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World Heritage forests

Carbon sinks under pressure

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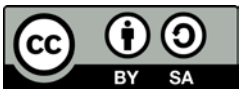

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World Heritage forests

Carbon sinks under pressure

Short summary

Quantifying climate benefits from World Heritage forests

Forests are some of the most biodiverse habitats on Earth and play a crucial role in climate regulation by absorbing carbon dioxide (CO_2) from the atmosphere. Forests in UNESCO World Heritage sites cover 69 million hectares (roughly twice the size of Germany) and are collectively strong net carbon sinks responsible for absorbing approximately 190 million tonnes of CO_2 from the atmosphere each year, equivalent to roughly half the United Kingdom's annual CO_2 emissions from fossil fuels.

However, despite their global recognition and protection status at the national level, 10 World Heritage forests were net carbon sources between 2001 and 2020 due to anthropogenic stressors, including land use and climate change. Resource use and more intense and increasingly frequent disturbances such as wildfires are likely to weaken World Heritage forest carbon sinks in the coming years.

Ensuring strong and sustained protection of World Heritage forests and surrounding landscapes is crucial for maximizing their value as solutions to climate change mitigation, climate change adaptation and biodiversity conservation.

190 million

tonnes of carbon dioxide absorbed (net) from the atmosphere each year

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"Since wars begin in the minds of men and women, it is in the minds of men and women that the defences of peace must be constructed."

Contents

Highlights

- UNESCO's 257 natural and mixed (natural and cultural) World Heritage sites contain 69 million hectares of forests (roughly twice the size of Germany), but their climate benefits have not been quantified before due to a lack of available data.
- This report combines recently published maps of global forest carbon fluxes between 2001 and 2020 with site-level monitoring to estimate forests' climate impacts and the climate consequences of threats to UNESCO World Heritage forests.
- World Heritage forests were collectively strong carbon sinks between 2001 and 2020, with net absorption of approximately 190 million tonnes of carbon dioxide (CO_2) from the atmosphere each year, equivalent to roughly half the United Kingdom's annual CO_2 emissions from fossil fuels.
- Long-term sequestration by World Heritage forests has resulted in total carbon storage of approximately 13 billion tonnes, which exceeds the carbon in Kuwait's proven oil reserves.
- Despite their global recognition and protection status at the national level, 10 sites were net carbon sources during the 2001-2020 period due to different stressors and disturbances. In the coming years, heightened emissions from anthropogenic stressors including land-use pressures and climate change are likely to occur at a growing number of sites worldwide. These disturbances could weaken the ability of forests to absorb carbon from the atmosphere.
- Strong and sustained protection of World Heritage forests and surrounding landscapes can contribute to effective solutions for climate change mitigation, climate change adaptation and biodiversity conservation.

Executive summary

While forests play an important role in the global carbon cycle, evaluating the climate impacts of specific sites across diverse regions is often hampered by a lack of data. Around a quarter of the more than one thousand sites on the UNESCO World Heritage List have been inscribed specifically for their natural values, and many contain large tracts of forests[1]. Covering 69 million hectares[2] (roughly twice the size of Germany), World Heritage forests provide multiple goods and services, benefitting nature and people. Despite having a general understanding of the climate benefits provided by these forested sites, the degree to which they serve as sources or sinks for atmospheric CO_2 had not been quantified until now.

Combining global maps with site-level monitoring tells the carbon story. This report assesses for the first time forest greenhouse gas (GHG) emissions, sequestration (CO_2 removals), and carbon (C) storage within all 257 natural and mixed (both natural and cultural) UNESCO World Heritage sites as inscribed until 2021, using recently published global maps of forest carbon fluxes between 2001 and 2020 (Figure ES-1)[3]. Based on this analysis, several sites showed spikes in emissions and/or had emissions exceed removals and were further investigated. These and other sites were cross-checked against on-the-ground information compiled from the monitoring process of the World Heritage Convention[4] and the IUCN World Heritage Outlook of 2020[5], which helped to identify the specific pressures that were most likely to have influenced a landscape's local carbon budget over the last 20 years.

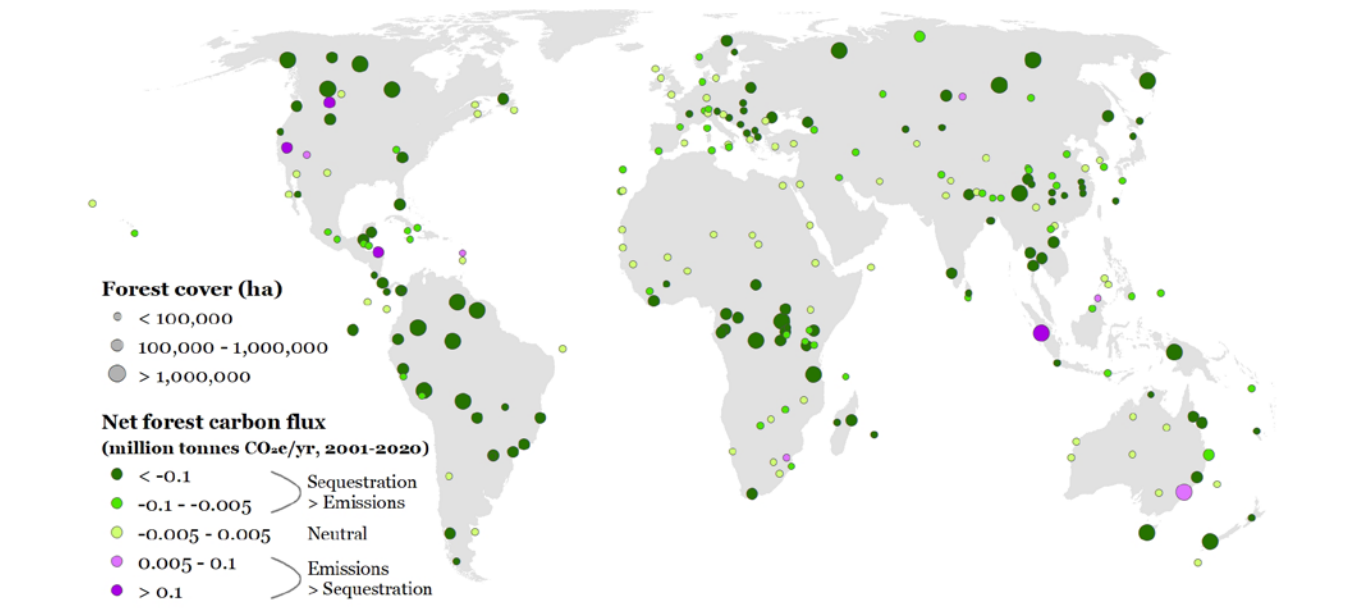
On average, forests in natural and mixed UNESCO World Heritage sites have absorbed approximately 190 million tonnes of CO_2 from the atmosphere annually since the year 2000. This net CO_2 removal by forests is equivalent to roughly half of the United Kingdom's annual CO_2 emissions from fossil fuels in 2019[6]. Sequestration over centuries or millennia by World Heritage forests has resulted in total carbon storage of approximately 13 billion tonnes, which exceeds the carbon in Kuwait's proven oil reserves[7]. The sites with the largest net carbon sinks and stores were generally in tropical and temperate regions.

World Heritage forests provide critical climate benefits only if safeguarded from threats. Despite their globally recognized and protected status, forests in 10 World Heritage sites were net carbon sources during the 2001-2020 period. In the future, ongoing removal of atmospheric CO_2 by forests at these sites is not guaranteed if threats to their conservation continue. Emissions due to forest loss from land use pressures have increased at some sites, such as the Tropical Rainforest Heritage of Sumatra in Indonesia and the Río Plátano Biosphere Reserve in Honduras. Others have experienced natural and anthropogenic climate-related disturbances, such as intense wildfires. Some of the wildfires released greenhouse gas emissions greater than 30 million tonnes CO_2e in a single year, higher than the national annual emissions from fossil fuels of more than half of the countries in the world[8]. Both direct land use pressures and climate change endanger sites' carbon stores and ongoing sequestration.

[1] UNESCO World Heritage List available from https://whc.unesco.org/en/list/.
[2] Analysis of Hansen et al., 2013.
[3] Harris et al., 2021.
[4] Paragraph 169 of the Operational Guidelines for the Implementation of the World Heritage Convention: https://whc.unesco.org/en/guidelines/.
[5] Osipova et al., 2020.
[6] Global Carbon Project, 2021.
[7] US EIA, 2021.
[8] Using 2018 emissions according to CAIT data on Climate Watch (www.climatewatchdata.org).

World Heritage forests and their surrounding landscapes require strong and sustained protection to maintain their roles as carbon sinks and stable carbon stores for future generations. Three pathways for achieving this objective include rapidly and effectively responding to climate-related events such as wildfires; maintaining and strengthening ecological connectivity through improved landscape management; and integrating the continued protection of World Heritage sites into international, national and local climate, biodiversity and sustainable development agendas. The successful implementation of these pathways requires the use of best available knowledge generated through reliable data and interdisciplinary decision-making, as well as the mobilization of public and political support for sustainable financing and investments.

Figure ES 1: Net forest carbon fluxes in natural and mixed UNESCO World Heritage sites. Values are annual averages between 2001 and 2020.



Source: Analysis (Box 1) of Harris et al. 2021 data in UNESCO natural and mixed World Heritage sites.
Notes: CO_2 equivalent (CO_2e) is a measure used to aggregate the emissions from various greenhouse gases on the basis of their global warming potentials over 100 years, by equating non-CO_2 greenhouse gases to the equivalent amount of CO_2.

69 million hectares
of forest cover
(roughly twice the size of Germany)

190 million tonnes
of carbon dioxide absorbed (net) from the atmosphere each year
(equivalent to approximately half of the United Kingdom's annual CO_2 emissions from fossil fuels)

13 billion tonnes
of carbon stored in trees and soil
(more carbon than Kuwait's proven oil reserves)

10 sites
were net carbon sources from 2001 to 2020 due to natural and anthropogenic disturbances, including climate change

Central Highlands of Sri Lanka (Sri Lanka) © UNESCO

World Heritage sites and their role in climate regulation

1.1 World Heritage sites: protecting the planet's most iconic natural places

Adopted in 1972, the Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention) unites 194[9] countries in a shared objective to protect and cherish the world's most outstanding natural and cultural heritage. Under this unique international Convention, more than a thousand natural, cultural and mixed (both natural and cultural) sites are currently recognized for their Outstanding Universal Value (OUV) – "*cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity*"[10] – and inscribed on the UNESCO World Heritage List[11]. About a quarter of these World Heritage sites are inscribed on the List on the basis of their natural values. They are distributed across more than 110 countries and cover approximately 350 million hectares (Mha), roughly the surface area of India (Table 1). Collectively, they include almost 1% of the Earth's land surface and 0.6% of the world's oceans.

Table 1: Number of sites and total area and forest area in natural and mixed UNESCO World Heritage sites

Region	Number of sites	Site area (Mha)	Forest area in 2000 (Mha)
Africa	44	40	13
Arab states	8	10	0
Asia-Pacific	79	114	16
Europe, Canada and US	80	142	22
Latin America and Caribbean	46	43	19
Global Total	**257**	**349**	**69**

Source: UNESCO World Heritage List

Notes: Sites are as of October 2021. UNESCO organizes its Member States into five regional groups: Africa, Arab States, Asia and the Pacific, Europe and North America, and Latin America and the Caribbean. Within each site, forest area was estimated as the area with tree canopy density >30% in 2000, based on Hansen et al., 2013. Forest areas were identified in 223 sites.

Natural and mixed UNESCO World Heritage sites[12] cover diverse ecosystems such as caves, deserts, islands, lakes, wetlands, glaciers, mountains, volcanoes, coastal and marine areas, savannas, and forests. They include landscapes that harbour singular natural beauty, places representing major stages of Earth's history, habitats where significant ecological and biological processes take place, as well as biodiversity hotspots that shelter unique and threatened species[13]. In addition to their Outstanding Universal Value and globally important contribution to biodiversity conservation, these sites also

[9] Countries that have adhered to and have ratified the World Heritage Convention are known as State Parties.

[10] Paragraph 49 of the Operational Guidelines for the Implementation of the World Heritage Convention: https://whc.unesco.org/en/guidelines/.

[11] 897 cultural, 218 natural and 39 mixed as of October 2021. Among the 257 natural and mixed sites, 50 have been inscribed for their marine values. Site list available from https://whc.unesco.org/en/list/.

[12] The combination of natural and mixed sites is hereafter referred to as World Heritage sites.

[13] Managing Natural World Heritage: https://whc.unesco.org/en/managing-natural-world-heritage/.

contribute to the well-being of local communities and wider human society. They support the heritage, livelihoods and traditional lifestyles of Indigenous Peoples, and play a key role in regional and national socio-economic development by providing countless products and services to millions of people. For example, over 90% of listed natural sites create jobs and provide income to local communities from tourism and recreation[14]. World Heritage sites also provide crucial ecosystem services, as two-thirds of sites are critical sources of fresh water, and about half help prevent hazards such as floods or landslides[15].

Many natural sites protect unique forest ecosystems, from the tropical rainforests of Salonga National Park[16] in the Democratic Republic of the Congo to the boreal landscapes of Pimachiowin Aki[17] in Canada **(Figure 1)**. The integrity of these ecosystems is essential for maintaining the ecological processes that underpin both their Outstanding Universal Value and their provisioning of ecosystem services, including carbon sequestration and storage[18].

Figure 1: **The tropical rainforests of Salonga National Park in the Democratic Republic of the Congo (left) and the boreal landscapes of Pimachiowin Aki in Canada (right)**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1.2 Forests in the global carbon cycle

Carbon dioxide (CO_2) is constantly exchanged between terrestrial vegetation, the ocean, and the atmosphere as part of the global carbon cycle **(Figure 2)**. This transfer of carbon is sometimes referred to as the "fast" carbon cycle, as carbon cycles through these systems several orders of magnitude faster than the relatively "slow" carbon cycle, during which carbon moves among rocks, soil, ocean and atmosphere and is buried underground or deep in the ocean[19]. The global carbon cycle is balanced when the amount of carbon released into the atmosphere is equal to the amount absorbed from the atmosphere by the ocean and land. By burning fossil fuels such as coal, petroleum and natural gas, humans have been disrupting the "fast" carbon cycle by adding "old" carbon from the "slow" carbon cycle to the atmosphere at a faster rate than terrestrial vegetation and the ocean can absorb and store the excess carbon[20]. This leads to the buildup of CO_2 in the atmosphere, resulting in global climate change.

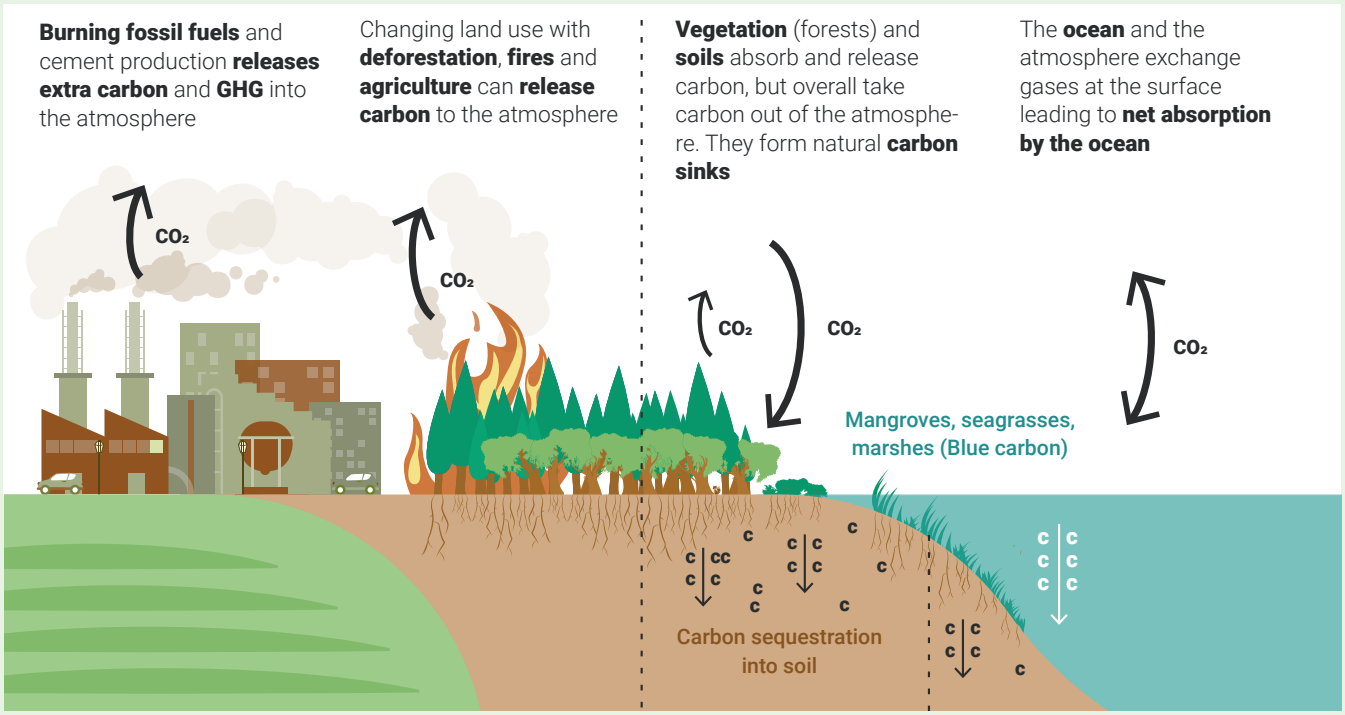
Over long time periods, forests naturally absorb more carbon from the atmosphere than they release into it, making them carbon sinks even into very old age[21,22]. Under no or minimal human disturbance, this results in forest ecosystems with large, stable carbon stocks strengthened by high ecosystem integrity, that can store that carbon for millennia or longer[23]. In fact, more carbon is stored in the

[14] Spenceley et al., 2021.
[15] Osipova et al., 2014.
[16] https://whc.unesco.org/en/list/280/.
[17] https://whc.unesco.org/en/list/1415/.
[18] Osipova et al., 2014.
[19] NASA, 2011.
[20] IPCC, 2019.
[21] Duque et al., 2021.
[22] Qie et al., 2017.
[23] Barber et al., 2020.

world's forests (roughly 861 gigatonnes of carbon (Gt C) or 3,160 Gt CO_2[24,25]) than in extractable fossil fuel deposits (roughly 750 Gt C or 2,750 Gt CO_2[26]). Carbon in forests is mainly stored in trees (aboveground biomass), roots (belowground biomass) and soils[27].

The rate at which forests remove carbon from the atmosphere depends on the age and productivity of the forest, as well as the composition of tree species and environmental conditions[28]. However, human activity can turn forested areas into a net source of carbon. Dead trees that are burned or left to decompose release a portion of their carbon into the atmosphere, while fires also produce other potent greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). When forests are cleared, degraded or burned, either as a management practice to clear land for a new land use, or due to natural and human-driven forest disturbances, these gases are released into the atmosphere[29,30]. Over the last few centuries, land use change, deforestation, forest degradation and agricultural expansion have contributed (to a lesser degree than fossil fuels[31]) to higher concentrations of CO_2 in the atmosphere[32].

Figure 2: Simplified overview of the movement of carbon through the planet's living (biotic) components, sometimes referred to as the "fast" portion of the global carbon cycle.



Source: UNESCO

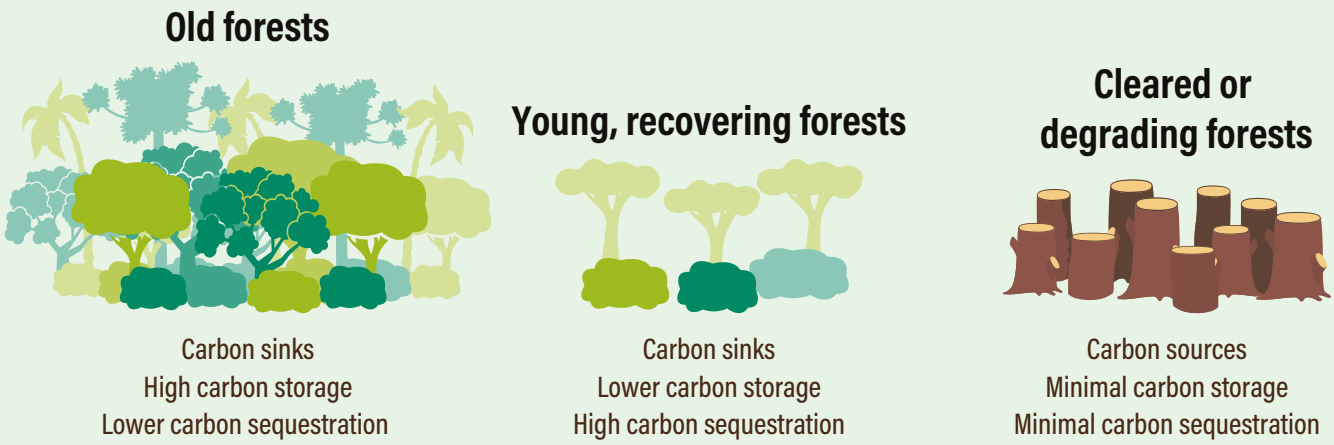
The amount of carbon forests release and absorb over time depends on a few major factors. The primary determinants affecting emissions are disturbance type and intensity, as well as the amount of carbon stored in the forest and released into the atmosphere upon clearing[33]. Given that older, more mature forests generally store more carbon per unit area than younger or recovering forests, emissions are highest when these forests are completely and permanently cleared **(Figure 3)**[34,35]. However, disturbances and associated emissions occur along a continuum. Low intensity disturbances, such as understory fires, usually only release a small amount of the stored carbon, and can be

[24] 1 gigatonne of carbon (Gt C) released into the atmosphere corresponds to 3.67 gigatonnes of CO_2 (Gt CO_2).
[25] Pan et al., 2013.
[26] Heede and Oreskes, 2016.
[27] Pan et al., 2013.
[28] Cook-Patton et al., 2020.
[29] IPCC, 2019.
[30] Janowiak et al., 2017.
[31] Blanco et al., 2014.
[32] IPCC, 2019.
[33] Baccini et al., 2012.
[34] IPCC, 2006.
[35] Alexandrov, 2007.

beneficial to ecosystem functioning[36], whereas high intensity disturbances, such as the complete removal of trees for the expansion of agricultural land, can release all the carbon stored in trees, as well as some of the carbon stored in soil[37].

While deforestation and other major forest disturbances lead to a relatively fast rate of emissions, forests remove carbon from the atmosphere more gradually as they grow. In general, younger forests recovering from past disturbances capture carbon more quickly than do mature forests, and lower latitude (tropical or subtropical) or wet forests capture carbon more quickly than higher latitude (temperate or boreal) or dry forests[38]. Disturbances followed by forest recovery result in a pulse of emissions followed by renewed carbon capture[39]. However, in cleared forests that have been permanently deforested, or degraded forests where the degrading pressures are sustained, not only has the stored carbon been emitted, but future carbon capture does not occur, as the forest carbon capture "pump" is effectively shut off **(Figure 3)**.

Figure 3: **Carbon storage, emissions, and removals across different forest and land use profiles.**



Source: World Resources Institute

1.3 World Heritage forests are strong carbon sinks

While scientific understanding of the role of forests in the global carbon cycle has improved thanks to data synthesis efforts and large-scale monitoring[40,41,42], evaluating forest climate impacts on a local scale has often been hampered by a lack of available monitoring data, particularly in the many countries that lack comprehensive and repeated forest inventories[43]. Recent research has combined limited ground measurements with remote sensing observations, enabling forest-atmosphere carbon fluxes to be assessed at higher spatial resolution over larger geographic areas[44,45]. Quantifying carbon stocks and forest-atmosphere fluxes (the carbon stored in forests and the CO_2 released into or absorbed from the atmosphere, respectively) is crucial for assessing the contribution of World Heritage sites to climate regulation and for understanding their potential role in climate change mitigation.

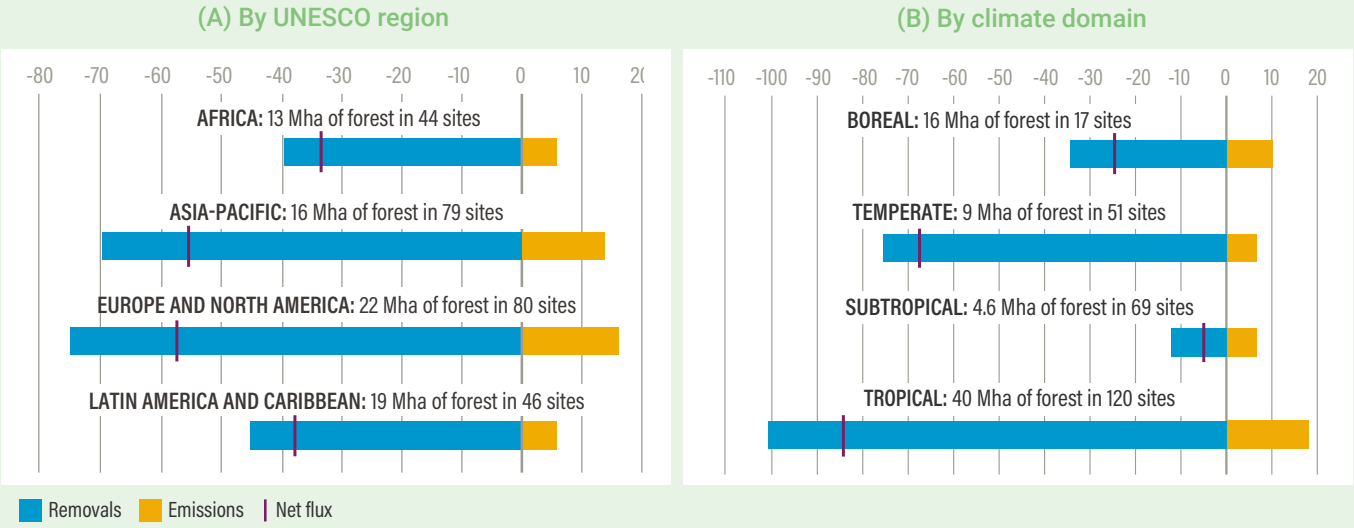
This report presents results derived from a new analysis of carbon fluxes occurring within World Heritage sites **(Box 1)**. The data indicate that, over the past 20 years, the 69 million hectares of forests[46] (roughly twice the size of Germany) within these sites have collectively served as a net carbon sink of

[36] Goetz et al. 2012.
[37] Zhou et al., 2013.
[38] IPCC, 2006.
[39] Williams et al., 2012.
[40] https://www.globalcarbonproject.org/.
[41] Malhi et al., 2021.
[42] FAO, 2020.
[43] Nesha et al., 2021.
[44] Baccini et al., 2017.
[45] Xu et al., 2021.
[46] Forest area is as of the year 2000, using Hansen et al., 2013. This value includes 2.9 Mha in terrestrial components of marine World Heritage sites.

approximately 190 million tonnes of CO_2 equivalent per year (Mt CO_2e/yr)[47]. This annual carbon sink estimate is equivalent to about half of the United Kingdom's annual CO_2 emissions from fossil fuels in 2019[48] and reflects the balance between 230 Mt CO_2/yr of carbon removals from forest growth and 42 Mt CO_2e/yr of emissions from anthropogenic and natural forest disturbances.

In aggregate, World Heritage forests in all UNESCO geographic regions and climate domains were net sinks. Despite relatively similar total forest areas distributed across sites in each UNESCO region, Europe and North America and Asia and the Pacific were stronger net carbon sinks than Latin America and the Caribbean and Africa **(Figure 4a)**. When net carbon fluxes are summarized by broad climate domain rather than geographic region, tropical and temperate sites were the strongest net sinks, with subtropical sites closest to neutral **(Figure 4b)**.

Figure 4: Forest greenhouse gas fluxes (average 2001-2020, Mt CO_2e/yr) in natural and mixed UNESCO World Heritage sites aggregated by (A) UNESCO region; and (B) climate domain.



Source: Analysis (Box 1) of Harris et al., 2021 data summarized for natural and mixed UNESCO World Heritage sites.
Notes: UNESCO organizes its Member States into five regional groups: Africa, Arab States, Asia and the Pacific, Europe and North America, and Latin America and the Caribbean. The Arab States region is not included in this graph because its forest fluxes are significantly lower than those of other regions. It is included in all other analyses.

Between 2001 and 2020, out of the 257 natural and mixed sites, 166 were net sinks and 10 were net sources, with the remaining 81 being nearly neutral, with very small estimated annual fluxes[49] **(Figure 5a)**. The 10 net source sites were distributed across all UNESCO regions and climate domains. The net sink was concentrated within just a few sites, the five largest being: Tasmanian Wilderness (Australia), Te Wahipounamu (New Zealand), Central Amazon Conservation Complex (Brazil), Salonga National Park (Democratic Republic of the Congo) and Canadian Rocky Mountain Parks (Canada) **(Table 2)**. Collectively, these five sites accounted for around one third of the total forest net carbon sink in the World Heritage network, while just 10 sites accounted for half of the total sink.

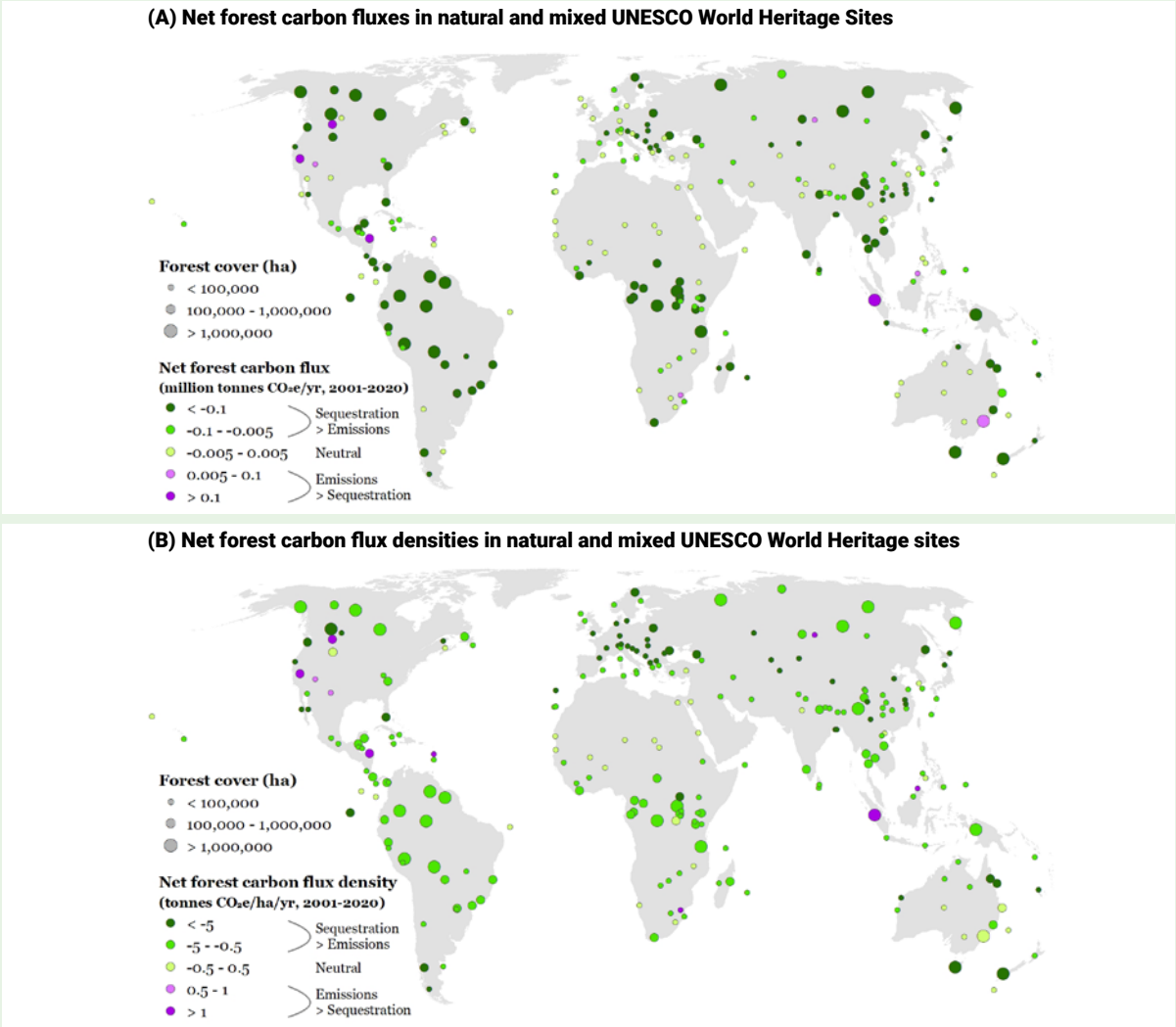
[47] CO_2 equivalent (CO_2e) is a measure used to compare the emissions from various greenhouse gases on the basis of their global warming potentials over 100 years, by equating non-CO_2 greenhouse gases to the equivalent amount of CO_2. Throughout this report, we refer to greenhouse gases for emissions (since estimates include CO_2, CH_4 and N_2O emissions) and CO_2 for carbon removals. For simplicity, the terms "net carbon sink", "net carbon source", and "net carbon flux" are used as shorthand to reflect the difference between forest-related greenhouse gas emissions and CO_2 removals, despite the fact that net values are reported in units of CO_2e.

[48] Global Carbon Project, 2021.

[49] Neutral sites had net fluxes between -5 and 5 tonnes CO_2e/yr. Their fluxes are included in all other analyses.

The five sites with the largest total net sinks were not necessarily the strongest sinks per unit area **(Table 2)**, meaning that these sites may not be the most consequential in terms of ongoing carbon capture per hectare of forest. Sites that are not large net sinks can still play a considerable role in regional and local climate regulation if they have high rates of carbon sequestration per hectare. In fact, 55 sites had annual net carbon sequestration rates of more than 5 tonnes CO_2e/ha/yr, i.e., an average hectare of forest absorbed more carbon each year than a typical passenger vehicle emits[50] **(Figure 5b)**. On average, the rate of carbon sequestered by a hectare of forest within the World Heritage network was 50% higher than the global average within forests and similar to the average rate within global protected forests[51,52]. The average net rate of carbon sequestration within forested portions of sites that are primarily marine (-5.9 tonnes CO_2e/ha/yr) is considerably higher as these sites contain highly productive mangrove forests[53].

Figure 5: **(A) Net forest carbon fluxes and (B) flux densities (net carbon flux per hectare of forest) in natural and mixed UNESCO World Heritage sites. Values are annual averages between 2001 and 2020.**



Source: Analysis (Box 1) of Harris et al., 2021 data in natural and mixed UNESCO World Heritage sites.

Notes: The classification of some sites as neutral, sinks (sequestration > emissions) and sources (emissions > sequestration) is different between the two maps because of the cut-offs between categories. Forest cover is tree cover in 2000 from Hansen et al., 2013.

[50] US EPA, 2018.

[51] -2.7 tonnes CO_2e/ha/yr (World Heritage network), -1.8 tonnes CO_2e/ha/yr (forests), -2.7 tonnes CO_2e/ha/yr (protected forests).

[52] Global and protected area net fluxes calculated from Harris et al., 2021. Protected areas are World Database of Protected Areas categories Ia/b and II.

[53] UNESCO, 2021.

Table 2: Top five natural and mixed UNESCO World Heritage sites ranked by the size of the net carbon sink (total and per hectare)

Rank	Net carbon sink (million tonnes CO_2e/yr)	Net carbon sink per unit area (tonnes CO_2e/ha/yr)
1	**Tasmanian Wilderness** (Australia) (21)	**Los Glaciares National Park** (Argentina) (16)
2	**Te Wahipounamu** (New Zealand) (13)	**Tasmanian Wilderness** (Australia) (14)
3	**Central Amazon Conservation Complex** (Brazil) (10)	**Laurisilva of Madeira** (Portugal) (13)
4	**Salonga National Park** (DRC) (9.3)	**Plitvice Lakes National Park** (Croatia) (12)
5	**Canadian Rocky Mountain Parks** (Canada) (8.3)	**Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe** (18 countries) (11)

Source: Analysis (Box 1) of Harris et al., 2021 in natural and mixed UNESCO World Heritage sites.
Notes: Table includes sites that are not primarily marine, as including these sites would result in the top five sites by net carbon sink per unit area being marine sites with highly productive mangrove forests

Box 1: Methodology used to assess forest carbon fluxes and stocks in World Heritage sites

This report uses data[54] produced by combining Earth observation data with the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[55] to estimate forest greenhouse gas emissions, carbon removals and net fluxes between 2001 and 2020 at 30-m resolution globally. Emissions include all carbon pools (above- and belowground biomass carbon, dead wood, litter, and soil carbon) and three major greenhouse gases (CO_2, CH_4, N_2O). Emissions estimates are based on maps of tree cover loss, carbon density maps, and contextual information such as drivers of tree cover loss and fire extent. Emissions from peatlands were based on areas presumed drained and/or burned. Estimates of forest carbon removals include accumulation in above- and belowground biomass and are based on benchmark tree cover extent maps and spatialized removal factors derived from a variety of sources. Net flux is estimated as the difference between emissions and removals. Emissions are calculated annually, but removals and net flux are calculated as annual averages due to limited geospatial data on temporal trends in forest sinks.

Carbon stocks in aboveground live woody biomass in 2000 were derived from a combination of ground inventory measurements, airborne and spaceborne light detection and ranging (LIDAR), and optical satellite imagery, which may underestimate carbon storage at high densities[56]. Belowground biomass, dead wood and litter carbon values were derived from aboveground carbon values. Soil carbon was estimated based on version 2 of the SoilGrids database[57].

This is the first time that forest carbon fluxes have been estimated across all natural and mixed UNESCO World Heritage sites. Shapefiles of sites' boundaries were retrieved and adapted from the World Database on Protected Areas[58]. Emissions, removals and net flux estimates were analysed over the study period within terrestrial areas of site boundaries to generate the statistics presented in this report. Carbon stock estimates come from the same data source.

The carbon stock and flux data used in this report were produced as the first iteration of a flexible data integration framework which permits updates to different input data layers. As Earth observation advances and geospatial data related to forests improve, the accuracy and precision of the estimates will also improve. Three limitations of the data include: the underestimation of emissions due to the omission of numerous small-scale disturbances and forest fragmentation impacts not captured by the Landsat satellite sensor, which may result in significant emissions globally and in certain regions[59]; carbon removal estimates that do not account for tree cover gain after the year 2012 and that are based on limited spatial information; and a lack of uncertainty values around the estimates due to the lack of available data to calculate them at site level.

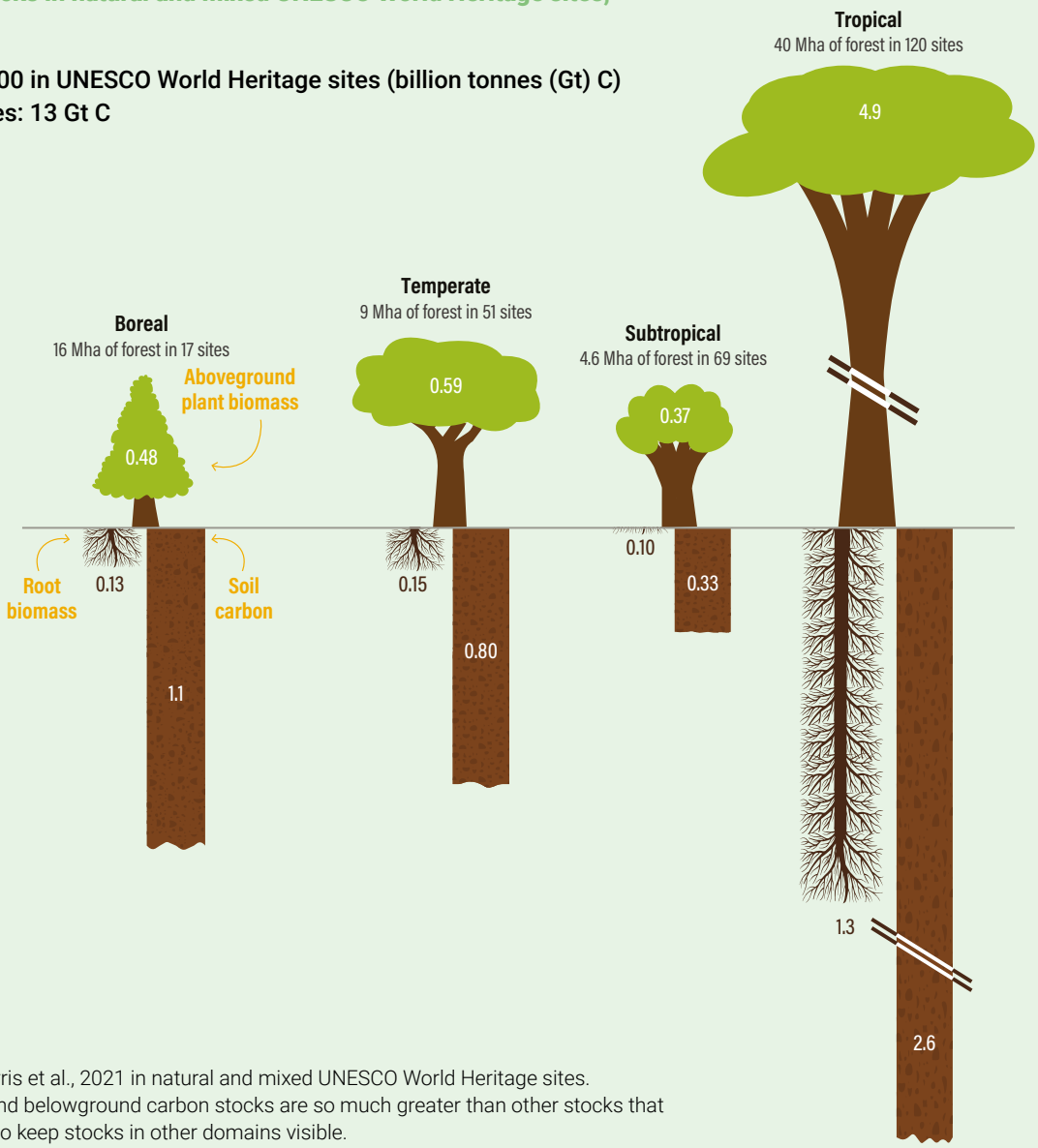
[54] Harris et al., 2021.
[55] IPCC, 2006.
[56] Issa et al., 2020.
[57] Hengl et al., 2017.
[58] UNEP-WCMC and IUCN, 2021.
[59] Pearson et al., 2017.

1.4 World Heritage forests are major carbon stores

World Heritage forests are intended to be ecosystems with high integrity that ensure stable, long-term carbon storage. Although other methods have been used previously to estimate the amount of carbon stored in World Heritage forest ecosystems[60], the network of sites has expanded since previous assessments. In addition to assessing carbon fluxes (Section 1.3), this report also presents a new analysis of forest biomass and soil carbon stored across the entire network of World Heritage sites **(Box 1)**.

Figure 6: Total carbon stocks in natural and mixed UNESCO World Heritage sites, by climate domain

Forest carbon stock in 2000 in UNESCO World Heritage sites (billion tonnes (Gt) C)
Total carbon stored at sites: 13 Gt C



Source: Analysis (Box 1) of Harris et al., 2021 in natural and mixed UNESCO World Heritage sites.
Notes: Tropical aboveground and belowground carbon stocks are so much greater than other stocks that breaks are shown in the figure to keep stocks in other domains visible.

[60] Pandey, 2012 reported 10.5 Gt C (6.3 Gt C in biomass and 4.1 Gt C in soils) in 106 sites. Osipova et al., 2014 reported 5.7 Gt C of forest carbon biomass in 130 sites in the pantropical regions.

Forests in World Heritage sites held an estimated 13 billion tonnes of carbon (Gt C) in their aboveground biomass (6.3 Gt C), root biomass (1.7 Gt C), and soil (4.8 Gt C). The carbon stored in World Heritage forests exceeds the carbon contained in Kuwait's proven oil reserves[61]. If entirely released into the atmosphere as CO_2, this would represent almost 1.3 times the global total annual CO_2 emissions from fossil fuels[62]. Forests in tropical sites contained almost 70% of the World Heritage network's total carbon store, while having about 60% of the forest cover **(Figure 6)**. Across all sites, carbon stored in tree biomass was two-thirds greater than that stored in soils, although sites in boreal forests predominantly stored their carbon in soil.

As with carbon fluxes, carbon storage was concentrated in only a few sites. Five large tropical sites collectively stored almost 30% of the forest carbon across the World Heritage network **(Table 3)**, while the 12 sites with the largest carbon stocks collectively stored over half of the carbon. All but three of these twelve sites are in the tropics, further emphasizing the high proportion of forest carbon stored within tropical World Heritage sites.

The average biomass carbon density (aboveground plus belowground) across World Heritage forests was 116 tonnes C/ha, similar to the amount of carbon contained in 100 barrels of oil[63] and 24 tonnes C/ha greater than average forest carbon density globally[64]. Fully terrestrial sites with the highest carbon densities are found in temperate and tropical regions **(Table 3)**. The average soil carbon density across World Heritage forests is 69 tonnes C/ha and fully terrestrial sites with the highest soil carbon densities are Lorentz National Park (Indonesia), Te Wahipounamu - South West New Zealand (New Zealand), Tasmanian Wilderness (Australia), Tongariro National Park (New Zealand), and Rwenzori Mountains National Park (Uganda) **(Table 3)**. Some marine and coastal sites also store carbon (known as blue carbon) at very high densities, in seagrass meadows, tidal marshes, and mangroves **(Box 2)**.

Box 2: Marine UNESCO World Heritage sites: blue carbon assets

Beyond forests, coastal and marine ecosystems also play an important role in carbon sequestration by capturing significant amounts of "blue carbon". Blue carbon is organic carbon – mainly from decaying plant leaves, wood, roots and animals – that is captured and stored by coastal and marine ecosystems. Blue carbon ecosystems include seagrass meadows, tidal marshes and mangroves. Forming a narrow strip that fringes the world's coastlines, blue carbon ecosystems are highly productive, playing important ecological roles in nutrient and carbon cycling, as nurseries and habitat for a broad range of marine and terrestrial species, in shoreline protection and in sustaining the livelihoods and well-being of local communities. Despite representing less than 1% of the global ocean area, the 50 sites inscribed on the UNESCO World Heritage List for their unique marine values, and their immediate surrounding areas for which data were available, comprise at least 15% of global blue carbon assets. These carbon stores are estimated at around 1.4 Gt C, and the five sites with the highest blue carbon stocks are: Great Barrier Reef (Australia) (502 Mt C), Everglades National Park (United States) (400 Mt C), Banc d'Arguin National Park (Mauritania) (110 Mt C), The Sundarbans (Bangladesh) (110 Mt C) and Sundarbans National Park (India) (60 Mt C)[65].

[61] 13 Gt C in World Heritage forests vs. 12 Gt C contained in 102 billion barrels of Kuwait's crude oil reserves. Kuwait's crude oil reserve estimate is from US EIA, 2021 and the carbon estimate per oil barrel (0.118 t C/barrel) is from US EPA, 2021.

[62] 36.4 Gt CO_2e from fossil fuels according to the Global Carbon Project, 2021, versus 47 Gt CO_2 (13 Gt C) stored at UNESCO natural and mixed World Heritage sites.

[63] At 0.118 tonnes C/barrel, from US EPA, 2021.

[64] Harris et al., 2021.

[65] UNESCO, 2021.

Table 3: Top five natural and mixed UNESCO World Heritage sites ranked by forest carbon storage metrics

Rank	Total carbon stored (million tonnes C)	Biomass carbon storage density (tonnes C/ha)	Soil carbon storage density (tonnes C/ha)
1	**Central Amazon Conservation Complex** (Brazil) (1020)	**Redwood National and State Parks** (USA) (302)	**Lorentz National Park** (Indonesia) (130)
2	**Salonga National Park** (DRC) (840)	**Olympic National Park** (USA) (280)	**Te Wahipounamu - South West** (New Zealand) (130)
3	**Tropical Rainforest Heritage of Sumatra** (Indonesia) (720)	**Yosemite National Park** (USA) (250)	**Tasmanian Wilderness** (Australia) (120)
4	**Lorentz National Park** (Indonesia) (670)	**Okapis Wildlife Reserve** (DRC) (220)	**Tongariro National Park** (New Zealand) (120)
5	**Chiribiquete National Park** (Colombia) (570)	**Sangha Trinational** (Cameroon, Central African Republic, Congo) (220)	**Rwenzori Mountains National Park** (Uganda) (110)

Source: Analysis (Box 1) of Harris et al., 2021 in natural and mixed UNESCO World Heritage sites.
Notes: Lists includes only sites that are not primarily marine, as including highly productive mangrove-rich sites would dominate the carbon storage density metrics. Blue carbon in World Heritage sites was covered in more detail in UNESCO, 2021. Total carbon storage and biomass carbon storage density may be underestimated due to limitations of satellites to estimate very high carbon densities[66].

[66] Issa et al., 2020

Ivindo National Park (Gabon) © Lee White*

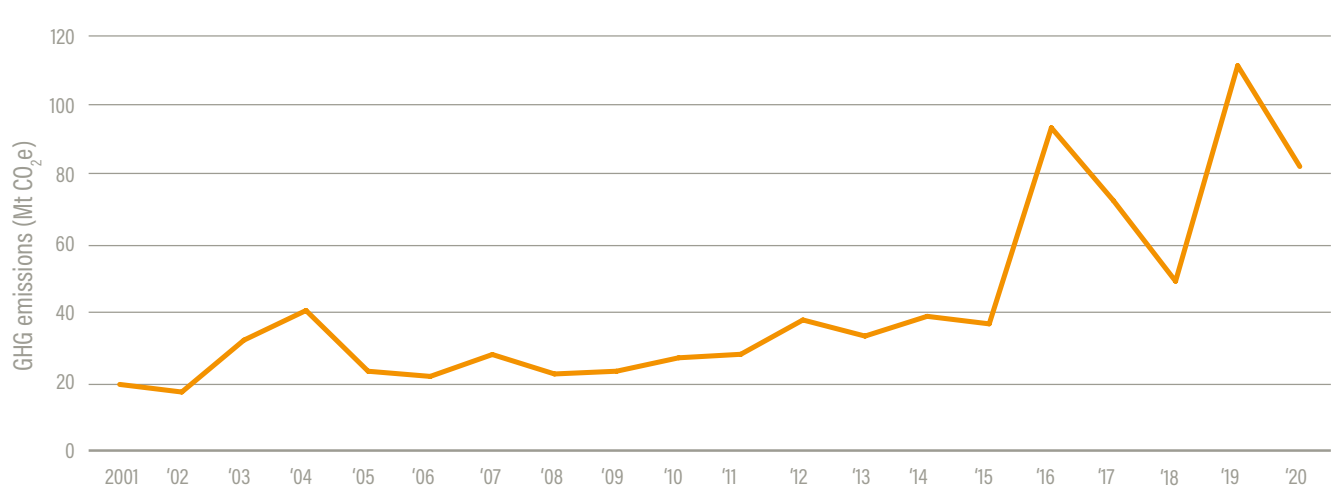
2

Carbon sinks and stores under threat

As some of the world's best protected forests, it is alarming that World Heritage sites have lost 3.5 million hectares of forest (gross loss larger than the size of Belgium) since 2000[67]. Emissions have increased over the past 20 years **(Figure 7)**, and 10 sites were estimated to be net carbon sources between 2001 and 2020 **(Table 4)**. However, these are not the only sites with concerning emissions. Other sites, despite remaining net carbon sinks, showed spikes or clear upward trajectories in emissions that threaten the strength of the future sink and the stability of the existing carbon stock. Given that World Heritage forests are generally assumed to be net carbon sinks with relatively low emissions and stable storage for carbon due to their protected status, it is important to understand why some sites emitted more carbon than they captured and others had spikes or clear upward trajectories in their annual emissions.

To better understand these dynamics, the impacts of the main threats to carbon sinks and stores at World Heritage sites were evaluated using information from the reactive monitoring process of the World Heritage Convention[68] and the IUCN World Heritage Outlook of 2020[69] **(Box 3)**. These two sources of information reveal that the two most widespread threats to World Heritage sites are climate change and associated severe weather (e.g. fires, storms, floods, droughts, temperature extremes, and habitat shifting/alteration) and land-use pressures associated with various human activities such as illegal logging, wood harvesting, and agricultural encroachment due to livestock farming/grazing and crops. These types of pressures are each reported in about 60% of World Heritage sites. The impacts of other threats, such as the presence of invasive species, tourism, management and institutional factors were not evaluated in this report as data on them comes from field surveys or institutional assessments, which do not lend themselves to analysis using the geospatial carbon flux data presented here. The impacts of these two main threats on emissions were evaluated in the 10 net carbon source sites **(Table 4)** and in specific sites where they have been identified by the reactive monitoring process of the World Heritage Convention and the IUCN World Heritage Outlook of 2020.

Figure 7: Estimated annual gross forest greenhouse gas emissions across natural and mixed UNESCO World Heritage sites



Source: Analysis (Box 1) of Harris et al., 2021 data in natural and mixed UNESCO World Heritage sites.
Notes: Changes in the methodology and data sources between 2011 and 2015 may result in higher estimates for emissions in recent years compared to earlier years. Collectively, these changes may overestimate the increase in emissions. For more about the methodology changes, see[70].

[67] According to Hansen et al., 2013.
[68] State of Conservation Information System: https://whc.unesco.org/en/soc/.
[69] Osipova et al., 2020.
[70] https://www.globalforestwatch.org/blog/data-and-research/tree-cover-loss-satellite-data-trend-analysis/

Box 3: Monitoring the state of conservation of natural and mixed UNESCO World Heritage sites

The World Heritage Convention aims to protect the globe's most treasured places, recognized for their Outstanding Universal Value (OUV). To this end, it has developed a mechanism to monitor the state of conservation for sites inscribed on the UNESCO World Heritage List: the reactive monitoring process[71]. This process consists of reporting on the "state of conservation of specific World Heritage properties that are under threat [. . .]" and allows for the identification of emerging conservation issues - both within and beyond the immediate boundaries of sites - that threaten their Outstanding Universal Value. Each year, about 60 reports on the most threatened natural and mixed UNESCO World Heritage sites are prepared and submitted to the World Heritage Committee, the governing body of the World Heritage Convention[72]. These reports allow the World Heritage Committee to assess the conditions at the sites and, eventually, to decide on the necessity of adopting specific measures to resolve recurrent problems[73]. Since 1979, over 1,500 state of conservation reports have been prepared for more than 180 natural and mixed sites, and they continue to represent one of the most comprehensive sources of documentation for tracking conservation issues of any international convention.

To monitor sites that are not that are not included in the reactive monitoring process of the World Heritage Convention and to provide a comprehensive assessment of all natural and mixed sites at once, the technical Advisory Body to the Convention on nature – the International Union for Conservation of Nature (IUCN) – has developed the IUCN World Heritage Outlook[74]. The reactive monitoring process of the World Heritage Convention and the IUCN World Heritage Outlook apply a standard list of threats that is based on the Open Standards for the Practice of Conservation threats classification[75], a classification widely used in the field of nature conservation. It comprises more than 10 broad categories of threats, each of which has sub-categories. The four categories and respective sub-categories of threats considered in this analysis were:

- climate change and severe weather (including sub-categories storms/flooding, temperature extremes, droughts, habitat shifting/ alteration),
- natural system modification (including sub-categories fire/fire suppression),
- agriculture (including sub-categories livestock farming/grazing, crops, forestry/wood production),
- biological resources use (including sub-categories logging/wood harvesting),

Despite fires being part of natural ecological processes in many dry temperate/tropical and boreal forests, and often induced by human activities[76], they are considered climate-related threats in this analysis because intense fires that have considerable impacts on emissions are usually associated with extreme temperatures and drought conditions that are driven by climate change[77]. Additionally, the agriculture and biological resources use categories have been combined under the more general term "land-use pressures" to reflect the fact that other land uses besides agriculture can encroach on World Heritage sites.

[71] Paragraph 169 of the Operational Guidelines for the Implementation of the World Heritage Convention: https://whc.unesco.org/en/guidelines/.
[72] State of Conservation Information System: https://whc.unesco.org/en/soc/.
[73] One of such measures could be the inscription of a property on the List of World Heritage in Danger.
[74] Osipova et al., 2020.
[75] https://conservationstandards.org/library-item/threats-and-actions-taxonomies/.
[76] McLauchlan et al., 2020.
[77] Pechony and Shindell, 2010.

Table 4: Natural and mixed UNESCO World Heritage sites with forests that were net greenhouse gas sources over the past 20 years, ranked by net flux.

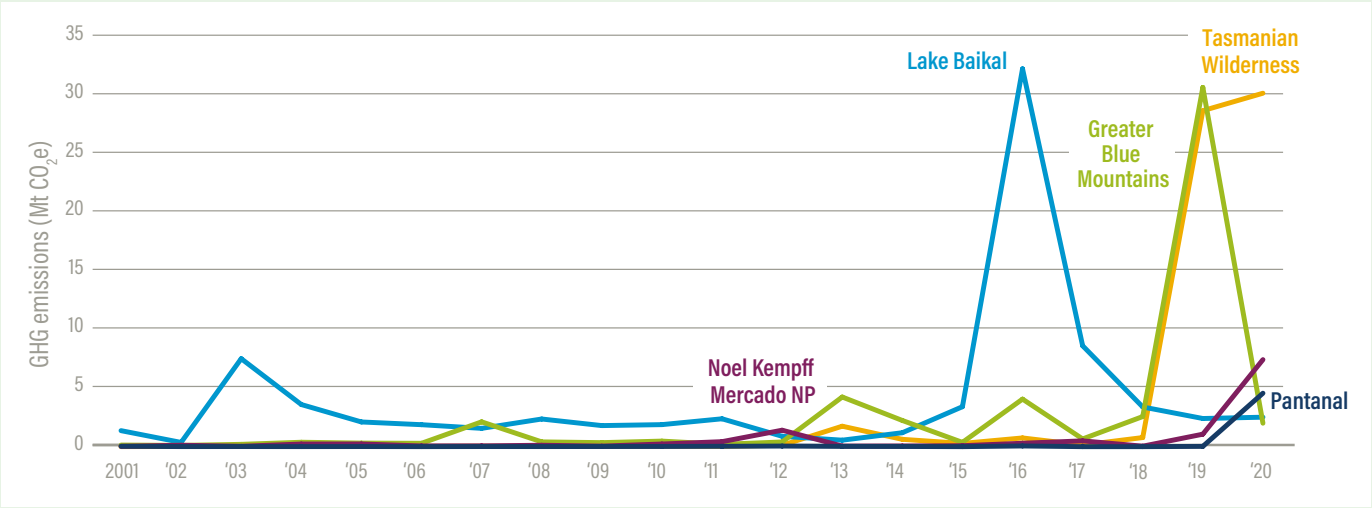
Rank	Site (country)	Net emissions (thousand tonnes CO_2e/yr)	Emissions (thousand tonnes CO_2e/yr)	Removals (thousand tonnes CO_2e/yr)	Primary threat(s)/factor(s)
1	**Tropical Rainforest Heritage of Sumatra** (Indonesia)	3000	4200	1200	Logging/wood harvesting, crops
2	**Río Plátano Biosphere Reserve** (Honduras)	1200	2600	1400	Logging/wood harvesting, livestock farming/grazing, fire/fire suppression
3	**Yosemite National Park** (USA)	700	990	300	Fire/Fire Suppression
4	**Waterton Glacier International Peace Park** (Canada, USA)	280	1000	750	Temperature changes, fire/fire suppression
5	**Barberton Makhonjwa Mountains** (South Africa)	91	350	260	Crops, forestry/wood production, livestock farming/grazing
6	**Kinabalu Park** (Malaysia)	85	99	14	Crops, Earthquake in 2015*
7	**Uvs Nuur Basin** (Russian Federation, Mongolia)	46	91	45	Livestock farming/grazing, fire/fire suppression
8	**Grand Canyon National Park** (USA)	36	85	50	Droughts
9	**Greater Blue Mountains Area** (Australia)	30	3200	3100	Habitat shifting/alteration, droughts, temperature extremes, storms/flooding), fire/fire Suppression
10	**Morne Trois Pitons National Park** (Dominica)	9	32	22	Climate change and severe weather (Temperature extremes, Storms/Flooding - including Hurricane Maria in 2017)

Source: Analysis (Box 1) of Harris et al., 2021 in natural and mixed UNESCO World Heritage sites. Threats are directly taken from the standard sub-categories of the reactive monitoring process of the World Heritage Convention and the IUCN World Heritage Outlook of 2020.
Note: Values are rounded to two significant digits, so net emissions may not be exactly equal to emissions minus removals.
*The earthquake in 2015 triggered large-scale landslides that resulted in a loss of over 2000 ha of forest.

2.1 Unprecedented wildfires fueled by climate change cause emissions to spike

Since the mid-2010s, intense wildfires associated with extreme temperatures and drought conditions[78,79] have been a cause of high emissions at some sites. The most prominent examples are wildfires in the Russian Federation's Lake Baikal in 2016[80], and in Australia's Tasmanian Wilderness[81] and Greater Blue Mountains Area in 2019 and 2020[82]. Each of these wildfires generated greenhouse gases emissions above 30 Mt CO_2e in a single year, higher than the national annual emissions from fossil fuels of more than half of the countries in the world **(Figure 8)**[83]. Other recent fires have burned tropical forest ecosystems where fire has historically been rare, such as in Bolivia's Noel Kempff Mercado National Park in the Amazon Basin.

Figure 8: Estimated annual gross forest greenhouse gas emissions among select natural and mixed UNESCO World Heritage sites with substantial fire activity

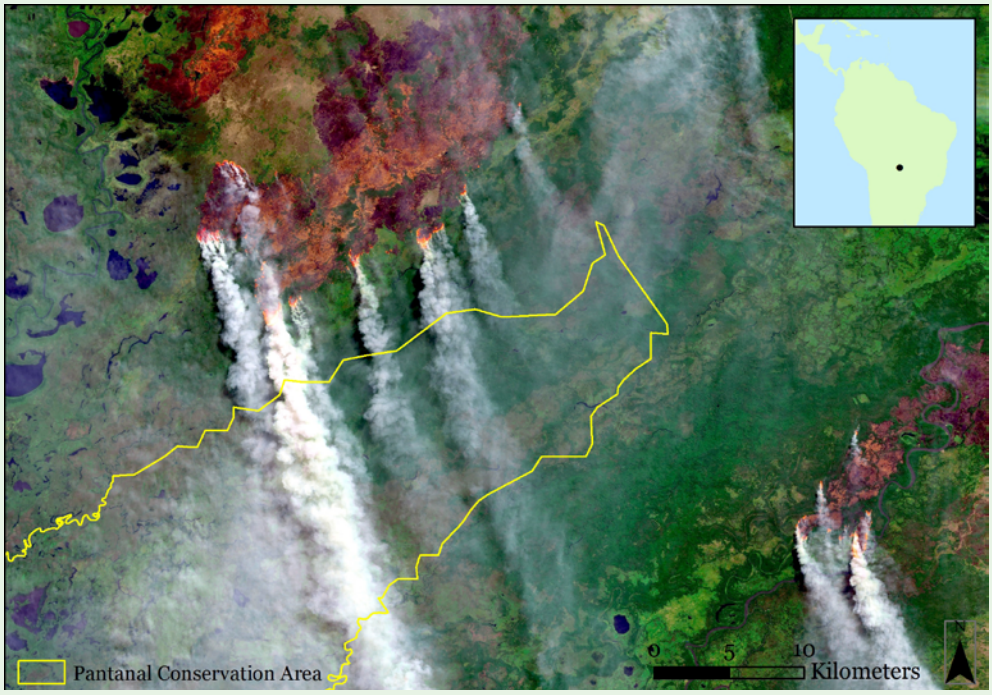


Source: Analysis (Box 1) of Harris et al., 2021 among selected World Heritage sites. Selection of sites with fire activity is based on the reactive monitoring process of the World Heritage Convention and the IUCN World Heritage Outlook of 2020.

In some cases, wildfires are ignited outside World Heritage site boundaries, where effective fire management is weaker, rather than inside[84]. Consequently, emissions from fires inside World Heritage sites (as estimated in this report) likely represent only a small portion of total fire emissions from the larger forest landscape that burned. For instance, emissions stemming from the 2020 fires that affected the Pantanal Conservation Area World Heritage site in Brazil account for less than 5% of the emissions that year from the broader biome located in the Pantanal Biosphere Reserve[85] **(Figure 9, Box 4)**.

[78] Safronov, 2020.
[79] van Oldernborgh et al., 2021.
[80] State of Conservation Information System: https://whc.unesco.org/en/soc/3618.
[81] State of Conservation Information System: https://whc.unesco.org/en/soc/4128.
[82] State of Conservation Information System: https://whc.unesco.org/en/soc/4174.
[83] Using 2018 emissions according to CAIT data on Climate Watch (www.climatewatchdata.org).
[84] State of Conservation Information System: https://whc.unesco.org/en/soc/4263.
[85] The Pantanal is the largest tropical wetland in the world and extends mainly into the Brazilian states of Mato Grosso do Sul and Mato Grosso, and into national territories of the Plurinational State of Bolivia and of Paraguay. In 2000, part of this ecoregion, the Pantanal Conservation Area, accounting for 1.3% of the Brazilian Pantanal, was inscribed on the UNESCO World Heritage List. That same year, 26.4 million hectares were named a UNESCO Biosphere Reserve.

Figure 9: **Satellite image showing wildfires close to the Pantanal Conservation Area World Heritage site in Brazil on 14 August 2020. By early October 2020, the wildfires had encroached on a small portion of the site.**



Source: Copernicus. Imagery acquired by Copernicus Sentinel-2 satellites on August 14, 2020

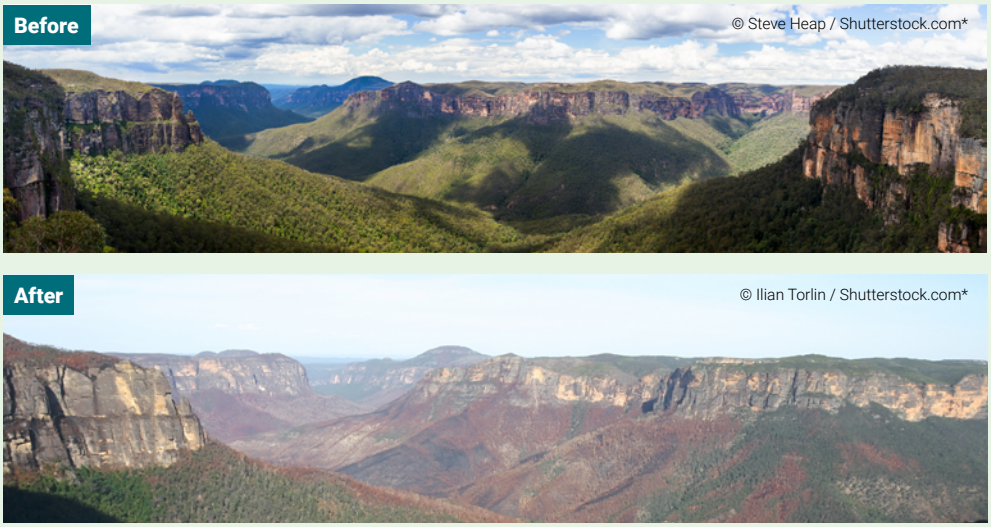
As climate change causes warmer and drier conditions that lead wildfires to become more intense and droughts more severe[86], the ability of some forests to fully recover from such events may become increasingly hampered, potentially exacerbated by past or present land management practices. Recovery may be difficult even in areas where recurring wildfires constitute an integral part of ecosystem dynamics because human-induced climate change impacts disrupt these dynamics. More intense fires could lead to short-term emissions spikes and reduced capacity for sequestration in the longer term, thus reducing overall carbon storage in sites that do not have a history of fires. Some sites, such as the Greater Blue Mountains Area (Australia), Yosemite National Park (United States), and Waterton Glacier International Peace Park (Canada/United States) have experienced such intensification, frequency and elongation of fire seasons since 2000 that they have become net carbon sources **(Table 4, Figure 10)**[87].

Other climate-related events, such as storms, can also lead to considerable loss of tree cover, for example, at Morne Trois Pitons National Park (Dominica) following Hurricane Maria in 2017. While forests here are adapted to hurricanes and will slowly recover over time, the higher frequency and severity of storms may reduce forests' ability to permanently store the same amount of carbon as they did when disturbances were less frequent and severe.

[86] Seidl et al., 2017.

[87] van Oldenborgh et al., 2021.

Figure 10: **Wide aerial views over the Grose Valley in the Greater Blue Mountains Area World Heritage site in Australia before (top) and after (bottom) massive wildfires. Brown areas indicate burn scars.**



2.2 Increased land-use pressures from human activities weakens forest carbon sinks

Despite their globally recognized and protected status at the national level, land-use pressures associated with specific human activities (e.g. illegal logging, wood harvesting, and agricultural encroachment due to livestock farming/grazing and crops) have been reported to occur inside about 60% of all World Heritage sites[88] **(examples shown in Figure 11)**. Resource extraction is associated with illegal activities in the majority of cases and is becoming one of the most prevalent threats to sites in Africa, Asia and the Pacific, and Latin America and the Caribbean[89].

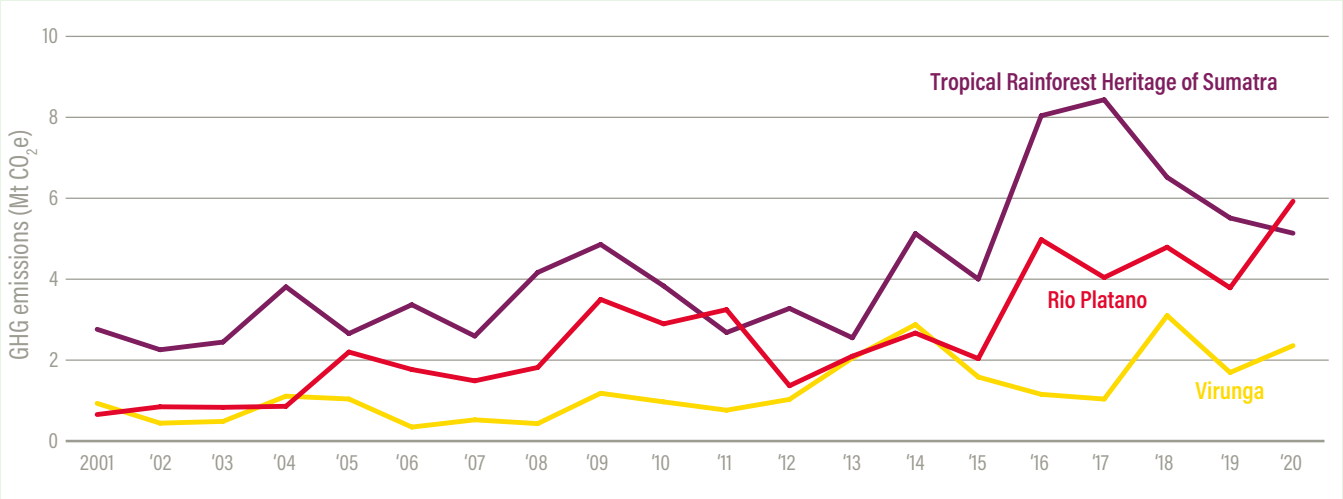
Figure 11: **Human pressures at the Virunga National Park World Heritage site in the Democratic Republic of the Congo: illegal land clearance inside the park (left) and farmland at the park's edge (right)**

[88] Based on data from the State of Conservation Information System and in the IUCN World Heritage Outlook of 2020.

[89] Osipova et al., 2020.

Sites such as Río Plátano Biosphere Reserve (Honduras), Virunga National Park (Democratic Republic of the Congo) and Tropical Rainforest Heritage of Sumatra (Indonesia) have lost around 20%, 10% and 5%, respectively, of their tree cover since 2001[90]. The extraction of forest biomass in these sites has led to increased emissions since 2001, weakening the forest carbon sinks that would have been stronger in the absence of these human-caused disturbances **(Figure 12)**. Greenhouse gas emissions at forested sites such as Tropical Rainforest Heritage of Sumatra (Indonesia) and Río Plátano Biosphere Reserve (Honduras) have been so sizeable that, over the past twenty years, emissions have exceeded removals and they have been net carbon sources, with average net emissions of 3.0 Mt CO_2e/yr and 1.2 Mt CO_2e/yr, respectively. Substantial portions of these emissions may be due to expansion of agricultural commodity production[91].

Figure 12: Estimated annual gross forest greenhouse gas emissions at select natural UNESCO World Heritage sites subject to land-use pressures



Source: Analysis (Box 1) of Harris et al., 2021 among selected World Heritage sites. Selection of sites with land use pressures is based on the IUCN World Heritage Outlook of 2020.

In addition to land-use pressures occurring inside World Heritage sites, pressures from outside can also affect the carbon inside those sites. The persistent loss and fragmentation of biodiverse and ecologically productive habitats due to land use in areas adjacent to some World Heritage sites[92] likely result in emissions that are not quantified in the data underlying this analysis. Landscape fragmentation can disrupt ecological connectivity, including some essential ecological processes and the unimpeded movement of species. Loss of connectivity leads to landscape "patchiness," that is, isolated "islands"[93] that can undergo ecosystem decay in the form of tree mortality and reduced resilience to climate change and anthropogenic disturbances[94]. The result is persistent emissions[95,96]. Biodiversity loss and defaunation as a result of poaching can also have wide implications for broader ecosystem functioning and the stability of carbon stocks. For example, the disappearance of forest elephants, which is being driven by poaching[97], could result in economic losses estimated at around US$43 billion and a loss of as much as 7% of the carbon stocks in Central African forests due to carbon-rich tree species being out-competed[98].

[90] This is one of the reasons why these sites have been inscribed on the UNESCO List of World Heritage in Danger.

[91] Analyzed with Curtis et al., 2018.

[92] Decisions 44 COM 7B.97, 7B.99, 7B.105, 7B.114, 7B.174, 7B.188 of the World Heritage Committee: https://whc.unesco.org/en/decisions/

[93] Hilty et al., 2020.

[94] Laurance et al., 2000.

[95] Brinck et al., 2017.

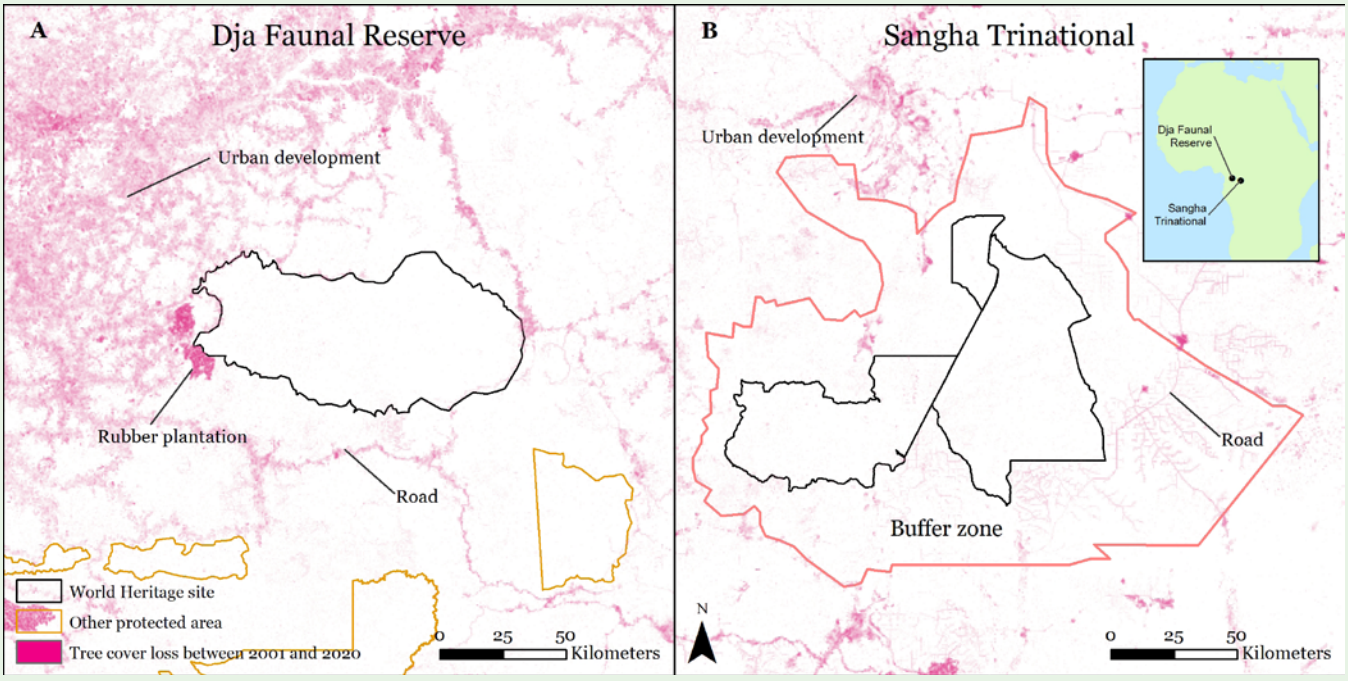
[96] Maxwell et al., 2019.

[97] Maisels et al., 2013.

[98] Berzaghi et al., 2019.

Integrated land management and buffer zones can provide a layer of protection for sites and engage local stakeholders in planning and economic activities. Moreover, well managed buffer zones can also act as net carbon sinks. For example, the Dja Faunal Reserve (Cameroon) in Africa's Congo Basin is an example of a site without a buffer zone that is threatened by reduced landscape connectivity[99]. Urban development, agricultural activities and roads intervene between the World Heritage site and the closest other protected areas **(Figure 13a)**. While the immediate surrounding area remains a net carbon sink, forest emissions are substantial just outside the site due to urban development and rubber plantations, and some of this land-use change may be expected to produce emissions within the site itself. On the other hand, Sangha Trinational (0.75 Mha of forest in Cameroon, the Central African Republic, the Republic of the Congo) is surrounded by a buffer zone (1.8 Mha of forest) where sustainable logging is practiced, and the net carbon sink of the buffer zone is more than twice as large as the World Heritage site itself (4.6 Mt CO_2e/yr. vs. 2.1 Mt CO_2e/yr, respectively) **(Figure 13b)**.

Figure 13: Buffer zone management can reduce pressures on sites. Tree cover loss around (A) Dja Faunal Reserve (Cameroon), which does not have a buffer zone, has been significantly higher than in (B) Sangha Trinational (Cameroon, Central African Republic, Republic of the Congo), which does have a buffer zone.



Source: Hansen et al., 2013 Tree cover loss and tree cover extent in the vicinity of World Heritage sites and other protected areas, as provided by UNEP-WCMC and IUCN, 2021.

[99] Decisions 43 COM 7B.29 and 44 COM 7B.173 of the World Heritage Committee: https://whc.unesco.org/en/decisions/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3

Pathways for action to protect World Heritage carbon sinks

While World Heritage forests were found to be collectively strong carbon sinks, forests in 10 World Heritage sites were identified as net greenhouse gas sources between 2001 and 2020. With rapid and accelerating climate change and increasing anthropogenic disturbances and pressures, it is likely that forest carbon storage, emissions and sequestration will be affected at an increasing numbers of sites worldwide[100]. To protect the Outstanding Universal Value, integrity and authenticity of World Heritage sites from the adverse impacts of climate change and other threats, several institutional policies, strategies and guidelines that are relevant for climate action have been developed (see list at end of report).

In line with these policies, strategies and guidelines, and considering the two main threats to forest carbon discussed in the previous section, this report frames three pathways that could directly help World Heritage forests remain strong carbon stores and sinks for future generations. These pathways are not an exhaustive list of actions for protecting and addressing threats at World Heritage sites. Rather, they focus on specific actions for preserving the carbon that is already stored in World Heritage forests and allow additional carbon to continue being removed from the atmosphere. The first and second pathways are connected to the two main threats discussed in the previous section, while the third pathway connects the first two from a broader policy perspective. Although the proposed pathways focus on a subset of climate and land use-related pressures, improving effective management that addresses the whole range of management challenges and environmental threats is still crucial.

3.1 Rapid and effective responses can help prevent devastation from climate-related events

Since the early 2000s, concerns over the impacts of climate change on World Heritage sites have been brought to the attention of the World Heritage Committee, the governing body of the World Heritage Convention. World Heritage sites are increasingly affected by climate-related events, such as wildfires and storms, which can have devastating consequences if they are not addressed rapidly and effectively. When such events occur, precious days are often lost in organizing an emergency intervention due to lack of funding and reliable data, while during this time, extensive emissions can be released **(Box 4)**. Some World Heritage sites have already taken steps to better manage climate-related risks by adopting climate change adaptation plans (e.g. Wet Tropics of Queensland[101] in Australia and Mount Kenya National Park/Natural Forest[102] in Kenya), implementing integrated fire management programmes (e.g. Cerrado Protected Areas: Chapada dos Veadeiros and Emas National Parks[103] in Brazil), and supporting disaster risk reduction initiatives through coastal protection and flood regulation (e.g. The Sundarbans in Bangladesh and Sundarbans National Park in India). However, the number of World Heritage sites with established policies, plans or processes for managing or reducing risks associated with disasters remains low[104,105].

[100] Osipova et al., 2020.
[101] https://www.wettropics.gov.au/climate-adaptation-plan-for-the-wet-tropics-20202030
[102] https://whc.unesco.org/document/133484
[103] Schmidt et al., 2018.
[104] Osipova et al., 2020.
[105] https://whc.unesco.org/en/review/74

Box 4: Supporting rapid response to wildfires

To quickly respond to emergencies, UNESCO launched the Rapid Response Facility (RRF) in 2006 to channel emergency grants to World Heritage sites (or an internationally recognized site of high biodiversity value) in developing countries where rapid alternative funding is unavailable[106]. In 2019 and 2020, RRF provided emergency grants to scale up firefighting efforts in Mount Kenya National Park (Kenya) and Pantanal Conservation Area (Brazil) that brought fires under control before they caused irrevocable damage to these World Heritage sites.

Fire-fighting efforts in Mount Kenya National Park (Kenya) in 2019

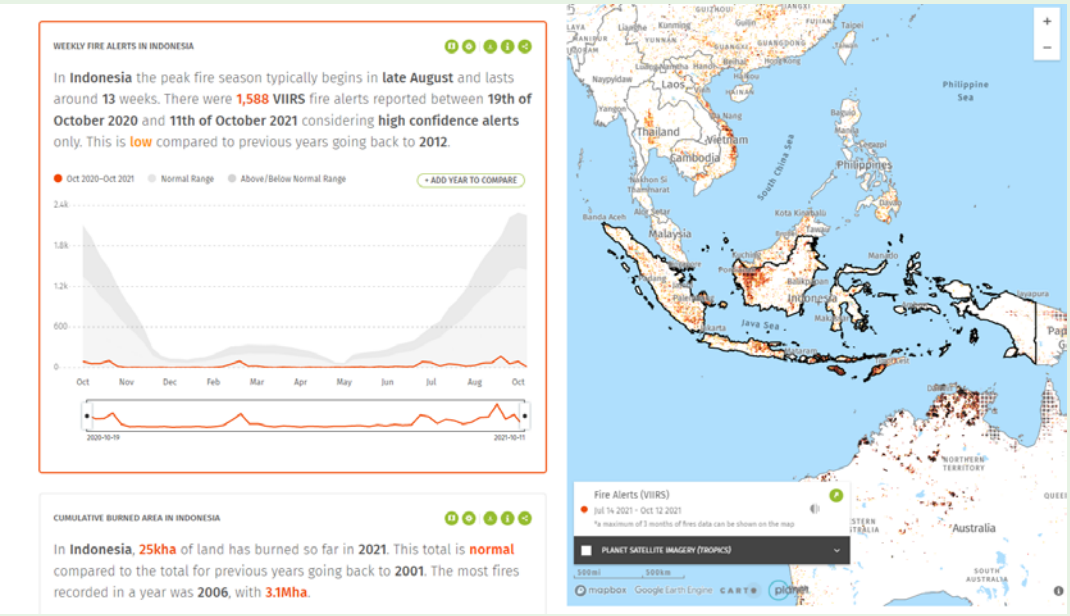
© Mt Kenya Trust

Fire-fighting efforts in Pantanal Conservation Area (Brazil) in 2020

© Instituto Homem Pantaneiro

Extinguishing fire sources before they develop into conflagrations can avoid producing extensive emissions in sites in which they have not historically occurred. By using real-time tools like fire alert data on Global Forest Watch[107] (GFW), government agencies in Indonesia have shown that it is possible to reduce fire response time by 80 percent, in this case from 30 hours or more down to just two to four hours[108].

Source: Global Forest Watch (GFW) online platform



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[106] Rapid Response Facility (RRF): https://whc.unesco.org/en/rapidresponse/

[107] For example, https://gfw.global/3AyMecP

[108] Putraditama et al., 2014.

3.2 Support mechanisms that maximize intactness and connectivity of forests

Protected areas are a key element of strategies for conserving nature and preventing disruption of ecological processes and their associated benefits to people, including climate regulation. However, many protected areas, including World Heritage sites, face increasing challenges from human land-use pressures occurring primarily outside their boundaries[109,110]. This results in protected areas becoming isolated islands within altered landscapes. However, the ecosystem dynamics that constitute the outstanding universal value of many World Heritage sites often depend on broader landscapes and large inter-connected areas[111]. Dividing forests into smaller fragments may contribute around 30% of emissions from tropical deforestation due to increased tree mortality at the edges of new forest patches[112], and similar effects can be expected at World Heritage sites as well. Maintaining ecological connectivity is therefore necessary to ensure that the integrity of those sites, including their carbon storage and sequestration functions, is preserved. Integrated landscape management and the creation of ecological corridors and buffer zones have been promoted as initiatives to address these challenges, and the creation of buffer zones is specifically recommended in the guidelines for nomination and management of World Heritage sites[113]. World Heritage sites also offer an opportunity to recognize and involve Indigenous Peoples and local communities as effective stewards of forests[114,115]. This is the case in the Wet Tropics of Queensland World Heritage site in Australia, where a cooperative management framework between Indigenous Peoples and the local government was established, thereby providing public acknowledgement of the communities' rights to own and sustainably manage their land[116].

3.3 Integrate World Heritage sites into climate, biodiversity, and sustainable development agendas

In the current context of global climate change and increasing human pressures[117,118], coordinated action is needed at national and international levels. Explicitly including World Heritage sites in countries' national policies can contribute to international initiatives, such as the Sustainable Development Goals (SDGs), climate action plans (e.g., Nationally Determined Contributions under the Paris agreement), and biodiversity strategies under the Post-2020 Global Biodiversity Framework, as they have the inherent potential to serve as living laboratories and trigger policy processes. For example, Gabon's research programme at Lope National Park since the early 1980s has underpinned many of the country's conservation- and climate-related national policies. The subsequent implementation of such policies led Gabon to become the first country in Africa to receive results-based payments for reduced emissions from deforestation and forest degradation in 2021[119] .

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[109] Geldmann et al., 2019.

[110] Osipova et al., 2020.

[111] Kormos et al., 2015

[112] Brinck et al., 2017.

[113] Paragraph 103 of the Operational Guidelines for the Implementation of the World Heritage Convention: https://whc.unesco.org/en/guidelines/

[114] Fa et al., 2020.

[115] https://whc.unesco.org/en/activities/496/

[116] https://www.wettropics.gov.au/involvement-in-world-heritage

[117] Venter et al., 2016.

[118] Ward et al., 2020.

[119] https://www.un.org/africarenewal/magazine/july-2021/gabon-becomes-first-african-country-receive-payment-reducing-co2-emissions

Conclusion

By combining remote sensing data with site-level monitoring, this report has quantified the climate benefits of World Heritage forests for the first time, assessed the impacts on carbon of common threats to World Heritage forests and identified sites that are net carbon sources. It therefore provides information to facilitate dialogues between policymakers and local stakeholders in the development of effective policies to protect the role of World Heritage forests as sinks and stable carbon stores for future generations. The high profile, global reach, and inspirational power of World Heritage sites underpin a strong case for action. However, lack of sustainable funding has been identified as the most prevalent issue hampering effective protection and management of sites[120]. The successful implementation of the pathways presented above therefore requires the mobilization of key stakeholders (e.g., governments, civil society, Indigenous Peoples, local communities and the private sector) to develop sustainable financing and investments and promotion of interdisciplinary knowledge-sharing for decision-making.

World Heritage sites and other protected areas can serve as living laboratories for monitoring environmental changes. The analysis presented here should be expanded beyond World Heritage sites and replicated for other networks of protected areas such as other UNESCO-designated sites (i.e., Biosphere Reserves and Global Geoparks) and internationally recognized areas of high biodiversity value (e.g., Ramsar, Key Biodiversity Areas) to raise awareness both at global and local levels on the key role protected areas can play in climate change mitigation, climate change adaptation and biodiversity conservation.

Ivindo National Park (Gabon) © Lee White*

[120] Osipova et al., 2020.

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Relevant UNESCO policies, strategies and guidelines on World Heritage and climate action

Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention):

https://whc.unesco.org/en/conventiontext/

Operational Guidelines for the Implementation of the World Heritage Convention:

https://whc.unesco.org/en/guidelines/

State of Conservation Information System:

https://whc.unesco.org/en/soc/

Policy Document on Climate Action for World Heritage:

https://whc.unesco.org/en/climatechange/

Climate Change Adaptation for Natural World Heritage Sites – A Practical Guide:

https://whc.unesco.org/en/series/37/

Policy for the Integration of a Sustainable Development Perspective into the Processes of the World Heritage Convention:

https://whc.unesco.org/en/sustainabledevelopment/

Strategy for Risk Reduction at World Heritage Properties:

https://whc.unesco.org/en/disaster-risk-reduction/

Managing Disaster Risks for World Heritage:

https://whc.unesco.org/en/managing-disaster-risks/

Managing Natural World Heritage:

https://whc.unesco.org/en/managing-natural-world-heritage/

World Heritage forests
Carbon sinks under pressure

World Heritage forests: Carbon sinks under pressure, a report by UNESCO, World Resources Institute (WRI) and the International Union for Conservation of Nature (IUCN) provides the first global scientific assessment of greenhouse gas emissions and sequestration in forests found in UNESCO World Heritage sites.

World Heritage forests, whose combined area of 69 million hectares is roughly twice the size of Germany, are some of the most biodiversity-rich habitats on Earth and play a crucial role in climate regulation by absorbing carbon dioxide (CO_2) from the atmosphere. However, these forests are under increasing anthropogenic pressures, including climate change.

By combining remote sensing data with site-level monitoring, this report has quantified the climate benefits of World Heritage forests for the first time, assessed the impacts on carbon of common threats to World Heritage forests and identified sites that are net carbon sources. It therefore provides information to facilitate dialogues between policymakers and local stakeholders for the development of effective solutions aimed at maintaining the continuing role of World Heritage forests as sinks and stable carbon stores for future generations.

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