Vulnerability and climate risk analysis of the Amazon biome and its protected areas
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Figure 2.


Figure 14.

Ficus maxima

Guerrit Davidse

Ateles belzebuth

Pete Oxford

Brachyotum nodosum

Christian Zagler

Panthero onca

Frans Larding

Batusia xarquador

Adriano S. Charoelito

Apple snout

Steven Paton, Smithsonian Tropical Research Institute

Phyllostomus discolor

Programa de Conservación de los Murciélagos de Paraguay – PCMPy

Blu cuscus

Nicole Hransenam

Damarisca kiliganus

Ryan Shaw

Cuniculus paca

David Cook

Caxias birmanus

V. Bulsoso

Mano amaschoy

Mian Korbik

Cabos stenonotus

Bruno Salassi

Cebus chrysogaster

Francisco Estévez

Mauritia flexuosa

www.rarepalmseeds.com

Astrocaryum chambira

www.beamazon.org

Euterpe precatoria

Mateo Hernández

Caryocar villosum

Renan Chisté

Ara macao

parfaitimage.com

Sarcoramphus papa

Alessandro Abdala

The Amazon is the biome with the greatest area of continuous tropical forest in the world. In fact, its size is twice that of the second largest watershed, the Congo River. Additionally, it is the most important water system in the Planet, containing almost 20% of the world’s fresh-water. It harbors refugia for hundreds of species and five of the 17 of the world’s mega diverse countries are in the Amazon. The biome provides critical ecosystem services to humankind, serving as climate regulator not only of the region, but also of the Planet; 10% of the world’s carbon is found in its forests; and its water cycle guarantees this resource for distant regions through its “flying rivers” – moist water masses traveling throughout South America, providing this vital liquid to faraway lands. The Amazon houses more than 30 million inhabitants, including close to 350 indigenous communities and cultures.

However, this enormous wealth is particularly vulnerable to the effects of climate change, which are multiplied by a series of unsustainable activities related to the growth of the agricultural frontier, the construction of infrastructure and the extraction of non-renewable resources, among other factors. The current study, conducted by an extraordinary team of professionals, with active participation of Amazonian governments, provides an analysis, with a regional perspective, of climate vulnerability and risk in the Amazon and its protected areas. The document indicates, among other things, that factors related to climate change and land use change will very probably affect the quality and quantity of ecosystem services provided by the Amazon biome. Studies show that the regions with the highest climate change risk and the greatest sociocultural vulnerability are those in the eastern Amazon region, also close to Manaus in Brazil and Iquitos in Peru, as well as in the Colombian and Peruvian piedmont in the western part of the biome.

An important conclusion of this study is acknowledging the role played by protected areas, as basic buffer zones of climate change impact on biodiversity and in reducing related risks. The study also shows that protected areas are important tools for adapting to and mitigating climate change, and that conservation as a whole is fundamental in reducing vulnerability—very much in line with REDPARQUES’ declaration at the Conference of the Parties in Paris in 2015 during the United Nations Framework Convention on Climate Change. Both protected areas and indigenous territories are fundamental to guaranteeing that the Amazon region continues providing its services.

We hope that this study serves as an input in guiding governments and civil society in making decisions on conservation and effective management, enabling Amazonian countries—with support from the international community—to maintain the ecological functionality and integrity of the biome, and to develop and implement an agenda of resilience to climate change for this very important region of our Planet.

TARSICIO GRANIZO PEDRO GAMBOA
Coordinator - Amazonian Coordination Director, National Protected Areas Service, Unit, WWF LAC SERNANP, Peru – REDPARQUES Regional Coordinator

Quito and Lima, August 2016
Introduction

Recent, detailed, fine-scale data on climate, variability and climate change has not been suf- ficient to establish how biodiversity, communities and economic sectors will be exposed and threatened by climate change or to support decision making at different levels of public policy.

The international community adopted a conceptual framework and invested important re- sources in climate change vulnerability evaluations as the sole indicator, not understanding the need to analyze existing and expected climate risks and variables at different scales and in highly complex systems that determine their capacity to withstand and recover from negative impacts.

Vulnerability and climate risk analyses conducted in the framework of the Amazon Vision and presented in this publication, include other elements in an integrated approach that enabled defining climate change adaptation strategies linked to protected areas effectively, and strengthening resilience of the Amazon biome. Our analyses focus on contributing efforts to the goal of the Latin American Network for Technical Cooperation on National Parks, other Protected Areas, and Wild Flora and Fauna (REDPARQUES, from its name in Spanish) of consolidating an Amazon Conservation Vision that acknowledges the importance of the Amazon biome not only for its rich biodiversity but for its supply of ecosystem services at a local, regional and global scales.

This document presents the results of the analyses carried out through a highly collaborative process, in its seven main sections, in addition to this introduction. First, a brief synthesis of the conceptual and methodological framework used in the analyses; second, a reference to variability and climate change in the Amazon biome, including the Regional Climate Change Index. The third section includes analyses of ecosystem services related to water resources, carbon storage and biodiversity, specifically in relation to the habitat of different species. The fourth section, dedicated to the main transformation drivers, defines the Ecological Risk Index in the Amazon biome; and the two indices mentioned contribute to the Integrated Risk Index presented in the fifth section. The role that protected areas could play in enhancing the biome’s resilience is briefly discussed. Lastly, the conclusions section summarizes the main results and based on these, presents recommendations for further action to address climate change adaptation in the Amazon biome.

Paris Agreement – United Nations Framework Convention on Climate Change

In the 21 Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), conducted in December 2015, the Parties signed the Paris Agreement, mainly because there was an implicit acknowledgement that mitigation and adaptation efforts had been insufficient, and that evidence indicated a progressive increase in magnitude and rate of incidence of anthropogenic activities on global climate.

As a consequence, Article 5 of the Agreement encourages the parties to incentivize and support conservation, sustainable forest management, increase in carbon forest reserves, and more “alternate policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests”. To this end, all local, subnational, national and international management levels are being urgently convened to double efforts at equivalent and relevant scales to reach an adequate reduction in both greenhouse gas emissions and in climate risk, in synergy with development pathways that nurture sustainable development objectives.

The Amazon Conservation Vision plays an important role in this context. Since its inception, after a process starting in 2008 at the initiative of Amazon countries members of REDPARQUES, efforts have tried to mainstream this vision in participatory Amazon biome conservation planning and management strategies. One of the goals is consolidating representative, complete and effectively managed protected areas systems in the Amazon. Another goal is learning how to face the most urgent pressures, threats and change factors, including those derived from climate change, while identifying opportunities to benefit local communities. The initiative is a joint effort of REDPARQUES, institutions involved in each country’s national parks, the International Union for the Conservation of Nature (IUCN), the United Nations Food and Agriculture Organization (FAO) and the World Wildlife Fund (WWF)—all of which share common objectives and in addition provide the knowledge, resources and leadership required to achieve results demanded by the Vision.

Since 2014, as part of the implementation of the Amazon Conservation Vision, REDPARQUES and WWF, through the projects SNACC and IAPA, have directed efforts to improve understanding of transformation processes in the Amazon biome originating in or triggered by climate change, of priority actions for conserving and managing the biome in a “climate-smart” way, and of mechanisms for strengthening planning and management of protected areas systems.

1 The Amazon Conservation Vision currently has two projects being implemented in the framework of this initiative: 1) Protected Areas, Natural Solutions to Climate Change (SNACC, from its name in Spanish) - financed by the German Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety (BMUB, from its name in German) and WWF Germany; 2) Integration of Protected Areas in the Amazon biome (IAPA, from its name in Spanish) – financed by the European Union and FAO.
Introduction

The last report of the Intergovernmental Panel on Climate Change (IPCC), AR5-2014, states that adaptation to climate change requires an approach in its risk analysis that takes into account interactions between climate, and socio-ecological systems. The report highlights the need to construct “climate-resilient pathways” that, in the case of the Amazon biome, combine climate risk reduction and increase in climate resilience to achieve the objective of conserving a healthy and sustainable Amazon landscape.

Our work seeks to contribute to evaluating climate adaptation needs in the biome and integrating this evaluation in the Amazon Conservation Vision, based on the following concepts: focus on analyzing climate vulnerability and risk and on identifying the sources of ecosystem services and resilience in the biome. We try to guarantee the inclusion of critical links between climate (climate change, variability and extreme climate events) and biodiversity (species, ecosystems and ecosystem services), especially in the context of protected areas. We develop an applied methodology partially based on the IPCC’s AR5 and other proven tools which, combined, have aggregated value. This approach gives flexibility to our analysis in its development both in the context of specific protected areas in the Amazon biome, and in the context of needs and capacities of each of the countries involved.

Methodological framework

Technical vulnerability and risk studies (Figure 1) are intended to provide inputs for strengthening planning and management in protected areas, in a broad context that includes climate management objectives, such as mitigation, adaptation and resilient development, and low carbon. Throughout the conceptual design and execution of the analysis, project partners agreed that technical studies would address each of these specific objectives, which necessarily implies integrating multiple scales, sources of information, spatial modelling techniques and analyses.

Consequently, the first steps to fulfill this integration goal are related to technical studies that:

- Enable understanding both average conditions as well as variability of historical, current and expected climate in the Amazon biome.
- Identify the incidence of potentially dangerous physical phenomena and threats triggered by or originating in climate conditions.
- Update the baseline of climate, biological, social, economic and institutional data of the Amazon biome.
- Model the biome’s current and future capacity to provide ecosystem services, regulate water systems, capture and sequester carbon and provide habitats for species, under changing conditions in land use and climate scenarios.
- Analyze and evaluate climate risks, understood as potential losses in the biome’s functionality.footnote
- Identify biophysical factors of the Amazon biome that are potential sources of climate resilience.
- Support policies and development models required for intervening territories with a conservation and social development commitment, and that nonetheless are under threat and transformation due to changes in climate conditions to which they are not adapted.

We try to guarantee the inclusion of critical links between climate (climate change, variability and extreme climate events) and biodiversity (species, ecosystems and ecosystem services), especially in the context of protected areas.footnote

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footnote

2 Functionality understood as the capacity to provide ecosystem services.
Strengths, weaknesses and limiting factors

This analysis is an important step forward in understanding the impacts of climate variability and change in the Amazon biome and its relationship to the protected areas system and ecosystem services provision. It provides information and key data for decision making at the regional level, as a complement to defining strategies for facing the challenges of global climate change in the Amazon region. The document gathers several studies conducted in the region, that provide technical references on different themes (hydrology, climate, and physical and biological aspects); we invite the reader to consult these studies which provide greater detail and clarity on the technical elements studied.

In spite of the variety of information sources during the revision of bibliographic and geographic information, large data gaps were observed, most having to do with scarcity of properly referenced climate, hydrology and biological data. As is common, there are biases in favour of areas with greater access. Also, little is known on the status of the vulnerability of species in the face of expected impacts in climate variability and change, which became a factor limiting the development of this study.

On the other hand, during the different discussions and exercise development processes, the proposal was presented to assign greater relevance to the social context role of the Amazon in the vulnerability analysis. However, differences in existing indicators in Amazon countries with regard to their temporality, concepts and measuring methods did not allow us to completely integrate these aspects.

Little is known on the status of the vulnerability of species in the face of expected impacts in climate variability and change, which became a factor limiting the development of this study.

Geographic scope of the analysis

The SNACC Project’s technical committee agreed to delimit the study area based on the concept that the Amazon biome is a biogeographic area, previously defined by Olson and Dinerstein (1998). The resulting polygon covers 6 851 583.24 km² within the jurisdiction of eight countries (Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela) and an overseas territory (French Guiana, Figure 2).

Almost 30% of the Amazon biome (1 945 769 km²), is under some kind of protection IUCN category (Figure 3). This includes 439 protected areas of all IUCN categories, 11 Ramsar sites, 7 UNESCO Biosphere Reserves and 7 UNESCO World Heritage sites (IUCN and UNEP-WCMC 2015, Ramsar 2015). These areas are the core of REDPARQUES’ work in building resilience in the Amazon biome to face the negative impacts of climate change. However, only 145 protected areas, 28% of the protected territory (i.e., 513 764 km² or 11.9 % of the biome) are in IUCN’s stricter categories: Ia, Ib and II.
Figure 3. Extension of protected areas in the Amazon biome. Sources: Ministries of the environment of Bolivia, Brazil, Colombia, Ecuador and Peru. IUCN 2015: Venezuela, Guyana, French Guiana and Suriname. The borders of the Amazon river watershed do not necessarily coincide with those of the Amazon biome, which also includes areas of other watersheds: Orinoco River in the northeast, Essequibo, Courantyne and Maroni rivers in the north, and Gurupí and Tocantins rivers in the east. In the Andean zone, in the western part of the region, the biome does not include the glacial and subglacial zones in the water divide of the watershed.

Variability and climate change in the Amazon biome

The borders of the Amazon river watershed do not necessarily coincide with those of the Amazon biome, which also includes areas of other watersheds: Orinoco River in the northeast, Essequibo, Courantyne and Maroni rivers in the north, and Gurupí and Tocantins rivers in the east. In the Andean zone, in the western part of the region, the biome does not include the glacial and subglacial zones in the water divide of the watershed.

Protected areas are the core of REDPARQUES’ work of strengthening resilience of the Amazon biome in order to face the negative impacts of climate change.

Vulnerability and climate risk analysis of the Amazon biome and its protected areas

Protected areas sources:
Bolivia, Brazil, Colombia, Ecuador and Peru: Data were given by each country’s Environmental Ministry.
Venezuela, Guyana, French Guiana and Suriname: IUCN and UNEP-WCMC (2015); The World Database on Protected Areas (WDPA) [On-line], 08/2015], Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net

Percentage of the Amazon biome under protection in each country

Number of hectares per country included in protected areas (inside the biome)

Contribution by each Amazon country to the biome’s protected areas system

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Introduction

Because of its huge size, climatic patterns in the Amazon are affected by extreme climate variability phases and have specific subregional characteristics (Espinoza et al. 2009). Given the biome’s geographic position and the movement of the inter-tropical convergence zone, the Amazon biome exhibits an annual climatic bipolarity, which means that humid and dry months in the northern zone are opposite of those in the southern zone. In other words, when precipitation is low in the northern region, it is high in the southern region, and vice versa.

To determine the degree of influence of global atmospheric phenomena on climate variability in the Amazon, the relation between precipitation and temperature was analyzed using 10 climate indices available in the database of the Climatic Research Unit at 134 stations (CRU 2015, Jones et al. 2012). Analysis of these data showed extreme variations expressed in critical events, such as the 2005 and 2010 droughts and the 2002, 2008 and 2015 floods. This section discusses results of these analyses and climate change models, using multiannual precipitation and temperature averages, with a current reference period and a future scenario equivalent to an RCP of 8.5 for 2030. Longer periods were used for the biodiversity analyses: to years 2050 and 2080. Finally, an integrated risk index was generated for the conditions of the present century.

Inter-annual and inter-decadal variability (long term)

At the regional scale, many of the climate variability indicators show a much more evident relationship with climatic processes in the tropical Pacific than with those in the Atlantic (Figure 4 and Table 1). The El Niño phenomenon in the Pacific East results in precipitation deficits in large areas of the Amazon region during all seasons, especially between December and February (the austral summer). Air temperature anomalies also have a different spatial distribution, with greater positive values during the austral summer.

Table 1. Climate variability indices in the Amazon biome

<table>
<thead>
<tr>
<th>Sector of the Amazon with the greatest effect.</th>
<th>Precipitation</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-annual variability</td>
<td>Very significant effect in the northwest, north and south of the Amazon. Not significant in other areas.</td>
<td>Very significant direct positive effect of El Niño and La Niña in the northern part of the region.</td>
</tr>
<tr>
<td>Temperature variability in the northern Atlantic</td>
<td>No noticeable effect on precipitation.</td>
<td>Evident effect on temperature.</td>
</tr>
<tr>
<td>Inter-decadal variability in the Pacific</td>
<td>Significant inverse effect in the extreme eastern part of the watershed.</td>
<td>No effect.</td>
</tr>
<tr>
<td>Inter-decadal variability in the Atlantic</td>
<td>No effect.</td>
<td>Noticeable inverse effect in the extreme eastern part of the watershed.</td>
</tr>
</tbody>
</table>

Climate variability and changes in net forest productivity

Extreme climate events also have an effect on the structure and functioning of the Amazon forest. The water flow in Amazon forests during the dry periods is regulated mainly by the access of roots to water in the soil and its redistribution in the forest ecosystem, which involves high rates of transpiration and photosynthesis (Malhi et al. 2008). Due to the influence of soil moisture on the capacity of Amazon forests to respond to drought impacts, areas with the greater deficit of soil moisture have a net biomass loss during those events (Meir et al. 2009, Phillips et al. 2009). For example, during the 2005 drought, more than 70 million ha of the western Amazon basin underwent a severe water deficit (Saatchi et al. 2013, Figure 5).
Evidence of climate change in the Amazon has been repeatedly highlighted by several authors (IPCC 2012, 2013, Marengo 2009, Valverde and Marengo 2011). Results of simulation modeling for the RCP 8.5 scenario confirm findings regarding the increase in temperature in the Amazon biome. The increase affects the whole territory and fluctuates between 0.3 and 3.0°C. Consequently, there will also be an overall increase in the water moisture content. The response of precipitation to climate change in the Amazon is diverse and differs by regions. One possible cause can be the high percentage of precipitation recycling that depends on the water supply and the type of vegetation.

**Changes in climate variables**

The greatest increases can be seen during the period February to May, with certain hot spots in the northern region, with increases close to 2°C and a broad southern sector where increases are as high as 3.6°C.

**Temperature**

Overall, an increase in temperature between 0.3 and 3.0°C can be observed when analyzing spatial distribution of average monthly multitemporal temperature changes for the current (Figure 6A) and future (Figure 6B) periods, in addition to differences between the two periods (Figure 6C). The greatest increases can be seen during the period February to May, with certain hot spots in the northern region with increases close to 2°C, and a broad southern sector where increases are as high as 3.6°C. Some southern and western sectors exhibited reductions in temperature (≤0.2°C) during the period from June to August, and again during the period between September and January over a strip running from the northwest to the east. The distribution of anomalies among average annual temperatures shows an overall warming between 0.35 and 1.2°C, with peaks in broad sectors of southern, eastern, northern and central Amazon.

**Precipitation**

Modeling shows the effect of the relative position of the Earth with respect to the sun and the rotational angle on the oscillation of the Inter Tropical Convergence Zone (ITCZ) along the biome, and its consequences on the presence of mid-year, high-precipitation nuclei towards the north and towards the south early in the year. The spatial distribution of changes in precipitation each month between the periods analysed, as well as anomalies between both periods (Figures 7A-C), suggest that the February-June period would show a marked increase in precipitation in the southwest (Bolivian and Peruvian Amazon) and in the south and east, while there would be a reduction in precipitation in the north (Colombian and Venezuelan Amazon). Distribution of changes is inverted during the period July-November, with increases in the north and reduction towards the south. November, December and January would experience an increase in the eastern sector, over the delta of the Amazon River in the state of Pará. A marked reduction would take place in the southern and eastern sectors of the region between October and March. On average, reductions close to 20% can be observed in the southeast and east of the region, and some nuclei of increases close to 20% in the north. Precipitation increases predominate in the southwest, west and northwest, with values close to 10%, while the rest of the watershed has values between -6% and +6%, in other words, without significant changes (Figure 7C).

**Results of simulation modeling for the RCP 8.5 scenario confirm findings regarding the increase in temperature in the Amazon biome. The increase affects the whole territory and fluctuates between 0.3 and 3.0°C.**

Figure 6. Multianual monthly average temperatures (°C) for A) Current B) Future and C) Differences in multianual monthly averages for both periods.

Figure 7. Multianual monthly average precipitation (mm) for A) Current B) Future and C) Differences in multianual monthly averages for both periods.
The Regional Climate Change Index (RCCI; Giorgi & Bi 2005, Giorgi 2006) shows how temperature and precipitation changes will be distributed throughout the Amazon biome, taking into account intraannual temperature and precipitation variability in comparison with current and future climate periods. To calculate these, we used the climate characterization of Malhi et al. (2008) which establishes the dry period for the northern region in December-February, broadening to include November, March and April, while June-August would be the dry period for the central and southern regions, broadening to include May, September and October.

As stated by Giorgi (2006), the main objective of the RCCI analysis is comparing regions among each other, more than providing an absolute measure of change. Thus, climate change effects will be greater in the south eastern zone of the biome, in the states of Pará, Mato Grosso and Rondônia (Figure 8). The Colombian and Ecuadorian piedemont, the Atlantic coast in the Guianas, and the state of Maranhão in Brazil are the regions with the least influence of climate change in the Amazon. In Bolivia, the provinces of El Beni and Pando in the east have the greatest climate change index. Distribution varies across regions in Peru; however, the greatest variability is expected in the frontier with Brazil and Bolivia.

Figure 8. Regional Climate Change Index (RCCI) for the Amazon biome.
From a biophysical point of view, the response of the Amazon biome to variability and climate change is not uniform at all (Figure 10). For example, during the periods 1996-1997, and 2005-2010, the south eastern part of the Amazon underwent severe drought, especially in 2005 when the drought period was the longest in the last 40 years and had the greatest intensity in the last 100 years (Marengo et al. 2008, Tomasella et al. 2011). During these extreme events, navigation on the Madeira river and the central part of the Amazon river had to be interrupted, and local communities had to be moved to other places to avoid isolation due to the low water levels (Pinho et al. 2014). This happened again in October 2015 (Telesur 2015, Figure 9A). In February of the same year, the municipalities of Brasileia and Epitãciolandia in Brazil and Cobija in Bolivia were flooded (Figure 9B), with great subsequent shore erosion processes (Globo 2015, Sol de Pando 2015).

Even though drought and floods are part of the region’s natural variability (have occurred in the past and will continue to happen in the future), during the last decade their intensity has been unprecedented in recent history. This indicates that, in spite of the high levels of uncertainty about climate information, it is possible to ascertain that floods and droughts will continue to increase in the future with higher frequency and magnitude (Marengo et al. 2013).

On average, no drastic change in water yields is expected in future scenarios in the Amazon watershed, drastic changes are actually observed in some watersheds in the region. Hydrological modelling using NatCap’s InVEST model (Skansi et al. 2013) shows that even though, on average, no drastic change in water yields is expected in future scenarios in the Amazon watershed, drastic changes are actually observed in some watersheds in the region (Figure 10), with differences ranging from 0.78% to 50.17% below the average for the reference period and from 0.18% to 295.47% above this average. The greatest reduction in water yields (39% and 50%) will be in the watersheds of the Caroni, Caura and Cushabatay rivers, and those with the greatest increase (36% and 295%) will be in the watersheds of the Amapá Grande – Macar and Caño Mono rivers.

On the other hand, when comparing the percentage of protected areas in each of the subwatersheds in terms of the effect of climate variability on water yield during the 2005 drought, we observe that the most extreme variations in terms of water resources take place in basins with the least territory in protected areas, highlighting the importance of protected areas in mitigating the effects of climate variability (Figure 11).

Is possible to ascertain that floods and droughts will continue to increase in the future with higher frequency and magnitude.

**Figure 9.**
A) Drought caused serious navigation problems in areas surrounding Manaus in October 2015.

**Figure 10.**

**Figure 11.** The role of protected areas on water regulation.
Undoubtedly, one of the most important ecosystem services provided by the Amazon biome at a global scale is carbon storage, regulating in a great manner our planet’s climate. As shown in the map (Figure 12A – Baccini et al., 2012), carbon density in tropical areas, forests in the Amazon biome store 166,256.61 megatons of carbon, which correspond to 56.2% of all carbon stored by forest aboveground biomass in the world (FAO 2015). Furthermore, the amount stored per hectare in protected areas is much greater than in non-protected areas in all countries, being Colombia and Peru the countries with the highest carbon storage values (Figures 12B y C).

However, using the HadGEM2-ES climate model of the Hadley Centre in Great Britain (Collins et al. 2011) and the RCP 8.5 scenario of carbon emissions, a decrease in carbon content is predicted in three quarters of the Amazon. Until 2030 more than 60% of the area will undergo negative changes in carbon content up to 8%. Nonetheless, it is important to highlight that information is limited due to the spatial resolution of the atmospheric model. When calculating average multiannual, annual and monthly variations between the current and the future periods (Figure 13), the greatest weighted carbon losses could happen in the eastern and southern zones of the biome and, to a lesser degree, in the piedmont of Peru and Ecuador. A slight increase in stored weighted carbon could take place in the central zone of the Amazon.

Biodiversity–Species habitats

Almost 40% of tropical rain forests of the world are found in the Amazon. These neotropical forests are presumed to be the richest in species (Gentry 1988). One very outstanding fact is that a hectare of Amazon forest can host 200 to 300 different species of trees, more than are known in all the European Union. The Amazon biome is the habitat for approximately 40000 species of plants, 427 of mammals, 1294 of birds, 378 of reptiles, 427 of amphibians and 3000 species of fish (Silva et al. 2005, Mittermeier et al. 2002, 2003).

We evaluated the impact on the distribution of representative species with different functional attributes in the Amazon biome, assuming that the ecological integrity of protected areas depends on maintaining ecological relationships among their conservation objects. For our analysis, we used both current and future global bioclimatic data, based on a trajectory of RCP emissions of 8.5 W/m² (Hijmans et al. 2005). We also used data on changes in species distribution generated by the Wallace Initiative (Warren et al. 2013), which in turn used bioclimatic variables and optimization algorithms of the species’ climate niche to model potential future climate refugia (MaxEnt, Phillips et al. 2006).
Ecosystem services

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Castro-Vásquez 2010, Instituto Sinchi et al.

...2007, Parolín 2002).


In spite of constituting a minimum sample of biodiversity in the Amazon, the analysis of changes in species distribution is a step forward in understanding the possible future impacts on interspecific relations resulting from the change in climatic conditions.

In spite of constituting a minimum sample of biodiversity in the Amazon, the analysis of changes in species distribution is a step forward in understanding the possible future impacts on interspecific relations resulting from the change in climatic conditions.

Figure 14. Network of relations between species analyzed and ecosystem services.

At the base of this network, are species with an important value for the structure, function and supply of ecosystem services in the Amazon forest.

The network also includes a set of frugivorous, omnivorous and neotropical species that depend, in a greater or lesser degree, on the plant species mentioned above (Castro-Vásquez et al. 2010, Galetti et al. 2001, Montenegro 2005) and which contribute as seed dispersers and regulators. Additionally, they represent a source of food for human communities and for carnivorous and scavengers in the biome (Fragoso et al. 2003, Pozo 2004, Instituto Sinchi 2007), which in turn contribute to controlling other populations, including disease vectors. It is worth highlighting that, in addition to the already mentioned ecosystem services provided by this set of species in the biome, several species are considered to have important cultural and religious values, such as the jaguar, the boa, and the scarlet macaw, among others (Aranda 1994, Hilty & Brown 2001, Wallace & Stanley 1987, Renjifo et al. 2002).

At the base of this network, are species with an important value for the structure, function and supply of ecosystem services in the Amazon forest.

Ecosystem functionality

Unlike most current modeling studies, the main criteria for selecting species to be modeled in the Amazon biome in this study was the existence of interspecific ecological relations, supported by scientific information and with sufficient georeferenced records available in the database needed to feed the modeling exercise. Thus, most species presented in the analysis interact with other species included in the list in one manner or the other. To verify interspecific relations, we consulted scientific articles and books that mentioned the existence of these interactions. We also took into account other criteria such as their IUCN category of threat, if they had been previously selected as conservation objects, their sensitivity to climatic factors, and their contribution to connectivity and supply of ecosystem services.

Therefore, we generated a simplified network of hypothetical relations (Figure 14) made up of several trophic levels, links between ecological functionality and supply of ecosystem services generated by the species, which were key for maintaining the biome’s integrity. In spite of constituting a minimum sample of biodiversity in the Amazon, the analysis of changes in species distribution is a step forward in understanding the possible future impacts on interspecific relations resulting from the change in climatic conditions.

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Figure 14. Network of relations between species analyzed and ecosystem services.

At the base of this network, are species with an important value for the structure, function and supply of ecosystem services in the Amazon forest.

The network also includes a set of frugivorous, omnivorous and neotropical species that depend, in a greater or lesser degree, on the plant species mentioned above (Castro-Vásquez et al. 2010, Galetti et al. 2001, Montenegro 2005) and which contribute as seed dispersers and regulators. Additionally, they represent a source of food for human communities and for carnivorous and scavengers in the biome (Fragoso et al. 2003, Pozo 2004, Instituto Sinchi 2007), which in turn contribute to controlling other populations, including disease vectors. It is worth highlighting that, in addition to the already mentioned ecosystem services provided by this set of species in the biome, several species are considered to have important cultural and religious values, such as the jaguar, the boa, and the scarlet macaw, among others (Aranda 1994, Hilty & Brown 2001, Wallace & Stanley 1987, Renjifo et al. 2002).

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The analysis also shows that new areas apt for the presence of different species could arise (climate refugia). These areas need to be considered carefully since their existence in the future does not necessarily imply that they will be colonized, particularly by plant species, whose mobility depends on their dispersion dynamics and strategies. The presence of appropriate edaphic, luminosity and humidity factors for their physiological needs, as well as recruitment of plantlets in new locations, among other factors. As mentioned by the IPCC (2014), plants, in comparison to other taxa such as mammals or insects, are expected to have a lower rate of displacement and colonization of new areas under climate change conditions. Considering the importance of plant species in the trophic networks of a biome such as the Amazon, it is possible that the diverse species that depend on food sources provided by plants remain in the same zones linked to the slow colonization process of their source of food, even if they have new climate niches available.

According to the analyses, all cornerstone species will probably lose area of their current climate niche, being thus forced to change their distribution and placing their associated interspecific relations at risk. On the other hand, the potential area loss in the future for highly threatened species will probably be a factor that will further increase this condition. Furthermore, according to the analysis, the more generalist species will have a greater extension of climatically stable areas in the future, which hypothetically implies that these species have a greater capacity of adapting to expected changes in their climate niche.

When analyzing expected changes within protected areas, no homogeneous behavior is observed in terms of maintaining species richness of the selected groups, indicating that currently established protected areas in the biome do not necessarily guarantee mitigation of climate change impacts on species studied. Bearing this in mind, in order to facilitate adaptation processes of biodiversity and to maintain the ecosystem services supplied by said biodiversity, new conservation areas have to be created, and strategies to increase connectivity habitats implemented within the Amazon biome.

Vulnerability and climate risk analysis of the Amazon biome and its protected areas.
Figure 17. Climate refugia.

Modelling of the future climate niche shows a difference of 9.3% for the best case scenario and of 3.2% for the worst case scenario, between the percentage of species that will maintain their climate niche, both in the current system of protected areas and in the entire biome (Table 2).

Table 2. Percentage of species estimated to maintain their niche in best and worst case climate change scenarios

<table>
<thead>
<tr>
<th>Biome</th>
<th>Best case scenario</th>
<th>Worst case scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibians</td>
<td>53</td>
<td>39</td>
</tr>
<tr>
<td>Reptiles</td>
<td>65</td>
<td>38</td>
</tr>
<tr>
<td>Birds</td>
<td>63</td>
<td>36</td>
</tr>
<tr>
<td>Plants</td>
<td>57</td>
<td>32</td>
</tr>
<tr>
<td>Mammals</td>
<td>64</td>
<td>37</td>
</tr>
</tbody>
</table>

These results indicate that protected areas do exhibit a slight trend to maintain a greater number of species in the context of climate change in comparison to the biome.
Deforestation in the Amazon biome during several time periods.

At a regional level for the 2000-2013 period, average deforestation was 20,767 km² per year. This is equivalent to deforesting every year an area twice the size of the National Amazon Park in Brazil or the National Yasuní Park in Ecuador. From a regional perspective, the annual rate of deforestation has been diminishing in recent years (Figure 19). Because Brazil has such a large share of the biome, actions in this country significantly affect data and regional statistics. Thus, for the 2000-2013 period, annual average deforestation rate was reduced by 50%. However, the opposite situation was true for the remaining Amazon countries where an increase was observed in annual average deforestation rate in Bolivia, the Guianas, Peru and Venezuela.

During the 2000-2013 period, an area equivalent to the size of the United Kingdom was deforested.

Deforestation in protected areas (Table 3) is very low in comparison to that of the biome, but slightly greater than in indigenous territories (RAISG 2015, WWF 2016). It also shows that most deforestation in the Guianas took place in the last 3 years (2010-2013).

Table 3. Deforestation data within the protected areas system in the Amazon biome

<table>
<thead>
<tr>
<th>País</th>
<th>Total number of protected areas studied</th>
<th>Total area deforested (%) Historic deforestation</th>
<th>Total area deforested (%) for the 2000-2013 period, happening between 2010 and 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>47</td>
<td>3.85%</td>
<td>29%</td>
</tr>
<tr>
<td>Brazil</td>
<td>247</td>
<td>3.66%</td>
<td>9%</td>
</tr>
<tr>
<td>Colombia</td>
<td>30</td>
<td>1.50%</td>
<td>18%</td>
</tr>
<tr>
<td>Ecuador</td>
<td>17</td>
<td>5.60%</td>
<td>14%</td>
</tr>
<tr>
<td>French Guiana</td>
<td>15</td>
<td>0.70%</td>
<td>67%</td>
</tr>
<tr>
<td>Guyana</td>
<td>6</td>
<td>0.56%</td>
<td>83%</td>
</tr>
<tr>
<td>Peru</td>
<td>45</td>
<td>1.00%</td>
<td>13%</td>
</tr>
<tr>
<td>Suriname</td>
<td>13</td>
<td>0.96%</td>
<td>62%</td>
</tr>
<tr>
<td>Venezuela</td>
<td>19</td>
<td>2.50%</td>
<td>29%</td>
</tr>
<tr>
<td>Total</td>
<td>439</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>2.95%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Forest fires in the Amazon

Climate variability has a direct effect on forest fires in the Amazon, due to already mentioned changes in precipitation and temperature, and indirectly due to resulting changes in the vegetation’s composition and structure (Cochrane & Barber 2009, Pausas & Bradstock 2007). Consequently, large forest fires in the Amazon are conditioned by large-scale climate variability, with events such as El Niño (Figure 5A; Cochrane et al. 1999, UNEP 2002, Alencar et al. 2006). Nonetheless, dry periods and forest fires, such as those in south eastern Amazon in 2005, were not necessarily linked to the El Niño phenomenon (IPCC 2007, Figure 20A).

Current fire patterns are undoubtedly different from historic patterns, as a consequence of human activity. Changes in frequency, intensity and location are dramatic since the decade of 1970’s (Cochrane & Barber 2009), when construction of a network of roads connecting the Brazilian Amazon to the rest of the country opened colonization fronts. This network drove changes in forest fires since slash and burn practices were commonly used to establish and maintain large areas dedicated to agriculture and pastures in zones neighboring the road network. The increase in density of forest fires for the 2001-2005 period is concentrated in Brazil, in the south eastern part of the biome, where frequency is highly correlated with the austral summer, and in the Colombian piedmont, the Beni region in Bolivia and the Pucallpa region in Peru were the main deforestation fronts (Figure 20B).

Fires with the greatest magnitude during the 2000-2014 referenced period in the biome took place in August and September 2010. The severe effects generated by these fires were captured by satellite sensors, showing severe effects mainly in Brazil, south of the Pará region and north of Mato Grosso (Figure 21).
Ecological Risk Index

Being aware of the importance of understanding the ecologic risk of anthropic origin in the Amazon biome ecosystems, we used the Ecological Risk Index (ERI) conceptual approach developed by Mattson & Angermeier (2006), which integrates the frequency of several degradation agents with estimates of their potential impact on certain important environmental factors, such as water quality, habitat quality, biotic interactions and water regime (Figure 23).

Several potential effects resulting from anthropogenic change drivers were initially identified in natural landscapes, as well as more adequate analysis units, which, in this case, were the watersheds defined by WWF’s Hydrosheds (Lehner et al. 2008).

Frequency and severity scores were determined for each of the drivers, based on the study conducted by Riveros et al. (2009) for the Amazon River basin, and then integrated into the analysis units.

The main drivers of anthropogenic change are evidently related to deforestation (Figure 22A), the extension and intensity of areas devoted to crops and livestock (Figure 22D), mining concessions (Figure 22G) and road networks (Figure 22H).

When the partial scores for all drivers are integrated (ERI-C, Figure 23), the areas under greater risk of degradation become evident in the southern and eastern zones of the biome, in the states of Acre, Rondônia, Mato Grosso and Pará in Brazil; and in the western zones of the Andean piedmont in Bolivia, Colombia, Ecuador and Peru. A medium-risk hotspot can also be observed in the northern part of the state of Roraima in Brazil and in the northern zone of Guyana.
A total of 112 protected areas, 25,123,470 hectares, are in high risk (13.16% of the total number).

The effect of protected areas is mainly evident in terms of water yield during extremes in climate variability, as they serve to buffer the response to these extreme climate events. Extreme volumes of water are mainly present in basins with less than 50% of their surface within protected areas. In an ecosystem that is sensitive to certain climatic conditions, extreme climate variability represents a greater threat than long-term changes caused by global warming. At the regional scale, climate change is the result of global warming plus local anthropogenic changes, such as changes in land use. Protected areas have a significant effect on the latter. Thus, an important reduction in carbon content is only evident by year 2030 in areas with less anthropogenic pressure, where the percentage surface in protected areas is low.

Bolivia is the country with the greatest relative percentage area at risk, followed by Brazil, Colombia and Peru (Figure 25). Venezuela did not show areas at risk in the analysis, but this may be explained by gaps in the information, given the difficulty to collect data in this country.
Figure 25. Distribution in terms of relative extent of the Integrated Risk Index in protected areas of the five Amazon countries.
Developing the climate resilience concept

The Amazon Conservation Vision initiative decided to face the challenge of developing theoretical and practical elements aimed to strengthen the role of protected areas in adaptation to climate change. This has also implied addressing the challenges pondering about the challenges of climate resilience in the Amazon biome, and how this concept can be integrated in the framework of REDPARQUES Amazon Conservation Vision, and overall, on the different actors involved in conservation processes and management of the Amazon biome.

The starting point is acknowledging there is no simple way to address the issue of climate resilience, may it be trying to conserve current characteristics elements of the biome’s biodiversity, or following initiatives and measures designed to add flexibility to conservation and management objectives in a context of quick global change.

During the participatory process of constructing the concept of resilience for the Amazon Conservation Vision and the SNACC project, theories and concepts from three main fields of knowledge have been highlighted: social sciences, biological sciences and engineering. Changes or impacts on individuals and/or systems resulting from tensions on those subjects, have been studied, and the different perspectives provided have facilitated the identification of a broad range of adjustments and responses of these individuals or systems based on their initial configurations and giving way to different arrangements.

A “contemporary” challenge is the inclusion of climate change as a factor of transformation in the analysis of resilience. The challenge lies basically in the permanent nature— at least at a time-frame of 50 to 100 years— and the irreversible nature of climate change. The increase in the concentration of greenhouse gases in the atmosphere, caused by anthropogenic actions and the consequent changes in world climate will prevail for many more years, given the conditions in which these gases will persist after being emitted. Therefore, a climate resilience model must necessarily address a diversity of climatic shocks and disturbances, as well as permanent change in the climate’s own conditions.

Based on the above, an initial definition of climate resilience applied to the Amazon biome in the framework of the SNACC Project is: “the capacity of a socio-ecological system to maintain key conditions of its biological, social and functional identity, within permanent transformation processes, both in its environments and in the elements inherent to its structure and composition”.

Basic elements of an agenda focused on climate resilience

This definition of climate resilience requires a theory of change that acknowledges the relationship between conservation of biological and social diversity in the biome, and the intrinsic challenges of climatic resilience. Thus, this theory needs to address conservation management within the Amazon biome, especially in those landscapes that include protected area systems, with objectives conceived in a broad framework, identifying pressures and transformation drivers resulting from climate change, and explicitly addressing dynamic management situations.

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Avoid change: This approach to the biome’s climate resilience is based on developing a theoretical component that includes technical studies and proposes the design of management strategies that guarantee the Amazon biome’s capacity to provide three main ecosystem services: (i) water regulation (Figure 10); (ii) carbon capture and sequestration (Figure 13); (iii) habitat quality for species (Figure 18). This approach implies that a significant part of the biome’s “identity” lies on maintaining its functional capacity, with two priority change conditions: climate change and land use changes. In practice, technical studies have thus tried to:

- Quantify the current capacity to provide ecosystem services.
- Identify scenarios of land use change and climate change.
- Quantify changes in the capacity to provide ecosystem services.
- Evaluate zones of the biome with the lower threshold of functional loss (Resilient zones - avoid change).
- Identify biophysical conditions that attribute resilience to these zones and propose management actions.

The resilience approach that seeks to avoid change is based on identifying the areas of the biome where technical studies have quantified lower percentages of change in the supply of ecosystem services (measured as the difference between the base line and the future scenario). The next step would be to develop a set of biophysical attributes that explain these results (for example, forest cover, ecological integrity, water network, soil humidity, among others) and then propose management actions associated with those attributes. The resulting resilience agenda focused on avoiding change would try to adopt a specific management scheme of biophysical elements that would act as the main components in determining and maintaining the biome’s functionality (in terms of ecosystem services).

The resilience approach that seeks to avoid change is based on identifying the areas of the biome where technical studies have quantified lower percentages of change in the supply of ecosystem services. 3 Adapted from definitions proposed by: (i) Stockholm Resilience Centre—accessed at http://www.stockholmresilience.org; (ii) Franco F. and Andrade G. 2014. Buscando respuestas en un entorno cambiante. Capacidad adaptativa para la resiliencia socio ecológica de las Áreas Naturales Protegidas.
Acknowledged change: This second focus to climate resilience for the biome is based on following up on the evolution in the management strategies for various biodiversity components. As indicated by its name, this approach differs from that of avoiding change in that it favors an intentional effort to monitor, understand and integrate in its management situation the pathway of change of a large part of the biome’s biodiversity, with emphasis on what are known as conservation objects and on management of protected areas. Adopting this focus could be considered “conventional”, in that the approach is based heavily on “in situ conservation” strategies (for example, monitoring and follow up) of the status of species and ecosystems; the difference lies in that it includes an aggregated approach by incorporating changes in this status over time.

Thus, in the perspective of climate resilience, considering conservation and management objectives should include some of the following actions in the future agenda of the Conservation Vision and of other initiatives:

- Improve species and ecosystems monitoring and research protocols in the context of climate change, and their synergy with other biodiversity loss drivers in the biome. Information resulting from these protocols would feed models to anticipate and manage progressive change in the status of these elements.
- Identify possible management actions to conduct and/or prepare change of current conservation objects.

Consequently, a possible synergy could be established between the traditional conservation agenda and these initial elements of climate resilience, starting by understanding pathways of change of current conservation and management objects. A new comprehension of alternatives to influence this change (for example, stopping, reversing, influencing, managing it, etc.) could result in new paradigms for institutions and organizations involved in planning future objectives, scenarios and management situations in the Amazon biome.

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Climate resilience and ability to facilitate change

In practice, the technical and conceptual elements of this first approximation to climate resilience in the framework of the SNACC Project have enabled identifying key inputs for constructing a theory of change in the context of protected areas systems in the Amazon biome, and for REDPARQUES’ Vision and Work Plan. These are:

- The current conservation paradigm—based on maintaining certain conditions of the status of biodiversity, by controlling pressures and threats on those objects—must be adjusted to include current knowledge and perspectives on climate change. Specifically, changes in average precipitation and temperature conditions expected in climate change scenarios have a permanent character, and thus, considering their geographic and temporal scale, this change factor cannot be reverted.
- Changes in biodiversity in the biome will take place, and therefore actors involved in the Amazon Vision must anticipate change as much as possible, so that it happens in conditions of space and time that permit avoiding scenarios of species extinction or loss of ecosystems, for example.
- Understanding the evolution of ecological processes is fundamental for planning management of the Amazon biome. SNACC’s first efforts focused on those processes associated to priority ecosystem services (water regulation, carbon capture and sequestration, habitats for species) and their possible change in the context of climate change and deforestation projections, and how this reflects on management actions that enable future high functionality of these processes.
- Some characteristics of functionality of the Amazon biome may remain over time, even if the ecological structure and the interspecific relation among its elements is different from what we currently know. Therefore, decision makers must have a future balance of the Amazon biome showing the conservation levels of its biodiversity, its ecological processes and functionality (ecosystem services), in support of decisions that are being taken now for those future conditions.

Possibly, one of the most determinant factors in the agenda of climate resilience is the scale of management. The geographic units in which technical studies are conducted and management actions planned must be consistent with the consideration that it is in these units that change takes place.

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- The process of natural adaptation to change is possibly the best scenario for climate resilience by minimizing interactions with pressures and threats of anthropological origin.
Main results of the analysis

The challenges that climate change imposes on the Amazon biome are globally important. We hope that these studies contribute to decision-making processes that facilitate effective conservation and adequate management of Amazon ecosystems and their functionality, in circumstances in which the biome is undergoing important transformations and where resilience is becoming a priority in the sustainable development agenda at the regional level.

Climate patterns in the Amazon biome are difficult to characterize since they are influenced by both climate change and extreme phases of variability related to atmospheric processes in the Pacific and Atlantic oceans. The biome also exhibits particular subregional characteristics related to changes in altitude and the relative position of the ITCZ. Our results show the probability of a continuous increase in temperature between 0.3 and 3°C for the period 2021-2030, along with a series of changes in precipitation in different parts of the biome, as well as the persistence of extreme climate events, such as the 2002, 2008 and 2015 floods, and the 2005, 2010 and 2015 droughts, of unprecedented intensity in recent history. The regional climate risk index shows greater influence of climate change in the Brazilian states of Pará, Mato Grosso and Rondónia in the south eastern zone of the biome.

The quantity and temporality of the supply of key Amazon ecosystem services will probably change due to the incidence of risks related to climate and to changes in land use. The three services studied—carbon storage, supply of fresh water and availability of habitats for several species—will be affected by the impacts of climate change. For example, several watersheds in the Amazon will probably undergo drastic changes; three of them will experience a reduction in water yield ranging from 39 to 50%, while two other watersheds will experience an increase in water yield ranging from 36 to 295%. Additionally, carbon content in the Amazon forest will probably be reduced up to 8% over three-fourths of the biome, and by the year 2030 the whole biome, with the exception of a nucleus in its extreme north eastern part, will undergo negative changes in its carbon storage capacity.

Analysis of modifications in the distribution of species in the face of possible climate change impacts indicate a high level of dependency of these on natural vegetation coverage and great sensibility to the frequency and magnitude of extreme events. Twenty-four cornerstone species included in the study will probably lose areas of their habitat, which are currently part of their climatic niche. This could trigger changes in their distribution and disturbances in interspecific relations, in the provision of ecosystem services associated with these species, as well as a situation of aggravated stress for the species that are currently under threat.

In some cases, potential new areas of adequate habitats will arise, but this not necessarily guarantees the colonization of these areas. The analysis of climate refugia indicates there are less potential refugia for plants and amphibians, and more potential refugia for birds and reptiles. Impacts linked to increases in frequency and magnitude of extreme temperature and precipitation events related to climate change were confirmed to have the greatest impacts on the biome’s biodiversity.

In terms of ecologic risk of anthropogenic origin—ecologic risk index—we found that the most negative transformation drivers for the Amazon ecosystems are deforestation, expansion of the surface and intensity of areas destined for agriculture and livestock, mining activities and road building. With respect to protected areas, 36 are facing a very high level of risk, and 76, a high level of risk. In total, 25,123,470 ha are in one of these levels.

Conclusions and recommendations
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The role of protected areas

We studied the role of protected areas as elements required for enhancing resilience in the biome, from a regional perspective. Our results support the premise that Amazon protected areas can play an important role in mitigating the impact of climate change and in reducing climate-related risks to the biodiversity of the biome.

We found, for example, that there is a greater carbon content per hectare in protected areas in all Amazon countries and that stability in carbon content is greater in areas of the biome that have a greater percentage of area being protected, in spite of the presence of strong anthropogenic pressures. The presence of protected areas also mitigates the impacts of extreme climatic events by maintaining water yield levels during periods of drought and other instances of intense variability. Specifically, we noticed that watersheds with less than 50% of their surface within protected areas tend to exhibit more discharge extreme events. Additionally, we found that the presence of protected areas is linked to a reduction of 21.43% in the climate risk index. However, in terms of provision of habitats for the species in the context of climate change, existing protected areas in the biome are not sufficient for guaranteeing zones that mitigate the impact of climate change for the species included in the analysis.

Our results support the premise that Amazon protected areas can play an important role in mitigating the impact of climate change and in reducing climate-related risks to the biodiversity of the biome.

An important contribution of this study is the conceptual approach towards a resilience agenda to be applied in the Amazon biome, focused on the system’s capacity to maintain key conditions of its biological, social and functional identity in the face of climate change. Drawing from the identification of pressures and transformation drivers originating in climate change, we identify two possible complementary approaches that have different implications for dynamically managing the biome: avoiding change and acknowledging change. The first tries to maintain the biome’s functional identity and therefore requires evaluating those zones that exhibit a lower threshold of functional loss in scenarios of climate change and the characterization of biophysical conditions that are responsible for the resilience of these zones, in order to strengthen them.

The second approach, with emphasis on managing change, identifies the need to develop monitoring and research protocols that enable following up on changes in the conditions of the status of species and ecosystems, in order to anticipate and manage these conditions. In some cases, resulting management actions in implementing these two approaches for the biome’s resilience will be in synergy with the traditional conservation agenda.

In this exercise we were able to identify the main inputs for constructing a theory of change in the context of protected areas systems in the biome that responds to challenges in constructing climatic resilience and facilitating change. Responding to these challenges will force us to rethink the current conservation paradigm and will require developing new capacities, including greater comprehension of current ecological processes and their possible evolution, in order to anticipate changes. Considering existing characteristics of the Amazon biome’s functionality that could persist over time, it is necessary that decision makers understand that the challenge lies in maintaining a balance among conservation priorities, ecological processes and functionality of ecosystems within this territory, in order to preserve the integrity of the biome.

A general recommendation would be that from now on, policies for conserving the Amazon should include climate change and resilience criteria for planning and managing protected areas systems in the region, and consider the need for a stronger socio-institutional adaptive capacity that can facilitate natural processes for adapting to climate change. A better understanding of the ecosystem’s functioning that influences the biome’s integrity and the health of its ecosystems and communities will be fundamental for consolidating a regional Amazon Conservation Vision in which protected areas systems can contribute to the construction of the biome’s resilience in the face of present and future climate impacts.

Determining the challenges to come is not an easy task, given the high levels of uncertainty in climate predictions, the multiplicity of factors that affect the biome’s integrity and the health of its ecosystems and species. Even so, the creation of new protected areas or the expansion of existing ones, especially in zones where conservation and resilience potentials are high, their inclusion in landscape approaches and the implementation of strategies that strengthen connectivity within the biome, become fundamental actions for facilitating the process of biodiversity adaptation to climate change and maintaining the supply of ecosystem services in the long term in the Amazon biome.

Regional and biome-level approaches are required, to enable the design and management of large scale ecologic networks that promote trans-boundary interactions for managing national protected areas systems. Another issue is to promote research on the role of protected areas in reducing vulnerability in the face of climate change, and their integration in the institutional context of Amazon governments as effective and cost-efficient ecosystem-based adaptation and mitigation strategies. Finally, protected areas and their role in the arena of climate change must be included in public policies related to management of climate change at the sectorial, regional, national and local levels.

An important contribution of this study is the conceptual approach towards a resilience agenda to be applied in the Amazon biome, focused on the system’s capacity to maintain key conditions of its biological, social and functional identity in the face of climate change.

Constructing a regional resilience agenda

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