Report

Current Biology

Catastrophic Declines in Wilderness Areas Undermine Global Environment Targets

Highlights

- Globally important wilderness areas are ignored in conservation policy
- We reveal that extensive losses of wilderness have occurred in the last two decades
- Efforts aimed at protecting wilderness areas are failing to keep pace with its loss
- International policy must recognize the actions needed to maintain wilderness areas

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In Brief

Watson et al. discover that the Earth's wilderness areas are disappearing at a rate that has significantly outpaced their protection over the past two decades. Despite their ecological, climatological, and cultural importance, wilderness areas are ignored in multilateral environmental agreements, highlighting the need for urgent global policy attention.

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Report

Catastrophic Declines in Wilderness Areas Undermine Global Environment Targets

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SUMMARY

Humans have altered terrestrial ecosystems for millennia [1], yet wilderness areas still remain as vital refugia where natural ecological and evolutionary processes operate with minimal human disturbance [2–4], underpinning key regional- and planetary-scale functions [5, 6]. Despite the myriad values of wilderness areas—as critical strongholds for endangered biodiversity [7], for carbon storage and sequestration [8], for buffering and regulating local climates [9], and for supporting many of the world's most politically and economically marginalized communities [10]—they are almost entirely ignored in multilateral environmental agreements. This is because they are assumed to be relatively free from threatening processes and therefore are not a priority for conservation efforts [11, 12]. Here we challenge this assertion using new comparable maps of global wilderness following methods established in the original "last of the wild" analysis [13] to examine the change in extent since the early 1990s. We demonstrate alarming losses comprising one-tenth (3.3 million km^2) of global wilderness areas over the last two decades, particularly in the Amazon (30%) and central Africa (14%). We assess increases in the protection of wilderness over the same time frame and show that these efforts are failing to keep pace with the rate of wilderness loss, which is nearly double the rate of protection. Our findings underscore an immediate need for international policies to recognize the vital values of wilderness and the unprecedented threats they face and to underscore urgent large-scale, multifaceted actions needed to maintain them.

RESULTS AND DISCUSSION

Contemporary Wilderness Loss

We mapped decline of wilderness areas, defining "wilderness" as biologically and ecologically largely intact landscapes that are mostly free of human disturbance [2–4, 11]. These areas do not exclude people, as many are in fact critical to certain communities, including indigenous peoples [14, 15]. Rather, they have lower levels of impacts from the kinds of human uses that result in significant biophysical disturbance to natural habitats, such as large-scale land conversion, industrial activity, or infrastructure development. We measured temporal change in wilderness extent by producing a global map of wilderness and assessing it against a spatially comparable map for the early 1990s (Figures 1 and S1). Both maps were devised using the same methodological framework as the original "last of the wild" map published in 2002 [13], but taking advantage of recently available datasets of in situ anthropogenic pressures. Following established practice, we exclude Antarctic and other "rock and ice" and "lake" ecoregions [16, 17].

We discovered that a total of 30.1 million km^2 (or 23.2% of terrestrial areas) of the world's land area now remains as wilderness, with the majority located in North America, North Asia, North Africa, and the Australian continent (Figures 1 and S1). An estimated 3.3 million km^2 has been lost since the early 1990s (approximately a 9.6% loss in two decades; Figure 2), with the most loss occurring in South America (experiencing 29.6% loss) and Africa (experiencing 14% loss).

Encouragingly, the majority of wilderness (82.3%, or 25.2 million km^2) is still composed of large contiguous areas of at least 10,000 km^2. Although this is an arbitrary threshold, wilderness areas of this size are often considered as globally significant wilderness blocks [2, 11]. This is also the size threshold for identifying sites hosting intact ecological communities, adopted in the International Union for Conservation of Nature and Natural Resources (IUCN) standard for Key Biodiversity Areas [18]. Yet there was substantial erosion of these large wilderness areas over the past two decades, with losses amounting to 2.7 million km^2 (Figure 1). A total of 37 of the 350 wilderness blocks that

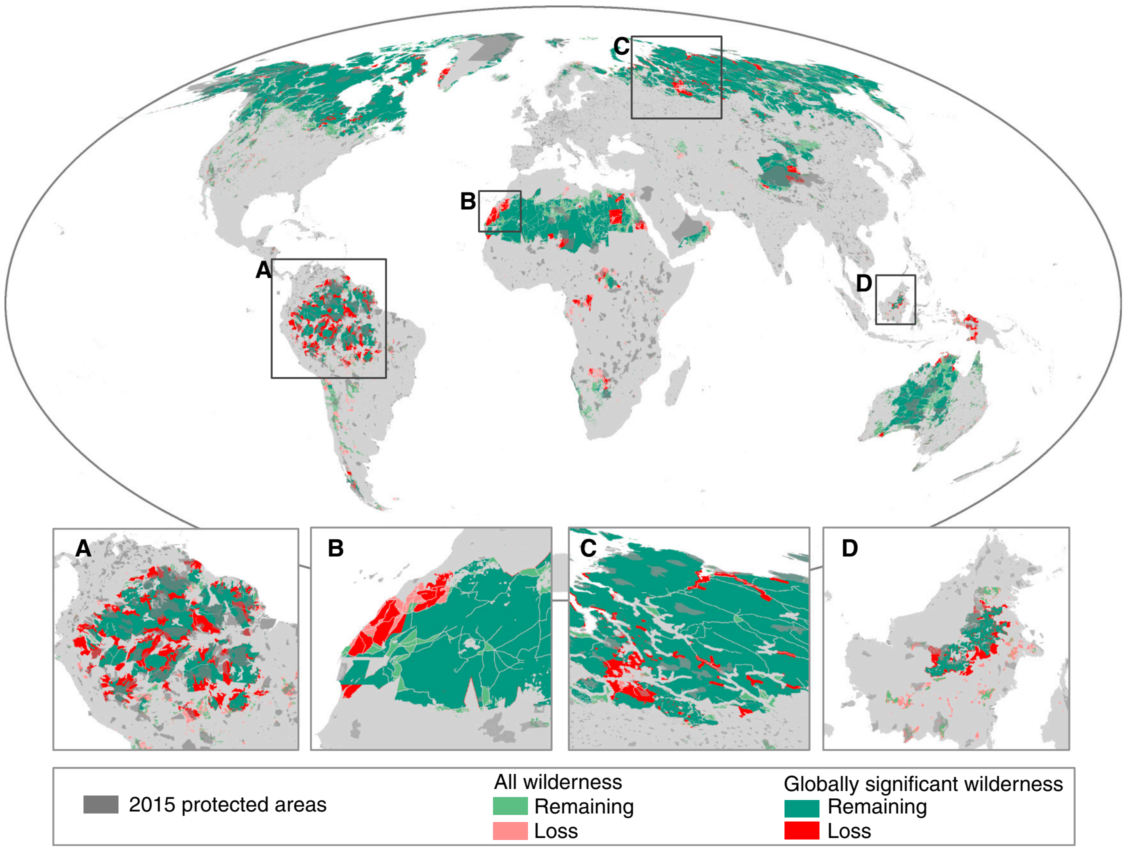

Figure 1. Change in the Distribution of Wilderness and Globally Significant Wilderness Areas since the Early 1990s

Globally significant wilderness areas are defined as wilderness areas >10,000 km^2. The insets are focused on the Amazon (A), the western Sahara (B), the West Siberian taiga (C), and Borneo (D). See also Figures S1 and S2.

were present in the early 1990s have fallen below the area threshold used here for categorization as globally significant, and 74% of all blocks experienced erosion in areal extent. A total of 27 ecoregions (environmentally and ecologically distinct geographic units at the global scale [19]) have lost all of their remaining globally significant wilderness areas since the early 1990s, including those areas in the Northwestern Congolian Lowland Forests and the Northern New Guinea Lowland Rain and Freshwater Swamp Forests ecoregions. South America suffered particularly high losses in the Amazon basin, with the largest wilderness block being reduced from 1.8 million km^2 to 1.3 million km^2 (a loss of over 30% in extent; Figures 1 and S1), and wilderness areas in the Ucayali Moist Forests and Iquitos Varzeá ecoregions dropping below the globally significant threshold. This trajectory of wilderness loss in the Amazon is particularly concerning, given that overall deforestation rates reportedly dropped significantly across the Amazon Basin between 2005–2013 [20].

These recent losses have contributed further to existing biases in the geographical distribution of globally significant wilderness. Of Earth's 14 terrestrial biomes, three located mostly in the tropics (Tropical and Subtropical Coniferous Forests, Mangroves, and Tropical and Subtropical Dry Broadleaf Forests) now have no globally significant wilderness area remaining, with the last areas disappearing from two of these biomes over the last two decades. A further five biomes now have less than 10% wilderness remaining (Figure 2).

Disparity between Wilderness Protection and Loss

Protected areas spearhead global efforts to conserve nature, and when properly managed they are particularly effective for combating the effects of habitat loss and degradation [21]. Since its inception, and through work plans such as the Aichi Targets of The Strategic Plan for Biodiversity 2011–2020 [22], the Convention on Biological Diversity (CBD) has promoted protected areas as a vital conservation mechanism. Consequently, there has been a pronounced expansion of the global protected area estate over the past two decades, with its extent being an almost doubled since the Rio Earth Summit in 1992 [16]. However, despite this growth, the increase in protection of wilderness has lagged significantly behind losses over the past two decades: 2.5 million km^2 of wilderness areas (including 2.1 million km^2 considered globally significant) was newly protected, whereas 3.3 million km^2 (including 2.7 million km^2 considered globally significant) was lost. In some biomes, there has been a stark contrast between the area lost and the amount protected (Figure 2). For example, the Mediterranean Forests, Woodlands, and Scrub biome lost 37% of its globally significant wilderness extent since the early 1990s, yet there was no reciprocal protection of the remaining wilderness areas. Similarly, 23% of the

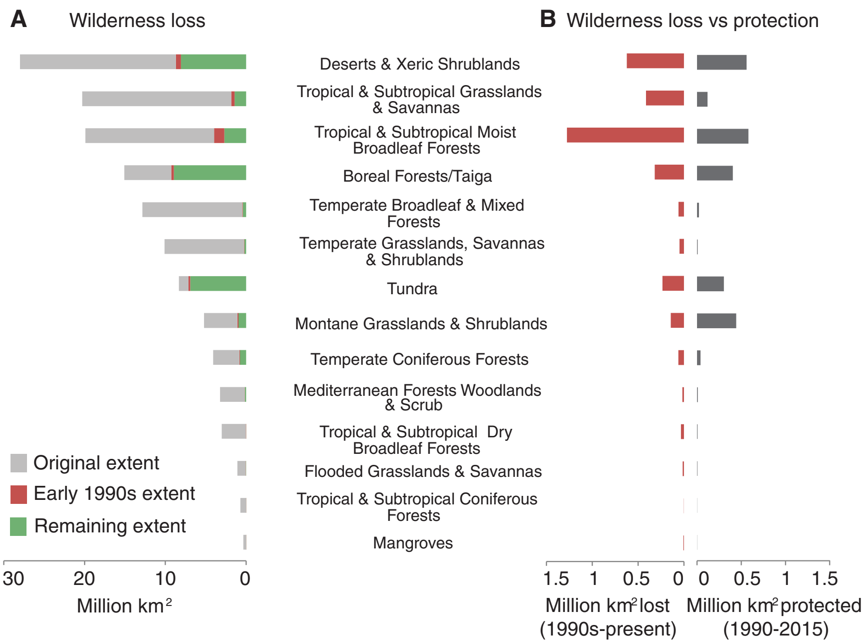

Figure 2. Historic and Current Extent of All Wilderness Area and the Degree to which It Is Protected

(A) Historic (gray) and current (green) extent of all wilderness area, as well as the area lost since the early 1990s (red) across the world's terrestrial biomes.

(B) The wilderness area lost (red) and protected (gray) during 1990–2015.

See also Figure S2.

globally significant wilderness was lost from the Tropical and Subtropical Grasslands, Savannas, and Shrublands, with only 8.5% protected in the last two decades.

Consequences of Continued Wilderness Loss

The current levels of non-protection and consequent loss of wilderness areas across the planet have important ramifications for achieving global climate mitigation goals [8]. For example, the total stock of terrestrial ecosystem carbon (~1,950 petagrams of Carbon [Pg C]) is greater than that of oil (~173 Pg C), gas (~383 Pg C), coal (~446 Pg C), or the atmosphere (~598 Pg C) [23], and a significant proportion of this carbon is found in the globally significant wilderness areas of the tropics and boreal region [8, 24]. It is estimated that 32% of the total global stock of forest biomass carbon is stored in the boreal forest biome [24] and that the Amazon region stores nearly 38% (86.1 Pg C) of the carbon (228.7 Pg C) found above ground in the woody vegetation of tropical America, Africa, and Asia [25]. Thus, avoiding emissions by protecting the globally significant wilderness areas of the boreal and Amazon in particular will make a significant contribution to stabilizing atmospheric concentrations of CO_2. Protection of intact forest ecosystems from industrial land uses is particularly important, given that they store more carbon than degraded forests and are more resilient to external perturbations, including climate variability, fire, and illegal logging, poaching, and mining [8, 26].

Although both the boreal and Amazon have suffered significant forest loss and degradation, these landscapes still support globally significant wilderness areas and are increasingly threatened by industrial forestry, oil and gas exploration, anthropogenic fire, and rapid climate change. If allowed to continue unchecked, these impacts will result in depletion of ecosystem carbon stocks and significant CO_2 emissions, converting the biome into a large carbon source [27]. For example, on Borneo and Sumatra in 1997, human-induced fires burned into recently converted wilderness areas harboring large peat carbon stores, causing the release of over 1 Pg C [28], which is equivalent to about 10% of all annual anthropogenic CO_2 emissions [29].

In terms of biodiversity values, an analysis of the IUCN Red List for terrestrial mammals—one of the taxonomic groups that has been most completely assessed—shows that Earth's remaining wilderness areas also sustain the last strongholds of many imperiled species (see Table S1). The geographic ranges of one-third of all terrestrial mammal species overlap with globally significant wilderness areas, including extensive parts of the distribution of 12% (143) of all threatened mammal species. Thus, ongoing and rapid loss of wilderness increases the risk of extinction for species that are already highly threatened. It is also well established that wilderness areas are critical for wide-ranging and migratory species reliant on intact ecosystems (and their associated ecological processes) and represent residual habitats for disturbance-sensitive species and for those that have a conflictual coexistence with humans, such as many of the world's large carnivores [30].

Wilderness areas also provide benefits derived from their large-scale and self-organization [13], and in many instances they are likely to operate as entire systems, where losses in one area inevitably affect long-term environmental outcomes in another [31–33]. For example, in the Amazon, it is thought that at least 60% of the forest cover is required to maintain the hydrological cycle [34], and so conservation action at the scale of the whole ecosystem is required to ensure that this large wilderness area is maintained. In Australian rangeland and desert ecosystems, the ecological influence of large spatial-scale surface-groundwater hydrological dynamics is pervasive, and losses in one area can degrade habitat quality elsewhere, with significant, long-term implications for biodiversity [35, 36]. In the Anthropocene era, where the human footprint is now altering many of Earth systems processes [37], wilderness areas serve as natural observatories where we can study the ecological and evolutionary impacts of global change. They also serve as natural controls for comparison with areas where intensifying land use and land cover changes are occurring. As intact, large-scale ecosystems become rarer, their value is increasingly appreciated. For instance, we are already seeing growing efforts to "rewild" some human-dominated ecosystems in Europe and North America [38]; remaining

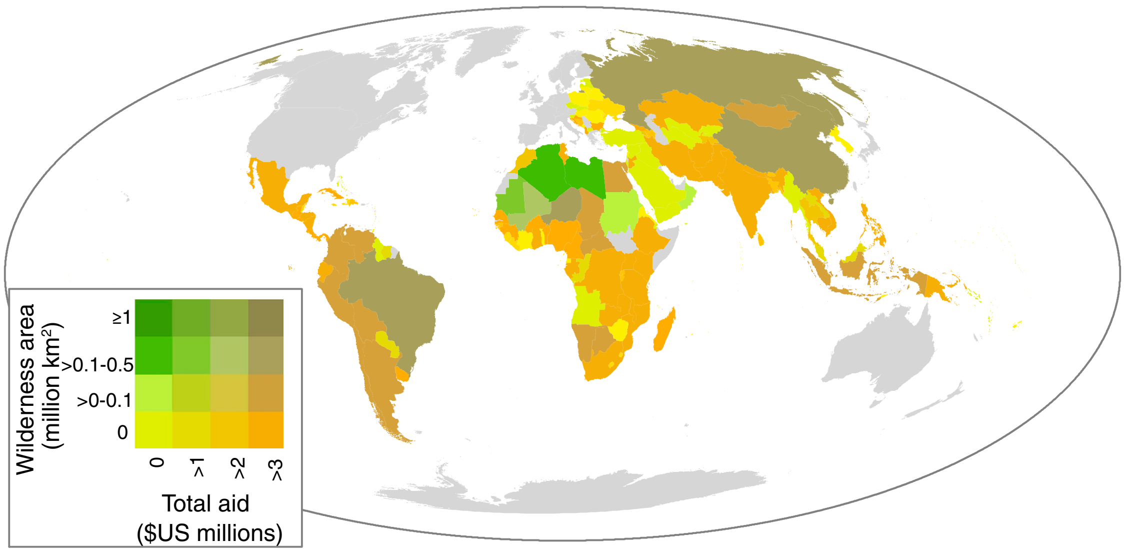

Figure 3. Amount of Conservation Aid and Extent of Wilderness Now Remaining per Country

Amount of conservation aid is shown in millions of US$, and extent of wilderness is shown in million km^2. Gray areas indicate countries that received no aid. See also Figure S3.

wilderness areas provide the reference points and biological feedstock for these initiatives. Without concerted preservation of existing wilderness areas, there will be a diminished capacity for large-scale ecological restoration.

Implications for Multilateral Environmental Agreements

The recent severe loss of wilderness is impacting options for achieving strategic goals outlined in key multilateral environmental agreements, including the CBD's 2020 Aichi Targets and the United Nations Framework on Climate Change (UNFCCC) Paris Agreement [22, 39]. There are a number of reasons why globally significant wilderness areas are ignored in policy deliberations. International definitions of forests have not differentiated between types of forests and in some cases actually treat primary forests, degraded forests, and plantations as equivalent [40]. International polices do not acknowledge the special qualities and benefits that flow from ecosystem processes operating at large scales. For example, there is no formal text within the UNFCCC, United Nations World Heritage Convention (WHC), or CBD that prioritizes or even recognizes the benefits derived from large intact landscapes for nature and people. An emphasis on degraded, fragmented, and altered ecosystems has ramifications for national environmental strategies. The tendency is to focus national biodiversity conservation plans on remnant habitats and endangered populations [3, 41], with few nations clearly articulating conservation goals for wilderness area.

The lack of recognition of wilderness in global accords and national policy also has implications for international funding programs such as the Global Environment Facility, Green Climate Fund, and Critical Ecosystems Partnership Fund, which are distributing billions of dollars in support for programs to help achieve the goals of multilateral environmental agreements. Within the CBD funding mechanisms, for example, 80% of funds have been allocated to nations with <20% of all wilderness area (Figures 3 and S2). The neglect of wilderness is arguably even more acute in funding under the UNFCCC and Paris Agreement finance discussions. Although there is strong financing for forest conservation under the UNFCCC REDD+ mechanism to reduce emissions from deforestation and degradation, the rules stipulate that this financing must target areas with high baseline levels of deforestation [42]. Such efforts, though valuable for other purposes, serve to direct funds away from forested wilderness areas that are presumed safe from deforestation and degradation. As our results demonstrate, however, wilderness is under immense land use pressures, and there is an urgent need for greater conservation effort in these areas to help maintain their ecological intactness and integrity of function.

What would it take to halt the rapid loss of wilderness and of globally significant areas in particular? Achieving meaningful changes in policy at the global level is more likely if there is first a critical mass of support at the national level. Ideally, this should be evidenced through national strategies and plans that recognize the values of wilderness areas and specify policies for their protection. In any case, by creating clear text within operational guidelines, work plans, and ongoing negotiations of key multilateral environmental agreements, international conservation investments can then be mobilized and focused in a manner that can fund activities to help protect wilderness areas. These activities will vary based on the specific context of different nations and regions, but there is a clear need to focus on halting current threatening activities that have been leading to the recent erosion of wilderness areas, including limiting road expansion [43]; preventing industrial mining, forestry, and other large-scale agricultural operations [43]; and enforcing existing legal frameworks considering that half of all tropical forest clearing between 2000 and 2012 was illegal [44–46]. A key goal could be to proactively fund conservation interventions in wilderness areas where degrading activities are currently absent but are projected to occur in the near future.

Conservation actions should include (1) creating large and, where necessary, multi-jurisdictional protected areas; (2) establishing mega-conservation corridors between protected areas; and (3) enabling indigenous communities to establish community conservation reserves [15]. Funding could also be used to establish payments for ecosystem service programs that recognize the direct and indirect economic benefits that wilderness areas provide, such as being a secure source of fresh water, reducing disaster risks, and storing large carbon stocks [9]. There are some encouraging examples where these types of activities are being undertaken. For example, in Brazil, the Amazon Region Protected Areas (ARPA) program supports the creation and management of protected areas and sustainable natural resource management reserves [47]. The overarching aim of these protected areas and reserves is to maintain forest carbon stocks, protect large-scale ecological processes, and establish sustainable use by local peoples. This program is now extending beyond Brazil to Peru and Colombia. The Canadian Boreal Forest Conservation Framework is a similar example, with an overall aim of conserving the long-term integrity of the boreal forest biome by protecting at least 50% of the Boreal in a network of large interconnected protected areas and supporting sustainable communities via ecosystem-based resource management and stewardship practices across the remaining landscape [48].

These positive examples are too few, and we argue that immediate action to protect the world's remaining wilderness areas on a large scale is now necessary, including in global policy platforms. All wilderness areas, regardless of their size threshold, warrant immediate scrutiny for conservation action, especially in regions with low levels of remaining wilderness areas. The continued loss of wilderness areas is a globally significant problem with largely irreversible outcomes for both humans and nature: if these trends continue, there could be no globally significant wilderness areas left in less than a century. Proactively protecting the world's last wilderness areas is a cost-effective conservation investment and our best prospect for ensuring that intact ecosystems and large-scale ecological and evolutionary processes persist for the benefit of future generations.

SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures, three figures, and one table and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2016.08.049.

AUTHOR CONTRIBUTIONS

Conceptualization and Methodology Development, J.E.M.W., D.F.S., M.D.M., J.A., W.F.L., E.S., B.M., and O.V.; Formal Analysis, J.E.M.W., D.F.S., M.D.M., J.A., and O.V.; Writing – Original Draft, J.E.M.W., D.F.S., M.D.M., J.A., O.V., and B.M.; Writing – Review & Editing, J.E.M.W., D.F.S., M.D.M., J.A., W.F.L., E.S., B.M., and O.V.

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REFERENCES

1. Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., and Ludwig, C. (2015). The trajectory of the Anthropocene: the great acceleration. The Anthropocene Review *2*, 81–98.
2. Kormos, C.F., Bertzky, B., Jaeger, T., Shi, Y., Badman, T., Hilty, J.A., Mackey, B.G., Mittermeier, R.A., Locke, H., Osipova, E., et al. (2015). A wilderness approach under the World Heritage Convention. Conserv. Lett. *0*, 1–8.
3. Watson, J.E.M., Fuller, R.A., Watson, A.W.T., Mackey, B.G., Wilson, K.A., Grantham, H.S., Turner, M., Klein, C.J., Carwardine, J., Joseph, L.N., et al. (2009). Wilderness and future conservation priorities in Australia. Divers. Distrib. *15*, 1028–1036.
4. Leslie, R.G., Mackey, B.G., and Preece, K.M. (1998). A computer-based methodology for the survey of wilderness in Australia. Environ. Conserv. *15*, 225–232.
5. Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C.J.A., Laurance, W.F., Lovejoy, T.E., and Sodhi, N.S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. Nature *478*, 378–381.
6. Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D., Lovejoy, T.E., Sexton, J.O., Austin, M.P., Collins, C.D., et al. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. Sci. Adv. *1*, e1500052.
7. Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., et al. (2014). Status and ecological effects of the world's largest carnivores. Science *343*, 1241484.
8. Houghton, R.A., Byers, B., and Nassikas, A.K. (2015). A role for tropical forests in stabilizing atmospheric CO_2. Nat. Clim. Chang. *5*, 1022–1023.
9. Martin, T.G., and Watson, J.E.M. (2016). Intact ecosystems provide best defence against climate change. Nat. Clim. Chang. *6*, 122–124.
10. Mackey, B., and Claudie, D. (2015). Points of contact: integrating traditional and scientific knowledge for biocultural conservation. Environ. Ethics *37*, 341–357.
11. Mittermeier, R.A., Mittermeier, C.G., Brooks, T.M., Pilgrim, J.D., Konstant, W.R., da Fonseca, G.A.B., and Kormos, C. (2003). Wilderness and biodiversity conservation. Proc. Natl. Acad. Sci. USA *100*, 10309–10313.
12. Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., and Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature *403*, 853–858.
13. Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., and Woolmer, G. (2002). The human footprint and the last of the wild. Bioscience *52*, 891–904.
14. Gorenflo, L.J., Romaine, S., Mittermeier, R.A., and Walker-Painemilla, K. (2012). Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. Proc. Natl. Acad. Sci. USA *109*, 8032–8037.
15. Schwartzman, S., Boas, A.V., Ono, K.Y., Fonseca, M.G., Doblas, J., Zimmerman, B., Junqueira, P., Jerozolimski, A., Salazar, M., Junqueira, R.P., and Torres, M. (2013). The natural and social history of the indigenous lands and protected areas corridor of the Xingu River basin. Philos. Trans. R. Soc. Lond. B Biol. Sci. *368*, 20120164.
16. Juffe-Bignoli, D., Burgess, N.D., Bingham, H., Belle, E.M.S., de Lima, M.G., Deguignet, M., Bertzky, B., Milam, A.N., Martinez-Lopez, J., Lewis, E., et al. (2014). Protected Planet Report (UNEP-WCMC).
17. Venter, O., Fuller, R.A., Segan, D.B., Carwardine, J., Brooks, T., Butchart, S.H.M., Di Marco, M., Iwamura, T., Joseph, L., O'Grady, D., et al. (2014). Targeting global protected area expansion for imperiled biodiversity. PLoS Biol. *12*, e1001891.

18. IUCN (2016). A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0, First Edition (IUCN).

19. Olson, D.M., and Dinerstein, E. (2002). The Global 200: priority ecoregions for global conservation. Ann. Mo. Bot. Gard. *89*, 199–224.

20. Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Seroa da Motta, R., et al. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science *344*, 1118–1123.

21. Secretariat of the Convention on Biological Diversity (2008). Protected Areas in Today's World: Their Values and Benefits for the Welfare of the Planet. Technical Series No. 36. https://www.cbd.int/doc/publications/cbd-ts-36-en.pdf.

22. Secretariat of the Convention on Biological Diversity (2011). Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets (Secretariat of the Convention on Biological Diversity).

23. Ciais, P., and Sabine, C. (2013). Carbon and other biogeochemical cycles. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, eds. (Cambridge University Press), pp. 465–570.

24. Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., et al. (2011). A large and persistent carbon sink in the world's forests. Science *333*, 988–993.

25. Walker, W., Baccini, A., Schwartzman, S., Ríos, S., Oliveira-Miranda, M.A., Augusto, C., Ruiz, M.R., Arrasco, C.S., Ricardo, B., Smith, R., et al. (2014). Forest carbon in Amazonia: the unrecognized contribution of indigenous territories and protected natural areas. Carbon Management *5*, 479–485.

26. Thompson, I., Mackey, B., McNulty, S., and Mosseler, A. (2009). Forest Resilience, Biodiversity, and Climate Change. A Synthesis of the Biodiversity/Resilience/Stability Relationship in Forest Ecosystems. Technical Series No. 43. https://www.cbd.int/doc/publications/cbd-ts-43-en.pdf.

27. Bradshaw, C.J.A., Warkentin, I.G., and Sodhi, N.S. (2009). Urgent preservation of boreal carbon stocks and biodiversity. Trends Ecol. Evol. *24*, 541–548.

28. Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.D.V., Jaya, A., and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature *420*, 61–65.

29. Le Quéré, C., Moriarty, R., Andrew, R.M., Canadell, J.G., Sitch, S., Korsbakken, J.I., Friedlingstein, P., Peters, G.P., Andres, R.J., Boden, T.A., et al. (2015). Global Carbon Budget (Global Carbon Project).

30. Crooks, K.R., Burdett, C.L., Theobald, D.M., Rondinini, C., and Boitani, L. (2011). Global patterns of fragmentation and connectivity of mammalian carnivore habitat. Philos. Trans. R. Soc. Lond. B Biol. Sci. *366*, 2642–2651.

31. Peres, C.A. (2005). Why we need megareserves in Amazonia. Conserv. Biol. *19*, 728–733.

32. Laurance, W.F. (2005). When bigger is better: the need for Amazonian mega-reserves. Trends Ecol. Evol. *20*, 645–648.

33. Cochrane, M.A., and Laurance, W.F. (2008). Synergisms among fire, land use, and climate change in the Amazon. Ambio *37*, 522–527.

34. Sampaio, G., Nobre, C.A., Costa, M.H., Satyamurty, P., Soares-Filho, B.S., and Cardoso, M. (2007). Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys. Res. Lett. *34*, L17709.

35. Soulé, M.E., Mackey, B.G., Recher, H.F., Williams, J.E., Woinarski, J.C.Z., Driscoll, D., Dennison, W.G., and Jones, M.E. (2004). The role of connectivity in Australian conservation. Pac. Conserv. Biol. *10*, 266–279.

36. Soulé, M.E., Mackey, B.G., Recher, H.F., Williams, J.E., Woinarski, J.C.Z., Driscoll, D., Dennison, W.G., and Jones, M.E. (2006). The role of connectivity in Australian conservation. In Connectivity Conservation, K. Crooks, and M. Sanjayan, eds. (Cambridge University Press), pp. 649–675.

37. Venter, O., Sanderson, E.W., Magrach, A., Allan, J.R., Beher, J., Jones, K.R., Possingham, H.P., Laurance, W.F., Wood, P., Fekete, B.M., et al. (2016). Sixteen years of change in the global terrestrial Human Footprint and implications for biodiversity conservation. Nat. Commun. *7*, 12558.

38. Navarro, L.M., and Pereira, H.M. (2012). Rewilding abandoned landscapes in Europe. Ecosystems (N. Y.) *15*, 900–912.

39. United Nations (2015). Paris Agreement (United Nations). December 2015. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

40. Mackey, B., DellaSala, D.A., Kormos, C., Lindenmayer, D., Kumpel, N., Zimmerman, B., Hugh, S., Young, V., Foley, S., Arsenis, K., et al. (2015). Policy options for the world's primary forests in multilateral environmental agreements. Conserv. Lett. *8*, 139–147.

41. Ceauşu, S., Gomes, I., and Pereira, H.M. (2015). Conservation planning for biodiversity and wilderness: a real-world example. Environ. Manage. *55*, 1168–1180.

42. Venter, O., and Koh, L.P. (2012). Reducing emissions from deforestation and forest degradation (REDD+): game changer or just another quick fix? Ann. N Y Acad. Sci. *1249*, 137–150.

43. Laurance, W.F., Clements, G.R., Sloan, S., O'Connell, C.S., Mueller, N.D., Goosem, M., Venter, O., Edwards, D.P., Phalan, B., Balmford, A., et al. (2014). A global strategy for road building. Nature *513*, 229–232.

44. Edwards, D.P., Sloan, S., Weng, L.F., Dirks, P., Sayer, J., and Laurance, W.F. (2014). Mining and the African environment. Conserv. Lett. *7*, 302–311.

45. Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F., and Phalan, B. (2008). How will oil palm expansion affect biodiversity? Trends Ecol. Evol. *23*, 538–545.

46. Lawson, S., Blundell, A., Cabarle, B., Basik, N., Jenkins, M., and Canby, K. (2014). Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations. A report for Forest Trade and Finance. September 2014. http://www.forest-trends.org/documents/files/doc_4718.pdf.

47. World Wildlife Fund (2016). Amazon Region Protected Areas Programme http://wwf.panda.org/what_we_do/where_we_work/amazon/vision_amazon/models/amazon_protected_areas/financing/arpa/.

48. Boreal Leadership Council (2003). Canadian Boreal Forest Conservation Framework. http://borealcouncil.ca/wp-content/uploads/2015/03/Framework-2015ENG.pdf.

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Supplemental Information

Catastrophic Declines in Wilderness Areas

Undermine Global Environment Targets

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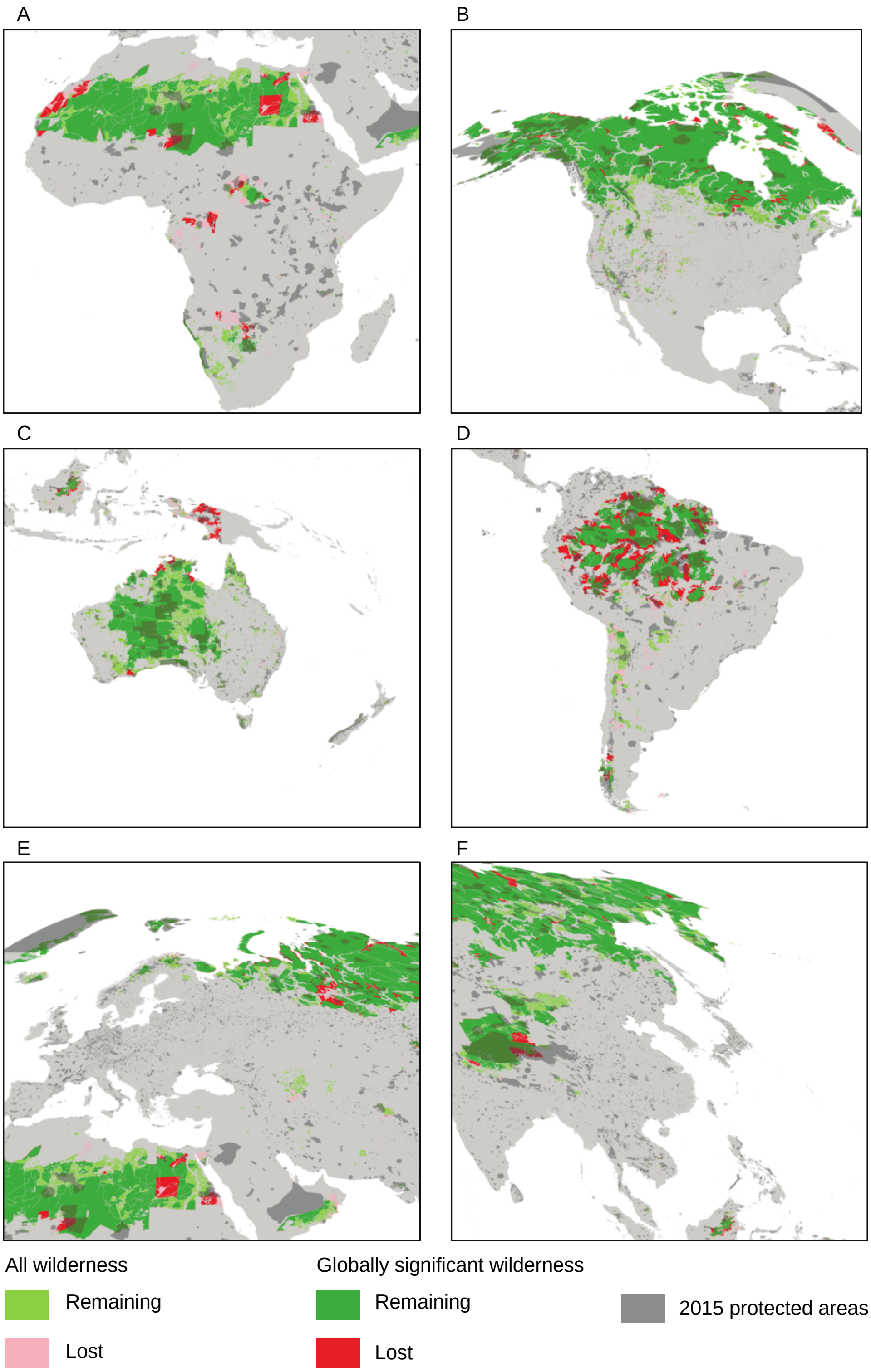

Figure S1. Loss of wilderness and globally significant wilderness since the early 1990s, for A. Africa; B. North America; C; Australasia; D. South America; E. Europe, the Middle East and western Russia; F. Eastern Russia and Asia. This figure relates to Figure 1.

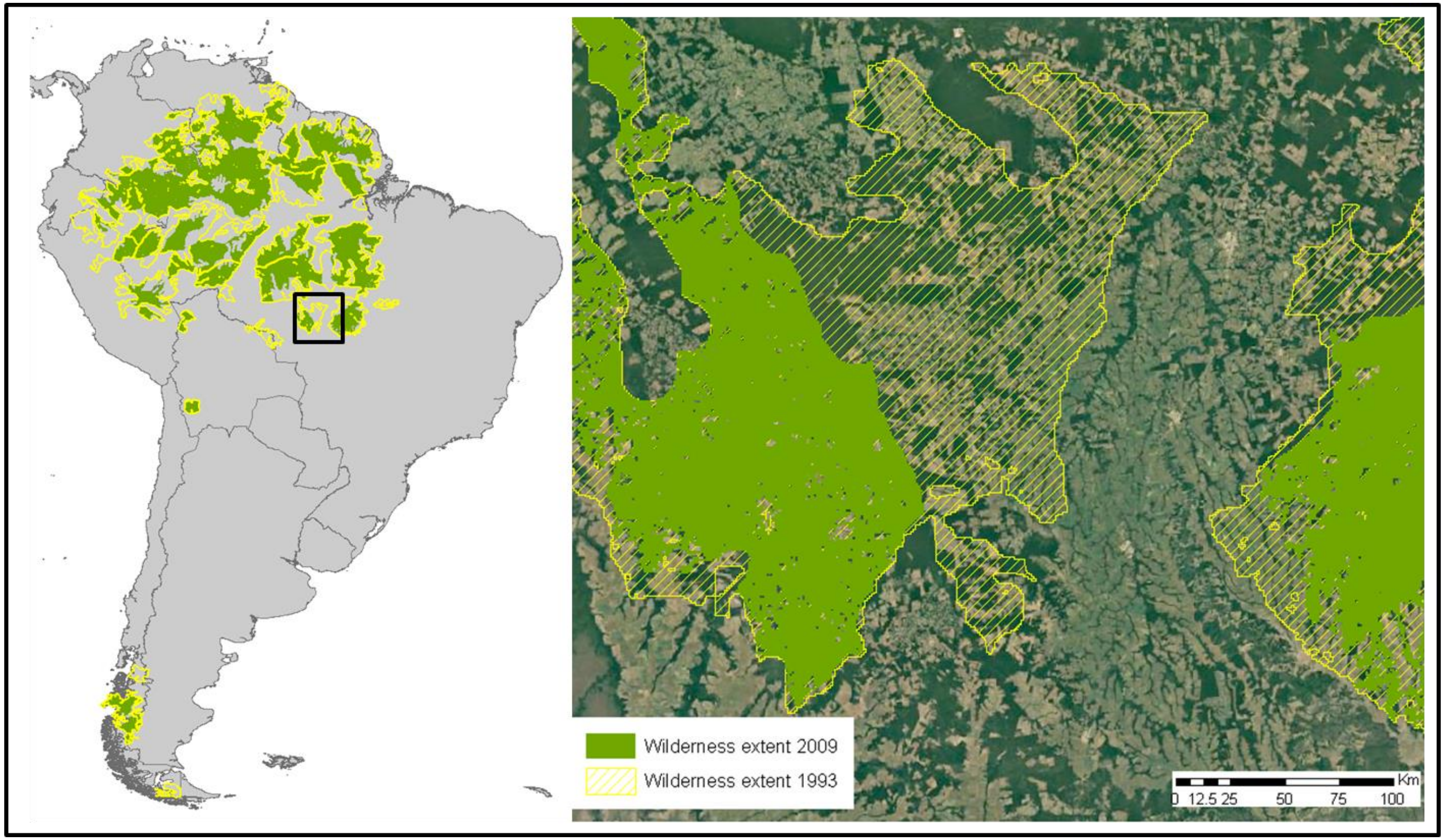

Figure S2. Example of loss of globally significant wilderness in the Amazon between 1993 and 2009. Yellow areas show the extent of wilderness in 1993, whilst the green areas show the wilderness extent remaining in 2009. The underlying image is Google Earth's best available imagery, which was developed from collection of images taken during the years 2012-2015. We can see that completely conversion of wilderness forest to agriculture has occurred across large extents of the central block. In some areas the forest still looks visibly intact, but increasing human population pressure and accessibility have led to these areas having a Human Footprint > 0, or a contiguous area < $10{,}000 km^2$. Therefore they are no longer considered globally significant wilderness areas. This figure relates to Figures 1 and 2.

Table S1. Number of terrestrial mammal species whose distribution overlaps with globally significant wilderness areas. The species are aggregated according to their IUCN Red List category, from high extinction risk to low extinction risk: CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern. The category DD refers to data deficient species, characterized by uncertain extinction risk status (reported here for comparison).

IUCN Red List category	n species	n species in wilderness	% species in wilderness	Average distribution range in wilderness
CR	198	12	6.06%	34.42%
EN	445	35	7.87%	19.94%
VU	476	96	20.17%	16.65%
NT	297	64	21.55%	14.08%
LC	2,996	1,281	42.76%	15.22%
DD	728	107	14.70%	22.86%

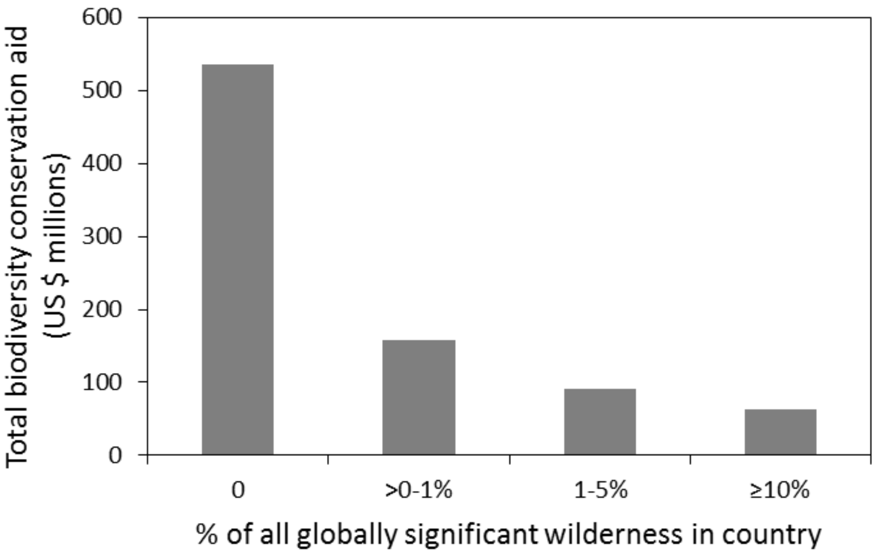

Figure S3. Proportion of biodiversity conservation aid spent in countries with varying proportions of all globally significant wilderness area. This figure relates to figure 3.

Supplemental Experimental Procedures

The analysis described in the main manuscript had four objectives:

1. Quantify the loss of wilderness between two time points (early 1990s to present day);
2. Calculate the increase in protection of wilderness between those time points;
3. Evaluate the extent of threatened mammal ranges overlapping with wilderness;
4. Estimate the proportion of biodiversity conservation aid allocated to countries with varying proportions of all wilderness.

All spatial data described here were processed using ESRI ArcGIS v10 and QGIS (threatened mammal analysis) in Molloweide equal-area projection.

Maps of wilderness were first developed identifying all areas with no measured human impact across the world's terrestrial surfaces for two time points: the early 1990s and present [S1]. We followed a well-accepted definition of wilderness as biologically and ecologically largely intact landscapes where natural ecological and evolutionary processes operate with minimal human disturbance [S2-S5]. We note that these areas are not exclusive of people, but rather of human uses resulting in significant biophysical disturbance to natural habitats, such as large scale land conversion or infrastructure development. As per the 'last of the wild' framework [S6], all terrestrial areas were first assumed to be candidate sites for consideration as wilderness if free of human pressures. We then iteratively used each of eight mapped human pressures on the environment to reject this assumption in places where these pressures were found to exist. These pressures include built environments, intensive agriculture, pasture lands, human population density > 4 people per km^2, night time lights, and the direct and access pressures of roads, railways and navigable waterways, all mapped at 1 km resolution, with the resulting wilderness map also at 1 km^2 resolution. While only places without mapped pressures were considered as wilderness, we note that these areas are not exclusive of people, but rather of human uses likely to result in significant biophysical disturbance. We also identified a subset of 'wilderness areas of global significance' which are characterized by a minimum size of 10,000 km^2 following previous methodologies [S2, S3] and the recently adopted International Union for Conservation of Nature [S7] Key Biodiversity Area Criteria C minimum-size threshold for areas of outstanding ecological integrity. Following established practice [S8, S9] we excluded terrestrial Antarctic ecoregions and ecoregions within the "Rock and Ice" and "Lakes" biomes from all analyses, including the creation of wilderness maps (biomes are described below). This left us with 132 million km^2 of terrestrial areas which were assessed for wilderness extent and values. The subsequent maps are the most complete and highest resolution globally-consistent terrestrial datasets on where humans are exerting pressures on the natural environment, and where these pressures are absent.

<u>Quantifying the loss of wilderness</u>
The wilderness and globally significant wilderness maps were used to estimate overall loss across continents. Furthermore, following previous analyses [S10, S11] loss was also estimated at the scale of biomes (n = 14; large spatial scale) and ecoregions (n = 825; finer spatial scale). These are environmentally and ecologically distinct spatial units at the global scale that are commonly used to guide global conservation activities [S12, S13]. Following the exclusion of terrestrial Antarctic ecoregions and ecoregions within "Rock and Ice" and "Lakes" a total of 792 ecoregions remained across the 14 biomes. Finally, we calculated loses within blocks of globally significant wilderness that were present in the early 1990s, and identified those that are no longer present.

<u>Calculating wilderness protection over time</u>
We estimated the increase in protected area coverage of wilderness and globally significant wilderness between the two time points (1990s to present day). To do this we calculated the protected area increase per year based on the year of protected area establishment recorded in the World Database on Protected Areas [S14]. This date was unknown for 17.7% of terrestrial protected areas, so for these protected areas we followed the methodology set out by Butchart, et al. [S15] to assign a year by calculating the median from 1000 random year selections (with replacement) from all protected areas within the same country with a known date of establishment. For countries with fewer than five protected areas with known year of establishment we carried out this same procedure from all protected areas with known dates. We followed the methods of previous global assessments [S9, S16, S17] and include only protected areas with a national designation (which excludes areas protected only by international agreements), and all protected areas with a status other than "designated". Where only central co-ordinates and total area were available for protected areas (n=11,997), a circular buffer was generated to simulate the spatial extent. Any protected areas that lacked polygonal representation or specified a real extent were excluded from analyses.

The resulting protected area data was overlaid with the present day wilderness maps to quantify the increase in protection of the current extent of wilderness between the two time points, both across the globe and within ecoregions and biomes.

<u>Evaluating the overlap between mammal ranges and wilderness</u>
We measured the overlap between the current geographic distributions of terrestrial mammal species and the current distribution of globally significant wilderness areas. The distribution of mammal species was derived from the geographic range polygons in the IUCN Red List database [S18], which we filtered to only included polygons with origin coded as native or reintroduced, and presence coded as extant, probably extant or possibly extinct [S19].

We analyzed a total of 5,140 extant terrestrial mammal species, with available spatial information on their geographic range. For each species, we measured the total range size and the proportional overlap between the range and the current globally significant wilderness areas. We then associated this information with the species IUCN Red List category, a measure of species extinction risk [S20].

Estimating country-level biodiversity conservation aid and wilderness

We estimated the proportion of biodiversity conservation funding allocated to countries with varying amounts of wilderness within their boundaries. We used a database developed by Waldron, et al. [S21] detailing country-level conservation funding flowing from sources including government, donors, trust funds, and self-funding via user payments (funding years included 2001–2008, in constant 2005 US dollars). We then calculated the current extent of globally significant wilderness within these countries by overlaying the current day wilderness map with the Global Administrative Boundaries layer (2016). We calculated the proportion of aid allocated to countries that cumulatively contain 20% of all globally significant wilderness area.

Supplemental References

S1. Venter, O., Sanderson, E.W.,, Magrache, A., Allan, J.R., Beher, J., Jones, K.R., Possingham, H.P., Laurance, W.F., Wood, P., Fekete, B.M., and Watson, J.E.M. (2016). Changes in the global Human Footprint and implications for biodiversity conservation. Nature Communications. In press.

S2. Kormos, C.F., Bertzky, B., Jaeger, T., Shi, Y., Badman, T., Hilty, J.A., Mackey, B.G., Mittermeier, R.A., Locke, H., Osipova, E., et al. (2015). A Wilderness Approach under the World Heritage Convention. Conservation Letters *0*, 1-8.

S3. Mittermeier, R.A., Mittermeier, C.G., Brooks, T.M., Pilgrim, J.D., Konstant, W.R., da Fonseca, G.A.B., and Kormos, C. (2003). Wilderness and biodiversity conservation. Proceedings of the National Academy of Sciences of the United States of America *100*, 10309-10313.

S4. Watson, J.E.M., Fuller, R.A., Watson, A.W.T., Mackey, B.G., Wilson, K.A., Grantham, H.S., Turner, M., Klein, C.J., Carwardine, J., Joseph, L.N., et al. (2009). Wilderness and future conservation priorities in Australia. Diversity and Distributions *15*, 1028-1036.

S5. Leslie, R.G., Mackey, B.G., and Preece, K.M. (1998). A computer-based methodology for the survey of wilderness in Australia. Environmental Conservation *15*, 225-232.

S6. Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., and Woolmer, G. (2002). The human footprint and the last of the wild. Bioscience *52*, 891-904.

S7. IUCN (2016). A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. First edition. (Gland, Switzerland: IUCN).

S8. Juffe-Bignoli, D., Burgess, N.D., Bingham, H., Belle, E.M.S., de Lima, M.G., Deguignet, M., Bertzky, B., Milam, A.N., Martinez-Lopez, J., Lewis, E., et al. (2014). Protected Planet Report. (Cambridge UK: UNEP-WCMC).

S9. Venter, O., Fuller, R.A., Segan, D.B., Carwardine, J., Brooks, T., Butchart, S.H.M., Di Marco, M., Iwamura, T., Joseph, L., O'Grady, D., et al. (2014). Targeting Global Protected Area Expansion for Imperiled Biodiversity. Plos Biology *12*.

S10. Hoekstra, J.M., Boucher, T.M., Ricketts, T.H., and Roberts, C. (2005). Confronting a biome crisis: global disparities of habitat loss and protection. Ecol. Lett. *8*, 23-29.

S11. Segan, D.B., Murray, K.A., and Watson, J.E.M. (2016). A global assessment of current and future biodiversity vulnerability to habitat loss-climate change interactions. Global Ecology and Conservation *5*, 12-21.

S12. Olson, D.M., and Dinerstein, E. (2002). The Global 200: Priority ecoregions for global conservation. Annals of the Missouri Botanical Garden *89*, 199-224.

S13. Funk, S.M., and Fa, J.E. (2010). Ecoregion Prioritization Suggests an Armoury Not a Silver Bullet for Conservation Planning. PLoS ONE *5*, e8923.

S14. UNEP-WCMC (2015). World Database on Protected Areas (Downloaded June 2015).

S15. Butchart, S.H.M., Scharlemann, J.P.W., Evans, M.I., Quader, S., Aricò, S., Arinaitwe, J., Balman, M., Bennun, L.A., Bertzky, B., Besançon, C., et al. (2012). Protecting Important Sites for Biodiversity Contributes to Meeting Global Conservation Targets. PLoS ONE *7*.

S16. Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., et al. (2004). Effectiveness of the global protected area network in representing species diversity. Nature *428*, 640-643.

S17. Jenkins, C.N., and Joppa, L. (2009). Expansion of the global terrestrial protected area system. Biological Conservation *142*, 2166-2174.

S18. IUCN (2015). The IUCN Red List of Threatened Species. Version 2015.2.

S19. Butchart, S.H.M., Clarke, M., Smith, R.J., Sykes, R.E., Scharlemann, J.P.W., Harfoot, M., Buchanan, G.M., Angulo, A., Balmford, A., Bertzky, B., et al. (2015). Shortfalls and Solutions for Meeting National and Global Conservation Area Targets. Conservation Letters *8*, 329-337.

S20. IUCN (2001). Red List Categories and Criteria, Version 3.1. (Gland, Switzerland: IUCN).

S21. Waldron, A., Mooers, A.O., Miller, D.C., Nibbelink, N., Redding, D., Kuhn, T.S., Roberts, J.T., and Gittleman, J.L. (2013). Targeting global conservation funding to limit immediate biodiversity declines. Proceedings of the National Academy of Sciences of the United States of America *110*, 12144-12148.