For: *Biological Conservation* as a research report

Recent increases in human pressure and forest loss threaten many Natural World Heritage Sites

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Highlights

- Natural World Heritage Sites (NWHS) are designated because of their global significance, yet there has been no systematic quantitative assessment of how humanity is negatively affecting them.
- Increases in human pressure and forest loss are occurring across the vast majority of forested NWHS.
- NWHS are becoming isolated by substantial increases in human pressure and forest loss in the landscapes surrounding them.
- We demonstrate how globally comparable quantitative metrics can be used to help monitor NWHS and provide crucial baseline information necessary for their long-term preservation.

Key Words

World Heritage, Habitat loss, Habitat fragmentation, Human Footprint, Forest loss, Monitoring, Cumulative threat mapping, Biodiversity conservation

Abstract

Natural World Heritage Sites (NWHS), via their formal designation through the United Nations, are globally recognized as containing some of the Earth's most valuable natural assets. Understanding changes in their ecological condition is essential for their ongoing preservation. Here we use two newly available globally consistent data sets that assess changes in human pressure (Human Footprint) and forest loss (Global Forest Watch) over time across the global network of terrestrial NWHS. We show that human pressure has increased in 63% of NWHS since 1993 and across all continents except Europe. The largest increases in pressure occurred in Asian NWHS, many of which were substantially damaged such as *Manas Wildlife Sanctuary* and *Simien National Park*. Forest loss occurred in 91% of NWHS that contain forests, with a global mean loss of 1.5% per site since 2000, with the largest areas of forest lost occurring in the Americas. For example *Wood Buffalo National Park* and *Río Plátano Biosphere Reserve* lost 2581km^2 (11.7%) and 365km^2 (8.5%) of their forest respectively. We found that on average human pressure increased faster and more forest loss occurred in areas surrounding NWHS, suggesting they are becoming increasingly isolated and are under threat from processes occurring outside their borders. While some NWHS such as the *Sinharaja Forest Reserve* and *Mana Pools National Park* showed minimal change in forest loss or human pressure, they are in the minority and our results also suggest many NWHS are rapidly deteriorating and are more threatened than previously thought.

1. Introduction

The World Heritage Convention was adopted in 1972 to ensure the world's most valuable natural and cultural resources could be conserved in perpetuity (UNESCO 1972). The Convention aims to protect places with Outstanding Universal Value that transcend national boundaries, and are worth conserving for humanity as a whole. These places are granted World Heritage Status, the highest level of recognition afforded globally (UNESCO 2015). A unique aspect of The Convention is that host nations are held accountable for the preservation of their World Heritage Sites by the international community, and must report on their progress to the United Nations Educational, Scientific and Cultural Organisation (UNESCO). Over 190 countries are signatories to The Convention, committing to conserving the 1031 World Heritage Sites listed at the time of this study (UNESCO 2015). Of these, 229 are Natural World Heritage Sites (NWHS), inscribed for their unique natural beauty and biological importance, including many of the world's most important places for biodiversity conservation such as the *Pantanal Conservation Area* in Brazil (UNESCO 2016a) and the iconic *Serengeti National Park* in Tanzania (UNESCO 2016b).

As the number of NWHS has increased over the last few decades, so have the pressures humanity is exerting on the natural environment (Rockstrom et al. 2009, Steffen et al. 2015, Venter et al. 2016b). Anthropogenic habitat conversion due to human activities such as agriculture and urbanisation are driving biodiversity extinction rates well above background levels, and the condition of many ecosystems is in decline worldwide (Barnosky et al. 2012, Hansen et al. 2013, Pimm et al. 2014, Watson et al. 2016). If significant human activity occurs inside a NWHS it could potentially damage the ecological condition of that site and compromise its Outstanding Universal Value, and is therefore incompatible with the objectives of the World Heritage Convention (UNESCO 2015). If a site's condition and values are compromised it could be placed on the list of World Heritage in Danger and, ultimately, its World Heritage Status can be revoked if the ecological condition inside a site continues to decline to the extent it loses the values that are the basis for its listing. The consequences for a host nation could be substantial, since they would be denied access to the World Heritage Fund and other financial mechanisms, technical support provided by UNESCO and the Advisory Bodies, and lose the sustainable development opportunities a World Heritage Site creates (Conradin et al. 2014). Accurate and transparent monitoring and reporting of both the human pressures facing NWHS, and the ecological condition within NWHS is therefore essential for both host nations and UNESCO.

Current monitoring of NWHS is summarised in site-level reports and surveys. This includes periodic reporting on progress and condition by States Parties on a 6-year regional cycle, reactive monitoring led by UNESCO and the Advisory Bodies in response to current issues, and site-level monitoring and evaluation systems (Hockings et al. 2006, Hockings et al. 2008, Stolton et al. 2012). The IUCN's World Heritage Outlook initiative and its expert-driven evaluations also provide important information on the conservation outlook for all NWHS (Osipova et al. 2014). These monitoring approaches are important and capture diverse site-level data, but do not include monitoring based on globally comparable quantitative datasets. We argue that these current monitoring approaches could be further strengthened by additionally using globally comparable datasets to assess increases in human pressure or changes in ecological state such as forest loss (Leverington et al. 2010). Thanks to recent advances in remote sensing technology, globally comparable data on human pressure and ecological state is now available, allowing trends to be analysed across the entire network of NWHS for the first time. This important baseline information allows States Parties to assess their progress in preserving their NWHS and enables rapid reporting of their progress to the World Heritage Committee.

In this study we quantify changes in spatial and temporal patterns of human pressure and ecological state across the entire global network of NWHS and their surrounding landscapes for the first time. We examine human pressure in NWHS in 1993 and 2009 using the most comprehensive cumulative threat map available, the recently updated Human Footprint (Venter et al. 2016b, Venter et al. 2016a) which is a temporally explicit map of eight anthropogenic pressures on the terrestrial environment. An increasingly popular approach for monitoring ecological state is to monitor forest cover, which responds to anthropogenic pressures (Nagendra et al. 2013, Tracewski et al. 2016). Therefore we also examine patterns of forest cover loss in NWHS between 2000 and 2012 using high resolution maps of global forest cover (Hansen et al. 2013). We identify which NWHS have suffered the greatest forest loss, and largest increases in human pressure, as well as sites which are performing well at limiting these negative changes and maintaining their ecological integrity.

2. Methods

2.1 World Heritage Site Data

Data on NWHS location, boundary and year of inscription was obtained from the 2015 World Database on Protected Areas (UNEP-WCMC 2015). We applied filtering criteria to identify which NWHS qualified for our analysis. Out of all natural sites, sites inscribed only under criterion (viii), which covers sites of geological importance including fossil sites and caves (UNESCO 1972), were excluded from this analysis, with the exception of *Vredefort Dome* in South Africa, *Phong Nha-Ke Bhang National Park* in Vietnam, *Lena Pillars Nature Park* in Russia *and Ischigualasto/Talampaya Natural Parks* in Argentina, because they are part of larger conservation areas. In addition, we constrained our analysis to terrestrial NWHS, and the terrestrial component of marine NWHS. Due to the 1km^2 resolution of the Human Footprint data, we chose to exclude NWHS smaller than 5km^2. Initially 190 NWHS qualified for our analysis.

2.2 Analyzing Human Pressure

To measure human pressure on the natural environment we used the recently updated Human Footprint (Venter et al. 2016a, Venter et al. 2016b), which is a globally-standardised measure of cumulative human pressure on the terrestrial environment. The updated Human Footprint is based on the original methodology developed by (Sanderson et al. 2002); however, the update is temporally explicit, quantifying changes in human pressure over the period 1993 to 2009. At a 1km^2 resolution, the Human Footprint includes global data on: built environments, crop lands, pasture lands, population density, night lights, railways, major roadways and navigable waterways. This makes the Human Footprint the most comprehensive cumulative threat map available (McGowan 2016). Still, it is important to note that it does not include data on all the possible threats and pressures facing NWHS. Other threats, including invasive species (Bradshaw et al. 2007), overabundant species (Ndoro et al. 2015), wildlife poaching (Plumptre et al. 2007, Wittemyer et al. 2014), tourism pressure (Li et al. 2008), and rapid climate change (Scheffer et al. 2015), are not directly accounted for in the Human Footprint data. Although in some cases the included pressure data, including population density, night lights, railways, major roadways and navigable waterways, can contribute to these threats (e.g. invasive species and some forms of poaching), we acknowledge that some threats are not well covered, which makes this a conservative assessment of threats.

In the Human Footprint, individual pressures were placed within a 0 - 10 scale and summed, giving a cumulative score of human pressure ranging from 0 - 50. A Human Footprint score below 3 indicates land which is predominantly free of permanent infrastructure, but may hold sparse human populations. A Human Footprint score of 4 is equal to pasture lands, and is a reasonable threshold of when land can be considered “human dominated” and species are likely to be threatened by habitat conversion (Watson et al. 2016). A Human Footprint score of 7 is equal to agriculture, above which a landscape will contain multiple pressures, for example agriculture with roads and other associated infrastructure, and is therefore highly modified by humans.

To compare mean changes in Human Footprint between NWHS and their surroundings, we calculated the mean change in Human Footprint between 1993 and 2009 in NWHS and a surrounding 10 km buffer zone. Calculating the Human Footprint in surrounding buffer zones allows us to infer how much pressure a NWHS is under from developments surrounding the protected area. Buffer zones were defined as a 10km buffer of land directly adjacent to and surrounding each NWHS, and were created using the Geographic Information System ArcMap version 10.2.1. Because NWHS inscribed post 1993 could potentially have been impacted before their inscription as a NWHS, we included only sites inscribed during or before 1993 when calculating the change in Human Footprint (n = 94).

2.3 Analysing Forest Loss

To assess forest loss, we followed Hansen et al. (2013), and defined forest cover as vegetation taller than 5m and forest loss as the complete removal of tree canopy at a 30m resolution (Hansen et al. 2013). Hansen forest-cover change data was extracted and processed in the Google Earth Engine (http://earthengine.google.org/), a cloud platform for earth-observation data analysis. Sites which had zero percent forest cover in 2000 were excluded from the analysis. Only NWHS inscribed during or before 2000 were included in the forest loss analysis (n = 134), since NWHS inscribed post 2000 could potentially have been impacted before inscription. We then calculated total forest loss between the years 2000 and 2012 as a percentage of forest extent in 2000 for all NWHS and buffer zones. We adapted JavaScript code developed by Tracewski (2016) for analysing Hansen forest-cover data within specified spatial zones, which is freely available online (https://github.com/RSPB/IBA). Gain in forest cover was not included in this analysis for two reasons: young forests are unlikely to support forest-dependant species, and much of the gain can be attributed to monoculture plantations of oil palm or rubber which are major threats to tropical forests (Tropek et al. 2014). There are limitations of satellite-derived estimates of global forest change, such as an inability to differentiate between ecologically valuable forest and agro-forests, such as oil palm, and lower accuracy in more arid environments (Hansen et al. 2013, Achard et al. 2014, Tropek et al. 2014).

Likewise, ground truthing is required to infer the causes of forest loss since the dataset does not differentiate between ecologically harmful clearing, and purposeful clearing for example of invasive species, which has a conservation benefit. But even with these limitations, the Hansen et al. (2013) forest data product is considered the most accurate global representation of temporal loss of forest available (McRoberts et al. 2016).

3. Results

3.1 Human Pressure

3.1.1 Human Pressure in NWHS

The average Human Footprint per NWHS in 2009 is 6.4, which is higher than the global average Human Footprint of 5.6, and there was considerable variation between regions and individual sites. Out of 94 NWHS considered in this analysis, the majority of them (63%, n=59) had an average Human Footprint ≥ 4, and many NWHS (38%, n=36) had a Human Footprint ≥ 7 meaning they are highly modified by humans. *Keoladeo National Park* in India was subject to the highest levels of human pressure of any NWHS, with a 2009 Human Footprint of 23. *Göreme National Park* in Turkey, *Mount Taishan* in China, and *Manas Wildlife Sanctuary* in India were also subject to some of the highest levels of human pressure, with a Human Footprint of 19, 17 and 17 respectively. European and Asian NWHS were under the highest levels of human pressure of all the continents, whereas NWHS in North America and Oceania are under the lowest (Table 1.). *Nahanni National Park* in Canada had the lowest 2009 Human Footprint of 0.08, along with *Kluane/ Wrangel-St. Elias/ Glacier Bay/ Tatshenshini-Alsek* in Canada/USA (0.3) and *Aïr and Ténéré Natural Reserves* in Niger (0.4). These three NWHS are essentially free of human pressure but no NWHS had a Human Footprint of zero (see supplementary Table A1 for a full list of NWHS and their Human Footprint scores).

3.1.2 Changes in Human Pressure in NWHS over time

The Human Footprint in NWHS increased far more slowly than the global average, rising 1.7% between 1993 and 2009, compared to the global increase of 9%. However, human pressure did increase in the majority of NWHS (63% n = 58) and across all continents except Europe (Figure 1.). In most cases the increases were small; however, 14 sites (15%) were subject to substantial increases in human pressure (average Human Footprint increase > 1) (Table 2.). The *Manas Wildlife Sanctuary* in India underwent the largest increase in human pressure of any NWHS, with its Human Footprint rising by 5 to a score of 17 and is now one of the most highly modified by humans. *Komodo National Park* in Indonesia also underwent one of the largest increases in human pressure with its Human Footprint rising by 4.

The largest increases in human pressure occurred in Asian NWHS, where the regional mean Human Footprint increased by 8% between 1993 and 2009 (Figure 2.). NWHS in Oceania and South America also underwent relatively large increases in human pressure, with their mean Human Footprints rising by 6.8% and 4.3% respectively. The Human Footprint in European NWHS decreased by 10% during the time period, however they were highly modified NWHS to begin with and thus still face the highest levels of human pressure of all continents. Some notable decreases occurred in the *Sinharaja Forest Reserve* in Sri Lanka, *Hierapolis-Pamukkale* and *Göreme National Park* in Turkey, whose Human Footprint decreased by 7, 6.5 and 4 respectively.

3.1.3 Comparison with Buffer Zones

The 2009 average Human Footprint per buffer zone is 7.8, which is slightly higher than the average Human Footprint per NWHS of 6.4. The trend of human pressure being higher in the landscapes surrounding NWHS held across all continents and for the majority of NWHS (78% n=70). European and Asian NWHS had the greatest levels of human pressure in their buffer zones, which were considerably higher than the global average. The *Danube Delta* in Romania had the greatest difference in human pressure compared to its buffer zone, with the relatively low 2009 average Human Footprint of 4.5 inside the NWHS compared to a relatively high 13.9 in its buffer zone. Interestingly, some NWHS such as *Sagarmatha National Park* in Nepal had very high levels of human pressure inside their boundaries compared to their buffer zones, with 2009 average Human Footprint scores of 6.5 and 3.7 respectively.

Globally, the average Human Footprint in buffer zones increased much faster than inside NWHS, rising by 4.5% compared to 1.7% between 1993 and 2009. These increases were largest in buffer zones in South America and Australia where the Human Footprint increased by 16% and 11% respectively. Many NWHS performed well at limiting increases in human pressure relative to the amount of pressure they are under from the surrounding landscape. For example in *Iguaçu National Park* in Brazil the Human Footprint stayed almost constant within the NWHS between 1993 and 2009, increasing by 0.2 compared to a large increase of 4.5 in its buffer zone. Likewise in *Mount Taishan* in China the Human Footprint only increased by 1.1 inside the NWHS but by 3.3 in its buffer zone. Conversely, some NWHS underwent larger increases in human pressure within their borders than in their buffer zones. These include *Manas Wildlife*

Sanctuary in India where the Human Footprint inside the NWHS increased by 5.3 compared to 2.2 in the buffer zone, and *Simien National Park* in Ethiopia where the Human Footprint inside the NWHS increased by 2.9, compared to 2.2 in its buffer zone.

3.2 Forest Cover Loss

3.2.1 Forest Loss in NWHS

Forest loss occurred in the majority of forested NWHS (91%, n=122) with a mean percentage loss of 1.48% per NWHS (Figure 4.). In the year 2000 there was 433,173 km^2 of forest cover inside all NWHS and by the end of 2012 the total area of forest cover lost was 7,271 km^2 (1.67%). The majority of NWHS suffered low levels of forest loss, with 72% (n=97) of NWHS losing < 1%. However, 8% (n=11) of NWHS suffered substantial forest loss (>5%), the majority of which are North American NWHS (Figure 5.). North American NWHS accounted for 57% of all the forest lost in NWHS globally (Table 3.). *Waterton Glacier International Peace Park* that crosses the Canadian and USA border lost almost one quarter of its forested area (23%, 540km^2), *Wood Buffalo National Park* in Canada lost 12% (2,582km^2) of forest cover, and *Yellowstone National Park* in the USA lost 6% (217km^2)(Table 4.). *Río Plátano Biosphere Reserve* in Honduras and *Lake Baikal* in Russia also lost large proportions of forest cover, 8% (365km^2) and 5% (1332km^2) respectively (see supplementary Table A2 for a full list of NWHS and forest loss statistics). After North America, Asian and South American NWHS lost the largest areas of forest within their NWHS. NWHS in Oceania lost an above average percentage of their forested area.

3.2.2 Forest Loss in Buffer Zones

Forest loss was higher in the buffer zones surrounding NWHS than in the sites themselves with a mean percentage loss of 2.9% per NWHS buffer zone. This trend held for all continents except for North America, where forest loss in the buffer zones was at very similar levels to inside NWHS. NWHS in Oceania lost the highest percentage of forest cover in their buffer zones and European NWHS the least. There was a clear increase in the number of NWHS suffering substantial forest losses of > 5% in their buffer zones (19% n=25), compared to within their boundaries. Forest loss was low (<1%) in only half of the NWHS buffer zones (48% n=58), while 72% of NWHS (n = 97) had low rates within their borders. Some notable NWHS which lost large proportions of forest in their buffer zones are the *Australian Fossil Mammal Sites (Riversleigh / Naracoorte)* which lost 33% (9km^2), *The Discovery Coast Atlantic Forests* in Brazil which lost 11% (192 km^2), and *Kinabalu Park* in Malaysia which lost 10% (150 km^2). Many NWHS performed well at limiting forest loss within their borders, despite considerable losses in their buffer zones (Figure 6). *Mount Wuyi* in China, for example lost only 1% (7km^2) within its borders compared to 9% (122 km^2) in its buffer zone. And *Iguazu National Park* in Argentina lost almost no forest inside its borders (0.02% <1km^2) compared to extensive loss in its buffer zone (13% 110km^2).

4. Discussion

Our analysis is the first globally comparable quantitative assessment of changes in human pressure and ecological state across the entire network of NWHS, which is important baseline information for the UNESCO World Heritage Convention, the IUCN as the advisory body to UNESCO for Natural World Heritage, and the States Parties to monitor their progress at conserving NWHS. We found that human pressure is increasing and forest loss is occurring in the majority of forested NWHS worldwide, threatening to undermine their Outstanding

Universal Value. Our most concerning finding is that a number of NWHS are severely threatened by large increases in human footprint (>1) (14 NWHS = 15% of the 94 NWHS analyzed), and extensive forest loss (>5%) (11 NWHS = 8% of the 134 NWHS analyzed). The negative impact occurring in these sites requires large scale conservation interventions to ensure their value remains protected and sustained in the future. Our findings support qualitative assessments from case-by-case reports, which corroborates that NWHS are becoming increasingly threatened globally, and that the condition of a third of NWHS is now of significant concern (Osipova et al. 2014, Wang et al. 2014). Our results also support other studies showing that habitat extent and condition are declining in many protected areas across the globe (Laurance et al. 2012, Geldmann et al. 2014). However our findings are particularly concerning since NWHS are flagship protected areas afforded the highest level of international protection.

There have been alarming rates of forest loss in the buffer zones surrounding nationally designated protected areas over the last three decades (DeFries et al. 2005, Bailey et al. 2016, Lui and Coomes 2016), and our results confirm this is also the case for many NWHS. We found that forest loss and increases in human pressure were considerably higher in the buffer zones surrounding the vast majority of NWHS. This suggests that NWHS may be performing well at limiting negative changes within their boundaries (Bruner et al. 2001). However our findings clearly show that NWHS are becoming increasingly isolated which is concerning since the ecological integrity of many NWHS depend on links with the broader landscape (Naughton-Treves et al. 2005, Kormos et al. 2015). Environmental degradation around NWHS could decrease their area and increase edge effects, which are important determinants of biodiversity persistence (Woodroffe and Ginsberg 1998, Hansen and DeFries 2007, Newmark 2008). Furthermore, Laurance et al. (2012) found that degradation occurring around a protected area strongly predisposes it to similar degradation within its borders, including trends in forest loss and human pressure. To avert further damage to NWHS the World Heritage Committee should consider directing more resources to conservation in the landscapes surrounding NWHS, and continue designating and strengthening official buffer zones around NWHS, where communities are engaged and low impact land uses promoted (Laurance et al. 2012, Kormos et al. 2015, UNESCO 2015, Weisse and Naughton-Treves 2016).

We found that North American NWHS suffered such high levels of forest loss, despite their protection and management being considered highly effective (Osipova et al. 2014). This forest loss is almost certainly due to the largest pine beetle outbreaks on record, which are causing widespread forest mortality, leaving dead trees prone to fires across large areas of North America and causing substantial ecological damage (Westerling et al. 2006, MacFarlane et al. 2013, True et al. 2014). This process is semi-natural; however, pine beetle outbreaks are being assisted by anthropogenic climate change, because winters are no longer cold enough or long enough to kill the beetles and reduce their numbers substantially (Westerling et al. 2006, Raffa et al. 2008). Pine beetle outbreaks are proving incredibly difficult to manage, making North American NWHS some of the most threatened worldwide with regard to forest loss. While pine beetle outbreaks may explain forest loss in North America, globally the drivers and mechanisms of forest loss in NWHS are diverse. For example, NWHS in Central America also lost some of the largest areas of forest, which can be directly attributed to direct deforestation activities undertaken by humans. Illegal drug trafficking in the *Río Plátano Biosphere Reserve* in

Honduras led to insecurity and instability, allowing widespread illegal deforestation and illegal settlement to occur. Our findings show that *Río Plátano* lost 8% (365km^2) of its forested area since 1993 and had an above average increase in Human Footprint, supporting the World Heritage Committee's decision in 2011 to inscribe it on the List of World Heritage in Danger.

We found that one third of NWHS underwent a decrease in human pressure, which is a good result for conservation and a benchmark for other NWHS and protected areas to strive towards. The Human Footprint decreased on average across European NWHS, which is also encouraging, however we suggest that decreases in the Human Footprint should be interpreted with care. Although the Human Footprint is the most comprehensive cumulative threat map available, it does not include data on all the possible threats and pressures facing NWHS, suggesting our results are conservative, and that NWHS may be even more threatened than we have demonstrated. For example in *Aïr and Ténéré National Park* in Niger we found that changes in the Human Footprint were minimal (0.1) but understand that political instability and civil strife, along with poaching are the main pressures threatening the park (UNESCO 2016c). These limitations can be largely overcome by combining our data with site level case-by-case reports and therefore our study complements statutory monitoring mechanisms under the World Heritage Convention (UNESCO 2015) and IUCN's World Heritage Outlook initiative (Osipova et al. 2014). As discussed in the methods section, there are also limitations with satellite derived estimates of global forest change, for example it is impossible to infer the causes of forest loss without the use of site-level data, and not all forest loss in NWHS is necessarily negative. For example, *iSimangaliso Wetland Park* in South Africa lost 18% (161km^2) of the forest in its buffer zone, but this is due to the purposeful clearing of pine and eucalyptus plantations for restoration (Zaloumis and Bond 2011), so clearly serves a positive conservation purpose. However, given the impacts of habitat loss on biodiversity (Maxwell et al. 2016) and the prevalence of forest loss in protected areas globally (Heino et al. 2015), we do assume in the majority of cases that forest loss is detrimental to the ecological state of NWHS. We also note that forest loss is also just one indicator of ecological state, and a measure of intact forest cover does not necessarily guarantee a NWHS is in good condition. For example the *Dja Faunal Reserve* in Cameroon lost almost no forest during the time period; however, it has suffered intense poaching in recent times threatening wildlife populations within its borders (UNESCO 2016d). The limitations of remotely sensed data are widely recognized and need to be acknowledged, yet it remains an increasingly important tool for conservation monitoring, and its overall utility is broadly acknowledged (Turner et al. 2003, Buchanan et al. 2009, Tracewski et al. 2016).

5. Conclusion

The World Heritage Convention should be one of the world's most effective conservation instruments globally, identifying and protecting the Earth's most valuable natural landscapes. Our aim is to highlight growing challenges which are undermining its success. New globally comparable data sets such as the Human Footprint and the Global Forest Change data have provided an urgently needed opportunity to measure how well NWHS are maintaining their ecological integrity (Watson et al. 2015). We used these metrics to analyse spatial and temporal trends in human pressure for 94 NWHS, and forest loss in 134 NWHS, presenting baseline data for the World Heritage Committee and the States Parties. There is a clear opportunity for the

World Heritage Committee to establish thresholds and targets with regard to human pressure and forest loss in NWHS, and measure the effectiveness of management interventions across sites. We urge the World Heritage Committee to assess the status of the NWHS which our analysis suggests are highly threatened, since urgent conservation intervention is now clearly needed to save many of these NWHS and their outstanding and unique values in perpetuity.

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Figure and Table Headings

Table 1. Global and continental mean Human Footprint score per Natural World Heritage Site (NWHS) and percentage change 1993 - 2009. Scores exceeding the global mean are shown in bold.

Table 2. Natural World Heritage Sites (NWHS) with the greatest increases and decreases in Human Footprint between 1993 and 2009.

Table 3. Global and continental mean percentage forest loss per Natural World Heritage Site (NWHS), and total area of forest lost between 2001 and 2012. Percentages exceeding the global average are shown in bold.

Table 4. Natural World Heritage Sites (NWHS) with high percentage forest loss between 2001 and 2012. The total area of forest lost over the time period is also shown.

Figure 1. Frequency distribution of changes in Human Footprint between 1993 and 2009 in Natural World Heritage Sites (NWHS). * indicates the median change in HF and the arrow indicates the mean change in HF. Colors specify the continent in which the NWHS is situated.

Figure 2. Change in mean Human Footprint between 1993 and 2009 across Natural World Heritage Sites (NWHS) inscribed prior to 1993. NWHS which experienced an increase (which may threaten their unique values) are shown in red, whilst NWHS which experienced a decrease are shown in green. Site boundaries are not to scale, and have been enlarged for clarity.

Figure 3. (a) Change in Human Footprint between 1993 and 2009 inside Natural World Heritage Sites (NWHS) versus buffer zones. NWHS are coloured according to continent. (b) NWHS below the identity line have undergone less change than their surrounding buffers indicating good relative performance. (c) NWHS below the x-axis have undergone a mean decrease in Human Footprint indicating good overall performance. (d) We can visualise sites performing well on both the absolute and relative scales (green), or poorly on both (red).

Figure 4. Frequency distribution of percent forest loss between 2000 and 2012 in Natural World Heritage Sites (NWHS). * indicates the median % loss and the arrow indicates the mean % loss. Colours specify the continent in which the NWHS is situated.

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Figure 6. Percent forest loss between 2000 and 2012 in Natural World Heritage Sites (NWHS) versus buffer zones. NWHS are coloured according to continent. NWHS below the identity line have suffered higher forest loss in the buffer zone compared to within the NWHS boundaries.

Tables and Figures:

Table 1. Global and continental mean Human Footprint score per Natural World Heritage Site (NWHS) and percentage change 1993 - 2009. Scores exceeding the global mean are shown in bold.

	Human Footprint 1993		Human Footprint 2009		% Change 1993 - 2009		
Continent	NWHS	Buffer	NWHS	Buffer	NWHS	Buffer	# sites
Africa	6.0	6.9	6.2	7.1	**2.9**	2.8	25
Asia	**9.3**	**11.4**	**10.0**	**12.0**	**8.1**	**4.6**	18
Australia	3.3	4.2	3.6	4.6	**6.8**	**10.5**	10
Europe	**11.2**	**12.5**	**10.2**	**12.4**	-9.6	0.0	13
North America	2.8	3.9	2.9	4.0	**2.9**	2.6	16
South America	4.2	5.4	4.5	6.3	**4.8**	**15.8**	12
Global	6.3	7.4	6.4	7.8	1.7	4.5	94

Table 2. Natural World Heritage Sites (NWHS) with the greatest increases and decreases in Human Footprint between 1993 and 2009.

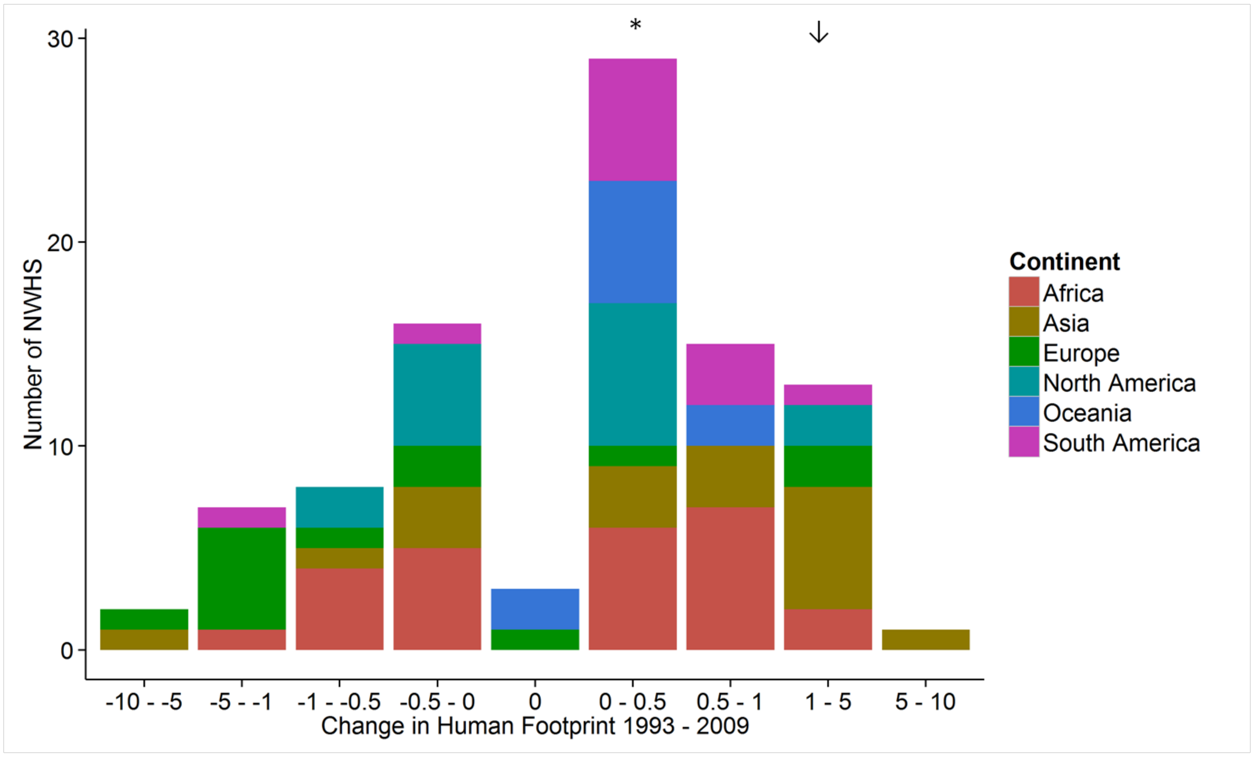
	Human Footprint 1993		Human Footprint 2009		Change 1993 - 2009	
	NWHS	Buffer	NWHS	Buffer	NWHS	Buffer
Increases						
Manas Wildlife Sanctuary	11.8	12.0	17.0	14.2	5.3	2.2
Komodo National Park	6.2	n/a	10.6	n/a	4.3	n/a
St Kilda	4.9	n/a	8.4	n/a	3.5	n/a
Chitwan National Park	11.5	13.9	14.5	17.5	3.0	3.5
Simien National Park	5.7	8.2	8.6	10.1	2.9	2.2
Decreases						
Sinharaja Forest Reserve	16.7	17.7	9.7	11.5	-7.0	-6.3
Hierapolis-Pamukkale	23.5	14.6	17.0	14.3	-6.5	-0.2
Bialowieża Forest	12.6	9.7	8.5	10.8	-4.1	1.2
Göreme National Park and the Rock Sites of Cappadocia	22.0	13.2	18.8	12.9	-3.3	0.0
Mana Pools National Park, Sapi and Chewore Safari Areas	9.0	8.9	6.2	6.7	-2.9	-2.2

Table 3. Global and continental mean percentage forest loss per Natural World Heritage Site (NWHS), and total area of forest lost between 2001 and 2012. Percentages exceeding the global average are shown in bold.

	Mean % forest loss per NWHS		Summed forest loss (km2)		
Continent	NWHS	Buffer	NWHS	Buffer	# sites
Africa	0.6	2.4	523.4	1220.4	32
Asia	1.2	2.3	1599.2	1628.9	31
Australia	**1.6**	**6.2**	237.8	524.6	12
Europe	1.5	1.9	51.1	89.0	16
North America	**3.9**	**3.8**	4131.8	1814.3	21
South America	0.7	2.7	728.0	1479.3	22
Global	1.5	2.9	7271.2	6756.6	134

Table 4. Natural World Heritage Sites (NWHS) with high percentage forest loss between 2001 and 2012. The total area of forest lost over the time period is also shown.

	% forest loss		Summed forest loss (km2)	
	NWHS	Buffer	NWHS	Buffer
Waterton Glacier International Peace Park	23.1	14.9	540.7	317.1
Shark Bay	12.4	14.3	5.8	2.7
Wood Buffalo National Park	11.7	8.9	2581.5	513.4
Grand Canyon National Park	9.8	1.1	38.2	5.1
Río Plátano Biosphere Reserve	8.5	10.1	365.6	252.0
Doñana National Park	7.3	0.8	2.1	1.0
Yellowstone National Park	6.3	3.1	217.0	59.4
Mount Athos	5.8	6.1	13.1	0.7
Canadian Rocky Mountain Parks	5.3	3.7	424.5	176.4
Lake Baikal	4.8	10.9	1332.6	1044.7



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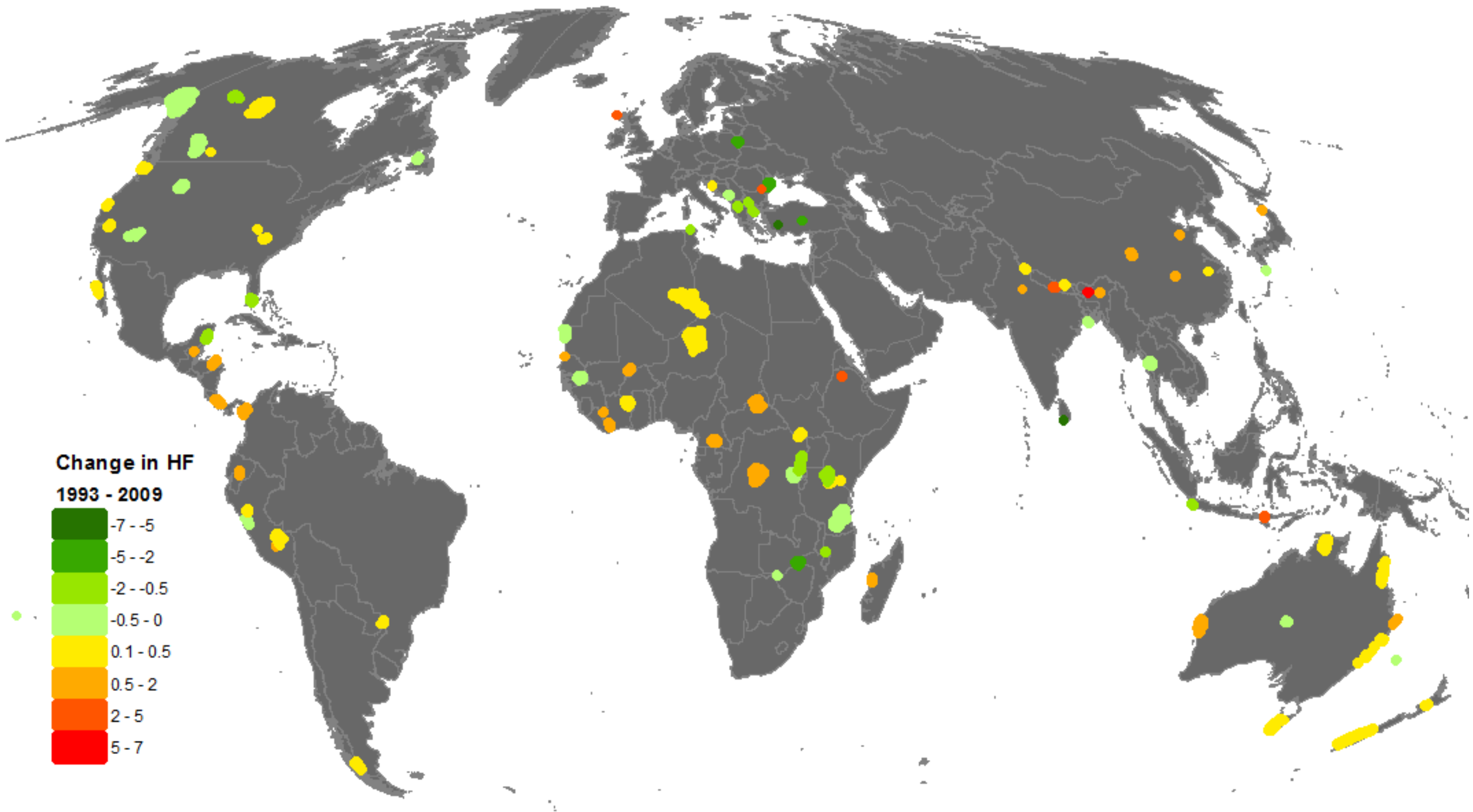

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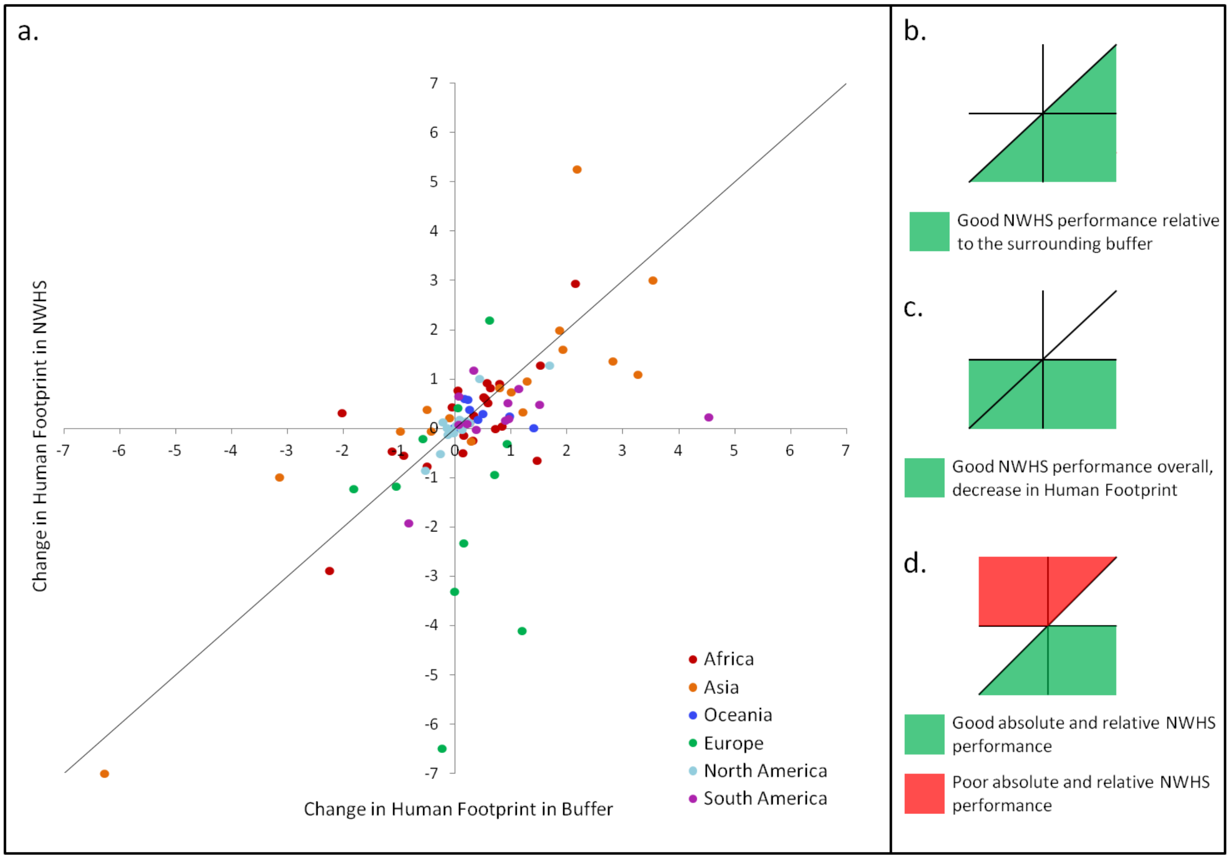

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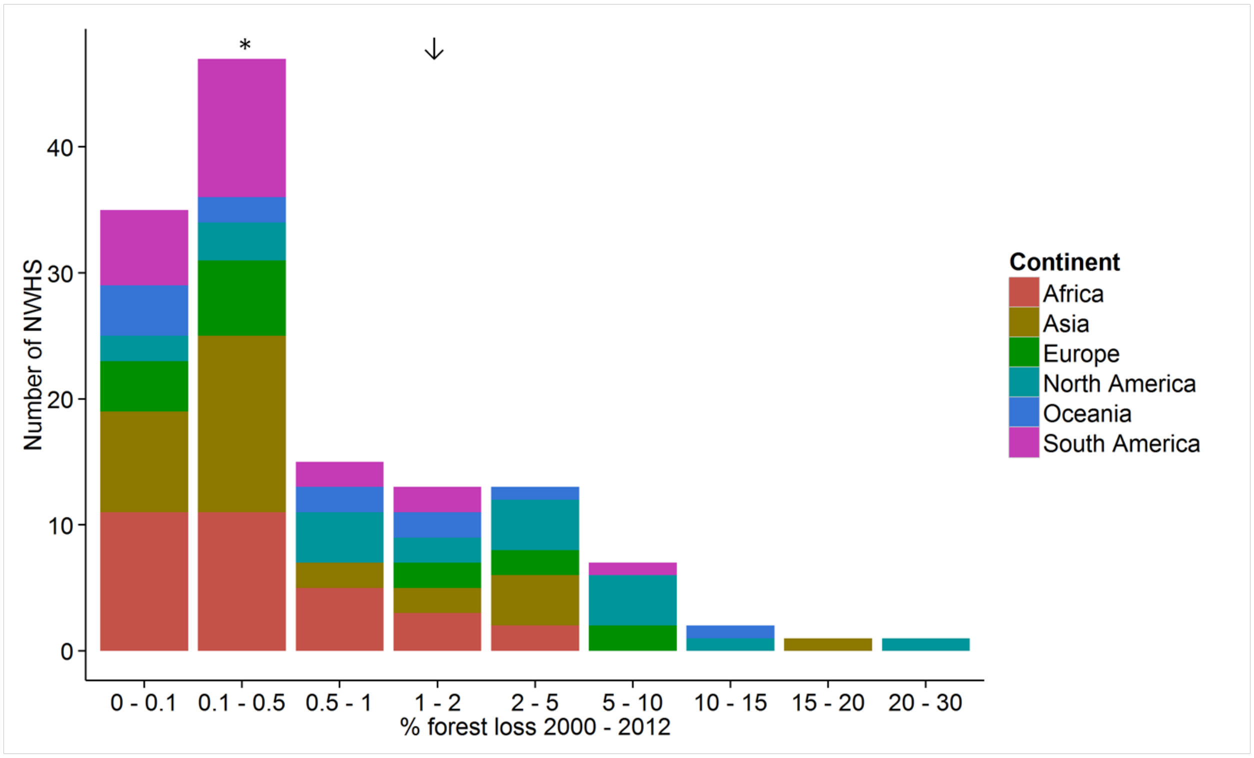

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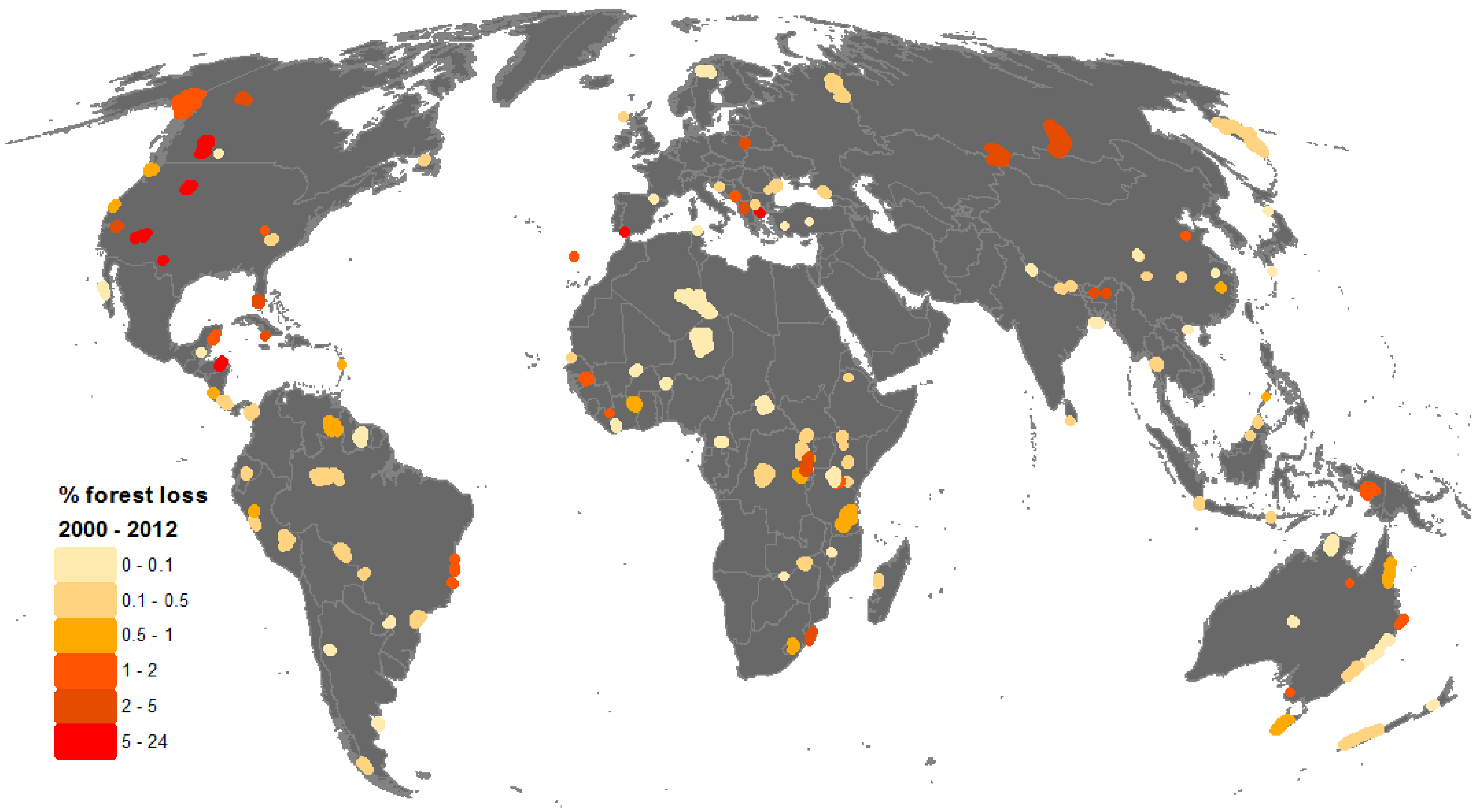

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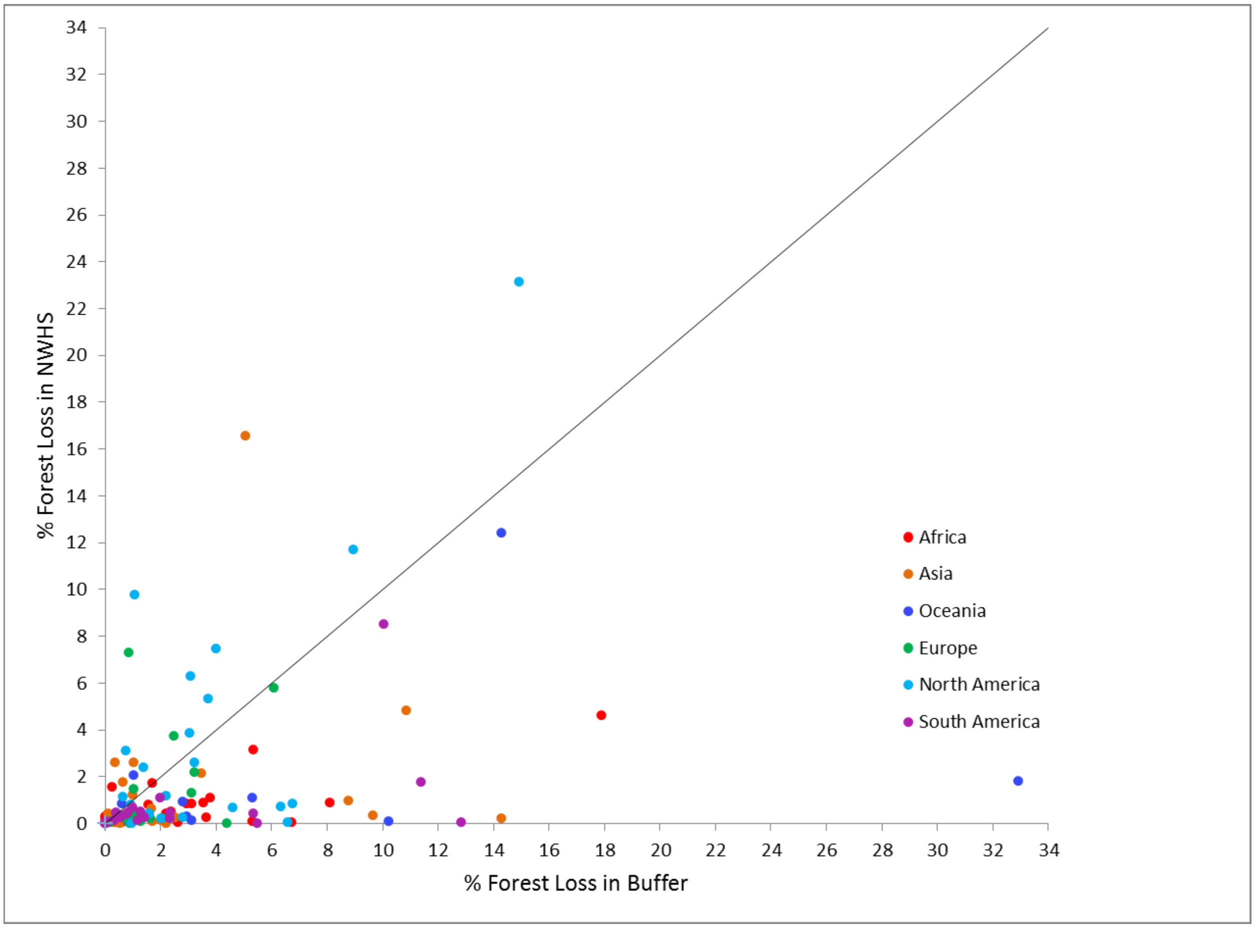

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