Forest Carbon in Amazonia: The Unrecognized Contribution of Indigenous Territories and Protected Natural Areas

A *Policy Focus* submission to *Carbon Management*

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Abstract

Carbon sequestration is a widely-acknowledged and increasingly-valued function of tropical forest ecosystems; however, until recently the information needed to assess the carbon storage capacity of Amazonian Indigenous Territories (ITs) and Protected Natural Areas (PNAs) in a global context remained either lacking or out of reach. Here, as part of a novel north-south collaboration among Amazonian indigenous and NGO networks, scientists, and policy experts, we show that the nine-nation network of nearly 3,000 ITs and PNAs stores more carbon above ground than all of the Democratic Republic of the Congo and Indonesia combined, and despite the ostensibly secure status of these cornerstones of Amazon conservation, a conservative risk assessment considering only ongoing and planned development projects puts nearly 20% of this carbon at risk, encompassing an area of tropical forest larger than Colombia, Peru, and Ecuador combined. International recognition of and renewed investment in these globally vital landscapes are therefore critical to ensuring their continued contribution to maintaining cultural identity, ecosystem integrity, and climate stability.

Key Terms

Amazonia: The most commonly referenced boundaries of the Amazon region are (a) biophysical, related to hydrography, topography, and/or vegetation and (b) administrative as recognized by the various nations for the application of protection and/or development policies. The limit of Amazonia used here (Figure 1) consists primarily of a biogeographical boundary of the Amazon ecosystem with exceptions for Ecuador and Brazil where add itional legal and administrative criteria are applied.

Indigenous Territories: Lands of the 385 indigenous peoples living in Amazonia, which include officially recognized areas of traditional use and occupation, as well as traditionally used and occupied areas lacking official recognition and territorial reserves or intangible zones set aside for peoples living in isolation.

Protected Natural Areas: Lands having official conservation status including (a) *Indirect Use* areas where natural resource extraction is prohibited, (b) *Direct Use* areas where extraction is permitted under management plans, and (c) areas of *Transitory (or mixed) Use*.

Aboveground Forest Carbon Density: The total amount of carbon contained above ground in the woody biomass of live vegetation. Forests contain more carbon above ground than nonforests but there can be considerable spatial variability in carbon density (e.g., megagrams of carbon per hectare) within a given forest type.

More than half (52%; 4.1 million km^2) of *Amazonia's* tropical ecosystems are contained within an extensive network of 2,344 *Indigenous Territories* (ITs) and 610 *Protected Natural Areas* (PNAs) spanning nine South American nations (Figure 1). These cornerstones of Amazon conservation are widely recognized for their exceptional biological, cultural, and linguistic diversity [1–3], and serve as both social and natural barriers to frontier expansion and fire [4–6]. In countries like Brazil, where deforestation has been high historically, they are also viewed as central to strategies designed to avoid atmospheric carbon emissions stemming from deforestation and forest degradation [7]. Carbon sequestration is an often-acknowledged service provided by tropical forest ecosystems worldwide, and while it is generally understood that the amount of carbon stored above ground in Amazonia is significant, until recently the information needed to quantify the contribution of Amazonian ITs and PNAs to carbon storage at the global scale remained either lacking or out of reach. A novel collaboration among scientists, Pan-Amazonian indigenous and NGO networks, and policy experts has linked newly compiled spatial data sets on pantropical *aboveground forest carbon density* [8], Amazonian ITs and PNAs, and risks to their integrity from current pressures and/or near-term threats [9]. Our analysis suggests that the carbon stored across these ostensibly secure landscapes is of a magnitude not previously appreciated in global terms, and is sufficient to either destabilize or contribute to the stabilization of the planet's atmosphere depending on the collective impact of ongoing and planned development projects. In this century alone, more than 253,000 km^2 of Amazonian rainforest – an area the size of the United Kingdom – have been lost [10] as a result of increasing pressures linked to climate change, agriculture expansion, road and hydroelectric plant construction, and the extraction of timber, fossil fuels, and precious metals [9,11]. During this same period, indigenous land rights and environmental regulation of forest land use, while largely unimplemented in some countries, have alternately advanced and come under political attack and could be compromised further under increasing demands for agricultural and energy commodities. The Government of Ecuador's signing of permits that allow for long-contested oil drilling to commence in Yasuni National Park – a UNESCO biosphere reserve containing pristine forests and uncontacted indigenous tribes – is a recent, however unexceptional, example of the very real and present risks to global culture, conservation, and climate facing landscapes commonly perceived as being out of harm's way [12].

Carbon Storage in Indigenous Territories and Protected Natural Areas

Amazonian indigenous leaders, cognizant of discussions centered on the role of tropical forests in international climate negotiations, called for an analysis to better understand the contribution of ITs and PNAs to global carbon storage, one increasingly acknowledged ecosystem function among the wide range of cultural and environmental services indigenous lands are recognized to provide. The investigation was an outgrowth of broader indigenous interests focused on building political, technical, and institutional competencies around the complexity of issues at the intersection of international climate change policy, sustainable economic development, and indigenous territorial rights. Indigenous organizations and communities actively participated in the process of data gathering and interpretation.

The results of the analysis reveal that the Amazonian region stores nearly 38% (86,121 MtC; Figure 1) of the 228,700 MtC found above ground in the woody vegetation of tropical America, Africa, and Asia [8]. By themselves, Amazonian ITs are responsible for storing nearly one third

(32.8%) of the region's aboveground carbon (28,247 MtC; Table S1) on roughly 30% (2.4 million km^2; Table S2) of the land area. This result is noteworthy when considering that more carbon is stored in Amazonian ITs than is found in all of the forests of the Democratic Republic of the Congo (DRC; 22,128 MtC) or the Republic of Indonesia (18,851 MtC) (Table S1), two countries where considerable international attention and investment is now being directed toward the long-term protection of these large yet vulnerable expanses of remaining tropical forest. The analysis was conducted by combining a pantropical dataset of aboveground carbon density derived from a novel combination of field and satellite measurements [8] with the most comprehensive database of IT and PNA limits available for the nine-nation region [see supporting online material (SOM)]. Expanding the scope of the analysis to include not only the aboveground carbon stocks of Amazonian ITs but also those of PNAs, we find that well over half (55%; 47,363 MtC; Figure 1) of the region's carbon is contained within this multi-nation network of forest-dominated landscapes. Remarkably, this is more carbon than is stored above ground in all of the DRC and Indonesia combined (40,979 MtC; Table S1) and, by recent accounts, sufficient to irreversibly alter continental-scale rainfall and climate regimes if released [13].

Assessing Pressures and Threats

While there is little debate about the impending risks to the Amazonian forest estate, its carbon stores, or any of the broad range of ecosystem services the region's forests provide at local to global scales, forecasting the likely areal extent of these risks across such an economically and politically diverse landscape is not without its inherent uncertainty. Here we performed a conservative yet spatially explicit risk assessment focused on the carbon currently stored above ground in Amazonian ITs and PNAs (Figure 1, SOM). Areas directly impacted by current (i.e., active and ongoing) development across primary production and infrastructure sectors, i.e., agriculture, grazing, mining, petroleum, timber, and transportation, were classified as *under pressure*, while areas likely to be impacted in the near term by projects or concessions described in current government and/or development agency planning documents were characterized as *under threat* [9]. Risk (i.e., pressure and/or threat) was then quantified based on the overlap with, and/or relative proximity to, current or planned development activities (SOM).

Our analysis indicates that more than half (53%) of the Amazonian region by area (i.e., approximately 4.2 million km^2) is at risk from either current pressures (65%) or near-term threats (35%; Figure 1, Table S3). In total, this vast expanse of at-risk land – equal to half the size of Brazil – is currently responsible for storing nearly 46% (39,743 MtC) of Amazonian aboveground carbon, which is more carbon than is stored above ground in all of Russia (32,500 MtC) or more than twice that stored in the United States (19,308 MtC) (Table S1). Approximately 43% of this at-risk carbon, or 17,017 MtC, an amount equivalent to 90% of the aboveground carbon stock of Indonesia, is contained within the borders of Amazonian ITs and PNAs, lands that are commonly assumed to be all but free from risk if only by virtue of their protected status. In fact, a remarkably large proportion of the land contained within Amazonian ITs and PNAs is at risk including 40% (794,030 km^2) of ITs, 30% (514,879 km^2) of PNAs, and 24% (90,280 km^2) of regions where the two overlap (Table S3). In total, the combined area of ITs and PNAs under either pressure or threat constitutes 18% (1.4 million km^2) of Amazonia, an area larger than Colombia, Ecuador, and Peru combined (Table S2).

This assessment was designed to be intentionally conservative where risks to IT and PNA carbon stocks are concerned insofar as it does not attempt to quantify illegal extractive activities or future deforestation threats (legal or illegal). For example, the analysis does not consider the loss of forest that predictably follows planned road construction or improvement and the expanded access to the forest interior that naturally accompanies such infrastructure development. Historically, the majority of Amazon infrastructure development and associated official government investment has been geopolitically motivated rather than economically driven [14]. Because the analysis was limited to development activities that were either active or planned, the results are likely to more accurately reflect investments – and the accompanying risks – stemming from geopolitical decision-making, which might otherwise be unaccounted for by more theoretically-based economic models.

Amazonian Protected Lands and Forest/Climate Policy

Tropical deforestation continued unabated globally over the period 2000–2012, increasing by approximately 2,100 km^2 yr^{-1}, notwithstanding Brazil's recent successes in curtailing large-scale forest losses [10]. The results of recent modeling efforts suggest that halting tropical deforestation, which accounts for 6-17% of global anthropogenic CO_2 emissions to the atmosphere [15], when combined with substantial reductions in emissions from fossil fuels and other sectors, would increase to 65% the probability of maintaining global warming below the UNFCCC target of 2° C above pre-industrial levels [16]. Given the enormous amount of carbon stored in Amazonian ITs and PNAs alone, maintaining the ecological integrity of these landscapes is a critical albeit insufficient step toward reducing emissions of CO_2 from land use change.

Recent research emphasizes that stemming the tide of large-scale tropical forest loss will depend on increasing the agricultural yield on existing farmland and degraded areas [17,18]. However, most estimates of the costs of reducing deforestation focus on opportunity costs of forgone agriculture production and omit the costs of not only maintaining ITs and PNAs [19], but also of creating the necessary sustainable development opportunities for their indigenous populations (Table S4). While corporate commitments to "zero deforestation" commodity supply chains together with multi-stakeholder processes such as The Consumer Goods Forum and commodity roundtables (e.g., Roundtable for Sustainable Palm Oil, Roundtable for Responsible Soy, Global Roundtable for Sustainable Beef, and Brazilian Roundtable on Sustainable Livestock) may reduce deforestation pressures on some forest landscapes, ITs and PNAs are not directly linked to commodity supply chains and these efforts will not, by themselves, achieve the development goals of indigenous and forest dwelling peoples, or provide for the effective implementation and maintenance of conservation areas. It follows that specific policies and investments in support of effective forest protection, sustainable development pathways for the populations that inhabit ITs and PNAs, and equitable valuation of their social and environmental services, are fundamental to realizing robust, large-scale reductions in emissions from land use change. In short, strategies – and national and international funding initiatives – for large-scale forest conservation need to include actions and investments on both sides of the agricultural frontier. While our analysis has focused on Amazonia, this conclusion is relevant to Indonesia as well, particularly in light of the widespread presence of indigenous peoples in its remaining forests as well as the extensive literature documenting the centrality of local community control over land and resources for sustainable management practices in the region [20].

The sheer scale of Amazonian ITs and PNAs, the forests they contain, and the carbon they store, combined with the substantial risks posed by present and near-future development, suggests that basin-wide incentives to upwardly harmonize and implement indigenous land and resource rights, together with forest protection and sustainable use policies, are justified on the basis of the climate benefits alone, but would also produce multiple social, cultural, and ecological co-benefits. Given that nearly 14% of the carbon stored above ground in Amazonian ITs is contained within territories lacking official government recognition, legally recognizing these territories as well as settling private land claims in PNAs is, by any measure, an urgent priority. While management systems for territories under indigenous control vary considerably across the region, they tend to be closely adapted to, and based on extensive knowledge of, local ecosystems. As a result, indigenous territorial management practices contribute directly to the development and maintenance of ecosystem composition, structure, and function [21–23]. Although the maintenance of forest carbon stocks in ITs cannot be attributed to indigenous management per se, the inextricable relationship between Amazonian indigenous cultural identity and tropical forest ecosystems, including their flora and fauna, forms the basis of indigenous peoples' ongoing political struggle for recognition of their land and resource rights and the extant indigenous territories. Whereas indigenous management systems have proved largely sustainable at least since the colonial era, they will require new technologies, capacities – and political alliances – in order to successfully meet the development challenges and market pressures of the 21st century. In recent years, indigenous peoples and their civil society supporters have had considerable success in incorporating social safeguards into existing and proposed guidelines for REDD+ [24–26], and Peru's inclusion of indigenous land titling and community forestry governance in its National Investment Plan for the Forest Investment Partnership financing offers a template for ongoing indigenous territorial rights discussions basin-wide.

Given the recognized potential of ITs and PNAs to limit or prevent deforestation and forest degradation [7], while at the same time acknowledging the widespread near-term risk to their forests, the indigenous and traditional communities that inhabit many of them, and the vast stocks of carbon they contain, bilateral and multilateral donors should devote a significant portion of capacity building and "payment for performance" funding to a comprehensive, integrated strategy for the protection and sustainable development of these landscapes. Amazonian nations that officially recognize indigenous territorial and resource rights, invest in sustainable livelihoods for forest peoples, develop and implement national protected area management plans and participatory national policies for indigenous territorial management (i.e., akin to Brazil's National Program for Environmental Management of Indigenous Lands; PNGATI), and commit national funds to match international donor investments, should be allowed to count some proportion of their IT and PNA carbon stocks toward post-2020 emissions reductions targets under the UNFCCC, and should be preferentially eligible for both REDD+ and climate adaptation financing. These resources should be complemented by infrastructure compensation funds, fines for environmental infractions, and government investment in monitoring and law enforcement.

Estimates of the costs of protecting Amazonian ITs and PNAs while developing sustainable economic development alternatives for local communities are inherently uncertain, and merit further research and analysis. However, a conservative approximation of the costs – likely on the order of $2-4 billion – required to create and consolidate ITs and PNAs, while at the same time establishing endowments to support fixed recurring costs, including administrative and monitoring operations, are easily within the scale of bilateral and multilateral funding presently committed to reducing deforestation (Table S5). Indigenous territories and inhabited PNAs also need budgetary outlays for social services such as healthcare and education. Ultimately, the sustainability of ITs and PNAs will depend on the strength and stability of the economies surrounding them. While a basin-wide transition to sustainable economic development pathways for rural and urban economies is likely to come at a significantly higher cost, it could also generate correspondingly higher benefits over time [13]. Bilateral and multilateral donor funds, philanthropy, private carbon finance, infrastructure development compensation and impact mitigation funds, as well as fines for environmental infractions, are all potential sources of financing.

Future Perspective

Previous attempts to predict the broad impacts of development on tropical forest cover, CO_2 emissions trajectories, and lands with conservation status have been either characterized by high uncertainties in the absence of consistent and accurate region-wide estimates of carbon density or restricted geographically (e.g., to the Brazilian Amazon) in the absence of a comprehensive basin-wide database of spatially explicit IT and PNA limits [7]. Efforts to model the potential feedbacks among climate change, fire, and forest loss while evaluating the probability of future large-scale Amazon drought and forest dieback have similarly been hampered by uncertainties surrounding the availability of data such as those compiled here [27]. Despite the uncertainty surrounding the mid- to long-term impacts of climate change on the Amazon, including changing regional temperature and precipitation regimes, releasing the carbon currently at risk in Amazon ITs alone – equivalent to clearing all of Peru's forests – would increase the probability of Amazon dieback [28], with deleterious and potentially irreversible effects on the atmosphere and the planet.

At the 2013 UNFCCC Climate Change Conference, 19th Conference of the Parties (COP 19), countries agreed to the Warsaw Framework for REDD+, establishing the principles and guidelines necessary for REDD+ to become operational (Decisions 9-16/COP 19). At the 2014 conference (COP 20) in Lima, Peru, negotiators are expected to agree that significant REDD+ financing should be part of the international climate change treaty scheduled for ratification at COP 21 in Paris, France. Some $8.5 billion in bilateral and multilateral funding has already been committed to REDD+ with only a fraction allocated to ITs and PNAs (Table S5) [29]. Policies to address climate change, including efforts to measure and monitor forest loss and associated carbon emissions, will inevitably continue to be national and subnational prerogatives, and consequently forest protection and sustainable development programs will be designed and implemented, as current policy frameworks mandate, at national and subnational levels. However, the global importance of Amazonian ITs and PNAs, not only to the planet's atmosphere, but also in consideration of the broad range of social and ecological benefits they provide, merits international recognition through the UNFCCC as well as large-scale, integrated investment in these landscapes and the people who inhabit them. While ITs and PNAs provide numerous environmental and social services with multiple material and immaterial values that extend well beyond carbon, these landscapes are of critical global importance on the basis of their carbon stocks alone and the role they necessarily have to play in maintaining the stability of the planet's climate.

Executive Summary

Background

- More than half of Amazonia (52%; ~4.1 million km^2) is contained within a network of 2,954 Indigenous Territories (ITs) and Protected Natural Areas (PNAs) spanning nine nations.

- These landscapes provide numerous environmental and social benefits of global importance including climate stabilization through forest carbon sequestration.

Carbon Storage in Indigenous Territories and Protected Natural Areas

- More carbon is stored above ground in Amazonian ITs than is stored in all the forests of the Democratic Republic of Congo (DRC).

- Amazonian ITs and PNAs store more than half (55%) of the region's aboveground carbon, which is more carbon than is stored above ground in all of the DRC and Indonesia combined.

Assessing Pressures and Threats

- More than half of the Amazonian region (53%; ~4.2 million km^2) is at risk from either current pressures or near-term threats associated with growth in the agriculture, grazing, mining, petroleum, timber, and transportation sectors.

- Approximately 43% of this at-risk carbon, an amount equivalent to 90% of the aboveground carbon stock of Indonesia, is contained within the ostensibly secure borders of Amazonian ITs and PNAs.

- The combined area of ITs and PNAs at risk constitutes 18% (~1.4 million km^2) of Amazonia, an area larger than Colombia, Ecuador, and Peru combined.

Amazonian Protected Lands and Forest/Climate Policy

- Nearly 14% of the carbon stored above ground in Amazonian ITs is contained within territories lacking official recognition; obtaining legal recognition for ITs and settling private land claims in PNAs are urgent priorities.

- The costs of creating and consolidating ITs and PNAs and establishing endowments to support administrative operations and monitoring is conservatively estimated at $2-4 billion, a sum well within the scale of present international commitments to reducing deforestation.

- Amazon nations that commit to protect and make social and economic investments in ITs and PNAs should be allowed to count some proportion of their IT and PNA carbon stocks toward post-2020 emissions reductions targets under the UNFCCC.

- The sustainability of ITs and PNAs will depend on the strength and stability of their surrounding economies necessitating a basin-wide transition to sustainable rural and urban economic development pathways.

- Given the carbon stored in Amazonian ITs and PNAs alone, international recognition of and renewed investment in maintaining the ecological integrity of these landscapes are critical to reducing emissions of CO_2 from land use change.

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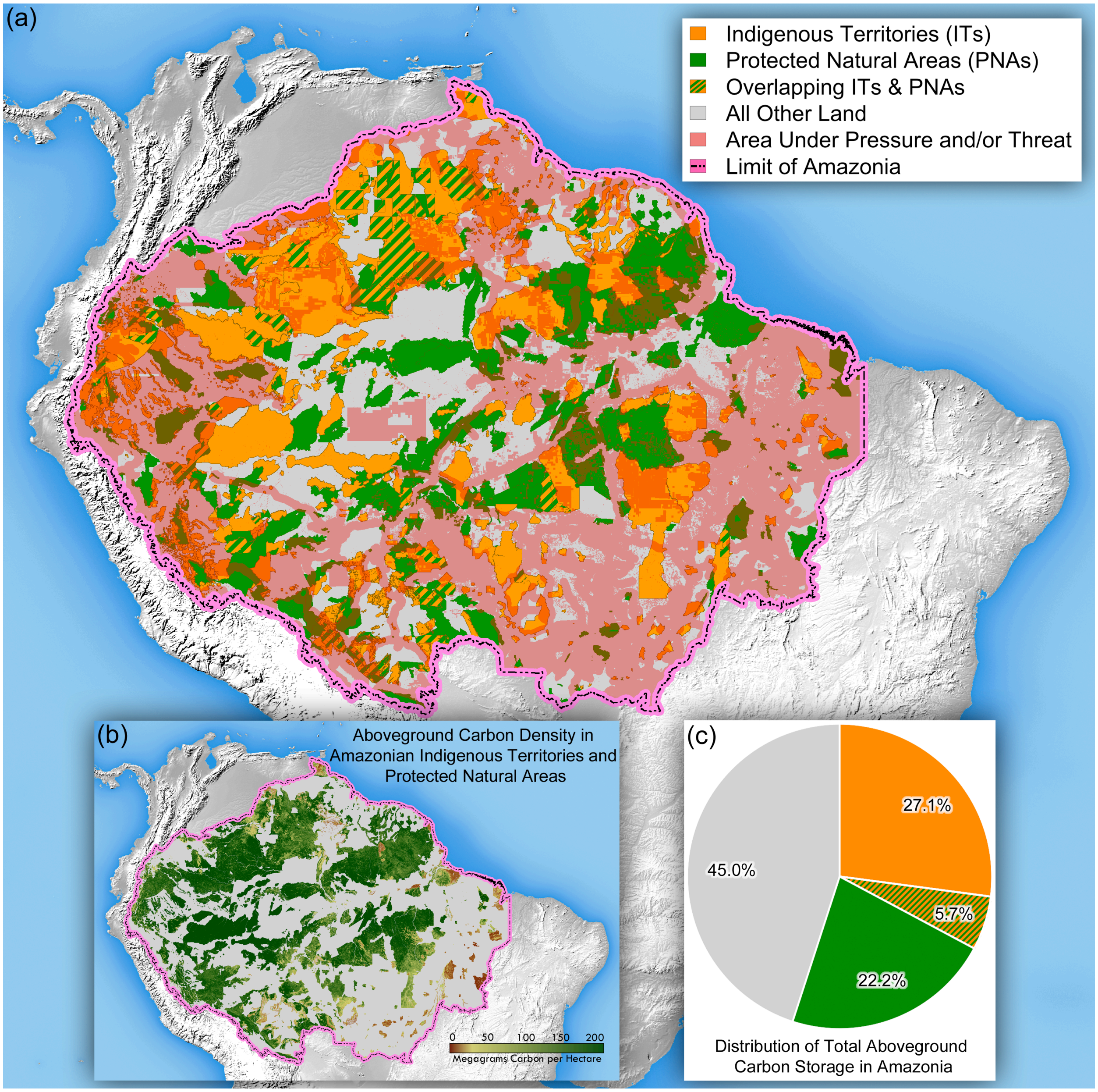

Figure 1. (a) Risks (i.e., current pressures and near-term threats; Table S3) to the distribution of (b) carbon stored above ground in the woody biomass of Amazonian tropical forests (c) as a percentage of the basin-wide total (i.e., 86,120 million metric tons; MtC): Indigenous Territories – 23,380 MtC (27.1%), Protected Natural Areas – 19,116 MtC (22.2%), areas of overlapping ITs and PNAs – 4,867 MtC (5.7%), and all other land – 39,376 MtC (45.0%) (Table S1).

Supplementary Information:

- Materials and Methods
- Tables S1-S5
- References

Carbon Storage in Indigenous Territories and Protected Natural Areas

Materials and Methods

The limit of the Amazon region referenced in Figure 1 of the main manuscript, and on which the analysis is based, consists primarily of the biogeographical boundary of the Amazon ecosystem [1] (www.raisg.socioambiental.org) with exceptions for Ecuador and Brazil where additional legal and administrative criteria are applied. The boundaries of indigenous territories (ITs) and protected natural areas (PNAs) were compiled by RAISG's member organizations from a range of government and non-government sources [1]. Because these boundaries change over time, the database, which is maintained for each country by the member organizations, is subject to periodic updates as new information is obtained.

The map of carbon stock was produced by the Woods Hole Research Center using an approach based on information acquired by Earth observation satellites [2]. The approach resulted in a continuous (i.e., wall-to-wall) estimate of the amount and distribution of carbon stored aboveground in the live woody biomass of vegetation across tropical America, Africa, and Asia for the period 2007-2008 at a resolution of circa 500 meters. The data set was generated using field measurements co-located with satellite-based Light Detection And Ranging (LiDAR) observations from the NASA Geoscience Laser Altimeter System (GLAS) together with a cloud-free temporal mosaic generated from NASA Moderate Resolution Imaging Spectrometer (MODIS) and Nadir Adjusted Reflectance (NBAR) data [2].

Country boundaries were derived following adjustments to national borders based on geographic considerations. Such adjustments were necessary to address, in an unbiased fashion, the coarse nature of existing boundary databases as well as ongoing boundary disputes between some countries. As a result, the limits used here cannot be considered strictly official. Together, the four data layers were analyzed in a geographic information system (GIS; ArcGIS 10.2) using a raster-based approach. The political-administrative layers were used as a basis for quantifying the amount and distribution of carbon contained within the various IT and PNA units across the Amazonia. Regions of IT and PNA overlap were analyzed separately from all other ITs and PNAs (Figure 1c). Additionally, ITs legally recognized by national governments were differentiated from those lacking legal recognition and PNAs characterized by direct use were distinguished from indirect and mixed use.

Results

The following tables include the complete results of the carbon storage analysis summarized in the main manuscript.

Table S1: Total aboveground woody carbon (millions of metric tons) distributed across the nine-nation Amazonian region (RAISG limit; Figure 1). Totals for six additional tropical (Democratic Republic of the Congo, Indonesia), temperate/boreal (United States, Russia) and austral (Australia, Chile) countries are included for reference.

	Amazonia (RAISG)					
Country	Protected Natural Areas†	Indigenous Territories†	PNA/IT Overlap†	All Other†	Total††	National Total
Bolivia	1,082	862	568	2,756	4,982	7,960
	(21.7)	(17.3)	(11.4)	(49.6)	(62.6)	
Brazil	13,592	13,401	1,023	23,679	51,695	65,240
	(26.3)	(25.9)	(2.0)	(45.8)	(79.2)	
Colombia	852	3,191	476	1,794	6,313	10,164
	(13.5)	(50.6)	(7.5)	(28.4)	(62.1)	
Ecuador	196	728	262	225	1,412	2,039
	(13.9)	(51.6)	(18.6)	(15.9)	(69.2)	
French Guiana	471	10	91	587	1,158	1,158
	(40.6)	(0.8)	(7.8)	(50.7)	(100.0)	
Guyana	123	338	13	2,098	2,572	2,572
	(4.8)	(13.1)	(0.5)	(81.6)	(100.0)	
Peru	2,349	2,537	458	5,873	10,884	11,564
	(21.6)	(23.9)	(4.2)	(50.9)	(94.1)	
Suriname	172	666	99	961	1,899	1,899
	(9.1)	(35.1)	(5.2)	(50.6)	(100.0)	
Venezuela	279	1,648	1,878	1,403	5,207	7,065
	(5.4)	(31.6)	(36.1)	(26.9)	(73.7)	
Total	19,116	23,380	4,867	39,376	86,121	109,660
	(22.2)	(27.1)	(5.7)	(45.0)	(78.5)	
Russia§						32,500
D.R. Congo§§						22,128
United States§						19,308
Indonesia§§						18,851
Australia§						6,641
Chile§						1,349

† Values in parentheses reflect the percentage of total carbon by country in each category relative to the Amazonian total for the country.

†† Values in parentheses reflect the percentage of total carbon by country in Amazonia relative to the total for the country.

§ FAO Global Forest Resources Assessment 2010. FAO Forestry Paper 163.

§§ Baccini et al. 2012.

Table S2: Total area (thousands of square kilometers) by category across the nine-nation Amazonian region (RAISG limit; Figure 1). Totals for six additional tropical (Democratic Republic of the Congo, Indonesia), temperate/boreal (United States, Russia) and austral (Australia, Chile) countries are included for reference[1].

	Amazonia (RAISG)					
Country	Protected Natural Areas†	Indigenous Territories†	PNA/IT Overlap†	All Other†	Total††	National Total
Bolivia	134	121	44	181	480	1,089
	(27.8)	(25.1)	(9.3)	(37.8)	(44.1)	
Brazil	1,178	1,115	81	2,660	5,035	8,547
	(23.4)	(22.1)	(1.6)	(52.8)	(58.9)	
Colombia	94	257	32	100	484	1,143
	(19.5)	(53.1)	(6.6)	(20.8)	(42.3)	
Ecuador	20	57	20	18	114	251
	(17.6)	(49.7)	(17.2)	(15.5)	(45.4)	
French Guiana	40	7	6	30	84	84
	(47.8)	(8.5)	(7.6)	(36.2)	(100.0)	
Guyana	10	32	1	168	210	210
	(4.9)	(15.0)	(0.5)	(79.6)	(100.0)	
Peru	185	200	29	374	788	1,297
	(23.4)	(25.4)	(3.7)	(47.4)	(60.8)	
Suriname	22	57	7	60	147	147
	(15.1)	(38.8)	(5.0)	(41.0)	(100.0)	
Venezuela	21	157	150	141	469	916
	(4.5)	(33.4)	(32.0)	(30.1)	(51.2)	
Total	1,704	2,002	372	3,733	7,811	13,684
	(21.8)	(25.6)	(4.8)	(52.2)	(78.5)	
Russia§						17,098
United States§						9,827
Australia§						7,741
D.R. Congo§						2,345
Indonesia§						1,905
Chile§						756

† Values in parentheses reflect the percentage of total area by country in each category relative to the Amazonian total for the country.

†† Values in parentheses reflect the percentage of total area by country in Amazonia relative to the total for the country.

§ The World Factbook (https://www.cia.gov/library/publications/the-world-factbook/). Accessed 6 July 2014.

Assessing Pressures and Threats

Data Layers

The risk to carbon stored aboveground in Amazonian ITs and PNAs was assessed in terms of (a) *pressures* associated with current (i.e., active and ongoing) development across primary production and infrastructure sectors and (b) *threats* associated with areas likely to be impacted in the near term by projects or concessions described in current government and/or development agency planning documents. Data on pressures and threats were represented using a suite of spatially explicit GIS layers that included transportation systems, oil and gas exploration, mineral extraction, and deforestation. A brief summary of each input data layer follows. The analysis builds on previous work presented in [1], where additional information on data and methods can be found.

Transportation

A georeferenced layer of primary paved, non-paved, and planned/projected roads and highways was compiled for each country from a range of government and non-government sources to identify and characterize the pattern and distribution of the transportation system across the nine-nation region. Roads in the process of being paved and those for which information was incomplete were treated as non-paved. Due to differences in the level of information available for each country, trails (i.e., "trochas"), as well as service roads within protected areas were excluded from the analysis. All roads were then buffered by 20 km as a means of approximating the extent of their influence on the surrounding landscapes and classified as either a source of *pressure* (paved and unpaved roads) or *threat* (planned/projected roads).

Oil and Gas

A georeferenced layer of oil and gas concessions was compiled for each country from secondary sources. Concessions were identified as being one of four types depending on their phase of development: potential (areas with possible reserves), permitting (areas for which administrative permits are pending), exploration (areas of active prospecting), and exploitation (active oil and gas extraction). Areas less than 9 ha in size were not included in the analysis. All remaining concessions were then classified as either a source of *pressure* (exploitation) or *threat* (potential, permitting, or exploration).

Mining

A georeferenced layer containing information on legal mining activities was compiled from official government data (data on illegal mining was not included) for each country, systematized, and categorized based on the phase of mining activity: potential (areas with possible reserves), permitting process (areas for which administrative permits are pending), exploration (areas of active prospecting), and exploitation (active mineral extraction). In Peru and parts of Ecuador it was not possible to differentiate the exploration and exploitation phases of mining activity. In these cases, the activity was labeled as exploration/exploitation.

Due to differences in data quality across sources, it was necessary to implement a series of quality control steps (i.e., topological corrections) prior to the spatial analysis. As a result, there may be minor differences between the results as presented here and the number of mining areas reported by individual countries. To prevent duplication and overestimation of the area covered by mining activities, concessions overlapping one another and in the same phase of activity were considered only once. Furthermore, mining areas less than 5 ha in size were not included in the analysis. All remaining concessions were then classified as either a source of *pressure* (exploitation or exploration/exploitation) or *threat* (potential, permitting, or exploration).

Deforestation

Two sources of information were used to produce a georeferenced layer that captured the pattern and distribution of deforestation impacts across Amazonia:

1. For the Andean Amazon region (Colombia, Ecuador, Peru, and Bolivia) and the Guianas (Venezuela, Guyana, Suriname, and French Guiana), preliminary data from a RAISG-led analysis were used. The analysis spanned the periods 2000-2005 and 2005-2010 and was derived from a spectral mixture analysis followed by classification using a decision tree algorithm.
2. For the Brazilian Amazon, deforestation data was obtained from the PRODES (Monitoring of the Brazilian Amazon Forest by Satellite) project. Published by INPE (National Institute for Space Research) in 2011, the data covered the period 2000-2010. For consistency, these data were reprocessed so as to reflect the same time periods (i.e., 2000-2005/2005-2010) available for the Andean Amazon and the Guianas.

In both instances, the year 2000 was used as baseline (base map) with subsequent deforestation through 2010 treated as a source of *pressure*. No data on deforestation *threats* were considered in the analysis.

Methods

A single spatial data layer, called *Pressures*, was obtained by overlapping the various *pressure* layers (i.e., transportation, oil and gas, mining, and deforestation). The output was converted from vector to raster format using the carbon stock grid of [2] as a spatial reference. Similarly, a second spatial data layer, called *Threats*, was obtained by overlapping the various *threat* layers (i.e., transportation, oil and gas, and mining) followed also by a vector-to-raster conversion. The amount and distribution of carbon was estimated for areas under (a) pressure, (b) threat, and (c) pressure and threat (i.e., total carbon at risk), where regions of overlap were counted only once. All spatial analyses were conducted using ArcGIS 10.2.

Results

The following tables include the complete results of the risk analysis summarized in the main manuscript.

Table S3a: Total carbon, total carbon under pressure, total carbon under threat, and the sum of carbon under pressure and threat (i.e., total carbon at risk) (millions of metric tons) by category for Amazonian (RAISG limit; Figure 1). Values in parentheses reflect the percentage of carbon in each category relative to the total carbon in Amazonia.

Category	Total Carbon†	Carbon Under Pressure†	Carbon Under Threat†	Total Carbon At Risk
PNAs	19,116	2,475	3,684	6,159
	(22.2)	(2.9)	(4.3)	(7.2)
ITs	23,380	3,131	6,549	9,680
	(27.1)	(3.6)	(7.6)	(11.2)
PNA/IT Overlap	4,867	466	712	1,178
	(5.7)	(0.5)	(0.8)	(1.4)
Total Protected	47,363	6,072	10,944	17,017
	(55.0)	(7.0)	(12.7)	(19.8)
All Other	38,758	13,739	8,988	22,727
	(45.0)	(16.0)	(10.4)	(26.3)
Total Amazonia	86,121	19,811	19,932	39,743
	(100)	(23.0)	(23.1)	(46.1)

Table S3b: Total area, total area under pressure, total area under threat, and the sum of the area under pressure and threat (i.e., total area at risk; thousands of square Kilometers) by category for Amazonian (RAISG limit; Figure 1). Values in parentheses reflect the percentage of area in each category relative to the total area of Amazonia.

Category	Total Area†	Area Under Pressure†	Area Under Threat†	Total Area At Risk
PNAs	1,704	257	258	515
	(21.8)	(3.3)	(3.3)	(6.6)
ITs	2,002	319	475	794
	(25.6)	(4.1)	(6.1)	(10.2)
PNA/IT Overlap	372	41	49	90
	(4.8)	(0.5)	(0.6)	(1.1)
Total Protected	4,078	617	783	1,399
	(52.2)	(7.9)	(10.0)	(17.9)
All Other	3,733	2,081	686	2,767
	(47.8)	(26.6)	(8.8)	(35.4)
Total Amazonia	7,811	2,697	1,469	4,166
	(100)	(34.5)	(18.8)	(53.3)

Climate Policy and Amazonian Protected Lands

The Future of Protection and Sustainability

Both ITs and PNAs have been shown to be effective barriers to frontier expansion and deforestation in Brazil [3-5], and have thus both contributed to the substantial reductions in greenhouse gas emissions observed for Brazil over the last decade [6]. Indigenous peoples have, in this sense, made a major, although largely unrecognized, contribution to combating climate change. However, it is important to emphasize that there is no justification for assuming that this contribution will continue into the future as though it were a natural consequence of indigenous occupation. While Amazon indigenous peoples generally value forests and forest resources highly, and have historically mobilized effectively to prevent outsiders from gaining access to, or control of, their forest estates, indigenous cultures and economies are not now and never were (as a cursory view of Amazon archeology attests) static. With few exceptions, indigenous peoples want access to modern technology and to markets, and face poor economic options. There are numerous examples of indigenous leaders or communities allowing unsustainable logging or mining in their territories in exchange for payment, particularly in the absence of more sustainable economic opportunities. The future ecological sustainability of Amazon ITs will thus depend on building a shared environmental agenda, including sustainable economic alternatives, with indigenous peoples – a goal that is central to most of the member organizations of the Amazon Geo-referenced Socio-Environmental Information Network (RAISG) and the Coordinator of the Indigenous Organizations of the Amazon Basin (COICA). At the same time, it is also important to note that the future sustainability of PNAs can, for several reasons, no more be taken for granted than can that of ITs. First, many PNAs are little more than "paper parks," prominently featured on official maps but lacking infrastructure or support and owing much of their protection to their current remoteness. Present-day inaccessibility is no guarantee of future ecological integrity under business-as-usual development trajectories. Second, the vast majority of PNAs, particularly those in the Brazilian Amazon, regardless of legal category (sustainable use vs. strict protection), are inhabited and thus face development challenges similar to ITs. In short, future forest protection and sustainability are not givens for either ITs or PNAs.

Costs of Maintaining ITs and PNAs

Estimates of the costs of effectively protecting and sustainably developing Amazon ITs and PNAs vary widely depending on the scale and timeframe addressed as well as assumptions about protection and development needs. Most estimates consider only the costs of establishing PNAs and maintaining them over time, while the few that contemplate ITs are relatively superficial. Nepstad et al. (2009) estimated that between \$3.6 and \$7.4 billion over ten years would be needed to allow indigenous peoples and family farmers to move to sustainable production systems in the Brazilian Amazon [7], but this estimate conflates the typically very different realities of indigenous and farming communities.

A recent analysis of PNAs in Pará State, Brazil, suggests that most of the state's PNAs are "paper parks" that were legally created but lack the investments in infrastructure and personnel needed for effective implementation [8]. Based on the analysis, \$54 million over four years would be needed to consolidate the 21 million ha of existing PNAs or a cost of approximately \$257 per km^2. If, as [8] maintains, the situation in Pará mirrors the rest of the Amazon, then some \$437 million could consolidate the whole of Amazonian PNAs.

As part of the Amazon Region Protected Areas (ARPA) program[1], the Brazilian government together with the World Bank and WWF invested roughly $81.5 million in the creation and consolidation of a 60.7 million ha network of strict protection and sustainable use areas, or a cost of approximately $134 per km². An investment at this level extrapolated to the scale of PNAs basin wide would require an investment of $228 million. ARPA also aims to create a $220 million endowment fund to protect these areas in perpetuity or a cost of about $362 per km². Applying this same rate basin wide, a $615 million endowment would provide support for all Amazonian PNAs.

The costs of creating the bases for the long term sustainability of Amazonian ITs cannot simply be extrapolated from estimates for PNAs, since very different social, cultural, and economic conditions exist across the nine-nation region, not to mention the differences in the needs and aspirations of very diverse populations (this also applies to the traditional populations resident in nearly all PNAs in the Brazilian Amazon and elsewhere). Brazil, for example, allocated R$ 1 billion from the federal budget for indigenous health in 2014, in addition to another R$ 1.2 billion for "protection and promotion of indigenous rights"[2]. The effectiveness of these investments is difficult to evaluate. Nevertheless, assuming that half of these funds were spent in the Brazilian Amazon, where roughly half of the national indigenous population resides, the investment would be approximately $500 per km². A rough estimate of the cost of maintaining Amazon ITs assumes that they would require initial as well as longer-term investments in territorial monitoring and capacity building similar to those for PNAs, in addition to budgetary outlays for health care and education on the order of the Brazilian federal budget. On this basis, Amazon ITs would require an initial investment of between $280 and $540 million, a long-term endowment of $760 million, and a budgetary allocation for social services on the order of $1.05 billion annually for a total of approximately $2.3 billion in initial investment, including consolidation and endowment funds, plus approximately 1 billion dollars per year thereafter (half of which Brazil already allocates in the federal budget). Even if a better-grounded estimate were to demonstrate that twice this amount was more realistic, initial investment and endowment funds would still be only about half of the $8.5 billion in bilateral and multilateral funds committed to REDD+ thus far.

Another approach to estimating the costs of sustaining ITs and PNAs is suggested by the Acre (Brazil) state government's investment in building a sustainable forest-based economy over the last 16 years. The government estimates it has invested about R$15 billion over the last 16 years on actions in both rural and urban areas in support of its sustainable development program[3]. As a result, the state has succeeded in reducing deforestation by about 75% since 2006 while at the same time increasing agricultural and cattle production, raising GDP, and improving social indicators. Currently about 47% of the state consists of ITs and state and federal PNAs. Since the long-term integrity of ITs and PNAs depends in some measure on the standard of living and economic opportunities for rural and urban populations outside of their borders, Acre's investments could be taken as an indication of the broader costs of transitioning to a sustainable economy, including creation and protection of ITs and PNAs. Based on the Acre example, some

[1] http://www.worldbank.org/projects/P058503/amazon-region-protected-areas-gef?lang=en
[2] http://www.contasabertas.com.br/website/arquivos/7607
[3] Alberto Tavares, President Acre Environmental Services Development Company (CDSA), personal communication, May 24, 2014.

$22 billion per year over more than a decade would be needed to scale Acre's experience to the whole of the Amazon basin.

Additional Information

The following tables include further information cited in the main text on sources of forest finance and costs of ending deforestation.

Table S4: Costs of ending deforestation

Time Frame	Reduction in Deforestation	Emission Reductions	Cost per unit $USD	Annual Cost $USD	Method	Source
2005-2030	10% (global net)	0.3-0.6 Gt CO^2 yr^{-1}	$2-$5 $^{t-1}$ CO_2	$0.4-$1.7 billion	*Ex-post* compensation reductions via predefined national baselines	[9]
	50% (global net)	1.5-2.7 Gt CO^2 yr^{-1}	$10-$21/ t^{-1} CO_2	$17.2-$28.0 billion		
	46% (global net)	70% (global net)	$1-2 (up to $10)/$t^{-1}$ CO_2	$7.0 billion (with a range of $3-15 billion)	Sum of individual opportunity cost payments to landholders	[10,11]
30 Years	?	?	$453/$km^2$	$16.6 billion plus $5 billion in compensation for opportunity costs to local communities	One-time expenditures of buying and managing nature reserves covering 15% global land area (10% strictly protected)	[12]
30 Years	?	50%	$0.38/ $^{t-1}$$CO_2$	$17-33 billion	Global carbon trading with $3.7 trillion in long-term benefits	[13]
30 Years	50% (global net)	?		$233-500 million	Global transaction costs of payments for environmental services (PES) to forest landholders	
30 Years	46% (global net)	65%	$2.8/$^{t-1}$$CO_2$	$12.2 billion	Bottom-up opportunity costs as endorsed by UNFCCC (2007)	
2010-2020	80-100% of Brazilian Amazon	~6.0 Gt CO_2 [95-98% global net]		$.652 - 1.8 billion	Brazilian landowner compensation, investment in law enforcement and protected area management. $37-111 billion in potential revenue	[7]

Table S5: Existing and pending (shaded) sources forest finance

Sponsor	Beneficiary	Time Frame	$USD Amount	Agency/Implementing Institutions	Notes
Bilateral					
Spain		2010-2012	49,000,000	International Cooperation and Development Agency (partially)	$55,000 to Mexico; future commitment unclear
Switzerland	Developing countries; Indonesia	2010-2012	24,000,000	FCPF grants; Indonesia REDD+ Presidential Task Force	Total FSF pledge $160 million
Switzerland	Unclear	2013	8,000,000	Swiss Federal Parliament	Expected to continue support
United Kingdom	Nepal	2001-2011	32,600,000	DFID	Community Forestry
United Kingdom		2001-2011	129,000,000	Forest Governance Markets and Climate Initiative	
United Kingdom	Colombia	2013	25,000,000		Low-carbon agriculture project pledge
United States	Indonesia	Unclear	75,000,000	Millennium Challenge Corporation	Forest and land use projects compact pledge
Australia	Indonesia, Papua New Guinea	2007-2013	182,220,000	International Forest Carbon Initiative	No pledges post 2012 announced
Germany	Developing countries	2010-2013	390,000,000	Federal Ministry for Economic Cooperation and Development (BMZ); ICI	Part of $500 million pledge
Germany	Brazil	2013	54,707,600	REDD Early Movers program (see below)	Future engagement depends on new government's policies post-2012
Japan	Indonesia, potentially Vietnam	2010-2012	720,000,000	Joint Crediting mechanism as complement to CDM	Grant aid, technical assistance, contributions to multilateral funds accounted for under 1/3
Norway	Guyana, Mexico, Tanzania	2012	Unclear		Separate agreements signed as part of $500 million annual REDD+ budget
Norway	Indonesia	2010	1,000,000,000		REDD+ and peatlands
Norway	Brazil	2012-2015	1,000,000,000	Amazon Fund	

Table S5 (cont.): Existing and pending (shaded) forest finance

Sponsor	Beneficiary	Time Frame	$USD Amount	Agency/Implementing Institutions	Notes
Multilateral/Multi-National					
FCPF (Donors: Australia, BP Technology Ventures, Canada, CDC Climate, Denmark, European Commission, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Switzerland, The Nature Conservancy, United Kingdom, and United States)		2009-	820,000,000	Hosted by World Bank; works with UNREDD. IADB and UNDP are delivery partners.	REDD Readiness
UN-REDD Program (Donors: Norway, Denmark, Spain, Japan, EU, Luxembourg)		2008-	222,000,000	FAO, UNDP, UNE	Phase I and II pledge
FIP (Donors: Australia, Denmark, Japan, Norway, Spain, Sweden, United Kingdom, United States)		2009-	639,000,000	World Bank Group, African Development Bank, Asian Development Bank, IDB	Phase II with support to Phase I activities
United Kingdom		2010-2012	500,000,000	FIP, Congo Basin Forest Fund, FCPF Readiness Fund, FCPF Carbon Fund	
United Kingdom		2013	120,000,000	BioCarbon Fund ISFL	Committed at COP19
United States	Indonesia, Brazil, Peru	2010-2012	887,000,000	Mostly USAID; GEF, FCPF, FIP	Part of $1 billion commitment 2010
United States		2013	25,000,000	BioCarbon Fund ISFL	Pledged at COP19
Norway		2014+	500,000,000	UNFCCC, World Bank, and bilateral channels	Annual budget
Norway		2013+	135,000,000	BioCarbon Fund ISFL	COP19 commitment
Other/Voluntary Market					
United Kingdom	Unclear	2013-2015	940,000,000	20% of International finance budget earmarked for deforestation	Possible advanced market mechanism
Germany	Brazil	4 years	31,982,900	Part of REM program (see above)	Pledge to buy 8 million tCO_2 from REDD+ activities in Acre

**Source: http://www.globalcanopy.org/sites/default/files/IFF%20report%20Jan%202014-Stimulating%20Interim%20Demand%20for%20REDD+_single%20pages.pdf*

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