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Putting a face on carbon with threatened forest primates

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The Bornean orangutan (*Pongo pygmaeus*) is among the charismatic, threatened primate species that have ranges within regions with high irrecoverable carbon. Framing CO_2 mitigation efforts around efforts to protect such species could help both endeavors. Image credit: Shutterstock/Katesalin Heinio.

In addition to great biodiversity, Earth's forests harbor enormous carbon stocks in soils and aboveground biomass—on the order of 861 Gt, which is equivalent to roughly 87 y of fossil fuel emissions at current rates (1, 2). Moreover, reforestation—a type of nature-based solution—can sequester significant (albeit highly uncertain) amounts of carbon out of the atmosphere, making it a key climate mitigation tool (3). However, conserving existing forests and allowing them to reach their ecological potential may be even more beneficial (4).

In particular, new research by Noon et al. (5) into irrecoverable carbon shows that approximately 139 Gt of forest carbon, if lost today, is unlikely to be recovered in the next 30 y. Thus, protecting irrecoverable carbon is absolutely essential to limiting future warming and avoiding the worst effects of catastrophic climate change (6). Unfortunately, it's increasingly apparent that existing strategies to mitigate tropical deforestation are inadequate (7). We advocate for a new approach that entails greater linkage of carbon mitigation efforts with species conservation campaigns.

Pairing Primates with Carbon

While conserving irrecoverable carbon is certainly a worthwhile goal, associated policies might be most appealing if they can be framed in the context of co-benefits. In particular, we argue that linking irrecoverable carbon in the tropics with threatened primate species could be a helpful framework for four reasons. First, as our closest relatives, non-human primates, such as gorillas (*Gorilla gorilla* and *Gorilla beringei*) and chimpanzees (*Pan troglodytes*), are often considered well-loved and charismatic. Second, 67% of forest primate species (340 of 505) are threatened with extinction

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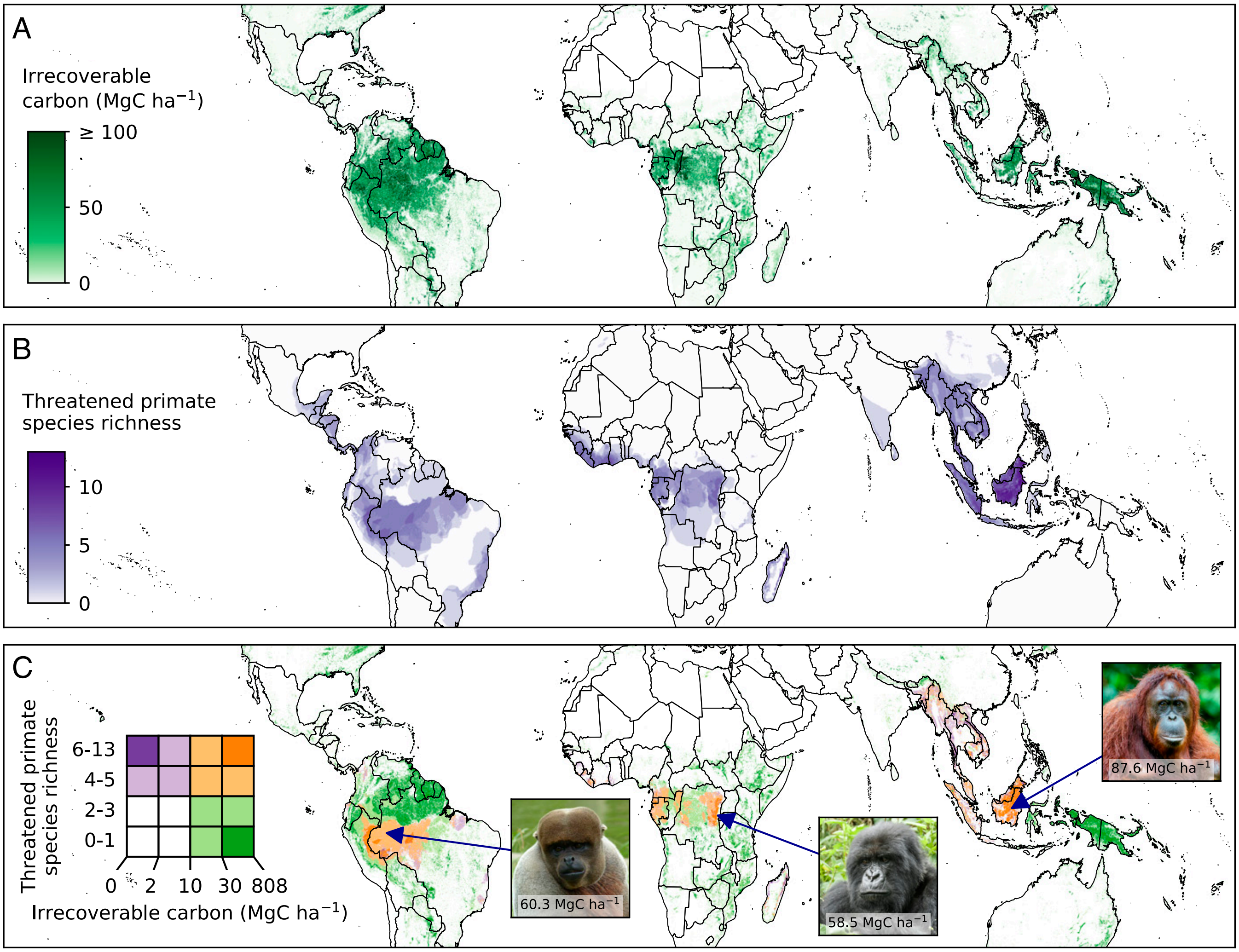

Fig. 1. Carbon-primate alignment: Irrecoverable carbon (*A*) and threatened forest primate species richness (*B*) have considerable overlap in the tropics (*C*). Examples of threatened primate species that have ranges within regions with high irrecoverable carbon include, from left to right, the common woolly monkey (*Lagothrix lagothricha*), the eastern gorilla (*Gorilla beringei*), and the Bornean orangutan (*Pongo pygmaeus*). Mean carbon densities for these three species are shown in the photos. Carbon data: Noon et al. (5); Species range maps: The IUCN Red List of Threatened Species, https://www.iucnredlist.org (10). Image credits (left to right): Shutterstock/guentermanaus, Shutterstock/Alberto Loyo, Shutterstock/Sergey Uryadnikov.

(*SI Appendix*, *SI Methods*), with tropical deforestation being one of the main contributing factors (8). Third, some primates can benefit forest regeneration through the ecological mechanism of seed dispersal (9). Finally, due to their habitat requirements, many primate species' geographic ranges overlap with significant amounts of irrecoverable carbon in the tropics (Fig. 1 and *SI Appendix*). In particular, there are 635,000 km^2 of land with the highest levels of irrecoverable carbon (≥ 30 mgC/ha) and threatened forest primate species richness (≥ 6) [Fig. 1]. This area contains a total of about 15.5 Gt CO_2-eq in irrecoverable carbon—an amount equivalent to roughly 43% of the world's current annual fossil fuel emissions (2). Note that threatened species are those with International Union for Conservation of Nature (IUCN) Red List category Vulnerable, Endangered, or Critically Endangered (10).

Flagship Species and Diverse Communities

Rather than consider primates as a monolithic group, focusing on individual flagship species could be an effective framing. As a case study and model example, the common woolly monkey (*Lagothrix lagothricha*) is a threatened species that lives in the upper Amazon basin in South America. It has substantial irrecoverable carbon reserves across its range (average density: 60.3 MgC/ha), and is an important seed disperser in forests, thereby facilitating forest regeneration and future carbon sequestration (9). Thus, efforts to protect this species may have cascading co-benefits for irrecoverable forest carbon via forest regeneration. In total, 51 threatened primate species across three geographic regions (Fig. 1) have at least 50 MgC/ha average irrecoverable carbon across their ranges, and 146 have at least 25 MgC/ha (*SI Appendix*, Table S1). These 51 primate species have 13.7% of their ranges strictly protected (IUCN categories I-IV), on average (*SI Appendix*). This group includes other potential flagship species such as the eastern gorilla (*Gorilla beringei*), and the Bornean orangutan (*Pongo pygmaeus*), both of which may be negatively impacted by deforestation. Altogether, 24% (n=82) of the 340 threatened forest primate species are Critically Endangered, 42% (n=143) are Endangered, and 34% (n=115) are Vulnerable (*SI Appendix*, Table S1). Furthermore, 99% (n=335) of these species have decreasing population trends (*SI Appendix*, Table S1).

Table 1. Carbon and primate hotspot statistics: The countries shown below have large hotspots (≥ 10,000 km² total area) with high (≥ 10 MgC/ha) irrecoverable carbon density and high (≥ 4) threatened forest primate species richness. The rightmost four columns show, for hotspots only, the total irrecoverable carbon, average irrecoverable carbon density, number of threatened forest primate species, and percentage of land that is strictly protected. Note that hotspots correspond to orange regions in Fig. 1

Continent	Country	Hotspot area (km^2)	C_{total} (Gt)	C_{mean} (Mg/ha)	Species	% Prot.
Africa	Dem. Rep. Congo	439,002	2.30	60.45	19	6.8%
	Gabon	160,988	0.85	56.31	6	2.2%
	Côte d'Ivoire	121,843	0.02	32.54	11	3.3%
	Congo	102,883	1.01	100.52	10	6.0%
	Cameroon	97,294	0.43	51.50	10	11.1%
	Liberia	75,607	0.10	41.06	6	0.0%
	Ghana	53,066	0.01	26.27	7	5.5%
	Sierra Leone	52,529	0.05	116.83	6	1.3%
	Madagascar	45,796	0.13	41.99	94	18.3%
	Equatorial Guinea	21,003	0.11	56.37	10	14.7%
	Guinea	20,068	0.02	90.63	6	1.2%
Asia	Indonesia	863,445	3.35	84.10	43	8.7%
	Malaysia	263,641	1.12	73.00	22	11.5%
	Myanmar	227,065	0.51	39.69	20	6.8%
	Thailand	204,527	0.13	40.96	17	14.4%
	Vietnam	105,172	0.12	31.04	21	5.1%
	Cambodia	75,017	0.15	39.87	12	37.0%
	India	73,295	0.13	34.20	7	0.2%
	Laos	72,131	0.16	32.95	17	5.1%
	China	44,448	0.10	46.10	13	0.0%
	Bangladesh	13,176	0.01	23.29	7	5.2%
South America	Brazil	1,431,419	8.29	67.14	39	8.5%
	Peru	252,046	1.63	65.81	16	12.9%
	Colombia	60,749	0.18	63.05	26	10.5%
	Bolivia	27,100	0.11	43.84	11	0.0%
	Ecuador	10,140	0.03	48.21	10	0.7%

In addition to possible flagship species, high irrecoverable carbon regions have extensive overlap with large and diverse primate communities, especially in the Amazon, the Congo rainforest, and Borneo (Fig. 1*C*). For example, 19 threatened forest primate species reside in Borneo alone, including the Critically Endangered Bornean banded langur (*Presbytis chrysomelas*). In total, significant irrecoverable carbon (≥ 10 MgC/ha) and primate species richness (≥ 4) hotspots occur in 26 countries on 3 continents (South America: 5, Africa: 11, Asia: 10) (Table 1). Despite their conservation and climate mitigation value, the hotspot areas in these countries are just 7.6% protected, on average (Table 1). Thus, efforts are needed to identify primate communities within these hotspots and educate the public and policymakers about their ecological effects and conservation status, thereby shifting attention from single species to entire communities.

Strategic Implications

The effectiveness of linking irrecoverable carbon and forest primates as a conservation and climate mitigation strategy will depend on specific policy implementation details. For example, certain primate species may be especially charismatic and have ranges that are closely aligned with irrecoverable forest carbon. Sustainable ecotourism could provide funding to simultaneously protect these primates and irrecoverable carbon. Any policies designed with co-benefits in mind need to account for local conditions and help support Indigenous populations and overall human wellbeing and sustainability. For example, socially just strategies to restrict the spread of palm oil plantations may be particularly effective in Borneo, a major hotspot for irrecoverable carbon, threatened primates, and many other forms of biodiversity (11). Beyond that, several general policy options could be investigated. REDD+ (reducing emissions from deforestation and forest degradation, and enhancing carbon stocks) is an approach that integrates forest carbon and biodiversity protection, but funding to date has been limited and greater local participation is needed (12). A potential REDD+ subprogram targeted toward irrecoverable carbon and associated threatened primates might be sufficiently compelling to bolster concern, funding, and participation rates in halting deforestation. As a potentially simpler option, irrecoverable carbon and primate alignment can help inform future reserve design, placement, and monitoring—even in areas where current deforestation pressure is still relatively low. Regardless, further research into the ecological effects of little-studied primate species is essential to any combined primate conservation and climate mitigation policy.

Admittedly, pairing irrecoverable carbon and primates as an overarching framework has several caveats. First, primates often face several threats in addition to deforestation and habitat loss, including hunting and trapping by humans and disease transmission (8). While protecting their habitats and the associated irrecoverable carbon stocks can help to mitigate many of these threats, other primate conservation measures are badly needed. Second, primates make up only a single taxonomic order, and are heavily concentrated in the tropics. Thus, efforts are needed to assess overlap between irrecoverable carbon and species in other taxonomic groups, especially in temperate regions. Lastly, effectively combining irrecoverable carbon and biodiversity protection will require extensive cross-disciplinary collaboration, not only among forest and wildlife ecologists, but also involving climate scientists, Indigenous communities, social scientists, and a diversity of other groups. This collaboration should be rooted in social justice and an understanding of how tropical deforestation and species endangerment are often driven by wealthy countries' demands for resources, including wood products, palm oil, and livestock feed (13).

Climate change and the biodiversity crisis are some of the greatest threats faced by life on our planet. Massive climate action cannot be accomplished by treating climate change as a standalone problem (14). Integrating climate mitigation and biodiversity protection by putting a tangible face on carbon has far greater mitigation potential and ability to attract support among the public and policy makers than trying to tackle climate change in isolation. Additionally, the possible benefits to biodiversity are vast, both from intrinsic value and ecosystem services perspectives. Specific biodiversity-related co-benefits can include clean air and water, tourism-related opportunities for local communities, and cultural benefits. While 'irrecoverable' carbon could take many decades to be restored, species extinctions may be permanent. Pairing irrecoverable carbon and irrecoverable species may be a winning strategy to motivate the transformative change that is so desperately needed.

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1. Y. Pan *et al.*, A large and persistent carbon sink in the world's forests. *Science* **333**, 988–993 (2011).
2. P. Friedlingstein *et al.*, Global carbon budget 2021. *Earth Syst. Sci. Data Discuss.* **2021**, 1–191 (2021).
3. J.-F. Bastin *et al.*, The global tree restoration potential. *Science* **365**, 76–79 (2019).
4. W. R. Moomaw, S. A. Masino, E. K. Faison, Intact forests in the United States: Proforestation mitigates climate change and serves the greatest good. *Front. For. Glob. Change* **2**, 27 (2019).
5. M. L. Noon *et al.*, Mapping the irrecoverable carbon in Earth's ecosystems. *Nat. Sustain.* **5**, 37–46 (2022).
6. IPCC, "Climate change 2022: Impacts, adaptation, and vulnerability" in *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, H.-O. Pörtner *et al.*, Eds. (Cambridge University Press, 2022).
7. Y. Feng *et al.*, Doubling of annual forest carbon loss over the tropics during the early twenty-first century. *Nat. Sustain.* **5**, 444–451 (2022).
8. D. Fernández *et al.*, The current status of the world's primates: Mapping threats to understand priorities for primate conservation. *Int. J. Primatol.* **43**, 15–39 (2022).
9. P. R. Stevenson, M. C. Castellanos, J. C. Pizarro, M. Garavito, Effects of seed dispersal by three ateline monkey species on seed germination at Tinigua National Park, Colombia. *Int. J. Primatol.* **23**, 1187–1204 (2002).
10. IUCN, The IUCN Red List of Threatened Species (Version 2021-3, 2021), 27 November 2021.
11. M. de Bruyn *et al.*, Borneo and Indochina are major evolutionary hotspots for Southeast Asian biodiversity. *Syst. Biol.* **63**, 879–901 (2014).
12. A. E. Duchelle, G. Simonet, W. D. Sunderlin, S. Wunder, What is REDD+ achieving on the ground? *Curr. Opin. Environ. Sustain.* **32**, 134–140 (2018).
13. N. T. Hoang, K. Kanemoto, Mapping the deforestation footprint of nations reveals growing threat to tropical forests. *Nat. Ecol. Evol.* **5**, 845–853 (2021).
14. W. J. Ripple *et al.*, World scientists' warning of a climate emergency 2021. *Bioscience* **71**, 894–898 (2021).