effective at forest
883 conservation when compared to non-protected land, but offer limited information on
884 other habitats, or on the kind of management input, if any, responsible for the
885 observed impact of protection. Biodiversity data from population time-series can be
886 used to evaluate specific management interventions on selected species. But an
887 intervention that works for one species may not work for another, so drawing general
888 conclusions for species is harder than for habitats where the basic unit of analysis is a
889 pixel in a remote sensing image,. This review has shown it is difficult to draw clear
890 conclusions from the available data due to the large variations in management
891 activities, types of reserves, species and geographical regions..

892

893 Population studies that did meet our review criteria were restricted primarily to those
894 addressing large mammals in Africa, where considerable effort to document the status
895 of wildlife in parks has been applied, and where protected areas play a central role in
896 preserving biodiversity. The most frequent types of intervention found to be effective
897 were 'anti-poaching', ranging from guards and patrols to fencing of reserves. This
898 was followed by 'adherence to management plans', but in general all types of
899 interventions had a positive effect, except cases where the stated purpose of
900 management was not well known and management therefore targeted the wrong
901 objective.

902

903 The geographical bias of the protected areas might be one of the reasons for the types
904 of interventions documented in the review; as anti-poaching activities would be
905 expected to be more important in an African savanna park than it would in the
906 protection of heath land bird species in Northern Europe or America.

907

908 For habitat, all but one study was on deforestation in tropical regions. Most studies
909 documented lower habitat loss inside protected areas than outside, though the
910 effectiveness was in large part controlled by factors not relating to management, but

911 instead to area intrinsic values that are both human controlled (population density,
912 roads railways and urban centers) and natural (e.g. elevation, slope and soil quality).
913 There is some evidence that areas under stricter IUCN governance categories lose less
914 forest than less restrictive categories, though this effect might be an attribute of
915 protected area size with areas in IUCN category I and II being larger on an average.

916

917 In all recorded cases; isolation and the slope of the landscape are strong predictors of
918 reduced habitat loss, so that more isolated and hilly protected areas do better than flat
919 and low laying areas independent of protection status. The same was the case for
920 human infrastructure, so that roads and cities were predictors of greater habitat loss.

921

922 We have documented the need for a more generic methodology for the studies of
923 population trends including full BACI (before/after and control/intervention) to ensure
924 that observed changes can be linked to the human conservation responses and thus
925 increasing our knowledge on what can be done to halt the ongoing loss of
926 biodiversity.

927

928

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930

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934 WCMC and Cambridge University.

935

936

937 **8. Potential Conflicts of Interest and sources of Support**

938

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941 University of Copenhagen, Denmark.

942

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1455 Table 4. Overview of population time-series studies included in this review.

Source	Countries	Protected area	Time period	Taxa	Input	Outcome	Overall trend	Manag. Outcome
Adams et al., 2008	USA	Gates of the Arctic national park and preserve	1986-1992	Mammals	Hunting regulations	Stable population	Stable	Positive
Amin et al., 2006	Africa, Asia	Multiple	Variable	Mammals	Anti poaching, fencing guard presence	Varied results but consistent positive effects from anti-poaching efforts across populations, species and ranges	Positive/Negative	Positive
Balme et al., 2010	South Africa	Phinda-Mkhuze Complex	2002-2007	Mammals	Protected areas size	Population increased towards core	Positive	Positive
Bhattacharya, 1993	India	Kaziranga National Park	1908-1991	Mammals	Establishment of protected area and enforcement by local militia	Increase in rhino population to stable levels	Positive	Positive
Brereton et al., 2008	England	Varies protected areas	1981-2000	Insects	Management in protected area	Increase in population size and range	Positive	Positive
Caro, 1999	Tanzania	Katavi national park	1995-1996	Mammals	Anti-poaching efforts inside park and increased guard presence	Higher animal densities inside national park than other types of protection	Positive	Positive
Caro, 2008	Tanzania	Katavi national park, Rukwa game reserve and 3 other protected areas	1988-2002	Mammals	Anti-poaching activities	Declines in populations do to lack of anti-poaching enforcement	Negative	No effect
Carrillo et al., 2000	Costa Rica	Corcovado national park and Golfo Dulce forest reserve	1990-1994	Mammals	Anti-poaching regulations stricter in more protected park	number of species and abundance of species higher in more protected areas	Stable	Positive
Catry et al., 2009	Portugal	Castro Verde spetial protection areas	1996-2007	Birds	Management through supplement of artificial nest sites	Increase in population	Positive	Positive
Devictor et al., 2007	France	All protected areas	1989-2003	Birds	Inside outside protected area	Species abundance was for most species higher inside protected areas	Positive	Positive

Eberhardt et al., 2007	USA	Yellowstone national park	70 years	Mammals	Anti poaching (hunting) restrictions.	Populations increased with reduced hunting pressure	Positive	Positive
Fellers and Drost, 1993	USA	Lassen Volcanic National Park	1978-1991	Amphibians	Grazing as management intervention	Decline in frog populations	Negative	Negative
Gough and Kerley, 2006	South Africa	Addo Elephant national park	1976-2002	Mammals	Fencing	Population increased after fencing	Positive	Positive
Harrington et al., 1999	South Africa	Kruger National Park	1977-1993	Mammals	closing of artificial water holes	Abundance increased in areas where water holes were closed	Negative	Positive
Herremans and Herremans-Tonnoeyr , 2000	Botswana	Mutable	1991-1995	Birds	grazing outside reserve	Decreasing abundance for all species closer to edge of reserve	Positive	Positive
Hilborn et al. 2006	Tanzania	Serengeti national park	1955-2005	Mammals	Anti-poaching activities	Buffalo increased after patrols were reinstated	Negative	Positive
Jachmann, 2008	Ghana	8 protected areas	2004-2006	Mammals	Guard presence	Higher guard density increased animal abundance	Positive	Positive
Laidlaw, 2000	Malaysia	7 Virgin Jungle reserve	1991-1992	Mammals	Size of protected area patches	Species richness increased with patch size	Positive	Positive
Ma et al., 2009	China	Yancheng biosphere reserve	1982-2003	Birds	Establishment of artificial feeding areas	Population declined, but increased in feeding areas	Negative	Positive
Mduma et al., 1999	Kenya, Tanzania	Serengeti national park	1958-1998	Mammals	Establishment of protected areas	Populations increased after establishment and also depended on water availability	Positive	Positive
Meijaard and Nijman, 2000	Indonesia	Pulau Kraget nature reserve	1997	Mammals	Management plan through translocation	Population collapsed	Negative	Negative
Metzger et al., 2010	Tanzania	Serengeti national park	1970-2008	Mammals	Anti-poaching activities	Declines inside reserve were less than outside	Negative	Positive
Ottichilo et al, 2000	Kenya	Masai Mara national reserve	1977-1997	Mammals	Inside outside protected area	Species declined inside and outside reserve.	Negative	No effect
Pedrono et al., 2009	Thailand	Yok Don, Cat Tien national parks, Ea So and Vinh Cuu nature reserves	1990-2005	Mammals	Anti-poaching activities	Declines in populations smaller inside protected areas than outside	Negative	Positive

Pettorelli et al., 2010	Tanzania	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 GR, Zoraning FR,	2004-2007	Mammals	Management and resources	higher species occurrence inside better protected reserves.	Positive	Positive
Schlicht et al., 2009	USA		1988-1996	Insects	Management with fires	Rarer butterflies declines	Negative	Negative
Sergio et al., 2005	Spain	Doñana national park	1989-2001	Birds	Fencing and guard presence	Stable populations	Stable	No effect
Sinclair et al., 2007	Tanzania	Serengeti national park	1955-2005	Mammals	Anti-poaching activities and vaccination programs	Populations decreased as anti-poaching activities stopped. Vaccination programs increased populations	Negative	Positive
Stoner et al., 2007	Tanzania	11 Protected areas	1980s-2000s	Mammals	Type of protection	Less species declined and declined less in stricter protected areas	Negative	Positive
Stoner et al., 2007	Tanzania	Burigi-Biharamulo, Greater Ruaha, Tarangire, Katavi, Serengeti, Ugalla and Selous-Mikumi national parks	1980s-2000s	Mammals	Inside outside protected area	Declines inside protected areas were less than outside	Negative	Positive
Struhsaker et al., 2005	11 African countries	16 protected areas	1966-2000	Biodiversity	Law enforcement, positive public attitude, NGO presence	Higher and better preserved biodiversity inside protected areas	N/A	Positive
Suarez et al., 1993	Spain	<u>Las Amoladeras reserve and Layna Paramos</u>	1989-1989	Birds	Hunting of natural predators	Decline in 3 species of birds	Negative	Negative
Sun et al., 2009	China	Wuyishan national natural reserve	2006-2007	Birds	Construction of road through population range	No effect on population	Stable	No effect

Tambling and Du Toit, 2005	South Africa	Pilanesburg national park	1995-2001	Mammals	Fencing	Populations declined more inside than outside as lion populations increased	Negative	Negative
Theberge et al., 2006	Canada	Algonquin provincial park	1988-1999	Mammals	Inside outside protected area	Wolf killings were most prevalent outside protected area	Negative	Positive
Vester et al., 2007	Mexico	Calakmul biosphere reserve	2000-2000	Trees/Lepidoptera	Inside outside protected area	Tree diversity and butterfly was greater inside protected area	N/A	Positive
Wegge et al, 2009	Nepal	Bardia National Park	22 years	Mammals	Anti-poaching activities and exclusion of grazing	Increase in tiger population	Positive	Positive
Western, 2009	Kenya	49 protected areas (23 national parks and 26 reserves)	30 years	Mammals	Inside outside protected area	Decline in population numbers were the same inside and outside reserve	Negative	No effect
Whitehead et al., 2008	New Zealand	Fiordland national park	2000-2006	Birds	Management of invasive predators through trapping	Increased breeding success	Positive	Positive

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1458 Table 5. Overview of studies of habitat change included in this review.

Source	Country	Protected area	IUCN	Positive Drivers	Negative Drivers	Method	Inside	Outside	measure	Outcome
Abbot and Homewood, 1999	Malawi	Lake Malawi National Park	II		Fuel wood collection	Inside analysis	-6.20%	-	Total change	N/A
Alados et al. 2004	Spain	<u>Cabo de Gata-Nijar Natural Park</u>	V	Increased slope, elevation, reduced soil quality	human settlement	Regression analysis	-	-	-	Positive
Alo and Pontius, 2008	Ghana	Fores reserves	-		Logging outside the reserve and agricultural conversion outside.	Inside-outside analysis	-	-	-	Negative
Andam et al. 2008	Costa Rica	150 protected areas	-	Isolation, elevation, increased slope	Human populations density	Matched inside-outside analysis	11.10%		Difference in loss	Positive

Armenteras et al. 2006	Columbia	11 protected areas	-	Isolation (indigenous areas)	Human population density, economic conditions, cattle grazing, rivers	Regression analysis	-	-	-	Positive
Armenteras et al. 2009	Columbia	Guyana Shield region: 3 NP, 2 national reservation and 44 indigenous areas	-	Reserve size and isolation, National parks >> Indigenous areas, Isolation	roads, coca plantations	Buffer and regression analysis	-0.07%	-0.28%	Annual Change	Positive
Arroyo-Mora et al. 2005	Costa Rica	Multiple (Chorotega region)	-	Governmental management, reduced cattle prices	Cattle grazing, logging	Inside-outside analysis	63.63%	29.34%	Total change	Positive
Bleher et al., 2006	Kenya	<u>Kakamega forest reserve, Kakamega National reserve</u>	-, II	Management for wildlife. National reserve > forest reserve	Logging	Ground based disturbance measure	-	-	-	Positive
Bray et al. 2008	Guatemala, Mexico	19 community forests and 11 protected areas	-	Remoteness	Human population density and distance to previous forest area	Inside - outside and regression analysis	-0.327	-	Annual Change	Positive
Brower et al. 2002	Mexico	<u>Sierra Chincua, Sierra Campanario, Cerro Chivati Huacal masiifs</u>	-		Logging, agricultural encroachment * before and after establishment	Inside-outside analysis	-1.03% -3.17%	-1.7% -2.41%	Annual Change ^α	Negative
Bruner et al. 2001	Global	93 protected areas	-	Number og guards, level of deterrent, fencing and compensation programs		Questionnaire survey	-	-	-	Positive
Chatelain et al., 1996, 2010	Cote d'Ivoire	Tai National Park	II		Human population density and encroachment	Inside-outside analysis	-0.28%	-2.87%	Annual Change	Positive
Chowdhury 2006	Mexico	Calakmul Biosphere reserve	VI	Management plan, community involvement, Elevation	distance to roads, settlements and previously forested areas	Regression analysis	-	-	-	Positive
Clark et al., 2008	Global	Multiple	-	IUCN categories		Meta-analysis	-	-	-	Positive

Cropper et al. 2001	Thailand	Multiple	-	Wildlife sanctuaries (-0.26%) > protected areas (-0.31%)	Human population density, roads	Regression analysis	-0.31% -0.26%	-0.43%	Probability of clearing	Neutral/positive
Curran et al. 2004	Indonesia	Gunung Palung National Park	II		Logging by timer concessions	Inside-outside analysis	-56%	-70%	Total loss	Positive
Cushman and Wallin 2000	Russia	Sikhote-alinskiy Biosphere Reserve	Ia		Fires and human infrastructure		-0.20%	-0.70%	Annual Change	Positive
DeFries et al. 2005	Global	198 protected areas	I and II		Encroachment	Inside-outside analysis	-3.32%	-8.65%	Total change	Positive
Ellis and Porter-Bolland 2008	Mexico	Calakmul Biosphere reserve + others	VI	community managed > protected area, external funding (GEF), Elevation	Distance to roads, settlements	Regression analysis	-0.3% -07%	- - 0.002%	Annual Change*	Positive
Forrest et al. 2008	Bolivia	Madidi National Park, Madidi Integrated Management Area ,Tierras Comunitarias de Origen Tacana	II, -, -	Elevation, Natural resource protection laws	Human settlements, roads	Inside-outside analysis	0.01%	-0.01%	Annual Change	Positive
Gaveau et al. 2009	Indonesia	Bukit Barisan Selatan National Park	II	Increased slope, elevation	Logging, roads, PA edge	Regression analysis	-0.50%	-2.56%	Annual Change	Positive
Gaveau et al., 2007, 2009	Indonesia	Multiple	-	National Park >> Nature Reserve and Wildlife Sanctuary. Law enforcement, Staffing, anti-logging campaigns and eviction of rural communities	Human populations density	Inside-outside analysis	-0.64%	-2.86%	Annual Change	Positive
Hayes et al. 2002	Guatemala	5 National parks 4 biological reserves	-		Elevation, roads and human infrastructure	Regression analysis	-0.16%	-0.75%	Annual Change	Positive
Honey-Rosés et al., 2011	Mexico	Monarch Butterfly Biosphere reserve	-	Legal status, financial programs, elevation	Accessibility	Matched inside-outside analysis		2.6%	Effect of protection	Positive

Ingram and Dawson, 2005	Madagascar	All protected areas	-		Logging and fires (for agricultural expansions)	Inside-outside analysis	-40.55%	-40.51%	Total change	Neutral/positive
Joppa and Pfaff 2010	Global	Global tropical forested PA's	-	Isolation, elevation, increased slope	IUCN category I and II were effective depending on method	Matched inside-outside analysis	7.67%		effect of PA	Positive
Joppa and Pfaff 2010	Global	all		Isolation, elevation and slope		Meta-analysis	-	-	-	Positive
Kinnaird et al. 2003	Indonesia	Bukit Barisan Selatan National Park	II	Increased slope	conversion to agriculture	Regression analysis	-2.00%	Forest gone	Annual Change	Positive
Larsson, 2002	Sudan	Rawashda forest reserve	-			Regression analysis	-6.22%	-	Total change	Positive
Linkie et al., 2004, 2008	Indonesia	Kerinci Seblat National Park	II	Guards, Integrated Conservation and development project	Logging concessions, road constructions	Regression analysis	-0.28%	-0.96%	Annual Change	Positive
Liu et al. 2001	China	Wolong Nature Reserve	V			Inside-outside analysis	-	-	-	Negative
Lung and Schaab, 2010	Kenya, Uganda	Budongo forest, Mabira forest, Kakamega-Nandi forest	-	Remoteness	Human population density	Inside-outside analysis	-	-	-	Positive
Luque 2000	USA	New Jersey Pinelands National Reserve	V	Management plan	Urban encroachment	None-matched inside-outside analysis	-	-	-	Positive
Maiorano et al. 2008	Italy	716 Natura 2000 areas	-	size of PA, national governmental management	Local government management	Inside-outside analysis	-	-	-	Positive
Mapaure and Campbell, 2002	Zimbabwe	Sengwa Wildlife Research Area	-	Regulation of Elephant populations and fires	Large elephant populations	Inside-outside analysis	-1%	-	Annual Change	Positive

Mas 2005	Mexico	Calakmul Biosphere Reserve	VI	Elevation and increased slope	Human population density, roads	Regression analysis	-0.30%	-1.3%	Annual Change	Positive
Mendoza and Dirzo 1999	Mexico	Monte Azules biosphere Reserve	VI	Wildlife sanctuaries (-0.26%) > protected areas (-0.31%)	Human population density	Regression analysis	-0.14%	-2.79%	Annual Change	Positive
Mertens et al. 2004	Bolivia	Amboro NP, Noel Kempff, Mercado NP, BR, the Rios Blanco and Negro WR	-	Isolation	Human settlements, roads, favorable agricultural conditions	Regression analysis	-	-	-	Positive
Messina et al. 2006	Ecuador	Cuyabeno Wildlife Production Reserve	VI		human population density, poverty, urban expansion	Inside-outside analysis	-1.89%	-20.42%	Total change	Positive
Mosugelo et al., 2002	Botswana	Chobe National Park	II		Elephant populations, possibly fires	Inside analysis	-50%	-	Total change	
Mulley and Unruh, 2004	Uganda	Kibale National Park	II	management plan, tea growing outside PA	Human encroachment	Inside-outside analysis	-18%	-82%	Total change	Positive
Nagendra 2008	Global	40 protected areas	-	Industrial countries	developing countries	Meta-analysis	-	-	-	Positive
Nagendra et al. 2008	Nepal	Chitwan national park and Parsa wildlife reserve	II,IV	Isolation	Grazing and fuel wood extraction	Inside-outside analysis	-	-	-	Positive
Naughton-Treves et al., 2005	Latin America	49 protected areas	-			Meta-analysis	-	-	-	N/A
Nelson and Chomitz, 2009	Global	All tropical forested protected areas	-	Indigenous land and multi use protected areas		Matched fire frequency analysis	-	-	-	Positive
Nelson et al. 2001	Panama	Darién National Park	II	Indigenous land > National Park, increased slope, isolation		Regression analysis	-10%	-	Total change	Positive
Nepstad et al. 2006	Brazil	15 parks, 121 indigenous areas, 10 extractive reserves, 18 national forests	-	Land tenure to indigenous people. Stricter protection	Fires	Inside-outside analysis	-0.04%	-0.7%	Annual Change†	Positive

Oestreicher et al. 2009	Panama	<u>San Lorenzo, Soberanía, Chagres, Altos de Campana</u>	-	Guard numbers, funds and NGO involvement	Agricultural expansion and logging concessions	Interviews and qualitative comparative analysis	-	-	-	Positive
Oliveira et al. 2007	Peru	all in the amazon region	-	protected areas > Indigenous lands		Inside-outside analysis	-1.15%	-4.76%	Total change	Positive
Pelky et al., 2000	Tanzania	All protected areas	-	Management under national jurisdiction, guard patrols	Sub-national management jurisdiction	Regression analysis	-	-	-	Positive
Sader et al. 2001	Guatemala	Maya Biosphere reserve (12 protected area)	-	Isolation	Human settlement, roads and rivers	Inside-outside analysis	-0.20%	-2.29%	Annual Change	Positive
Sanchez-Azofeifa et al. 2002	Costa Rica	Corcovado National Park	II			Inside-outside analysis	0	-1.13%	Annual Change	Positive
Sanchez-Azofeifa et al. 2003	Costa Rica	27 protected areas	-	Isolation	logging for agriculture	Inside-outside analysis	-	-0.50%	annual change	Positive
Scharlemann et al. 2010	Global	5,787 tropical forested PA's	-	Stricter protection IUCN I-II > IUCN III-VI		Inside-outside analysis	-	-	-	Positive
Shearman and Bryan 2011	Papua New Guinea	34 protected areas	-	Isolation, elevation, increased slope	Human population density	Inside-outside analysis	-8.90%	-24%	Total change	Positive
Smith 2003	Nicaragua	Bosawas Natural Resource Reserve	VI	Buffers	End of civil war.	Inside-outside analysis	0%	-	Total change	Positive
Songer et al. 2009	Burma	Chatthin Wildlife Sanctuary	III	Staff and research program	Logging	Inside-outside analysis	-0.45%	-1.86%	Annual Change	Positive
Southworth et al. 2004	Honduras	Celaque National Park	II	Increased slope, NGO initiatives	Agricultural expansion, increased coffee prices	Inside-outside analysis	-3.87%	-25.12%	Total change	Positive

Tabor et al., 2010	Kenya Tanzania	75 protected areas	-	AZE sites		Inside- outside analysis	-0.10%	-0.80%	Annual Change	Positive
Tole 2002	Jamaica	Hellshire Hills	-		Subsistence encroachment, human settlements, Edge effect	Inside- outside analysis	Core: -1%	Edge: -15%	Annual Change	Positive

1459 *before / after, ¶1988-2000/2000-05 (outside = community managed), † Bottom line for indigenous areas

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