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

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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*. 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 2581 km^2 (11.7%) and 365 km^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

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(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 1 km^2 resolution of the Human Footprint data, we chose to exclude NWHS smaller than 5 km^2. Initially 190 NWHS qualified for our analysis.

2.2. Analysing 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 1 km^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 to 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 10 km 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 5 m and forest loss as the complete removal of tree canopy at a 30 m 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 0% 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