Amazon’s vulnerability to climate change heightened by deforestation and man-made dispersal barriers

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In response to climate change, species are predicted to shift their geographic distributions, or “migrate”, to remain at equilibrium with climate.

For example, species are predicted to shift their distributions poleward or upward to compensate for rising temperatures.

Migrations will be especially challenging for lowland tropical species:

Temperature does not change with latitude within the tropics.

In order to migrate to colder temperatures, tropical species must migrate upslope.

For lowland species migrating upslope may not be an option due to low topographic relief.

Range of surface temperatures on land. Bars indicate the ranges of mean monthly temperatures from 1961-1990, sampled over all longitudes. Dark Gray bars = New world; light gray bars = Old world. Sunday et al. 2011
Amazonian species will have to rapidly migrate huge distances to remain at equilibrium with changing temperatures.

Distance to “cold” refugia
(Wright et al. 2009)

Temperature change velocities
(Loarie et al. 2009)
Most estimates of required migration rates only consider changes in mean annual temperature.

Temperature is only one facet of the environment.

Other climatic/environmental variables may show different spatial patterns now and in the future.
Most estimates of required migration rates do not consider the impacts of other human disturbances.

Deforestation and human land use may influence the distances that species will need to migrate to keep pace with climate change.

Deforestation may eliminate climate analogs.

Deforestation may create barriers to species movements thereby increasing the effective distance between climate analogs and the distances that species will need to migrate to remain at equilibrium with changing climates.
Questions

1. How fast will Amazonian species be required to migrate in order to remain in equilibrium with changes in temperature? With changes in temperature and rainfall?

2. How will deforestation affect the required migration rates of Amazonian species?
We calculated the distances between current “cells” and their closest future analog based on:

### Changes in Mean Annual Temperature

*Note: in identifying climate analogs we accounted for interannual variability and climate analogs were allowed to occur outside of the Amazon*

<table>
<thead>
<tr>
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<th>Current (2000)</th>
<th>Future (2050)</th>
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<td>5km</td>
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We calculated the distances between current “cells” and their closest future analog based on:

Changes in Mean Annual Temperature & precipitation

Note: in identifying climate analogs we accounted for interannual variability and climate analogs were allowed to occur outside of the Amazon
We calculated the distances between current “cells” and their closest future analog based on:

Changes in Mean Annual Temperature & precipitation & deforestation

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warming
Climate data (current vs. 2050):

Current temperature

Current annual rainfall

Change in temperature predicted for 2050

Change in rainfall predicted for 2050

IPSL_CM4

+2.49°C

IPSL_CM4

+6.33%

http://ccafs-climate.org/
Deforestation data:

Current (2002):
- ~25% of Amazon deforested

Future (2050):
- GOV: ~25% of Amazon deforested
- BAU: ~50% of Amazon deforested

Soares-Filho et al., 2006
RESULTS:
(a) Temperature

(b) Temperature & precipitation

(c) Temperature & precipitation & GOV deforestation

(d) Temperature & precipitation & BAU deforestation

21% w/o analog

55% w/o analog

Percent Amazon Rainforest With future climate analog

Migration Rate (km yr\(^{-1}\))
Migration Rate (km yr\(^{-1}\))

Percent Amazon Rainforest With future climate analog

(a): Temperature
(b): Temperature & precipitation
(c): Temperature & precipitation & GOV deforestation
(d): Temperature & precipitation & BAU deforestation

Average recorded migration rate = 2 km/yr
Fastest recorded migration rate = 14 km/yr
Average recorded migration rate = 2 km/yr

Fastest recorded migration rate = 14 km/yr

Percent Amazon Rainforest With future climate analog

Migration Rate (km yr\(^{-1}\))

- **a**: Temperature
- **b**: Temperature & precipitation
- **c**: Temperature & precipitation & GOV deforestation
- **d**: Temperature & precipitation & BAU deforestation

- 53\% w/o reachable analog
- 68\% w/o reachable analog
With extensive “disappearing climates”, many populations, species, and even entire communities may go extinct.
With extensive “disappearing climates”, entire communities may go extinct
The Purus-Madeira moist forest ecoregion
67,200 square miles
Characterized by high biodiversity and endemism in the flora and fauna.
Conservation Status: Relatively Stable/Intact
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Many ecoregions will be cut off from all, or almost all, of their future climate analogs:

<table>
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<tr>
<th>Ecoregion</th>
<th>Percent area with reachable future analog</th>
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<tr>
<td></td>
<td>GOV</td>
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<tr>
<td>Tocantins/Pindare moist forests</td>
<td>5.63%</td>
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<tr>
<td>Purus-Madeira moist forests</td>
<td>6.99%</td>
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<tr>
<td>Marajo Varzea</td>
<td>85.71%</td>
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<td>Tapajos-Xingu moist forests</td>
<td>26.29%</td>
</tr>
<tr>
<td>Xingu-Tocantins-Araguaia moist forests</td>
<td>25.00%</td>
</tr>
<tr>
<td>Mato Grosso seasonal forests</td>
<td>31.71%</td>
</tr>
<tr>
<td>Monte Alegre varzea</td>
<td>53.49%</td>
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<tr>
<td>Negro-Branco moist forests</td>
<td>87.06%</td>
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<tr>
<td>Guianan piedmont and lowland moist forests</td>
<td>89.61%</td>
</tr>
<tr>
<td>Peruvian Yungas</td>
<td>79.49%</td>
</tr>
<tr>
<td>Guianan savanna</td>
<td>90.60%</td>
</tr>
<tr>
<td>Napo moist forests</td>
<td>89.49%</td>
</tr>
<tr>
<td>Tumbes-Piura dry forests</td>
<td>94.43%</td>
</tr>
<tr>
<td>Rio Negro campinarana</td>
<td>95.65%</td>
</tr>
<tr>
<td>Guianan Highlands moist forests</td>
<td>92.66%</td>
</tr>
<tr>
<td>Solimoes-Japura moist forests</td>
<td>88.66%</td>
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These predictions may appear grim, but they are probably overly optimistic:
• Based on most conservative of all GCMs
• Do not account for other climatic factors (e.g., seasonality)
• Do not account for non-climatic environmental factors (e.g., soil type)
• Do not account for other anthropogenic disturbances (e.g., fire)
• Do not account for species interactions
• Allow species to migrate through unsuitable habitats

On the other hand, these predictions:
• Assume instant deforestation and do not allow species to “slip through”
• Assume that all deforested areas are impermeable
• Do not account for interactions between climate factors or “carbon fertilization”
Conclusions:

The inclusion of multiple climatic/environmental variables extends distances between analog climates and hence estimates of required species migration rates.

We know that species are responding to multiple variables.

Different species may respond to different climate variables resulting in novel communities.
Conclusions:

Deforestation will potentially create dispersal barriers increasing the effective distance between climate analogs and hence the required species migration rates.

Different species will respond differently to deforestation resulting in novel species communities.
Conclusions:

In extreme cases, deforestation can sever all connections between climate analogs resulting in “disappearing climates”

Many populations, species, communities and ecoregions will have no or few climate analogs, decreasing their ability to respond to climate change through migrations.

Many of the areas that will have no climate analog are also the same areas predicted to experience high rates of deforestation, decreasing/eliminating the ability of species in these areas to acclimate or adapt to climate change

Deforestation will accelerate the extinction of species due to climate change
Conclusions:

**Conservation strategies:** Efforts in the Amazon should focus on reducing deforestation and preserving/restoring migration corridors.

Results from analyses such as these can be used to identify keystone areas whose preservation will have the greatest impact on the greatest amount of habitat/species/communities.