Mapping Essential Natural Capital in Amazonia
Identifying important places for biodiversity and ecosystem services

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Rachel Neugarten, Paula Ceotto, Natalia Acero, Bruno Coutinho, Rodrigo Flores-Gutierrez, Michele Hierholzer, Thais Kasecker, Kellee Koenig, Juan Carlos Ledezma, Renata Pinheiro, Will Turner, and Timothy Max Wright
Contributions from: Nathaly Amado, Curtis Bernard, Ivo Encomenderos, Christian Martinez, Sheila Marhe, Maria Isabel Martinez, Eddy Mendoza, Manuel Peralvo, Cesar Ruiz, and Sebastian Troeng
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**Executive Summary**

Maps of *natural capital* - the species and ecosystems that support economic activity and human well-being - are needed by governments to support sustainable development planning, by development banks seeking to make decisions about project investments, by companies seeking to meet sustainability targets, and by civil society organizations seeking to conserve biodiversity and improve human well-being.

Amazonia, which encompasses parts of nine countries in South America, contains the largest tropical forest in the world, the richest biodiversity on the planet, almost a third of the world’s tropical biomass carbon, and produces 20% of the fresh water that reaches the world’s oceans. It is also home to 34 million people, including 375 indigenous groups, who depend on its ecosystems for food, livelihoods, climate regulation, and protection from severe flooding. Ongoing deforestation and climate change threatens to permanently alter this system, turning it drier, destroying its biodiversity, and interrupting the flows of benefits to its people.

Conservation International led a project to map *essential natural capital*, the most important areas for biodiversity and ecosystem services, to support multiple partners and goals across Amazonia. We brought together existing data and conducted new spatial analyses to identify places important for biodiversity, fresh water, climate mitigation and adaptation, and non-timber forest products. Products from these analyses include maps and spatial datasets that can be used by decision makers to identify the most important places to conserve and sustainably manage, to support biodiversity and human well-being.

**Biodiversity**

We identified areas of essential natural capital for biodiversity, including priority areas for conservation derived from national and regional assessments. Collectively, these areas comprise almost 70% of the total study area. More than a third of these areas are already within protected areas (PAs), and one-quarter fall within indigenous lands (ILs). Due to the overlap between these two categories, a total of around 50% of all conservation priority areas have some sort of formal land use designation.

We also identified important areas for endemic (range restricted) species, including areas in the Andes region and on the top of tepuis (rocky plateaus) in the Guiana Shield, as well as the várzea of the Amazonas River, the Brazilian Coast (“Salgado Paraense”), the transition area of Cerrado bioma in the Araguaia basin and the confluence area between the Negro and Solimões Rivers. By applying a threshold, we identified around 25% of the region as being “most important” for endemic species. Of those areas, around 27% are contained within protected areas, and 20% are within indigenous lands.

**Climate mitigation**

Amazonian forests are critically important for long-term global climate regulation because they sequester and store carbon dioxide (CO₂), a major greenhouse gas, from the atmosphere and, when they are lost, CO₂ is emitted back into the atmosphere. Thus we identified areas of importance for the long-term maintenance of biotic carbon stock within natural ecosystems, and the reduction of potential greenhouse gas emissions from deforestation. The highest forest carbon stocks are located in areas that remain undisturbed in the central Amazon Basin and the remote portions of the northern Amazon Basin and Guiana Shield. Based on recent trends, deforestation is predicted to continue to occur primarily along roads, rivers, and agricultural frontiers. There is high vulnerability to deforestation in the southern Brazilian Amazon, and portions of the Bolivian and Peruvian Amazon. The interior of the Amazonian region has relatively low rates of deforestation, primarily due to how inaccessible those areas are. Thus, areas of particular concern for potential emissions from deforestation include central Peru, where there has been a lot of loss within high biomass forests, and in the central Brazilian Amazon along what is known as the “soy road,” the route through which soy is transported from the fields in the south to the coast for export. Although PAs and ILs only cover 46% of the study area, they collectively account for 54% of the total carbon stock. Combined with deforestation rates of about a third of the regional average, there is strong evidence to suggest that protection and land tenure are effective in maintaining forest carbon stocks for climate mitigation.
Fresh water

Fresh water is one of the most essential and plentiful natural resources in Amazonia, a core component of both human well-being and a thriving economy. The Amazon River and its tributaries provide food, transportation, water for domestic use, and energy production, among other benefits. The Amazonian rainforest also plays a crucial role in the global and regional climate system via hydrological feedbacks. We identified essential natural capital for freshwater, areas important for the provision of realized freshwater services (water quality, quantity and flow regulation) supplied by ecosystems. Our focus was on ecosystems that support a relatively high provision of water for two key beneficiaries: population centers and existing hydropower facilities. We mapped areas important for potential freshwater ecosystem services (those that are supplied regardless if they are used) using an eco-hydrological model, WaterWorld. We then mapped realized freshwater services by linking supply areas to population centers and hydropower facilities.

In terms of potential services, the natural ecosystems providing the highest inputs for water quantity are located across the Andean mountain chain and the Orinoquian Basin, with areas of medium importance distributed in the central Amazon Basin. Important areas for flow regulation are located at the northern/central Amazon basin and Guiana Shield. The areas of highest importance for water quality, in terms of soil erosion, are located in the mountainous Andean region and the high elevation areas in the northeast around Venezuela, mainly due to their steep slopes. These areas have high sensitivity to vegetation loss, where natural ecosystems moderate the generation of sediments loads.

By applying a threshold, we also identified the most important areas for realized freshwater ecosystem services. These areas are located in the northwest, southwest and east of the Amazonia Region due to the distribution of beneficiaries in those areas. Depending on the threshold used, around 20-25% of these areas are contained within protected areas, and around 26-30% of the areas are contained within indigenous lands.

Non-timber forest products

Ultimately, all our food comes from nature. Ecosystems provide essential wild sources of food (fisheries and non-timber forest products) as well as essential services to agriculture systems including flows of water, soil fertility, pest and disease control, climate regulation, and pollination. For this analysis, we focused on non-timber forest products (NTFPs), which include fruits and nuts, vegetables, fish and game, medicinal plants, resins, essences and a range of barks and fibers such as bamboo, rattans, and a host of other palms and grasses. We used two approaches to map important areas for non-timber forest products: an approach based on land use categories and a modelling-based approach. For the land use-based approach we mapped indigenous lands, where people are known to depend on NTFPs, and added other areas identified by partners and local experts. This resulted in a map of large areas throughout Amazonia which have known or potential importance for NTFPs.

For the modeling-based approach, we combined data on species occurrences for 112 wild species of known importance for food, ecosystem type data from NatureServe, and an Accessibility model based on proximity to population, roads and rivers, urban areas, land cover, border crossings, elevation, and slope. This resulted in a map of areas of potential (modeled) importance for NTFPs, highlighting areas with larger human populations as well as areas more accessible to people, along the periphery of the region, as well as along roads and rivers.

Climate adaptation

Regional climate models suggest that the eastern Amazonia may become drier by the end of the century, while western Amazonia may experience increased precipitation and humidity. Extreme events - possibly caused by anthropogenic climate change - have already become frequent in the region, with a clear increase in the occurrence of droughts, fires and floods. While climate change has major impacts on species and ecosystems, our focus is on its impacts on humans, and the role of ecosystems in reducing those impacts. Around 45% of the people in Amazonia are considered to live in poverty, and are therefore arguably the most vulnerable to climate change. To evaluate the role of ecosystems in helping humans adapt to climate change, key steps involve identifying: 1) the key climate-related threats people face within a given geography (exposure); 2) where (spatially) people are most sensitive to those threats (sensitivity); 3) the resources those people have to ameliorate those
threats (adaptive capacity); and 4) the role that ecosystems can play in reducing the identified vulnerability(ies) (the composite of exposure, sensitivity and adaptive capacity).

While numerous climate-related impacts are predicted in Amazonia, we focused on droughts and floods, as these have been identified as among the most severe climate change-related impacts in the region. We selected a set of indicators of exposure (predicted changes in water balance), sensitivity (topography, land cover, soil type, and population density) and adaptive capacity (socioeconomic indicators) which interact to influence human vulnerability to climate change impacts in Amazonia. For the exposure analysis, an ensemble of 17 General Circulation Models (GCMs) was evaluated using the hydrological model WaterWorld. Based on this model, the highest exposure occurs in the northeastern and southern parts of the region due to a reduction of precipitation and increases in temperature. Under climate change, areas in the Andean foothills and central Amazonia play an important role in flow regulation. Ecosystems from the northwest play an important role in water regulation services under climate change, even though these areas were not as important under baseline conditions. By applying a threshold, we were able to identify the “most important” areas for flow regulation under climate change. Depending on the threshold applied, 18% of these areas are contained within protected areas, 31% are within indigenous lands. Collectively 46% of the most important areas fall within either category (due to overlap between PAs and ILs).

We mapped adaptive capacity using an index based on 10 socioeconomic indicators related to demographics, access to piped water, health, education, poverty, and inequality. Based on these indicators, there is a trend of lower adaptive capacity in the western Amazon. This may be related to the difficulties of providing education, health and other basic societal needs in remote areas, as in the majority of Amazonia. We combined the maps of exposure, sensitivity, and adaptive capacity in a single map of “vulnerability”, by scaling all the maps from 0-100 and multiplying them. The map shows that the more vulnerable areas are located in the Andean region, as these areas are highly prone to an increase in water flow, and the northeast, influenced by the relatively larger population density in the area, the reduction in water flow in this area and the lower adaptive capacity of its municipalities.

Integration of maps
Combining maps of natural capital can yield insights into areas that are important for multiple benefits, as well as differences. For this analysis, we used two methods to combine the maps: an approach that relies on thresholding, and an additive approach. Ideally, thresholds would be based on information about how much (biodiversity, fresh water, forest carbon) is actually needed in order to maintain human well-being or achieve effective biodiversity conservation in Amazonia. Unfortunately, this information is not available at the regional scale. Therefore, we applied arbitrary thresholds, taking the top 20% and 10% of pixels (1 km² grid cells), by value, for each map.

These map show both similarities and differences between types of natural capital. Collectively they identify large swathes of the region as important, including most of the Andean foothills and western Amazonian basin, large areas throughout the Guiana Shield, including the border of Venezuela and Guiana and most of French Guiana, and large areas along and south of the Amazon River in Brazil. Based on these analyses, we calculated that 22% of essential natural capital (defined as the top 10% of pixels) is contained within protected areas, 24% is contained within indigenous lands, and 43% is contained in either category (note there is some overlap between protected areas and indigenous lands). When we used the top 20% of pixels as the threshold, these percentages changed, but only slightly: 24% falls within protected areas, 23% within indigenous lands, and 44% falls within either category.

To identify areas important for multiple benefits, we conducted a second analysis, scaling all the individual maps of natural capital from 0-100 and adding them, giving all maps equal weight. Again, large areas of the Andes foothills and western Amazon basin show up as important, more limited areas in the Guiana shield, and large parts of the eastern Amazon basin in Brazil.
Policy applications
While all of Amazonia’s natural capital is important, the many maps presented here highlight the “most important”, or essential, natural capital within this important region. A considerable percentage of Amazonia’s essential natural capital is already under some kind of legal designation. However, deforestation continues to threaten the region, including within protected areas and indigenous lands. Information about the spatial configuration of natural capital could inform public and private policies aiming at reconciling conservation and development, such as those aimed at maintaining the quality and quantity of freshwater flows, or the definition of “no-go areas” for project investments. The maps could inform the development and tracking of national Sustainable Development Goal (SDG) targets, identifying areas to target for biodiversity conservation to support the Convention on Biological Diversity, to meet avoided deforestation commitments such as Guyana’s Low Carbon Development Strategy, national REDD+ policies, or INDCs submitted to the UNFCCC, or National Adaptation Plans of Action for addressing threats from climate change. Many relevant policy targets are summarized in the last section of the report and in Appendix 1.

More importantly, we believe the approaches developed in this project and the resulting maps and information could help to build a regionally-integrated vision for Amazonia’s sustainable development. The use of these region-wide results will be essential to maintain the coherence of policies developed nationally and sub-nationally. After all, recognizing that this is a connected region, and that nature has no political boundaries, is key to the success of sustainable development in Amazonia.
Introduction

Maps of natural capital - the species and ecosystems that support economic activity and human well-being - are needed by governments to support sustainable development planning, by development banks seeking to make decisions about project investments, by companies seeking to meet sustainability targets, and by civil society organizations seeking to conserve biodiversity and improve human well-being.

Amazonia, which encompasses parts of nine countries in South America, contains the largest tropical forest in the world. It makes up 53% of remaining tropical forests on the planet (Mittermeier et al. 2003). It is three times greater than the forests of Congo, in central Africa, and eight times greater than the forests of New Guinea. Amazonia is not only forest, however. Several other unique ecosystems exist in the region, from huge seasonally flooded grasslands to the most well protected mangroves on the planet. Its forests contain almost one-third of all tropical biomass carbon (Saatchi et al. 2007), and nearly 10% of the world’s endemic plant species (Mittermeier and Gil 2002). The region is also home to the largest and most voluminous river in the world: the Amazon River, which is responsible for 20% of the fresh water that reaches the world’s oceans (Macedo and Castello 2015).

Around 34 million people live in Amazonia, or 10% of the population of South America, the majority (65%) of whom live in urban areas (ARA, 2011). Around 45% of Amazonia’s population is considered to live in poverty. It is very culturally diverse, with a mix of indigenous, African and European influences. The indigenous culture is the strongest in rural Amazonia. Around 375 indigenous peoples, speaking about 240 languages, live in the region.

Local people, as well people throughout South America and the globe, depend on the ecosystems of Amazonia for numerous benefits. Amazonia’s forests, rivers, wetlands, and savannas harbor unparalleled numbers of species, provide flows of fresh water that supply cities, and food production; contain carbon stocks that mitigate global climate change; reduce the impacts of severe flooding; and provide wild sources of food, fuel, and raw materials for rural and traditional communities.

However, Amazonia is under threat. Deforestation has led to the loss of more than 13% of the region’s forest cover since 1970 (RAISG, 2015). Projections suggest that if the current pace of deforestation is not halted soon, climatic conditions will become drier and the system may become more open and drier, where fire risks are even higher and precipitation and humidity lower (Nobre 2014).

The most significant pressures include roads, which are at the beginning of the deforestation process. There is a high correlation between paved roads and deforestation: it is estimated that in 80% of the cases in Brazilian Amazon, deforestation is found within a distance of 30 km from paved roads (Barreto et al, 2006). Indeed, the presence of roads is an incentive to expand human settlements and intensify farming, logging, mining, and other human activities (RAISG 2013). Agriculture, legal and illegal mining, oil and gas extraction, logging, and hydropower dams are among the most important deforestation pressures in the region. The main environmental impacts of deforestation include loss of biodiversity, reduction of water availability and regional rainfall, and CO₂ emissions, which exacerbate global climate change (Fearnside 2005).

Conservation International led a project to map essential natural capital, the most important areas for biodiversity and ecosystem services, to support multiple partners and goals across Amazonia. We brought together existing data and conducted new spatial analyses to identify places important for biodiversity, fresh water, climate mitigation and adaptation, and non-timber forest products. Products from these analyses include maps and spatial datasets that can be used by decision makers to identify the most important places to conserve and sustainably manage, to support biodiversity and human well-being. The maps could, for example, be used to guide the government prioritization of areas for environmental protection or restoration, as a screening tool for multilateral finance institutions to avoid developing projects in sensitive areas, or to guide private sector funding for conservation. A number of relevant policy targets related to biodiversity, climate change, water, and food security from Amazonian countries are summarized in the Conclusion and in Appendix 1.
**Definition of study area**

We define Amazonia as the full extent of the vast region of tropical rainforest of northern South America, including the forests of great drainage basins of the Rio Amazonas and its tributaries, the forests of southern (in Venezuela) and southwestern (in Colombia) tributaries of the Rio Orinoco, and the forests of the Guianas, the rivers of which drain into the Atlantic. The boundaries are as follows:

<table>
<thead>
<tr>
<th>East and Northeast</th>
<th>the Atlantic Ocean</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>the eastern slopes of the Andes incorporating the headwaters of the Amazon River</td>
</tr>
<tr>
<td>Northwest</td>
<td>the transition zone between forest and the llanos of Colombia and Venezuela, which in Venezuela is demarcated by the mainstream of the Orinoco.</td>
</tr>
<tr>
<td>South</td>
<td>the legal limit of the Brazilian Amazon*</td>
</tr>
</tbody>
</table>

*The legal Brazilian Amazon contains portions of other biomes in Brazil (e.g. the cerrado) and is therefore larger than the Amazon biome. For this report, we chose to use the legal Brazilian Amazon, but the area can be reduced for subsequent analyses.

*Figure 1. Study area: Amazonia region*
Amazonia can be divided conceptually into three zones: Green, Red, and Yellow.

**Green Zone:** Approximately 44% of Amazonia falls within formally designated protected areas or indigenous lands and territories. These areas present opportunities for strengthening management in order to ensure conservation of biodiversity and ongoing provision of ecosystem services.

**Red Zone:** About 13% of Amazonian forests have been converted to agriculture, developed into cities, or degraded to meet demand for food, homes, power, and jobs as of 2010. These areas might be targeted for restoration or agricultural intensification, to take pressure off remaining natural habitats.

**Yellow Zone:** An estimated 46% of Amazonia remains as mostly forest or other natural habitat, and currently is unprotected. These areas are comprised of government-owned areas, private lands, concessions, or other land uses. They may present opportunities for protection, restoration, or other strategies such as community conservation agreements, payments for ecosystem services, or integrated conservation and poverty alleviation projects.

**Methods**

We mapped the Green / Yellow / Red Amazonia using a combination of data sources:

1. Protected Areas were based on the official and most updated information from every country, including both national and subnational (e.g. municipal) protected areas. The data sources are as follows: **Bolivia:** National Protected Areas, SERNAP 2009; municipal, departmental or regional protected areas data collected by Conservation International Bolivia in 2009. **Brazil:** Ministry of Environment (MMA) 2015. **Colombia:** IGAC 2015. **Ecuador:** Ministerio del Ambiente del Ecuador (MAE) 2015. **Peru:** SERNANP 2014. **Venezuela:** Geodatabase from the CBC Andes 2006.

2. Indigenous lands were also based on the official and most updated information from every country. **Bolivia:** INRA 2014; **Brazil:** FUNAI 2015; **Colombia:** IGAC 2015; **Ecuador:** CODENPE 2013; **Peru:** Instituto del Bien Común (IBC), 2014

3. Agricultural areas and deforested areas as of 2010 were based on NatureServe Ecosystems of South America (Comer et al. in prep). Urban areas were identified using ambient population values above 1,000/km², obtained from LandScan 2014.

4. Forest cover and other natural ecosystems as of 2010 were obtained from NatureServe Ecosystems of South America (Comer et al. in prep).
Figure 2. Green, Yellow, Red Amazonia

References for this section


Comer, P.J., J. Hak, and C. Josse. In prep. Long-Term Trends in Extent of Terrestrial Ecosystem Types of Temperate and Tropical North America and South America. For PloS ONE.


Mapping Essential Natural Capital for Biodiversity
Compiled by Thais Kasecker, Juan Carlos Ledezma, Timothy Max Wright, and Rachel Neugarten

Biodiversity—the variability among species, ecosystems, and ecological processes—is fundamental to the planet’s health and humanity’s survival. It is the essential base of natural capital which supports human well-being and economic activity.

Areas of essential natural capital for biodiversity include habitats harboring threatened and protected species, threatened and unique/rare ecosystems, exceptionally high species richness, endemic and restricted-range species, migratory and congregatory species, including spawning grounds, and areas where key evolutionary and ecological processes occur.

The Amazonian region is one of the richest areas of biodiversity on the planet. Its mega-diversity is the result of the interaction of climate, geology, and historical and geomorphological processes, among other factors. Amazonia contains around 2.5 million insect species, 2,200 fish, 1,294 birds, 427 mammals, 428 amphibians, 378 reptiles and 40,000 plant species (Rylands et al., 2002). This biodiversity favored the development of economic activities related to timber and non-timber forest products and wildlife. To date, there are over 2,000 species known to be useful for food, medicine, and other purposes. However, experts say our knowledge of useful Amazonian species is incipient, considering the immense biotechnological potential of the region.

The diversity, phylogeny and distribution of organisms in Amazonia is still poorly understood. There are many areas that scientists have never visited (Santos et al. 2015), and many specimens of numerous taxonomic groups collected during the last three centuries have not yet been studied in detail. However, based on the available information on terrestrial vertebrates, most species are not widely distributed in the region (Silva, 2005). Rather, they occur in clearly defined regions called "areas of endemism."

For this analysis, we focused on one dimension of importance for biodiversity: endemism. Endemism is generally defined as “restricted to a particular area” (Crisp et al. 2001). Measures of endemism are dependent on the geographical scale of interest (e.g. a species can be endemic to a local site, country, region, or even continent.)

Areas of endemism (also referred to as “endemism centers”) are important because they are considered the smallest geographical units for historical biogeography analysis and are therefore the basis for the formulation of hypotheses about the processes responsible for the formation of regional biota (Cracraft, 1985, 1994; Morrone, 1994; Morrone & Crisci, 1995). Moreover, they are home to unique and irreplaceable species. The hypothesis that Amazonia is not a unique biogeographical entity is an old one, and Wallace in 1852 divided the region into four areas of endemism (“districts”) based on an analysis of the distribution of primates: Guyana, Ecuador, Peru and Brazil. The boundaries of the districts he identified were the Amazonas-Solimões, Negro, and Madeira rivers. His hypothesis has been supported by studies of other vertebrate groups (Snethlage, 1910; Sick, 1967; Haffer, 1969, 1992; Caparella, 1988, 1991) and new analyses of the primates of the region, based on the most recent information available about their taxonomy and distribution (Rylands, 1987; Ayres and Clutton-Brock, 1992).

Haffer (1978, 1985, 1987), Haffer & Prance (2001) and Cracraft (1985) identified seven areas of endemism for birds in the lowlands, all contained in the biogeographical districts proposed by Wallace. Guyana remained a distinct area of endemism, the Ecuador district was divided into two districts (Imeri and Napo), the Peru district was renamed Inambari and the Brazil district was separated into three districts (Rondônia, Pará and Belém). Recent studies support this analysis of areas of endemism (e.g., Ávila-Pires 1995, lizards, Silva & Oren, 1996 primates; Ron, 2000, amphibians). Silva et al (2002) suggested that within the Para area, endemism is composed of two areas: Tapajós and Xingu, and Borges & Silva (2012) more recently suggested a new one: the Jaú Area of Endemism, between Solimões and Negro rivers, all of these based on new information on the distribution and taxonomy of bird species.

Thus, nine main areas of endemism have been recognized for terrestrial vertebrates in Amazonia. Endemic areas identified for forest butterflies (Brown, 1979; Tyler et al., 1994; Hall & Harvey, 2002) and vascular plants (Prance 1982) generally coincide or are within the proposed areas for terrestrial vertebrates, indicating good spatial
congruence in the distribution patterns of these different taxonomic groups. It is not yet clear whether the nine areas of endemism in Amazonia form a single biogeographic unit (that is, if they are historically more related to each other than to other areas of endemism outside Amazonia) (Morrone & Crisci, 1995). Thus, even though the areas of endemism in Amazonia share a large number of ecological characteristics, its biota is grouped independently. It cannot therefore be regarded as a single region for conservation planning purposes. These areas of endemism must be considered separately as priorities for conservation action because each one of them contains unique biota (Fjeldsa, 1993; Silva, 2005; Borges & Silva, 2012; Stattersfield et al. 1998).

Here, our aim is to identify intermediate-scale centers of endemism, or core areas for each area of endemism, recognized here as essential natural capital for biodiversity in Amazonia, containing unique biotas of great importance for recent evolutionary processes. Therefore, based on the endemism centers theory, which indicates nine important areas with different pools of species, these core areas could be identified by using species distribution analysis. Narrowly endemic species play an important role on highlighting these core areas and reinforce the need for conservation, since they are potentially threatened species (being rare by definition).

In addition to the areas of endemism at intermediate scales, an analysis of the political and regional context of official biodiversity conservation targets was also carried out for this study. Enormous and growing environmental problems and a chronic shortage of resources to tackle them require conservationists and politicians to set priorities for investment. Several global conservation prioritization exercises have been undertaken, using a range of different criteria, primarily relating to biological importance and levels of threat. They range in scale from large regions such as Biodiversity Hotspots (Mittermeier et al. 1998) to discrete sites such as Alliance for Zero Extinction sites (Ricketts et al. 2005), Important Bird Areas (BirdLife International 2008) and Key Biodiversity Areas (Langhammer et al. 2007). The ultimate goal of prioritization exercises is to facilitate the safeguarding of the most important sites. This is often achieved through legislative means by designation as protected areas. At the regional and country scale in Amazonia, some federal governments carried out their own official exercise of prioritizing areas for biodiversity conservation, involving universities, experts and policy makers in different fields. As a result, they establish policies, strategies and actions for prioritizing sites within each of the selected areas. This was the case for Brazil (MMA, 2007), Bolivia (Araujo et al, 2010), Ecuador (Cuesta et al, 2006), Peru (INRENA, 2008). For the Guiana Shield region (Suriname, Guyana, French Guiana, Venezuela and Colombia) a regional assessment for setting priority areas for conservation was conducted in 2002, reviewed in 2011 by a team from Conservation International (Bernard et al, 2011).

Methods – priority areas map
The priority areas for biodiversity map is based on data collected from national and regional prioritization exercises, where the most important sites for biodiversity conservation have been identified using different methods and were ranked using different criteria. In this sense, this analysis is a synthesis of national (or regional, in the case of the Guiana Shield) prioritization exercises which are important for defining national policies for biodiversity conservation in Amazonia. The analysis was conducted in consultation with staff from Conservation International in each country, and validated with partners (including representatives from other conservation NGOs) at a regional workshop in Manaus in October 2015. The existing ranks were reclassified as Very High, High or Medium, considering the original rank priority assigned in each case.

Methods – weighted endemism map
The creation of specialized geographical software such as ArcGIS to support Geographic Information Systems (GIS) has made it possible to conduct very large-scale studies in which variables such as species richness is mapped on a grid, and hotspots or centers are identified using common statistics or even visually by eye (Crisp et al., 2001). This is the approach used in the present study. As the concept of endemism is tied to particular areas, recognition of centers of endemism is dependent on scale (and the density of sampling). So, areas of endemism are identified through general patterns of species richness as a context for interpreting the core sites for each center of endemism.

For species distribution, the bird species database from BirdLife International and NatureServe (2014) was used, and for mammals, reptiles and amphibians the IUCN RedList database (2014) was used. The data is comprised of
GIS shapefiles or GIS Geodatabase which include polygons which define the distribution of each species. All species with ranges that intersect the Amazonia study area boundary were included, and the area occupied by each species in the study area was calculated. This was used to create an index of range rarity, calculated by dividing 1 by the area occupied by each species. The result of this analysis is that species with small ranges get assigned higher index values, while species with large ranges get assigned lower index values. The next steps of the analysis involved calculating the “weighted endemism” of a given pixel (by summing up all individual species range rarity indices; see Crisp et al. 2001 for detailed methodology). All these steps were conducted using data in a raster format with 1km resolution. The resulting values on the map ranged between 0-120, with the vast majority of the study area varying between zero and 0.04 (very low weighted endemism). To normalize the distribution for analysis purposes, the pixel values were multiplied by 1000 and the square root was taken (using ArcMap 10.3, Raster Calculator Tool).

For the analysis of weighted endemism within each endemism area, the study area was divided into endemism zones, primarily composed of nine endemism centers according to Cracraft (1985), Silva et al (2002) and Borges & Silva (2012). Since they do not cover the entire study area, five additional areas were defined:
- Tropical Andes, being the Biodiversity Hotspot limits inside the study area according to Mittermeier et al (1998);
- Marajó, an archipelago of islands in the mouth of Solimões river, which have not yet been associated with existing biogeographical areas;
- Guaporé-Mamoré, being the headwaters of the Guaporé and Mamoré rivers;
- Cerrado and Pantanal, according to Brazilian biomes, which have their own associated fauna/flora.

The resulting 14 zones of endemism are depicted in Figure 3.

![Figure 3. Zones of endemism used for this analysis](image)

It was decided that “essential natural capital for biodiversity” should be a combination of a regional assessment and an analysis by each endemism zone. The regional case identifies absolute regional essential natural capital, and the endemism zone analysis identifies the important areas within each zone that may have been overshadowed by the regionally dominant areas.
In order to define the final threshold, the range of values of the input raster cells were reclassified into five classes by equal area (using the ArcMap “Slice” Tool). This was done for the regional map (no-zones map) and for all the endemism zones. The highest classes from both assessments were combined into a single final map of essential natural capital for biodiversity.

Results and Discussion

Priority Areas

The priority areas for biodiversity conservation derived from national and regional assessments (Figure 4) comprise more than 566 million hectares, or almost 70% of the total study area. The Very High category is the most significant one, with almost 270 million hectares, while High and Medium priority areas comprise 128 and 161 million hectares, respectively.

![Priority Areas Map](image)

*Figure 4. Existing priority Areas for biodiversity conservation, based on national and regional exercises*

Protected areas and indigenous lands intersect with 34% and 25% of the total priority area, respectively. Due to the overlap between these two categories, in total around 50% of all biodiversity priority areas have some sort of formal land use designation.
Species richness

The database used for the weighted endemism analysis comprises 1057 Amphibians, 144 Reptiles, 743 Mammals and 2276 Birds, totaling 4220 species. (Note that the IUCN Red List of reptiles is not comprehensive of all species; only 144 of 378 known species have been assessed.) The species richness map ranges between 33 and 965 species (Figure 6). The areas that have the highest species richness are located in the headwaters of Javari, Juruá and Purus rivers, on the channel of the Napo River, on the coast of French Guiana, and on the frontier between Brazil, Guyana and Venezuela.

Weighted endemism
Weighted endemism (WE) was calculated for the entire study area (Figure 7) and separately for each endemism zone (Figure 8 b). The regional WE provides an indicator of the importance of an area for biodiversity across the entire region, while the WE by zone assumes that all of 14 areas are important and identifies areas of importance within each one. For the regional analysis, the areas in the Andes region and on the top of tepuis (rocky plateaus) in the Guiana Shield presented a very high level of endemism. This is attributed to the high number of very restricted range species that these places hold, compared to other places in Amazonia. There is a group of ~300 species with very high levels of endemism that “force” the highest ranking in the area in which they are present (mainly in the Andes region).

Figure 7. Weighted endemism at the regional scale

Next, thresholds were assigned to the map of weighted endemism values, to break the values into five classes of approximately equal area (Figure 8). Both assessments (regional and by zone) resulted in similar areas for the five classes, however, they have different spatial patterns. While the regional assessment emphasizes the importance of the Andes region and Guiana Shield for biodiversity, the analysis by zone was able to identify other important places within the Amazonian basin. Regions like the várzea of the Amazonas River, the Brazilian Coast (“Salgado Paraense”), the transition area of Cerrado bioma in the Araguaia basin and the confluence area between the Negro and Solimões Rivers also play an important role in Amazonian endemism.
Essential Natural Capital for Biodiversity within protected Areas and Indigenous Lands

Essential natural capital for biodiversity was defined by the sum of important places within each zone and regionally. So the highest class from each analysis was taken, and combined into a single map (blue area in Figure 9). The total area important for weighted endemism encompasses 212,639,167.727 hectares, representing around 25% of the region.

Figure 9. Essential Natural Capital for Biodiversity: areas of highest importance for weighted endemism, within each endemism zone and regionally
The percentage of essential natural capital for biodiversity within indigenous lands and in the protected areas network was calculated. This assessment indicates, as shown in Figure 10, that 27% of essential natural capital for biodiversity is found in protected areas, and 20% in indigenous lands.

**Limitations and assumptions**

There are a number of assumptions and limitations that should be taken into account in order to have a better understanding and interpretation of these results.

- There are many different ways of setting priority areas for conservation, and the national and regional assessments analyzed here used a wide range of different methodologies. The standardization of the results into three categories (medium, high, and very high priority) does not reflect a comparative analysis for the entire study area, but only consistent way to identify highest priority areas across the countries.

- Weighted endemism is only one way of prioritizing important areas for biodiversity; other prioritization methods typically take into account threatened and protected species, threatened and unique/rare ecosystems, exceptionally high species richness, migratory and congregatory species, including spawning grounds, and areas where key evolutionary and ecological processes occur. A more comprehensive assessment of priority areas for biodiversity in Amazonia should consider some or all of these other components.

- In addition, the systematic conservation planning literature recommends incorporating other, non-biodiversity related data for prioritization, including information on the cost and probability of success of conservation interventions, the level of threat, the level of existing investment or representation of biodiversity in existing protected area systems, and other considerations (e.g. Margules and Pressey 2000).

- This analysis was based on four taxonomic groups (amphibians, reptiles, mammals and bird), it is missing some known important groups for the analysis of endemism such as plants and invertebrates (insects);

- The compilation of the data depends on the input of experts and also constant integration of the IUCN Red List database. So some species distributions might be out of date or incomplete, and might not correspond with the recent findings;

- For example, the IUCN Red List data on reptiles is not comprehensive of all species; only 144 species of reptiles out of 378 known species have been assessed;

- The thresholds established for essential natural capital for biodiversity (five classes of approximately equal area) was defined by the team involved in the analysis and will be affected by the spatial limitations that original database might have.

**References and data sources for this section**


Slater, C., D Rosauer1 and F.Lemckert. 2007. An assessment of endemism and species richness patterns in the Australian Anura. J. Biogeogr. 34, 583–596


Mapping Essential Natural Capital for Climate Mitigation
Compiled by Timothy Max Wright

Introduction
Tropical forests are critically important for long-term global climate regulation because they sequester and store carbon dioxide (CO$_2$), a major greenhouse gas, from the atmosphere and, when they are lost, CO$_2$ is emitted back into the atmosphere. Recent studies have shown that deforestation accounts for between 12-20% of global greenhouse gas emissions, making it the second biggest contributor to global CO$_2$ emissions after the consumption of fossil fuels (Van Der Wurf et al., 2009). Amazonia is particularly important because it is the largest contiguous rainforest in the world and stores almost one-third of all tropical biomass carbon (Saatchi et al. 2007). Despite national and international efforts to stop deforestation in Amazonia, forests continue to be lost to agricultural expansion for soy, oil palm plantations, timber and cattle grazing (Godar et al. 2015). The ability to quantify the amount of carbon that is stored in Amazonian forests and identify where it is being lost is essential for informing international emission targets and national climate policies.

Methods
Mapping essential natural capital for climate mitigation involves identifying areas of importance for the long-term maintenance of biotic carbon stock within natural ecosystems and the reduction of potential greenhouse gas emissions from anthropogenic activities within those ecosystems, such as from land use change. To achieve these objectives two aspects of natural capital need to be mapped; biomass carbon stock and potential avoided CO$_2$ emissions. Both indicators need to be mapped in a way that is both spatially explicit and can be updated over time.

Mapping biomass carbon stock requires information on the current land cover (LC) and the density of vegetation biomass. It is important that the methods used for mapping biomass carbon be easily updated, so that the results can be monitored over time and that the framework can be adaptable so that it can take advantage of the best available scientific data for a given region of interest. Although forest biomass data is often only available for a single time period, there are datasets which monitor deforestation on an annual basis. Therefore a method of interpolation and updating was used to create a map of forest carbon stock that can be updated as additional deforestation information becomes available. For the purpose of this analysis only forest biomass, both above-ground and below-ground, was considered. Soil carbon was not included in the biomass carbon assessment, nor was post-deforestation land-use emissions, such as emissions associated with agriculture.

The potential avoided emissions map combines forest biomass information with the likelihood that a forested area will be deforested in order to assess areas that are both important CO$_2$ stocks and are highly vulnerable to deforestation. There are multiple spatial modeling methods for assessing vulnerability to deforestation. For this analysis, a simple proximity-based model was used to calculate the future rate of change based on the historical deforestation within 20 kilometers. This rate was combined with the remaining forest biomass carbon to get the projected carbon loss per year, and then converted to CO$_2$ equivalents (CO$_2$e) to get the projected annual emissions.

The outputs for the climate mitigation aspect of essential natural capital are continuous maps of forest biomass in the year 2014 across Amazonia and a continuous map of the potential avoided emissions based on historical deforestation from 2010 to 2014. Both maps cover the entire Amazonia region and have a spatial resolution of 1 square kilometer.

The methods used to create the maps of essential natural capital for climate mitigation are outlined below:

Creating forest cover and loss map (hectares per 1 km grid cell):
- Input data:
  - 30 m LC map recoded to forest and non-forest, 2010 (Chen et al. 2014)
  - 30 m forest cover change data 2011-2014 (Hansen et al. 2013)
  - 1 km grid cell “fishnet” (created for this analysis)
1. Calculate the number of forest and loss pixels per 1 km grid cell using “Summary report of Matrix” in ERDAS Imagine.
2. Convert pixel counts to area (ha) per 1 km grid cell based on the formula below:

\[
\begin{align*}
\text{Forest Area 2010 (ha)} &= \left( \text{Forest pixels per gridcell} \times \left( \frac{1111.111}{\text{pixels per gridcell}} \right) \right) \times 0.09 \\
\text{Loss Area 2011 – 2014 (ha)} &= \left( \text{Loss pixels per gridcell} \times \left( \frac{1111.111}{\text{pixels per gridcell}} \right) \right) \times 0.09
\end{align*}
\]


**Calculating the vulnerability to deforestation (percent/year):**
- **Input data**
  - 1 km resolution map of forest area 2010 (units are in ha)
  - 1 km resolution map of deforestation area 2011-2014 (units are in ha)

1. Use focal statistics to sum the total forest area and total forest loss within a 20 kilometer radius (20 pixels)
2. Using raster calculator, divide the forest loss area (2011-2014) by the starting forest area (2010), and then divide by 4 years to get the percent loss per year:

\[
\text{Percent loss per year} = \left( \frac{\text{Loss Area 2011 – 2014 (ha)}}{\text{Forest Area 2010 (ha)}} \right) / 4 \text{ years}
\]

**Calculating standing forest carbon stock (tonnes):**
- **Input data**
  - 1 km resolution map of forest area 2014 (ha)
  - 1 km resolution biomass density map (t/ha)

1. Create a forest biomass layer from the biomass density layer by identifying 1 km grid cells that are 99 percent or greater forest, these are referred to as “pure forest pixels”.
2. Interpolate the above ground biomass (AGB) density values from the pure forest pixel values to all 1 km pixels using inverse weighted distance or kriging.
3. Multiply the interpolated AGB density by the 2014 Forest Area per 1 km grid cell to get tons of AGB per grid cell.
4. Convert AGB values to Carbon using the following formula, which calculates below ground biomass (Mokany et al. 2006), and converts biomass weight to carbon weight:

\[
\text{Carbon (t)} = \frac{\text{AGB} + ((0.489) \times (\text{AGB})^{0.89})}{2}
\]

**Calculating the potential avoided emissions (tonnes CO\textsubscript{2}e per year):**
- **Input data**
  - 1 km resolution standing forest carbon stock (tC)
  - Vulnerability to deforestation (percent/yr)

1. Multiply the standing forest carbon stock by the vulnerability to deforestation to get the annual carbon stock loss
2. One tonne of carbon equals 44/12 (or approximately 3.6667) tonnes of carbon dioxide. Convert the carbon stock loss (tC) to CO$_2$e emissions (tCO$_2$e) by multiplying by 44/12 to get the potential CO$_2$e emissions per year.

Results: Forest carbon stock 2014

The above biomass map was created using the methodology previously outlined. The highest forest carbon stocks are located in areas that remain undisturbed in the central Amazon Basin and the remote portions of the northern Amazon Basin and Guiana Shield. There are low value along the Andean edge on the west, where the forests have naturally less biomass and there is a mix of both forest and natural non-forest land-cover, and in the southern/eastern portion of the Brazilian Amazon, which has been heavily deforested for agriculture.
Results: Vulnerability to deforestation

Figure 12. Recent deforestation 2010-2014

Figure 13: Vulnerability to deforestation based on recent deforestation from 2010-2014. Values range from 0% per year (low) to 20% per year (high) (per 1km square pixel).
The map of vulnerability to deforestation is based on the observed historical deforestation within a 20 km radius moving window. Therefore the predicted percent of deforestation within a given cell is equal to the total deforestation that occurred within 20 km of the cell between 2010-2014, divided by the amount of forest within 20 km in 2010, then normalized by the number of years. Based on this analysis, deforestation is predicted to occur primarily along roads, rivers, and agricultural frontiers. There is high vulnerability to deforestation in the southern Brazilian Amazon, and portions of the Bolivian and Peruvian Amazon. The interior of the Amazonian region has relatively low rates of deforestation, primarily due to how remote and inaccessible those areas are.

Results: Potential avoided emissions

The map of potential avoided emission is the combination of the carbon stock map and the vulnerability to deforestation map. The result identifies areas that have both high biomass carbon and are at risk of being deforested, and hence releasing that carbon into the atmosphere. There are some interesting differences between the potential avoided emission map and the previous vulnerability map. Two areas of particular concern are in central Peru, where there has been a lot of loss within high biomass forests, and in the central Brazilian Amazon along what is known as the “soy road,” the route through which soy is transported from the fields in the south to the coast for export.
Results: Carbon stock and land-cover change 2010 – 2014

Table 1: Deforestation and carbon stock by land-use

<table>
<thead>
<tr>
<th>Carbon stock estimates by land-use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amazon study area</strong></td>
</tr>
<tr>
<td>Total area (ha)</td>
</tr>
<tr>
<td>Total forest carbon stock 2014 (tC)</td>
</tr>
<tr>
<td>Forest Area 2010 (ha)</td>
</tr>
<tr>
<td>Forest Area 2014 (ha)</td>
</tr>
<tr>
<td>Average forest carbon stock (tC/ha)</td>
</tr>
<tr>
<td>Deforestation rate 2010-2014 (% yr-1)</td>
</tr>
<tr>
<td><strong>Protected areas</strong></td>
</tr>
<tr>
<td>Total area (ha)</td>
</tr>
<tr>
<td>Percent of total area</td>
</tr>
<tr>
<td>Total forest carbon stock 2014 (tC)</td>
</tr>
<tr>
<td>Percent of forest carbon stock</td>
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<tr>
<td>Forest Area 2010 (ha)</td>
</tr>
<tr>
<td>Forest Area 2014 (ha)</td>
</tr>
<tr>
<td>Average forest carbon stock (tC/ha)</td>
</tr>
<tr>
<td>Deforestation rate 2010-2014 (% yr-1)</td>
</tr>
<tr>
<td><strong>Indigenous land</strong></td>
</tr>
<tr>
<td>Total area (ha)</td>
</tr>
<tr>
<td>Percent of total area</td>
</tr>
<tr>
<td>Total forest carbon stock 2014 (tC)</td>
</tr>
<tr>
<td>Percent of forest carbon stock</td>
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<tr>
<td>Forest Area 2010 (ha)</td>
</tr>
<tr>
<td>Forest Area 2014 (ha)</td>
</tr>
<tr>
<td>Average forest carbon stock (tC/ha)</td>
</tr>
<tr>
<td>Deforestation rate 2010-2014 (% yr-1)</td>
</tr>
</tbody>
</table>

The table above highlights the deforestation rates and carbon stocks of protected areas (PAs) and indigenous lands (ILs). It is important to note that although PAs and ILs only cover 46% of the study area, they collectively account for 54.4% of the total carbon stock. (Note PAs and ILs overlap, so their combined carbon stock is slightly less than the sum of their individual carbon stocks as listed in the above table). Combined with deforestation rates of about a third of the regional average, there is strong evidence to suggest that protection and land tenure are effective in maintaining forest carbon stocks for climate mitigation.
Limitations and assumptions
A number of assumptions were made while conducting this analysis and there are limitations to the ways that the results can be applied.

1. Calculations of carbon storage are based on a global dataset. There are multiple forest biomass datasets and there is some level of disagreement between them, especially at the local level. Ideally, these data would be validated using ground-based sampling of biomass carbon stock.
2. Carbon stock is biotic carbon in above- and below-ground vegetation, but not soil carbon. Soil carbon values could be particularly important along the coastal mangroves, however it is currently not considered.
3. The model of vulnerability to deforestation is based solely on proximity and historical deforestation. While this assumption is reasonable, it is not necessarily true; as future deforestation can occur in areas that have no historical deforestation, especially in cases where the drivers of deforestation change, such as if a new road was constructed or a new dam was installed.
4. The 20km radius is based on the literature and expert opinion, as it approximates a realistic distance that people would be willing to travel from roads and infrastructure. It is assumed that areas within 20km of a given site will have similar land-use pressures to the site (managed unit or raster-analysis cell) in question.
5. These indicators should not be interpreted as an estimate of a Reduced Emissions from Deforestation and Degradation (REDD+) reference level or of emissions reductions; those would require more complex and rigorous methodologies (e.g. Voluntary Carbon Standards) to enter the carbon market. In contrast, these analyses are adequate for use in ranking the appropriateness of sites for potential future REDD+ feasibility studies and activities.

References and data sources for this section
Mapping Essential Natural Capital in Amazonia

Compiled by: Natalia Acero

Introduction
Water is considered to be the most essential natural resource (Vörösmarty et al., 2010) and a core component of both human well-being and a thriving economy (Viegestol and Aukema, 2011). Successful water management relies on the identification of water supply areas and the link to human consumption. Therefore, the Amazonian region is highly important as is the world’s largest source of freshwater relatively untouched by human activity. The Amazonian river system encompasses 6.9 million km², 13 major tributaries, and an extensive river network that discharges an average of 6,300 km³ of water to the Atlantic ocean annually, equivalent to 20% of global surface river flows (D’Almeida et al., 2006, Marengo, 2006, Macedo and Castello, 2015). The river network supports the regional economy, providing food, transportation, water for domestic use, and energy production, among other benefits (Macedo and Castello, 2015). The Amazonian rainforest also plays a crucial role in the global and regional climate system via hydrological feedbacks (Marengo et al., 2011).

Essential natural capital for freshwater consists of areas important for the provision of realized freshwater services related to water quality, quantity and flow regulation supplied by ecosystems along upland areas (referred to here as hill slopes) and river channels. Freshwater-influencing ecosystems are defined as those that play a role in the distribution of services, such as forests providing flow regulation and water quality maintenance, flood plains, lakes and river channels. Potential ecosystem services are those provided by ecosystems regardless if they are used by people. Realized ecosystem services are those that provide a good or service to beneficiaries: people or economic sectors, such as population centers, hydropower facilities, or other users that depend on fresh water.

Areas of essential natural capital for freshwater include ecosystems that support a relatively high provision of water for human use or hydropower production (water quantity), avoided erosion and sedimentation (water quality), or provide a stable flow of water (flow regulation). For hydropower production, we focused on existing hydropower facilities only, not proposed facilities.

Methods
In order to identify and map natural capital for fresh water, we implemented a potential ecosystem service quantification using an eco-hydrological model, followed by the identification of services realized by two key beneficiaries identified in Amazonia: population centers and hydropower facilities. We followed a framework for mapping essential natural capital for fresh water developed by Leonardo Saenz (Saenz et al. in review).

The potential services analysis identifies the spatial extent of ecosystems providing freshwater services, even if they are not used by people. Mapping potential freshwater services requires information on biophysical variables such as temperature, precipitation, land cover, solar radiation, and topography, among others. In order to make this methodology replicable in different geographies, without depending on the availability of local data, we used the spatially explicit eco-hydrological model WaterWorld (Mulligan, 2013), which uses globally available data. This allowed us to generate a hydrological baseline and evaluate freshwater ecosystem services.

Using the WaterWorld tool, we identified freshwater quantity and regulation services using the water balance, fog interception and runoff outputs as a proxy. Net soil erosion was used to evaluate water quality services in the region. The WaterWorld model takes as an input land cover data, including three classes: forests, herbaceous vegetation, and bare soil. In order to evaluate the role of ecosystems on the provision of freshwater services, and to obtain the potential services maps, we tested the sensitivity of freshwater ecosystem service variables to land cover change. We did this using an extreme hypothetical scenario in which all current land cover is converted into 100% bare soil. This allowed us to identify which ecosystems (forests and herbaceous vegetation) provide the highest level of potential freshwater ecosystem services.

The realized services analysis identifies the spatial extent of ecosystems providing freshwater services critical to one or more identified groups of beneficiaries. In order to achieve this, we have to identify and validate the
location of users and related upstream supplying sub-basins. Finally, to obtain the realized services maps, we weighted potential services by the amount of service demanded by each group of beneficiaries. In order to do this, we estimated the water demanded per group of beneficiaries as a proportion of the overall water availability. The demand for domestic use in population centers was calculated using number of people living in each population center, multiplied by the average estimated water use per person. For the Amazonian region, depending on socioeconomic status and rural versus urban requirements, estimated water use per person ranges between 100 and 200 liters per person per day (Colombia: IDEAM, 2002, Brazil: ANA 2005; Ecuador: CEPAL, 2012). The demand for hydropower dams was calculated using megawatt production capacity as a proxy.

The output of this analysis of essential natural capital for freshwater is a continuous combined map of realized freshwater services related to quality, quantity and flow regulation for two beneficiaries: population centers and hydropower dams, across the Amazonian region, with a spatial resolution of 1 square kilometer.

The following steps outline the methods used to create the maps of essential natural capital for freshwater:

- Defined specific ecosystem services related to the provision of water quantity, quality and flow regulation.
- Collected spatial data from secondary sources to implement the eco-hydrological assessment of service provision areas. Data on land cover, precipitation distribution, and beneficiaries, among others.
- Implemented ecosystem service quantification analysis for water quantity, quality and regulation using WaterWorld hydrological model (Mulligan et al. 2013).
- Mapped ecosystems of high potential service provision using land cover change sensitivity analysis based on an extreme hypothetical scenario (current land cover converted to 100% bare soil).
- Identified and validated the ecosystem service users, and their location and demand, such as dams and domestic water use, based on consultations with CI staff from seven countries in Amazonia and a partners workshop held in Manaus in October 2015.
- Mapped ecosystems supplying services realized by beneficiaries through use of freshwater by hydropower dams and population centers, weighting potential services by the amount of service demanded by each group of beneficiaries.
- Combined map of ecosystems supplying realized freshwater services in quality, quantity and regulation for these two beneficiaries across the Amazonian region.

Results

Potential Services

Figure 15. a) Important areas for water quantity services and b) Important areas for flow regulation services
The above maps show the important areas for water quantity and flow regulation. The natural ecosystems providing the highest inputs for water quantity, in terms of fog interception, are located across the Andean mountain chain and the Orinoquian Basin. Also there are areas of medium importance distributed in the central Amazon Basin. Values of fog inputs across the mountain areas are relatively low, on the order of 50 - 150 mm/year, and provide a small contribution to the overall water balance in comparison to the high rates of rainfall at the Amazonian region. Important areas for flow regulation are located at the northern/central Amazon basin and Guiana Shield. These areas provide the highest contribution to the overall water balance, and have high water availability throughout the year due to high rates of precipitation. Rates of runoff are positive throughout the year in these areas. Low values are found in the southern/eastern portion of the Brazilian Amazon. Due to seasonal water balance deficits in the southern/eastern region, runoff inputs from the northern/western areas are important to regulate water availability in the region. Areas with high importance on the flow regulation map include habitats with high sensitivity to land cover change, which results in an increase in water balance, thus these areas are providing an important flow regulation service.

The above maps show the important areas for water quality and combined potential freshwater ecosystem services. The areas of highest importance for water quality, in terms of soil erosion, are located in the mountainous Andean region and the high elevation areas in the northeast around Venezuela, mainly due to their steep slopes. These areas have high sensitivity to vegetation loss, where natural ecosystems moderate the generation of sediment loads. The combined potential services map is the average of water quantity, quality and regulation services. This map shows a higher importance of freshwater services in the northwest and central areas of the Amazonian region, with lower values in the southeast.

**Figure 16.** a) Important areas for water quality and b) Combined potential freshwater ecosystem services (quantity, quality, and flow regulation)

**Realized Services**
To map realized services, we defined two key beneficiaries in the Amazonian region: population centers and hydropower dams. In order to identify the location of users (Figure 17) and related upstream supplying sub-basins, we used LandScan global ambient population data from 2014 (Bright et al. 2015), and a compilation of dams datasets from national and global sources (see References and data sources, below).
Mapping Essential Natural Capital in Amazonia

Figure 17. a) Location of main cities (ambient population greater than 10,000 people/km²) (LandScan 2014) and b) Location of hydropower dams larger than 1 megawatt production capacity (Conservation International 2015 collection from multiple sources; see data sources listed below)

Figure 18. Important areas for combined, realized freshwater services: quantity, quality, and flow regulation for population centers and hydropower dams

This resulted in a combined map of realized freshwater services related to water quantity, quality and flow regulation for two beneficiaries: population centers and hydropower dams, across the Amazonian region (Figure
The areas of the highest importance for freshwater services are located in the northwest, southwest and east of the region due to the distribution of beneficiaries. It is important to highlight that even though the Guiana Shield has high potential freshwater ecosystem service values, the fact that there is not a large number of people using the available water downgrades its relative importance in the final map.

Next, we assigned arbitrary thresholds to identify areas with relatively higher importance realized freshwater services: areas above the regional mean value, or areas above the regional mean plus one standard deviation. We considered all areas above a given threshold to be “essential natural capital for fresh water.” We also evaluated the level of protection of essential natural capital for freshwater (defined using these two thresholds) within protected areas and indigenous lands.

**Essential Freshwater Natural Capital within Protected Areas and Indigenous Lands**

We calculated the percentage of essential natural capital for freshwater that falls within protected areas, using spatial data on protected areas boundaries (data collected from each country by Conservation International). As shown in Figure 19, the total extent of important natural capital for freshwater that is currently within protected areas is 19.9% if the mean value is used as a threshold, and 24.9% if the mean value plus one standard deviation is used as a threshold.

![Figure 19. Essential Natural Capital (ENC) for fresh water (in blue) within protected areas (in green) using two different definitions of ENC; a) all areas above the regional mean value and b) all areas above the regional mean plus one standard deviation](image)

We calculated the percentage of essential natural capital for freshwater in indigenous lands. This assessment indicates, as shown in Figure 20, that 25.7% of essential natural capital for freshwater is found in indigenous lands. This value is obtained when essential natural capital is defined as all areas above the mean value. If we use a threshold of the mean plus one standard deviation, the value of essential natural capital for freshwater that is within indigenous lands is around 30%. Essential natural capital for freshwater contained in the network of protected areas plus indigenous lands is 43% and 50%, respectively, using each of the thresholds.
Mapping Essential Natural Capital in Amazonia

**Figure 20.** Essential Natural Capital (ENC) within indigenous lands, using two definitions for ENC: a) areas above the regional mean value, and b) areas above the mean + one standard deviation

**Limitations and Assumptions**

There are a number of assumptions and limitations that should be taken into account in order to have a better understanding of the maps.

- The implementation of the methodology for the Amazonian region is based on a global dataset for precipitation (Hijmans et al., 2005), because consistent precipitation data was not available throughout the region. There is high uncertainty about the Amazonian water balance, however, depending on the input data. The global precipitation dataset should be replaced with local datasets for accurate validation and valuation exercises beyond this application.

- The definition of beneficiaries determines the distribution of essential natural capital for fresh water. Therefore, other important beneficiaries in the Amazonian region such as fisheries and transportation should be taken into account in future analyses in order to better understand water services in the region.

- For the water demand calculation, we assumed water use of 200 liters/person/day. Due to the limitation and quality of the data available, there was not data available on the megawatt production capacity or the height of some of the hydropower dams (needed for estimating water demand), so these dams were left out of the calculations. This means that hydropower demand is underestimated in the analysis. Further analysis on water demand in the area should be objective of future studies.

- Even though monthly seasonality of water availability was taken into account to identify flow regulation services (see Appendices), a comprehensive analysis of seasonality impacts and hydrological connectivity should be the focus of future work.

- This analysis is not ecosystem-specific, therefore the land use change sensitivity analysis using three categories (forest, herbaceous vegetation, and bare soil) should be considered a first attempt to understand the role of ecosystems in the provision of freshwater services to people. Future analyses could investigate the role of more diverse ecosystem types (such as different forest types, savannas, wetlands, or other ecosystems) in the provision of ecosystem services.

- Due to lack of data groundwater services are not included in this application, even though these services are of known importance in Amazonia. In Guyana, for example, most people get their drinking water from ground water wells, not surface water.

- This analysis does not address the potential impacts of proposed future hydropower dams throughout the Amazonian region, which are likely to have significant impacts on water availability. For this analysis we are focusing on the role of ecosystems in supporting existing hydropower facilities; this analysis should not be interpreted as promoting the construction of new hydropower facilities. Impacts of hydropower dams go well beyond those analyzed here, including changes in sedimentation patterns and increase in CO$_2$ emissions from flooded forest, among others. For this reason, new hydropower dams need to be carefully considered before investments proceed.
References and data sources for this section

Hydropower dams data sources: Conservation International 2015 collection from multiple sources, including:


Finer, M., Jenkins, CN (2012). Proliferation of Hydroelectric Dams in the Andean Amazon and Implications for Andes-Amazon Connectivity. PLoS ONE 7:e35126


ECUADOR: Consejo Nacional de Electricidad – CONELEC, 2014

PERÚ: Ministerio de Transportes y Comunicaciones – MTC, 2010


Finer, M., Jenkins, CN (2012). Proliferation of Hydroelectric Dams in the Andean Amazon and Implications for Andes-Amazon Connectivity. PLoS ONE 7:e35126;


Mapping Essential Natural Capital in Amazonia

Mapping Essential Natural Capital for Food Security: Non-Timber Forest Products
Compiled by: Kellee Koenig and Rachel Neugarten (Conservation International)
Key contributor: Manuel Peralvo (Consortium for the Sustainable Development of the Andean Ecoregion, CONDESAN)

Introduction

Ultimately, all our food comes from nature. Natural capital is important for providing numerous benefits that support food security, including game animals, fish, fruit, nuts, seeds, edible and medicinal plants, fuel wood used for cooking, and many others. Natural capital also provides soil and water quality, climate regulation, pollination, and pest control, which allows us to grow crops and livestock. Therefore, essential natural capital for food security is defined in two ways:

- Ecosystems that provide essential wild sources of food (fisheries and non-timber forest products) to vulnerable populations dependent upon them
- Ecosystems that provide essential services to agriculture systems that produce crops and livestock for consumption (e.g. freshwater, soil fertility, pest and disease control, climate regulation, and/or pollination.)

In Amazonia, examples of essential natural capital for food security include:
- Forests or other natural habitats that provide edible plants, fruits, nuts, habitat for hunted species, or other wild sources of food
- Freshwater ecosystems providing fish and other food sources
- Forests, grasslands, wetlands, or other habitats that provide soil and water quality, climate regulation, pest control, pollination, or other ecosystem services that support agricultural and livestock production

This analysis focuses on non-timber forest products. Freshwater fisheries are recognized extensively in the literature as important for food security in the Amazon (for a literature review, see Appendix 3). The Science for Nature and People (SNAP) Western Amazonia Working Group is currently mapping spatially important areas for fisheries (http://www.snap.is/groups/western-amazonia/); unfortunately, their results were not available within the timeframe of this analysis. Due to data limitations, we were unable to map essential natural capital for agricultural production.

Non-timber forest products

According to the International Centre for Forestry Research (CIFOR), non-timber forest products (NTFPs) are any product or service other than timber that is produced in forests. They include fruits and nuts, vegetables, fish and game, medicinal plants, resins, essences and a range of barks and fibers such as bamboo, rattans, and a host of other palms and grasses.

We used two approaches to map important areas for non-timber forest products: an approach based on land use categories and a modelling-based approach.

Methods: Land Use Categories Approach

A simple approach to mapping important areas for non-timber forest products is to compile land use categories that have known importance for NTFPs. This includes indigenous lands, where people are known to depend on NTFPs, and was supplemented by other areas identified by partners and local experts during and following an experts workshop in Manaus, Brazil in October 2015 (Table 2).
Table 2. Land use categories, by country, that permit NTFP extraction.

<table>
<thead>
<tr>
<th>Country</th>
<th>Type</th>
<th>Protected Area Category or Name (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>Indigenous Area</td>
<td>-</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>ANMI Departamental</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area de Inmovilización</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area de Inmovilización Prov. Federico Román</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area de proteccion de cuencas</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area de protegida</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area Natural de Manejo Integrado</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Area Natural de Manejo Integrado Nacional</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Parque Departamental</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Parque Municipal</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Parque Regional</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Refugio de Vida Silvestre</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Reserva científica ecológica y arqueológica</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Reserva de la Biosfera</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Reserva de la Biosfera y Territorio Indígena</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Reserva de Vida Silvestre</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Protected Area</td>
<td>Reserva Nacional de Vida Silvestre Amazónica</td>
</tr>
<tr>
<td>Brazil</td>
<td>Protected Area</td>
<td>Floresta</td>
</tr>
<tr>
<td>Brazil</td>
<td>Protected Area</td>
<td>Reserva de Desenvolvimento Sustentável</td>
</tr>
<tr>
<td>Brazil</td>
<td>Protected Area</td>
<td>Reserva Extrativista</td>
</tr>
<tr>
<td>Brazil</td>
<td>Protected Area</td>
<td>Floresta Nacional</td>
</tr>
<tr>
<td>Brazil</td>
<td>Rural Settlements</td>
<td>-</td>
</tr>
<tr>
<td>Brazil</td>
<td>Traditional Populations</td>
<td>-</td>
</tr>
<tr>
<td>Brazil</td>
<td>Indigenous Area</td>
<td>-</td>
</tr>
<tr>
<td>Colombia</td>
<td>Indigenous Area</td>
<td>-</td>
</tr>
<tr>
<td>Colombia</td>
<td>Protected Area</td>
<td>Cahuinari</td>
</tr>
<tr>
<td>Colombia</td>
<td>Protected Area</td>
<td>Nukak</td>
</tr>
<tr>
<td>Colombia</td>
<td>Protected Area</td>
<td>Plantas Medicinales Orito Ingi - Ande</td>
</tr>
<tr>
<td>Colombia</td>
<td>Protected Area</td>
<td>La Macarena Sur</td>
</tr>
<tr>
<td>Colombia</td>
<td>Protected Area</td>
<td>La Siberia</td>
</tr>
<tr>
<td>Ecuador</td>
<td>Indigenous Area</td>
<td>-</td>
</tr>
<tr>
<td>Ecuador</td>
<td>Intangible Zones</td>
<td>-</td>
</tr>
<tr>
<td>French Guyana</td>
<td>Protected Area</td>
<td>National Nature Reserve</td>
</tr>
<tr>
<td>French Guyana</td>
<td>Protected Area</td>
<td>National Park - Buffer zone/Area of adhesion</td>
</tr>
<tr>
<td>French Guyana</td>
<td>Protected Area</td>
<td>National Park - Core Area</td>
</tr>
<tr>
<td>French Guyana</td>
<td>Protected Area</td>
<td>Regional Nature Park</td>
</tr>
<tr>
<td>French Guyana</td>
<td>Zones de Droits d'Usage</td>
<td>Collectifs</td>
</tr>
<tr>
<td>Guyana</td>
<td>Indigenous Area</td>
<td>-</td>
</tr>
</tbody>
</table>
Results: Land use categories important for non-timber forest products

Indigenous areas are formally recognized and demarcated in the majority of Amazonian countries. These areas are of recognized importance for NTFPs, however data on the specific portions of these areas that are used for NTFPs was not available, therefore the full extents were included on the map for their potential importance (Figure 21). In French Guiana, Zones de Droits d’Usage Collectifs (Zones of Collective Use Rights) are similar to indigenous areas in purpose, and were included in their entirety. Additionally, some countries have select protected area designations that permit NTFP extraction by local communities and were included based on expert feedback. For example, in Brazil, reservas extrativistas and reservas de desenvolvimento sustentável (extractive and sustainable development reserves), and special agrarian reform settlements were included. In Colombia, permitted NTFP extraction is on a park-by-park basis. In Peru, Reservas Territoriales para Pueblos en Aislamiento Voluntario (Territorial Reserves for Peoples in Voluntary Isolation) were included. We were unable to get data on land use categories important for NTFPs in Suriname at the time of this analysis, therefore the map should be considered incomplete for this country.
Methods: Modelling Approach
The modelling approach was based on the work of the Ecosystem Services for Poverty Alleviation (ESPA) group (Porro et al. 2008). It combines two primary inputs:
1. Species occurrence data for species of known importance for NTFPs
2. Accessibility to people

Each of those inputs is itself derived from other data, as described below.

Species Occurrence
Point occurrences of 112 wild species important for food in Amazonia were provided by researchers involved in the ESPA project (Porro et al. 2008). The species included plant species (such as fruits, nuts, and palms) and animal species (such as mammals hunted for game) (see Appendix 2 for a complete list of species included). We focused on food species due to our interest in the role of natural ecosystems in supporting food security. The species occurrence input was created using data on potential ecosystem extent in South America from NatureServe (Comer et al. in prep). The ecosystem types included in the model were:

- Cool Semi-Desert Scrub & Grassland
- Mangrove
- Tropical Cliff, Scree & Other Rock Vegetation
- Tropical Flooded & Swamp Forest
- Tropical Freshwater Aquatic Vegetation
- Tropical Freshwater Marsh, Wet Meadow & Shrubland
- Tropical High Montane Scrub & Grassland
- Tropical Lowland Grassland, Savanna & Shrubland

Figure 21. Areas important for NTFPs, using the land use categories approach. Data on land use categories important for NTFPs in Suriname was not available at the time of this analysis.
Thus the model included natural ecosystems other than forests, if species important for NTFPs were located there.

These species location points were combined with the NatureServe ecosystem data by performing a Spatial Join on the points using a vectorized version of the ecosystem type layer. Once the ecosystem types were identified for all points, points outside the study area and any falling in the “Open Water” category were omitted (see Appendix 2). The number of NTFP species occurring within each ecosystem type (“NTFP species richness”) was calculated in Excel. The Reclassify tool converted the ecosystem raster to reflect each ecosystem’s NTFP species richness.
Figure 23. Number of species important for NTFPs per ecosystem type (Comer et al., in prep)

Table 3. NatureServe ecosystem types (Comer et al., in prep) and number of species important for NTFPs

<table>
<thead>
<tr>
<th>Ecosystem type</th>
<th>Species Richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool Semi-Desert Scrub &amp; Grassland</td>
<td>1</td>
</tr>
<tr>
<td>Mangrove</td>
<td>2</td>
</tr>
<tr>
<td>Tropical Cliff, Scree &amp; Other Rock Vegetation</td>
<td>2</td>
</tr>
<tr>
<td>Tropical Flooded &amp; Swamp Forest</td>
<td>54</td>
</tr>
<tr>
<td>Tropical Freshwater Aquatic Vegetation</td>
<td>2</td>
</tr>
<tr>
<td>Tropical Freshwater Marsh, Wet Meadow &amp; Shrubland</td>
<td>32</td>
</tr>
<tr>
<td>Tropical High Montane Scrub &amp; Grassland</td>
<td>1</td>
</tr>
<tr>
<td>Tropical Lowland Grassland, Savanna &amp; Shrubland</td>
<td>7</td>
</tr>
<tr>
<td>Tropical Lowland Humid Forest</td>
<td>58</td>
</tr>
<tr>
<td>Tropical Montane Grassland &amp; Shrubland</td>
<td>7</td>
</tr>
<tr>
<td>Tropical Montane Humid Forest</td>
<td>31</td>
</tr>
<tr>
<td>Tropical Seasonally Dry Forest</td>
<td>23</td>
</tr>
<tr>
<td>Tropical Thorn Woodland</td>
<td>12</td>
</tr>
<tr>
<td>Warm Desert &amp; Semi-Desert Scrub &amp; Grassland</td>
<td>2</td>
</tr>
</tbody>
</table>

Accessibility
The accessibility input was created by updating the ESPA model in ArcGIS’s Model Builder (Figure 24). This model uses spatial data on roads, rivers, trains, existing land cover types, urban areas, and international borders as all of these features influence travel time, an aspect of accessibility. Each spatial feature was converted to numeric values of travel time in kilometers per hour.
Figure 24. ArcMap Model Builder diagram of the Accessibility model (model provided by Manuel Peralvo, following Porro et al. 2008)
We used the transportation network (roads, rivers, railroads) from the ESPA project's data (Porro et al. 2008) and supplemented it using more recent roads data from several government and NGO sources (see citations at the end of this section) (Figure 25). Each type of transportation and road type was assigned a travel velocity (following Porro et al. 2008, see Table 4) and converted to a raster file. Rivers were assigned a value of 10 km/h.

Table 4. Road type and associated travel time

<table>
<thead>
<tr>
<th>Road type</th>
<th>NTFP model value (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paved</td>
<td>60</td>
</tr>
<tr>
<td>unknown/other</td>
<td>25</td>
</tr>
<tr>
<td>Unpaved</td>
<td>25</td>
</tr>
<tr>
<td>upgrade proposed</td>
<td>35</td>
</tr>
</tbody>
</table>

The dataset of existing ecosystem types from NatureServe (Comer et al. in prep) was dissolved into broad categories and reclassified based on travel velocities identified in Porro et al. 2008 (Table 5 and Figure 25).

Table 5. Land cover type and associated travel time

<table>
<thead>
<tr>
<th>Land cover (&quot;IVC class&quot; with macrogroups to fill in the blanks)</th>
<th>NTFP model value (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Vegetation</td>
<td>2</td>
</tr>
<tr>
<td>Forest to Open Woodland</td>
<td>2</td>
</tr>
<tr>
<td>Polar high Montane Scrub-Grassland</td>
<td>3</td>
</tr>
<tr>
<td>Shrubland-Grassland</td>
<td>3</td>
</tr>
<tr>
<td>Agriculture</td>
<td>4</td>
</tr>
<tr>
<td>Desert Semi-Desert</td>
<td>4</td>
</tr>
<tr>
<td>Pasture</td>
<td>4</td>
</tr>
<tr>
<td>Rock Vegetation</td>
<td>4</td>
</tr>
<tr>
<td>Urban</td>
<td>5</td>
</tr>
<tr>
<td>Open Water</td>
<td>10</td>
</tr>
</tbody>
</table>

Urban areas were identified by Porro et al. 2008 using a night lights dataset with a threshold of 30%, and reclassified to a value of 25 km/h (Figure 25). International borders were considered a barrier to accessibility, and were assigned a value of 1 km/h to take into account the increased travel time required to cross them.
These aspects were mosaicked together in ArcMap to yield a velocity surface, whose values were converted from units of km/h to minutes to cross a given pixel (Figure 26).

Figure 25. Transport (roads, railroads, and rivers), urban areas, land cover, and international borders symbolized by travel time in kilometers per hour

Figure 26. Velocity, in minutes, to cross a given pixel
Togographic constraints are also important aspects of accessibility. SRTM data (Jarvis et al. 2008) was modified to match the resolution of other model inputs, and analyzed for both elevation and slope. These were reclassified into categories, with higher numbers indicating higher elevation or steeper slope, suggesting decreased accessibility (Figure 27). The resulting Velocity, Elevation, and Slope layers were all multiplied together to create a Friction Surface, with higher values indicating greater time to cross a pixel (Figure 28).

![Elevation and slope factors. Higher numbers indicate reduced accessibility](image)

![Friction surface. Darker colors indicate increased traverse time](image)

This fed into the Cost Distance model (Porro et al. 2008), which calculated the least accumulative cost distance for each cell to the nearest population. To ensure all people who could rely on NTFPs were accounted for, ambient population data from LandScan 2014 (Bright et al. 2015) was included (all values above 0 persons/km$^2$ were included). Applying basic calculations using Raster Calculator converted the Cost Distance values to accessibility in hours from a given pixel to the nearest populated area (Figure 29).
The Species Occurrence and Accessibility inputs were combined for the final map by rescaling each input from 1 to 100 using a linear transformation so they would equally factor, and using the following equation:

\[
\text{Importance for NTFPs} = \text{Species Occurrence} \times \frac{1}{\text{Accessibility}}
\]

(Accuracy is the inverse of travel time (i.e. lower travel time equates with higher accessibility) thus we used the inverse in this equation.) Thus, areas with a higher number of known NTFP species, that are more accessible to people, are given a higher value. The result identifies areas that are potentially important for NTFPs.

Initially, potential ecosystem extent was intentionally included so we could calculate how much area might have been important for NTFPs in the past, but has been lost due to conversion/deforestation. Areas that have been deforested/agricultural/urban were then removed using the Set Null, Mosaic to New Raster, and Reclassify tools.

**Results: Modeling approach**

Results of this analysis indicate areas of importance for non-timber forest products in areas with larger human populations or in areas more accessible to people, along the periphery of the region, as well as along roads and rivers (Figure 30). The western Amazonian region, in the foothills of the Andes, comes up as particularly important, as does the coastal region of Guyana, the Rupununi savanna in Guyana, and the mouth of the Amazon river in Brazil, as well as along the main stem of the Amazon and its many tributaries.

While all of these areas should be considered important, this approach allows us to identify the areas that are most important. Applying an arbitrary threshold (in this case, all areas above the mean plus one standard deviation) yields a map of the areas most important for NTFPs (Figure 31).

In examining the results, it is clear that this modelling approach is heavily driven by the Accessibility component. Of the inputs, velocity, particularly transportation and land cover, are the biggest indicators of areas important for NTFPs.
Figure 30. Areas important for NTFPs, based on modeling

Figure 31. Areas important for NTFPs, model approach (with a threshold)
Limitations and assumptions

The land use results assume that all areas depended upon for NTFPs are captured in currently designated and zoned land use categories, and that their use is uniformly spread throughout the region. The missing data from Suriname and Venezuela reflect the lack of recognized and demarcated indigenous lands in that country, and the lack of data on other land use types important for NTFPs in that country.

The modeling-based approach is based on several assumptions, including:

1) Ecosystems with a larger number of known NTFP species are assumed to be more important for NTFPs, which may not be true; the quantity or economic value of the NTFPs contained in an ecosystem may outweigh the number of different species in determining its importance.

2) Ecosystems more accessible to people are assumed to be more important for NTFPs; however, it is known that people are sometimes willing to travel long distances for certain NTFPs (such as game animals). Also, the most accessible locations may be over-harvested and therefore have no value for NTFPs. On the other hand, some NTFP species (such as acai) are often cultivated near people’s homes and farms. Thus the relationship between accessibility and importance for NTFPs is complex and varies depending on the product, the location, and the level of extraction.

We understand there are many other NTFP species in Amazonia, but at the time of this analysis we only had spatial data (point locations) for 112 species, which we used to map ecosystem types where NTFP species are found (following Porro et al. 2008), and this is certainly not a comprehensive list. A related limitation is the different spatial scales and time periods of data sets which were combined for this analysis.

References and data sources for this section

*NatureServe ecosystem types:*
Comer, P.J., J. Hak, and C. Josse. In prep. Long-Term Trends in Extent of Terrestrial Ecosystem Types of Temperate and Tropical North America and South America. For PloS ONE.

*Indigenous lands:*
IIRSA (CI, 2006 building on AmazScen (CI / CABS together with the Woods Hole Research Center (WHRC) and the Instituto de Pesquisa Ambiental da Amazonia (IPAM))
Bolivia: INRA 2014; Brazil: FUNAI 2015;
Colombia: IGAC 2015;
Ecuador: CODENPE 2013;
Peru: Instituto del Bien Común (IBC), 2014;

*Non-timber forest products model:*
Provided by Manuel Peralvo, CONDESAN.

*Population:*

*Protected areas:*

*SRTM:

48 Mapping Essential Natural Capital in Amazonia

Roads:
Mapping Essential Natural Capital for Climate Adaptation
Compiled by: Paula Ceotto, Natalia Acero, Juan Carlos Ledezma, Renata Pinheiro, and Bruno Coutinho

Introduction

The IPCC and regional climate models suggest that the eastern Amazonia may become drier by the end of the century. An opposite trend of increased precipitation and humidity is projected for western Amazonia by the same period (IPCC, 2014). In fact, extreme events - possibly caused by anthropogenic climate change - have become frequent in the region, with a clear increase in the occurrence of droughts, fires and floods (Marengo et al., 2013). Other impacts related to climate change that have been identified as important in the region include landslides, which can be particularly severe in Peru; sea level rise, which is the main risk factor in Guyana and Suriname and threatens coastal communities in these countries; and indirect impacts of all these trends on food security throughout the region.

In addition to climate change effects, deforestation in the region creates a drying trend. There are projections suggesting that if the current pace of deforestation is not halted soon, climatic conditions will become drier and the system may become more open and drier, in which fire risks are even higher and precipitation and humidity lower (Nobre, 2014). This ‘savannization’ would potentially have large-scale impacts on climate, biodiversity and livelihoods locally, as well as globally.

While climate change has major impacts on species and ecosystems, for this analysis our focus is on its impacts on humans, and the role of ecosystems in reducing those impacts. The Amazonian region has a population of more than 33 million inhabitants, around 45% of which are considered to live in poverty (ARA, 2011). The poor are the most vulnerable people to climate change. At a regional or global scale, adaptation measures in Amazonia should aim at creating resilience in the region through a development model based on conservation and sustainable use of biodiversity.

Thus, it would be important to assess if and how ecosystem services may reduce risks of Amazonian peoples to extreme events. To evaluate the role of ecosystems in increasing local resilience to changes in the climate, key steps involve identifying (quantitatively where feasible, otherwise qualitatively): 1) the key climate-related threats (exposure) people face within a given geography; 2) where (spatially) people are most sensitive to those threats (sensitivity); 3) the resources those people have to ameliorate those threats (adaptive capacity); and 4) the role that ecosystems can play in reducing the identified vulnerability (ies) (the composite of exposure, sensitivity and adaptive capacity). It is first important to understand where events potentially caused by climate change are predicted to occur. Here, we assess the vulnerability of Amazonian peoples to droughts and floods, as these events have been identified as one of the most severe climate change-related impacts in the region.

Definitions

The definitions of exposure, sensitivity, adaptive capacity, and vulnerability for this exercise have been taken from the Fourth Assessment Report of the IPCC (AR4) and its conceptual framework of vulnerability assessment.

Exposure is directly linked to climate parameters, that is, the character, magnitude, and rate of change and variation in the climate. Typical exposure factors include temperature, precipitation, evapotranspiration and climatic water balance, as well as extreme events such as heavy rain and meteorological drought. Changes in these parameters can exert major additional stress on systems (e.g. heavy rain events). (Fritzsche et al., 2014)

Sensitivity determines the degree to which a system is adversely or beneficially affected by a given climate change exposure (Parry et al. 2007). Sensitivity is typically shaped by natural and/or physical attributes of the system including topography, the capacity of different soil types to resist erosion, and land cover type. But it also refers to human activities which affect the physical constitution of a system, such as water management and population pressure (Fritzsche et al., 2014).
Adaptive capacity refers to the ability of a system (or people) to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. It is, thus, a set of factors which determine the capacity of a system or people to generate and implement adaptation measures (IPCC 2007 – AR4).

Vulnerability refers to ‘the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity’ (Parry et al. 2007).

Methods
This analysis focuses on a single threat from climate change: impacts on water availability, which will result in changes in floods and droughts. Figure 32 below illustrates how selected indicators of exposure, sensitivity and adaptive capacity are believed to interact to influence human vulnerability to climate change impacts in Amazonia. Each set of indicators is described in more detail below.

![Conceptual diagram of the selected indicators believed to influence vulnerability of people to changes in water availability due to climate change. Exposure indicators are in blue, sensitivity indicators are in green, and adaptive capacity indicators are in orange.](image-url)
Indicators

EXPOSURE INDICATORS
The spatial distribution of predicted changes in water balance due to climate change was used as an indicator of climate change exposure. This component is based on modeling (see below), and is directly linked with the rate of change and variation in precipitation and temperature and their effects on water availability in the region.

SENSITIVITY INDICATORS
Sensitivity indicators include physical attributes which influence the susceptibility of people to changes in water availability, such as topography, land cover and soil type. They also include social attributes such as population density. The assumption here is that regions that are relatively less inhabited will be less vulnerable compared to regions with high population densities, given the same degree of exposure. We used population density derived from LandScan 2014 ambient population data (Bright et al. 2012) as a proxy for human sensitivity to climate exposure.

ADAPTIVE CAPACITY INDICATORS
The indicators included in the adaptive capacity analysis are socioeconomic indicators that were believed to represent the capacity of a given human system to cope with and adapt to climate change. Selection of indicators concentrated on five socioeconomic categories (demography, housing infrastructure, health, education, and income) and was based on a literature review of adaptive capacity indicators (Gall, 2007; Torres et al., 2012; Santos et al., 2014; Yang et al., 2015) Except for Suriname, Guyana and French Guiana, for which only national-level data was available, indicators were collected at the municipality level. Due to the large number of countries and municipalities composing the study area, data on several indicators was not available from every country. If data was available for at least 75% of the countries, it was considered sufficient to be included in the final list of indicators. See Table 6 for the 10 selected indicators.

Table 6. Indicators included in analysis of human adaptive capacity

| Demography | 1) Population under 5 years old - % of the population 5 or younger |
| Housing infrastructure | 2) Population above 60 years old - % of population 60 or above |
| Health | 3) Access to piped water - % of houses with access to piped water |
| | 4) Access to sanitation - % of houses with sanitation structure |
| Education | 5) Child mortality rate (under 5 years) – Rate of deaths of under 5 years old per 1000 |
| | 6) Life expectancy – mean lifespan of the population |
| Income | 7) Illiteracy rate - % of population above 15 years old with inadequate reading and writing skills |
| | 8) Men/women literate – proportion of men/women who are literate |
| | 9) Gini Coefficient – an inequality measure of statistical dispersion intended to represent the income distribution of a nation's residents |
| | 10) Population below the extreme poverty line - % of population living on less than US $1.25 a day |

EXPOSURE ANALYSIS
The analysis referred to in this section is an analysis of the changes in water balance in the system due to climate change (exposure) as well as the physical sensitivity indicators mentioned above (topography, land cover and soil type). The social sensitivity indicator (population density) is described below. To map predicted changes in water balance, an ensemble of mean outputs of 17 General Circulation Models (GCMs) of the IPCC Fifth Assessment Report was evaluated. The eco-hydrological model WaterWorld (Mulligan et al. 2013) was used to determine the change in water balance due to climate change, and accumulate the outputs downstream, focusing on projected changes in seasonal runoff. WorldClim maps are used to produce a hydrological baseline for 1950-2000 (Hijmans et al., 2005). For the ensemble of climate change scenarios, 1-km resolution downscaled projections for the period 2041-2060 provided by the Coupled Model Intercomparison Project Phase 5 (CMIP5, Taylor et al 2012) coordinated by the World Climate Research Programme (WorldClim, 2014) was used.
Variables of monthly temperature (minimum, maximum and mean) and precipitation are used in WaterWorld climate change scenarios to produce the mean values of the following 17 General Circulation Models (GCMs) from the Fifth Assessment Report (AR5):

1. CNRM-CM5 Centre National de Recherches Meteorologiques
2. MIROC Atmosphere and Ocean Research Institute (The University of Tokyo) et al.
3. MIROC-ESM Japan Agency for Marine-Earth Science and Technology et al.
4. GISS-E2-R NASA Goddard Institute for Space Studies
5. ACCESS1-0 CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
6. INMCM4 Institute for Numerical Mathematics
7. IPSL-CM5A-LR Institut Pierre-Simon Laplace
8. BCC-CSM1-1 Beijing Climate Center, China Meteorological Administration
9. HadGEM2-ES Met Office Hadley Centre
10. CCSM4 National Center for Atmospheric Research
11. NorESM1-M Norwegian Climate Centre
12. HadGEM2-AO National Institute of Meterorological Research/Korea Meteorological Administration.
13. HadGEM2-CC Met Office Hadley Centre
14. MIROC-ESM-CHEM Japan Agency for Marine Earth Science and Technology et al.
15. MRI-CGCM3 Meteorological Research Institute
16. MPI-ESM-LR Max Planck Institute for Meteorology (MPI-M)
17. GFDL-CM3 Geophysical Fluid Dynamics Laboratory GFDL-ESM2G

To evaluate vulnerability in the Amazonian region, the high greenhouse gas concentration Representative Concentration Pathways - RCP (Meinshausen et al 2011) was used. RCP8.5, which represents a high-emission, non-mitigation future, yields to a range of temperature outcomes of 4.0 to 6.1°C by 2100 (Rogelj et al., 2012; Knutti and Sedlácek, 2013).

For the exposure analysis we calculated the percentage change in water balance between the baseline and the mean of the ensemble of climate change scenarios. Positive change in the water balance means more water availability in the future, and negative change means less water availability. However for the exposure indicator, an absolute (positive) value is used in order to identify the areas that are exposed to the most change in water availability due to climate change (as a percentage), regardless if it is positive or negative. The indicators were rescaled by applying the min–max method. This method transforms all values to scores ranging from 0 to 100 by subtracting the minimum score and dividing it by the range of the indicator.

ADAPTIVE CAPACITY ANALYSIS
The selected socioeconomic indicators were aggregated into an Adaptive Capacity Index. As a first step towards composing the index, each indicator was rescaled by applying the min–max method, as described above, so that all values ranged from 0-1. In most cases, a given socioeconomic indicator (e.g. poverty) is inversely correlated with adaptive capacity (i.e. lower poverty indicates higher adaptive capacity). In these cases the normalized indicators were subtracted from 1, so that they became directly correlated with adaptive capacity. Each rescaled indicator was then summed and divided by the number of indicators (ten, in this case) to calculate the index by the formula:

$$ACI = \frac{\sum_{i=1}^{10} I_i}{10}$$

Where, ACI is the Adaptive Capacity Index and I is a rescaled indicator.

VULNERABILITY ANALYSIS
The vulnerability analysis was performed by combining the maps from the exposure, sensitivity, and adaptive capacity analyses. All three maps were first scaled 0-100. Note that the lower the adaptive capacity of people, the
higher their vulnerability. Therefore, adaptive capacity was subtracted from 100 so that low values would indicate low vulnerability. Thus, vulnerability was calculated using the following function:

\[
\text{Vulnerability} = \text{Exposure} \times \text{Sensitivity} \times (100 - \text{Adaptive Capacity})
\]

We then calculated the mean value of vulnerability per administrative unit (using the same administrative units used in the Adaptive Capacity map), and mapped the values.

**Results**

*Exposure and sensitivity analysis*

As described above, in order to examine the impacts of climate change in the Amazonian region, an ensemble of 17 General Circulation Models (GCMs) was evaluated using the hydrological model WaterWorld. For precipitation the mean output of the models shows increases in the Andes region and northwest part of Amazonia (200-400 mm yr\(^{-1}\)), and large decreases in the northeast part of the region (300 - 500 mm yr\(^{-1}\)) (Figure 33). As shown in Annex 1, decreases in precipitation in the eastern Amazonian region are consistent through the year. (For monthly output maps, see Appendix 4).

![Figure 33. Change in precipitation projected for the period 2041-2060 for a an ensemble of 17 General Circulation Models (GCMs) RCP8.5 for the Amazonian region (mm yr-1)](image)

For temperature change the different GCMs produce similar patterns in the area. The mean output of the models shows an increase throughout the extent of the Amazonian region of 2°C to 5°C (Figure 34). Highest warming trends are presented in the southeast part of the region.
Climate change produces significant differences in water balance and runoff throughout the basin. In general terms, water balance is reduced in the north and southeast parts of the region, but presents significant increases in the northwest and in the Andes (Figure 35). This generates increases of runoff of up to 100% in the Andes and decreases of up to 100% in central and eastern Amazonia (Figure 36). (For monthly results, see Appendix 4).
The previous information can be used to understand the spatial distribution of the exposure indicator. High percentage of exposure (approximately 30%) occurs in the northeastern and southern parts of the region due to a reduction of precipitation and increases in temperature (Figure 37). The central and northwestern parts of the region have lower percentages of exposure.

In order to investigate one of the key vulnerabilities in the region: change of water availability for human populations, we have to identify where the population centers that could be adversely or beneficially affected by climate change exposure are located. We use population density derived from LandScan 2014 ambient population data (Bright et al. 2012) as a proxy for human sensitivity.
Natural Capital for Climate Adaptation

Climate change is projected to increase exposure to change in water balance across northern and eastern Amazonia. Figure 40 a) shows elevated exposure levels in areas with high population density, overlaid with the forest areas that are most important for flow regulation, based on the WaterWorld model. To identify these important areas we analyzed the impacts on water availability of a hypothetical drastic land use change scenario (see Freshwater section, above) under the ensemble of climate change scenarios (Figure 39). We used the regional mean value plus one standard deviation as a threshold to define the most important natural capital for flow regulation under climate change (i.e. areas above the mean value +1SD were considered “essential natural capital”). Under climate change, areas in the Andean foothills and central Amazonia play an important role in flow regulation. Ecosystems from the northwest play an important role in water regulation services under climate change, even though these areas were not as important under baseline conditions. We also overlaid this map with maps of protected areas and indigenous lands (Figure 40 b). The total extent of essential natural capital for flow regulation under climate change (areas above the mean value +1SD) that is currently within protected areas or indigenous lands is 46%. Of that, 17.5% is classified as protected areas and 31% is within indigenous lands.
Human adaptive capacity analysis
The availability of socioeconomic data at the municipality level varied considerably among the different countries that compose the study area. Appendix 5 summarizes the data that could be gathered from each country and its municipalities. Data for French Guiana, Suriname, and Guyana were available only at the national level instead of municipality level.

In order to evaluate the impact of missing data in the results, we applied national (or departmental, when available) averages for the missing data and calculated the indicator and adaptive capacity maps using this “artificially completed” dataset. As the results of the adaptive index presented almost no change when the two methodologies were compared, it was considered that using the missing data dataset would be the preferable choice. Thus, the results presented below have been obtained with the incomplete dataset. In all the maps below, green colors (low values) indicate higher adaptive capacity and red colors (high values) indicate lower adaptive capacity.

Figure 41 below shows the distribution of the demography indicators. The number of children under five in the northern Amazon of Brazil is greater than that of the Brazilian southern Amazon. Numbers of children under five years old are also generally high in parts of Venezuela, Bolivia, and Ecuador as well. As per the population above 60 years old, higher levels are in southern Brazilian Amazon, small portions of Peru, Bolivia and Ecuador.
Figure 41. a) Age structure, population under 5 years old; b) Age structure, population above 60 years old. In the maps, frequency values are subtracted from 1, so that the lower values are the ones with the higher percentages of the indicator in question. Grey areas are those for which data were unavailable.

Concerning housing infrastructure (Figure 42), a great number of municipalities in Pará, Mato Grosso, Amapá and Rondonia States in Brazil, Peru, and Bolivia lack access to piped water, whereas sanitation facilities are also low in most of Peruvian and Bolivian amazon, and parts of Para state in Brazil.

Figure 42. a) Access to piped water; b) Access to improved sanitation facilities. Grey areas are those for which data were unavailable.
When it comes to health condition indicators (Figure 43), child mortality under five years old is high in Maranhão state in Brazil, Colombia, Venezuela and Guiana, and relatively lower in Mato Grosso, parts of Pará, Roraima and Amapá states in Brazil, as well as in Ecuador and French Guiana. Life expectancy is low in the eastern portion of the Brazilian Amazon, Bolivia and parts of Peru, being higher in Mato Grosso, parts of Pará, Roraima, Equador, Colômbia, French Guiana and parts of Peru.

Regarding education (Figure 44), the illiteracy rate is higher in Roraima, Amazonas, and Acre states, and in the eastern portion of the Brazilian Amazon, as well as in Guyana, Venezuela and French Guiana. Despite the large amount of missing data for the male/female literacy rate in many places, the data show a proportionately higher number of literate women in eastern portion of Brazilian Amazon, as well as a proportionately low number of literate women in Peru, Venezuela and parts of Amazonas state in Brazil.

The income indicators shown in Figure 45 point to lower levels of poverty in the southern portion of the Brazilian Amazon, as well as in parts of Peru, Bolivia, Suriname and Venezuela (numbers for these last two countries need to be further investigated as data sources were quite outdated). The Gini coefficient is considerably lower (indicating more inequality) in the whole of the Brazilian Amazon as compared to the other Amazonian countries. It would be important to further investigate this trend as well, as it is not clear why the Brazilian Amazon would be more unequal than the other countries in Amazonia.

Finally, the adaptive capacity index (Figure 46), which aggregates information from the ten indicators presented above, indicates that the southern and eastern portions of Brazil, parts of Peru, Colombia, Venezuela, Suriname and French Guiana have a better adaptive capacity as compared to other areas, such as most of Colombia, the western portion of the Brazilian Amazon, and parts of Bolivia. It is important to note, though, that the national-level data used for Guiana, Suriname and French Guiana may have biased the results of the analysis.
Figure 44. a) Illiteracy rate; b) Male/female literacy rate. In the maps, frequency values are subtracted from 1, so that lower values always indicate low literacy. Grey areas are those for which data were unavailable.

Figure 45. a) Population below the (extreme) poverty line; b) Gini coefficient. In the map of population below extreme poverty line, frequency values are subtracted from 1, so that the lower values indicate higher poverty. Grey areas are those for which data were unavailable.
Figure 46. Adaptive capacity index calculated at municipality level for Amazonia region. The higher the value, the higher the relative adaptive capacity of a given municipality.

Overall, there is a trend of lower adaptive capacity in western Amazonia, an area known to have high species endemism levels and to be a very important provider of ecosystem services. This may be related to the difficulties of providing education, health and other basic societal needs in remote areas, as in the majority of Amazonia.

Vulnerability analysis

The vulnerability map resulting from this analysis (Figure 47) was obtained using the maps of exposure (Figure 37), sensitivity (Figure 38), and the adaptive capacity index (Figure 46). All three maps were scaled from 0-100 and multiplied by each other. An average vulnerability value per administrative unit was then calculated. The resulting map indicates areas in which there is relatively high exposure (i.e. percent change in water availability), relatively high sensitivity (i.e. human population density more above 0), and/or relatively low adaptive capacity. Please note that the results of this analysis will be affected by the method used to combine the layers and their weights; alternative methods are currently being explored.

The map shows that the more vulnerable areas are located in the Andean region, as these areas are highly prone to an increase in water flow, and the northeast of Brazil, influenced by the relatively larger population density in the area, the reduction in water flow in this area and the lower adaptive capacity of its municipalities.
Assumptions and Limitations

**Exposure and sensitivity analysis**

- This analysis focuses on only a single type of climate-related impact: changes in water availability. A more complete analysis would include other types of exposure that will impact Amazonia, such as sea level rise along the coast, fires, and indirect impacts of climate change on agriculture and fisheries.
- We identify exposure to climate change in terms of percentage change in water balance regardless if it is a positive or negative change. Hence, we don’t calculate drought or flood risk, which would require more detailed data and probability analyses that are beyond the scope of this analysis. Flood and drought risk analysis should be the focus of future work, in order to better understand the role of natural capital that may provide specific adaptation services.
- We analyzed the eco-hydrological sensitivity of the Amazonian system evaluating the change in vegetation cover under climate change. The indicator is not habitat specific, and therefore there is a need for further work to establish the importance of different habitat types (flooded forest, humid forest, savannah, wetlands, etc.) in terms of their ability to provide adaptation benefits.
- We use a complete ensemble of GCMs which reduces the uncertainty in precipitation and temperature projections. However, there is a need for more representative data, especially for precipitation, to provide more representative predictions about water balance and the future impacts of climate change.
- Due to time and data limitations, we didn’t incorporate data on extreme events across the region such as the drought of 2005, likely driven by SST in the Atlantic, data on impacts of the El Niño-Southern Oscillation (ENSO) phenomena, and flooding events such as the ones in 2007 (Bolivia) and 2009 (Brazil),
that could improve the understanding of climate change impacts. Currently, such data is not available consistently for the entire region.

- We ignore the potential impacts of proposed hydropower dams throughout the Amazonian region, which are likely to have significant impacts on future water availability. While beyond the scope of this analysis, future work should consider such impacts in conjunction with climate modeling to understand their combined effects on water availability.

**Human adaptive capacity analysis**

- This analysis has been conceived under the premise that adaptive capacity and human well-being dimensions are correlated. In this sense, socioeconomic data selected to be part of the analysis were indicators generally used to measure human well-being. However, data more clearly related to droughts and flood events exist for some countries and municipalities. These are the primary events the vulnerability analysis intends to model, and to recommend potential adaptation strategies, such as the capacity to use more drought- or flood-resistant crops, human mobility possibilities, or other strategies. Unfortunately, the use of indicators more directly related to droughts and floods connected to climate change would require intensive data collection on the field, through the application of questionnaires, which was not an option within the scope of the present project.
- The socioeconomic indicators used in the analysis are part of national statistics assessments that are biased in the sense that they work with formal education, economics, and health indicators that do not take traditional cultures and knowledge into account. In this sense, the results of the present analysis are biased towards identifying urban centers (as these areas receive better provision of public services related to these dimensions) as the areas where adaptive capacity is higher. However, it is important to recognize that traditional cultures, although not through the usually valued socioeconomic dimensions, may be even more adapted at least in some aspects.
- The missing data and the fact that socioeconomic data came from different sources (census from each of the countries that have part of their territories in the region) may have biased the results.
- Data reliability is also an issue. There are a few anomalies in the data that were used, especially concerning Suriname, French Guiana, and Venezuela, which need to be further investigated for future iterations of the adaptive capacity index.

**Vulnerability analysis**

- The actual relationship between exposure, sensitivity, and adaptive capacity and their role in determining vulnerability of people in Amazonia to climate change is unknown, therefore the map is at best a crude estimate.
- Equal weights have been assigned to each of the maps used to compose the vulnerability results presented here, but one could argue for different weighting of exposure, sensitivity or adaptive capacity.
- Again, this map reflects only a single type of impact from climate change (changes in water availability) and therefore should not be used as a proxy of vulnerability to other types of impacts, such as sea level rise or indirect impacts on food security.

**Replication of Analyses**

Identifying essential natural capital for climate adaptation is challenging due the amount of data required and relevant technical capacity. However, for freshwater-related climate-driven vulnerabilities (e.g. drought or flood) the hydrological model WaterWorld could be equally applied in in any geography of interest using global data sets. The adaptive capacity index could also be applied in any geography of interest using local or national-level socioeconomic data, such as from census.

**References and data sources for this section**

*Socioeconomic data:*
Peru: Instituto Nacional de Estadística e Informática (INEI), 2007
Venezuela: Instituto Nacional de Estadística (INE), Censo 2011

Instituto Nacional de Estadística e Informática (INEI), 2007, Peru.
WorldClim, 2014. CMIP5 30-seconds Downscaled IPPC5 (CMIP5) data at 30 seconds resolution. Available online: www.worldclim.org/cmip5_30s
Integrating Maps of Natural Capital
Compiled by: Rachel Neugarten, Will Turner and Kellee Koenig

Understanding important areas for biodiversity, climate mitigation, fresh water, non-timber forest products, and climate adaptation is useful in and of itself. Combining maps of natural capital can yield insights into areas that are important for multiple benefits, as well as areas important for different types of natural capital. There are many ways to combine spatial data. For this analysis, we used two methods: an approach that relies on thresholding, and an additive approach.

Threshold-based approach
Targets or thresholds can be used to define the “most important” of the important natural capital. Ideally, targets would be based on information about how much (biodiversity, fresh water, forest carbon) is actually needed in order to maintain human well-being or achieve effective biodiversity conservation in Amazonia. Unfortunately, this information is not available at the regional scale. For example, it is currently unknown how much forest carbon is needed to maintain the local, regional, and global climate, or how much water is needed to meet demand of people and economic activities. Thus, for this analysis we defined arbitrary thresholds. Examples of such arbitrary thresholds are contained in the sections above. For example, all values above the regional mean, or all values above the regional mean plus one standard deviation, were used to identify “essential natural capital”, in the above sections.

For this section, we defined new arbitrary thresholds by taking the top 20% and the top 10% of pixels, by value, for each map. (A “pixel” is a unit of analysis, in this case each pixel is 1 square kilometer in size.) This resulted in similar-sized areas defined as “essential” for each type of natural capital. In some cases, it was not possible to identify exactly 20% (or 10%) of the pixels in the highest value category, due to many pixels having equal values. For example, at the regional scale, relatively small areas are vulnerable to deforestation. Therefore many pixels have 0 (or close to 0) value in terms of their importance for reducing potential emissions from deforestation. In this case, a smaller total area (less than 20% or 10% of the region) was included. We then combined the individual maps to identify a total extent of areas of essential natural capital, as shown in Figure 48 and Figure 49.
Figure 48. Top 20% of pixels (or all pixels of maximum value) important for each type of natural capital, combined

Figure 49. Top 10% of pixels (or all pixels of maximum value) important for each type of natural capital, combined
These maps show both similarities and differences in the spatial patterns of different types of natural capital. Areas important for forest carbon stock (high stock areas) are located in the western Amazon basin. Areas important for potential emissions from deforestation (areas with high carbon stock that are vulnerable to deforestation) and non-timber forest products tend to occur near more populated areas (on the periphery of the region) as well as along rivers and agricultural frontiers. Important areas for biodiversity (defined here as areas with large numbers of endemic species) occur along the foothills of the Andes, the western Amazon basin, large parts of the Guiana Shield, and locally along the Amazon River or other sites within Brazil. Important areas for freshwater ecosystem services are located in watersheds upstream of population centers and hydropower dams, particularly in the southeastern part of the region (central Brazil), southwestern (Bolivia), and central (northern Brazil) parts of the region. Important areas for flow regulation under climate change (“climate adaptation”) are also located in the southwestern part of the region, but new areas in the northwest (throughout Colombia, Ecuador and Peru) and northeast (southern Guiana and northern Brazil) are also highlighted.

In order to define the total extent of essential natural capital, we combined these areas in a single map, shown in Figure 50. This map collectively identifies large swaths of the region as important, including most of the Andean foothills and western Amazonian basin, large areas throughout the Guiana Shield, including the border of Venezuela and Guiana and most of French Guiana, and large areas along and south of the Amazon River in Brazil. Collectively, these areas should be the focus of ongoing conservation and sustainable management at the regional scale. While this map, and the maps above, might be useful for regional-scale prioritization, finer-scale analyses would be necessary for prioritization at the national or sub-national level.

![Figure 50. Top 20% and 10% of pixels important for all types of natural capital, combined](image)

**Additive approach**

While the above approach defines any area as “essential” if it is essential for a single type of natural capital (e.g. fresh water), we were also interested in identifying areas important for multiple types of natural capital. Therefore we conducted a second analysis using the continuous-scale (non-thresholded) maps. We scaled all the maps from 0-100 and summed their values, giving all maps equal weight (Figure 51). This results in a map that gives higher
importance to areas important for multiple ecosystem services. Either approach could be useful depending on the interests of the users.

Figure 51. All natural capital maps, rescaled from 0-100 and added together (weighted equally)

While there are some local differences between this map and the preceding maps, which are based on a thresholding approach, many of the overall spatial patterns are similar. Again, large areas of the Andes foothills and western Amazon basin show up as important, more limited areas in the Guiana shield, and large parts of the eastern Amazon basin in Brazil. Again, while these maps might be useful for regional-scale prioritization, finer-scale analyses would be necessary for prioritization at the national or sub-national level.

Protected areas and indigenous lands
Both resulting maps (resulting from a threshold-based approach and an additive approach) can be used to ask questions such as, “how much of essential natural capital in Amazonia is contained within protected areas and indigenous lands?” For illustration purposes, we used one of the threshold-based maps (top 10% of values), and overlaid both protected areas (PAs) and indigenous lands (ILs), and calculated how much of the area is contained within each category. The results are summarized in Figure 52 and Table 7, below. Based on these analyses, we calculated that 22% of essential natural capital (defined as the top 10% of pixels) is contained within protected areas, 24% is contained within indigenous lands, and 43% is contained in either category (note there is some overlap between protected areas and indigenous lands). When we used the top 20% of pixels as the threshold (map not shown), these percentages changed, but only slightly: 24% falls within protected areas, 23% within indigenous lands, and 44% falls within either category.
Table 7. Area calculations of essential natural capital (defined as the top 10% of pixels) contained within protected areas and indigenous lands

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected areas</td>
<td>211,240,000</td>
<td>N/A</td>
</tr>
<tr>
<td>Indigenous lands</td>
<td>173,041,600</td>
<td>N/A</td>
</tr>
<tr>
<td>Protected OR indigenous</td>
<td>365,292,060</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential natural capital (top 10% of pixels)</td>
<td>367,996,900</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential natural capital (top 10%) in protected areas</td>
<td>80,873,800</td>
<td>22%</td>
</tr>
<tr>
<td>Essential natural capital (top 10%) in indigenous lands</td>
<td>87,369,200</td>
<td>24%</td>
</tr>
<tr>
<td>Essential natural capital (top 10%) in either category</td>
<td>159,860,800</td>
<td>43%</td>
</tr>
<tr>
<td>Essential natural capital (top 20% of pixels)</td>
<td>581,997,800</td>
<td>N/A</td>
</tr>
<tr>
<td>Essential natural capital (top 20%) in protected areas</td>
<td>137,224,700</td>
<td>24%</td>
</tr>
<tr>
<td>Essential natural capital (top 20%) in indigenous lands</td>
<td>133,730,000</td>
<td>23%</td>
</tr>
<tr>
<td>Essential natural capital (top 20%) in either category</td>
<td>256,582,600</td>
<td>44%</td>
</tr>
</tbody>
</table>

It is also possible to overlay a map of vulnerability to deforestation (see Climate Mitigation section, above) in order to identify areas that are important for natural capital and also are highly threatened (Figure 53).
Conclusion
All of Amazonia’s natural capital is important. The region contains globally important biodiversity values, as well as a critical role in regulating the climate, producing flows of fresh water for cities and hydropower, and sustaining the food and livelihoods of people throughout South America. The many maps presented above highlight the “most important”, or essential, natural capital within this important region. The Andes foothills and western Amazon basin are highlighted, as are scattered areas throughout the Guiana shield, and large parts of the Amazon River estuary in Brazil. Depending on the integration method used, riparian areas along the Amazon River also appear as particularly important. The western Amazon region is known to be one of the most well-preserved areas of Amazonia. It has been shown to be particularly important for cloud formation and water provision for the rest of the Amazon basin, as well as for the unique biodiversity represented by great numbers of endemic species found there. The areas along the Amazon River, as well as its estuary, area periodically inundated and have particular ecological functions in the dynamics of the systems, being important for the flow of food and sediments to the eastern portion of the basin.

The analysis of protected areas and indigenous lands show that a considerable percentage of Amazonia’s essential natural capital is already under some kind of legal designation. However, deforestation continues to threaten the region, including within protected areas and indigenous lands. This pressure needs to be seriously considered in order for it to preserve the region’s ability to provide ecosystem services that are fundamental for human well-being. In addition, a number of studies indicate that the system may enter into a savannization process if more than 30 to 40% of its natural cover is lost (Nobre, 2014), which would have consequences at local, regional and global scales. This potential tipping point needs to be better understood in order to assess the potential impacts of management decisions and conservation opportunities.

The information on biodiversity and ecosystem benefits shown in the maps of natural capital above could be useful to inform public and private policies aiming at reconciling conservation and development, such as those aimed at
maintaining the quality and quantity of freshwater flows, or the definition of “no-go areas” for project investments. Other potential policy applications are summarized below:

**Sustainable Development Goals** - The proposed SDGs include reducing human exposure and vulnerability to climate-related events, food security, availability and sustainable management of water, and sustainable energy. Here, we have focused on types of natural capital (e.g. biodiversity and ecosystems) that support each of these goals and are most relevant in the Amazon region, including fresh water for domestic/hydropower use, non-timber forest products, and climate mitigation. These could help support setting national SDG targets and tracking performance.

**Convention on Biological Diversity / Aichi targets** - all countries except Bolivia and Venezuela have ratified the CBD. Results could support the identification of areas that are important for biodiversity and ecosystem service conservation and could drive the creation of future protected areas for "ecologically representative" biodiversity, which would better represent the globally significant biodiversity of the region.

**Avoided deforestation commitments** - These include national or regional deforestation targets, such as Guyana's Low Carbon Development Strategy, national REDD+ policies, and the INDCs that have been submitted to the UNFCCC. Here we focus on types of natural capital (e.g. high forest biomass carbon stock and areas vulnerable to deforestation) that are directly related to these policies. Please note that our analyses highlight broad areas of importance at the regional scale; however, higher-resolution analyses would be required for assessing national or site-level REDD+ feasibility.

**National Climate Adaptation Plans and Policies** - All countries have developed, or are developing, national climate adaptation plans of action. While the results of the vulnerability analysis presented here focus on only a single type of exposure (change in water availability) and are regional in scale, they could help guide resources for finer-scale analysis to the most vulnerable areas, as well as indicate ecosystem-based adaptation (EbA) solutions.

A number of relevant national-level policy targets related to biodiversity, climate change, water, and food security from Amazonian countries are summarized in Appendix 1.

In addition to the applications listed above, the approaches developed in this project and the resulting maps and information could help to build a regionally-integrated vision for Amazonia’s sustainable development. In order to apply the results to a number of national or sub-national policies of the region, there may be need to more detailed research and the development of similar maps at national or sub-national scales. However, the use of these region-wide results will be essential to maintain the coherence of policies developed nationally and sub-nationally. After all, recognizing that this is a connected region, and that nature has no political boundaries, is key to the success of sustainable development in Amazonia.

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