Appendices

Trends in protected area representation of biodiversity and ecosystem services in five tropical countries


Rachel Neugarten
Email: rachel.neugarten@gmail.com

This file includes:

Appendix 1. Relevant policy targets
Appendix 2. Data sources
Appendix 3. Methods details
Appendix 4. Limitations
Appendix 5. Additional results

Table A.1. Descriptions and sources of data

Figure A.1. Disputed boundary between Guyana and Suriname
Figures A.2. to A.6. Graphs: Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products
Figures A.7. to A.51. Maps: Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products, IUCN Red List species richness, IUCN Red List species range rarity

References

GIS data associated with this analysis can be downloaded from:
Appendix 1. Relevant policy targets

All five countries included in our study are signatories to the UN Convention on Biological Diversity (CBD). In Madagascar in 2003, the government committed to expanding PA system to 10% of its national territory (Gardner et al., 2018). In Cambodia in 2003, a government goal was established to expand protected areas to 25% of the country by 2005 (ICEM, 2003). In Liberia in 2003 the government set a goal of protecting 30% of the country’s forested area (Ministry of Foreign Affairs, 2003). In Guyana, the 2010 Low Carbon Development Strategy committed to protecting 10% of the country’s forested land (Office of the President, Republic of Guyana, 2010); subsequently the government committed to protecting 17% of land and inland waters by 2020 (EPA and Ministry of Natural Resources and the Environment, 2014). In Suriname, no specific protected area size targets were established; however, in 2006 the government stated that the existing system of protected areas “will be strengthened and expanded nationally and locally as is deemed appropriate within national economic and social development strategies” and in 2013 the government stated “the national system of legally protected areas needs to be expanded to accomplish 100% representation of all ecosystems and biological species” (Ministry of Labour, Technological Development and Environment, 2013, 2006).

Appendix 2. Data sources

Data sources are summarized in Table A.1 and in the following sections. Additional details on methods and data sources are also contained in a series of technical reports (7–10).

For Cambodia, Liberia, and Madagascar, all datasets were clipped to the relevant country boundaries using Vector Map level 0 from the National Geospatial Intelligence Agency. There is a disputed boundary between southern Guyana and Suriname (Fig. A.1); for the purposes of this analysis we used boundaries provided to us by each country. As a result, the disputed area was included in the analyses for Guyana and also the analyses of Suriname, and therefore was double-counted. The political and geographic designations shown on the below maps and included in the analyses do not imply the expression of any opinion on behalf of CI or any of its partners concerning the legal status or delineation of the frontiers of any country, territory, or area.

2.1 Protected areas

The only globally consistent database on biodiversity priority areas, the World Database of Key Biodiversity Areas (BirdLife International, 2018) was incomplete or out of date for four of the five countries at the time of this analysis, therefore we complemented or updated it with the best available PA data from each country.

2.2 Biodiversity priority areas

In Guyana and Suriname we used existing biodiversity priority area polygons that had been defined during a process to map proposed Key Biodiversity Areas for the Guiana Shield (Kasecker et al., 2007).

In Madagascar we used existing biodiversity priority area polygons that had been defined during a process to map Key Biodiversity Areas (CEPF, 2014).

In Liberia we included biodiversity priority areas defined by systematic conservation planning (Junker et al. 2015), as well as Key Biodiversity Areas defined for the Guinean Forests of West Africa (CEPF, 2015).

In Cambodia we included data on existing biodiversity priority areas including Key Biodiversity Areas (Tordoff et al., 2012) and Biodiversity and Protected Area Management Project (BPAMP) priority areas (Cutter, 2006).
Table A.1. Descriptions and sources of data

<table>
<thead>
<tr>
<th>Data type</th>
<th>Cambodia</th>
<th>Guyana &amp; Suriname</th>
<th>Liberia</th>
<th>Madagascar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity priority areas</td>
<td>Key Biodiversity Areas (Tordoff et al., 2012)</td>
<td>Proposed Guiana Shield Key Biodiversity Areas (Kasecker et al., 2007)</td>
<td>Conservation priority areas based on nationally representative data and modeling of chimpanzees, other large mammals, and tree diversity (Junker et al., 2015)</td>
<td>Key Biodiversity Areas (CEPF, 2014)</td>
</tr>
<tr>
<td>Species richness and range rarity</td>
<td>Global species richness and range size rarity for mammals, amphibians, and birds based on data from IUCN Red List (IUCN, 2017) and BirdLife International (BirdLife International and Handbook of the Birds of the World, 2017). Species richness and range size rarity of critically endangered (CR), endangered (EN), and vulnerable (VU) Red List species of mammals, amphibians, and birds also assessed separately.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest cover</td>
<td>Global land cover (ESA Climate Change Initiative - Land Cover project, 2017)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest carbon stock</td>
<td>Global tropical forest carbon stocks (Avitabile et al., 2016)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human population</td>
<td>Landscan 2011 (Bright et al., 2012)</td>
<td>Landscan 2014</td>
<td>Landscan 2014</td>
<td>Landscan 2011</td>
</tr>
<tr>
<td>Food insecurity</td>
<td>Cambodia Ministry of Planning (Cambodia Ministry of Planning, 2010)</td>
<td>Data not available</td>
<td>Data not available</td>
<td>Monitoring census survey of Madagascar (Moser et al., 2008)</td>
</tr>
</tbody>
</table>
2.3 Species richness and range size rarity
Global species richness and range size rarity for mammals, amphibians, and birds provided by Andy Arnell and Corinna Ravilious, UNEP-WCMC, based on data from IUCN Red List (IUCN, 2017) and BirdLife International (BirdLife International and Handbook of the Birds of the World, 2017). Species richness and range size rarity of critically endangered (CR), endangered (EN), and vulnerable (VU) Red List species of mammals, amphibians, and birds also assessed separately. These global data were considered inadequate for national-scale analyses, and so were not included in the main paper, but maps illustrating the results have been included here for reference.

Species richness was calculated at 1 km resolution (at the equator) for mammals, amphibians and birds. Species richness of critically endangered (CR), endangered (EN), vulnerable (VU) mammals, amphibians and birds also assessed. This data set is biased towards vertebrates as they are the only terrestrial comprehensively assessed taxonomic groups. Raw species range polygons were rasterized and summed across all species to show number of species potentially occurring there. This version is based on the raw IUCN ranges. So there may be a fair amount of unsuitable habitat in each range (a lot of commission errors). There is a version of this layer where we have refined all species ranges by altitude and landcover (i.e., extent of suitable habitat - ESH), but it is still in a beta version and so not ready for use publication at present.

Range size rarity is a proxy for endemism. This was also calculated at 1 km resolution (at equator) for mammals, amphibians and birds. Range size rarity of critically endangered (CR), endangered (EN), vulnerable (VU) mammals, amphibians and birds also assessed. Calculation based on area of raster grid cell (pixel) divided by total area of species range. (Thus, species with smaller range sizes will have higher range size rarity values.) Summed across all species to show aggregate importance of each pixel to the species occurring there. As with above, this version is based on the raw IUCN ranges. So there may be a fair amount of unsuitable habitat in each range (a lot of commission errors). There is a version of this layer where we have refined all species ranges by altitude and landcover (i.e., extent of suitable habitat - ESH), but it is still in a beta version and so not ready for publication at present.

Each asset was filtered based on the presence (Is/was the species in this area?), origin (Why/how the species is in this area?) and seasonality (What is the seasonal presence of the species in the area?) fields. We selected only species with presence = 1 (extant) or presence = 4 (possibly extinct) and origin = 1 (native) or origin = 2 (reintroduced) and seasonality = 1 (resident), 2 (breeding season), 3 (non-breeding season), 4 (passage) or 5 (seasonality occurrence uncertain). Calculations were applied at the species-season level, i.e. where a species that has more than one seasonality is treated as a separate species range, in effect treating them as distinct species. This is primarily applicable for birds and some migratory mammals, as each seasonal range could house globally relevant aggregation of a given species.

2.4 Forest cover
In all countries we mapped forest cover using the 300m annual global land cover time series for 2003 and 2015 (ESA Climate Change Initiative - Land Cover project, 2017). The data was clipped according to each country boundary and the raster classes that correspond to ‘tree cover’ were extracted (classes 50–90, 160, and 170). Total forest cover area, and forest cover area within protected areas, was calculated using the Tabulate Area function in ArcGIS for Desktop Advanced version 10.5 (Esri, 2017).

2.5 Biomass carbon stocks
In all countries we mapped biomass carbon stocks within forested areas by masking global forest biomass data from GEOCARBON (Avitabile et al., 2016) with forest cover data (ESA Climate Change Initiative - Land Cover project, 2017) for each country and year.

2.6 Non-timber forest products (NTFPs)
In all countries we modeled areas important for non-timber forest products (NTFPs) by weighting natural ecosystems based on their level of importance for NTFPs, as well as the proximity or accessibility of natural ecosystems to human populations. In Cambodia, the weighting was done...
based on a literature review (Conservation International, 2015a), in Madagascar using expert ranking (Conservation International, 2015b), in Amazonia (Guyana and Suriname) using richness of species of known importance for NTFPs (Conservation International, 2015c). In Liberia, no data on the importance of different ecosystem types for NTFPs was available so all ecosystems were given equal weight (Conservation International, 2017). Proximity to human populations was calculated using population data from Landscan (Bright et al., 2012) (Cambodia, Madagascar) or modeled using an accessibility model which included roads, land cover types, elevation and slope, and other inputs (Amazonia, Liberia) (Porro et al., 2008). See referenced technical reports for more detailed methods and data sources from each country.

2.7 Freshwater ecosystem services
In all countries we mapped realized freshwater ecosystem services (FES) by weighting the level of provision of freshwater quantity, quality, and flow regulation services modeled using WaterWorld (v2) (Mulligan 2013) and the estimated level of demand. Specific input datasets, including demand estimates of various beneficiaries (e.g. population centers, hydropower facilities, and irrigated agriculture) varied by country. Detailed methods are included in the corresponding technical reports from each country (Conservation International, 2017, 2015a, 2015b, 2015c).

Appendix 3. Methods details
We analyzed the spatial representation of biodiversity priority areas (BPAs), forested areas, and ES within PAs in the two time periods. For discrete areas (forests, BPAs) we calculated the total area of each contained in each country, and the percentage of these areas represented by PAs in each country.

For continuous values (forest carbon stocks, NTFPs and FES) we first calculated the total value of the service at a national level. For example, we calculated the total tons of carbon contained in a country’s forests. For NTFPs and FES, we mapped important areas using an index of importance and assigned an importance value to each square kilometer grid cell in the country, where 0 was lowest and 1 was highest importance. Therefore, the total national value of ES was the sum of all the individual grid cells in the country. For each country, we calculated the sum of the value of grid cells contained within PAs in 2003 and 2017 and divided it by the total value of ES for the country, resulting in a percentage of PA coverage for each ES for each time period.

We then compared our results to the total percentage of land area encompassed by PAs in 2003 and 2017. If the percentage of BPAs, forested areas, NTFPs or FES contained within PAs was higher than the percentage of land area encompassed by PAs, this indicates that PAs are spatially representing such areas better than they would be based on their size.

We also calculated the percentage of BPAs, forests, and ES that could hypothetically be represented if PAs were reconfigured to optimize for a given ES, following methods from (Turner et al., 2007). For example, if PAs represent 10% of the land area of a country, then we calculated the total BPA area, forest area, or ES value provided by the top 10% of grid cells for the country. If re-configuring PAs could capture more BPAs, more forest, or more ES value, then it indicates that a given country could hypothetically capture more of these important places within a PA network without expanding the total area under protection. This method is for comparison purposes only, as it does not account for PA size and shape, existing land tenure, political or economic feasibility, or contiguity of important areas. For example, it would be impractical to protect very small patches of forest scattered around the country.

Appendix 4. Limitations
While our analysis examined protected areas, forest cover, and forest carbon stocks in two time periods, due to lack of historic data we were only able to map biodiversity priority areas, freshwater ES, and NTFPs in a single time period (corresponding to the most recent data available when the analyses were completed: 2014 (Madagascar and Cambodia), 2015 (Guyana and Suriname), and 2016 (Liberia). As a result, our results might over- or under-estimate the
representation of these areas in the earlier (2003) time period. We expect the effect of this on our results for Guyana and Suriname to be relatively small, as these countries experienced little land cover change or population growth during the study period. We know that forest cover declined during the study period in Cambodia, Liberia, and Madagascar (and therefore forest carbon stocks, biodiversity, and the supply of forest-related ecosystem services also likely declined.) However, due to population growth the demand for ecosystem services likely increased during the same time period. Therefore we cannot speculate whether the areas that are important for realized ecosystem services (FES and NTFPs) increased or decreased during the study period in these three countries.

Current important areas for biodiversity were likely also important in the past, therefore we believe using the most recent data is a reasonable approximation for BPAs in both time periods. Biodiversity almost certainly declined during the study period, however, particularly in those countries that experienced relatively high rates of habitat conversion. Therefore, areas important for biodiversity in 2003 may have shrunk over time. It is unlikely that the reverse would be true (that there would be an increase in the size of BPAs.) Depending on where PAs were located relative to BPAs in 2003, our analysis might over-estimate or under-estimate the representation of BPAs within PAs in 2003. Similarly, the supply of freshwater ES and NTFPs may have decreased during the study period; however, demand for these ES might have increased, due to changes in population or poverty rates. Therefore, it is difficult to estimate whether the areas important for these services might have decreased, increased, or stayed the same during the study period.

We mapped several additional ES (coastal protection, flood regulation, inland fisheries, coastal fisheries, and nature tourism) in several of the countries, but results were not comparable between countries. Other ES such as pollination of crops and cultural/spiritual values of nature were identified as important in one or more of our study countries by in-country stakeholders, however, data were not available to map these services at the national level.

Due to lack of data on ES at national scales, we often had to rely on global data and spatial models. Our maps of NTFPs and FES were based on numerous assumptions, for example we assumed that proximity between people and natural ecosystems (in the case of NTFPs), or the location and population density of people downstream of natural ecosystems (for freshwater services) is an indicator of higher levels of use of ES. These assumptions may be invalid in certain circumstances. For example, people may rely on forest products from more distant ecosystems, or on groundwater resources for domestic water supply or irrigation. Some groups or individuals may be more dependent on NTFPs than other groups or individuals. Our results should therefore be interpreted as indicative of the relative level of ES provision within each country (ranging from low to high), and not as absolute estimates.

In general, our results are likely to be underestimates of important ES areas since we were unable to map many other services provided by ecosystems, such as pollination, local climate regulation, air purification, cultural and recreational values, and many others. Also, we were unable to map or estimate demand for all beneficiaries of ES in each country. Thus ecosystems are likely providing significantly more ES value to people in each country than we were able to account for in our analyses. Additional research on ES is needed, particularly on cultural and spiritual ecosystem services, as well as ES supporting agriculture (pollination, erosion control). Over time, we hope that data availability will improve which will enable more complete accounting of the benefits of nature to people globally.

Appendix 5. Additional results
Graphs summarizing percentages of each value contained within protected areas in 2003 and 2017, as well as hypothetical maximum values, are included below.

Maps showing overlays of protected areas with forest cover, biodiversity priority areas, forest carbon stocks, important areas for non-timber forest products, important areas for freshwater ecosystem services, vertebrate species richness, and vertebrate species range rarity for the five study countries are also included below.
Fig. A.1. Disputed border between Guyana and Suriname
Fig. A.2. Cambodia a) 2003 and b) 2017. Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products.
Fig. A.3. Guyana a) 2003 and b) 2017. Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products
Fig. A.4. Liberia a) 2003 and b) 2017. Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products
Fig. A.5. Madagascar a) 2003 and b) 2017. Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products.
Fig. A.6. Suriname in 2003 and 2017 (no change). Protected area representation of biodiversity priority areas, forest cover, forest carbon, freshwater ecosystem services, non-timber forest products.
Fig. A.7. Forest cover and protected areas, Cambodia, 2003 and 2017
Fig. A.8. Biodiversity priority areas and protected areas, Cambodia, 2003 and 2017
Fig. A.9. Areas important for non-timber forest products and protected areas, Cambodia, 2003 and 2017
Fig. A.10. Forest carbon stocks and protected areas, Cambodia, 2003 and 2017
Fig. A.11. Areas important for freshwater ecosystem services and protected areas, Cambodia, 2003 and 2017
Fig. A.12. Species richness of mammals, amphibians and birds and protected areas, Cambodia, 2003 and 2017
Fig. A.13. Species richness of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Cambodia, 2003 and 2017
Fig. A.14. Species range rarity of mammals, amphibians and birds and protected areas, Cambodia, 2003 and 2017
Fig. A.15. Species range rarity of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Cambodia, 2003 and 2017
Fig. A.16. Forest cover and protected areas, Guyana, 2003 and 2017
Fig. A.17. Biodiversity priority areas and protected areas, Guyana, 2003 and 2017
Fig. A.18. Areas important for non-timber forest products and protected areas, Guyana, 2003 and 2017
Fig. A.19. Forest carbon stocks and protected areas, Guyana, 2003 and 2017
Fig. A.20. Areas important for freshwater ecosystem services and protected areas, Guyana, 2003 and 2017
Fig. A.21. Species richness of mammals, amphibians and birds and protected areas, Guyana, 2003 and 2017
Fig. A.22. Species richness of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Guyana, 2003 and 2017
Fig. A.23. Species range rarity of mammals, amphibians and birds and protected areas, Guyana, 2003 and 2017
Fig. A.24. Species range rarity of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Guyana, 2003 and 2017
Fig. A.25. Forest cover and protected areas, Liberia, 2003 and 2017
Fig. A.26. Biodiversity priority areas and protected areas, Liberia, 2003 and 2017
Fig. A.27. Areas important for non-timber forest products and protected areas, Liberia, 2003 and 2017
Fig. A.28. Forest carbon stocks and protected areas, Liberia, 2003 and 2017
Fig. A.29. Areas important for freshwater ecosystem services and protected areas, Liberia, 2003 and 2017
Fig. A.30. Species richness of mammals, amphibians and birds and protected areas, Liberia, 2003 and 2017
Fig. A.31. Species richness of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Liberia, 2003 and 2017
Fig. A.32. Species range rarity of mammals, amphibians and birds and protected areas, Liberia, 2003 and 2017
Fig. A.33. Species range rarity of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Liberia, 2003 and 2017
Fig. A.34. Forest cover and protected areas, Madagascar, 2003 and 2017
Fig. A.35. Biodiversity priority areas and protected areas, Madagascar, 2003 and 2017
Fig. A.36. Areas important for non-timber forest products and protected areas, Madagascar, 2003 and 2017
**Fig. A.37.** Forest carbon stocks and protected areas, Madagascar, 2003 and 2017
Fig. A.38. Areas important for freshwater ecosystem services and protected areas, Madagascar, 2003 and 2017
Fig. A.39. Species richness of mammals, amphibians and birds and protected areas, Madagascar, 2003 and 2017
Fig. A.40. Species richness of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Madagascar, 2003 and 2017
Fig. A.41. Species range rarity of mammals, amphibians and birds and protected areas, Madagascar, 2003 and 2017
Fig. A.42. Species range rarity of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Madagascar, 2003 and 2017
Fig. A.43. Forest cover and protected areas, Suriname, 2003 and 2017
Fig. A.44. Biodiversity priority areas and protected areas, Suriname, 2003 and 2017
Fig. A.45. Areas important for non-timber forest products and protected areas, Suriname, 2003 and 2017
Fig. A.46. Forest carbon stocks and protected areas, Suriname, 2003 and 2017
Fig. A.47. Areas important for freshwater ecosystem services and protected areas, Suriname, 2003 and 2017
Fig. A.48. Species richness of mammals, amphibians and birds and protected areas, Suriname, 2003 and 2017
Fig. A.49. Species richness of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Suriname, 2003 and 2017
Fig. A.50. Species range rarity of mammals, amphibians and birds and protected areas, Suriname, 2003 and 2017
Fig. A.51. Species range rarity of IUCN Red List Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) mammals, amphibians and birds and protected areas, Suriname, 2003 and 2017.
References


ESA Climate Change Initiative - Land Cover project, 2017. Land Cover CCI (No. CCI-LC-PUGV2). European Space Agency Climate Change Initiative, Belgium.


