Tropical forest ecology:

Seasonality, tree distributions, and forest diversity
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Seasonality, tree distributions, and forest diversity

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Helmholtz Centre for Environmental Research
Leipzig, Germany
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Global Forest Observatory Network (GFON)

~ 8,200 species
~ 3 million trees monitored globally
CTFS Network

PANAMA - STRI
COLOMBIA - Instituto Humboldt
ECUADOR - Universidad Catolica de Ecuador, University of Aarhus (Denmark), Field Museum (USA)
PUERTO RICO - University of Puerto Rico, USDA Forest Service
BRAZIL - INPA, Universidade de Sao Paulo, Louisiana State University
INDIA - Indian Institute of Science
MALAYSIA - Forest Research Institute of Malaysia, Sarawak Forest Department, Osaka City University (Japan), Kyoto University (Japan), National Institute of Environmental Studies (Japan), Harvard University (USA)
PHILIPPINES - Isabela State University, PLAN International, Conservation International-Philippines, Harvard University (USA)
SINGAPORE - Nanyang Technological University, Singapore National Parks Board
SRI LANKA - University of Peradeniya, Sri Lanka Forest Department, University of Sri Jayawardenepura
THAILAND - Royal Forest Department, National Institute of Environmental Studies (Japan), Harvard University (USA)
CAMEROON - University of Buea, Oregon State University
DEM. REP. CONGO - CEFRECOF, Wildlife Conservation Society
TAIWAN - Tunghai University
<table>
<thead>
<tr>
<th>Location</th>
<th>Species ≥ 1 cm dbh</th>
<th>Annual Rainfall (mm)</th>
<th>Dry Season (months)</th>
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<tbody>
<tr>
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* species in exactly 25 hectares unless noted with asterisk (16-20 ha)
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The dry season as driver of forest patterns:

- Most trees reproduce annually, with peaks Mar-Jun
- Leaf flushing tied to seasonal cycle
- Herbivore populations limited by dry season loss of food
- Fruit failures attributed to altered dry season
- Mast events follow ENSO following a weak dry season
- Bird & mammal populations track fruit failures & masts
- 1983 drought had conspicuous effect on ~10% of tree species
Dry season intensity...

Astronium graveolens
Panama Canal Authority rainfall gauges
3-100 year records
Defining dry season intensity

mean daily rainfall 47 years

smoothed daily PET

mean daily rainfall 47 years
Defining dry season intensity

- Smoothed daily PET
- Mean daily rainfall 47 years
- Moisture deficit

Diagram showing daily rainfall and smoothed PET with annotations.
Cumulative moisture deficit
\[ \sum \text{daily}(\text{rainfall-PET}) \]
Gambo, Panama
1992 dry season
Cumulative moisture deficit
\[ \sum_{\text{daily}} (\text{rainfall} - \text{PET}) \]

Gamboa, Panama
1992 dry season

arbitrary beginning

rain starts 1991

rain ends 3 Dec 91

good rain 24 April 92

moisture recovers 15 May 92
Cumulative moisture deficit
\[ \sum \text{daily}(\text{rainfall-PET}) \]

Gamboa, Panama
1992 dry season

max. moisture deficit:
-997 mm

arbitrary beginning

rain starts 1991
Dry season comparison

- Esperanza rain
- Gatun rain
- PET (BCI)

Day of year

Rainfall

-755
-246
-904
Dry season comparison

Esperanza rain

Gatun rain

PET (BCI)
Dry season comparison

Cristobal rain

BCI rain

PET

-849

-822
Dry season duration (days) & dry season intensity (moisture deficit)

BCI 1931-2006

moisture loss with no rain and PET=-6.6/day
Dry season duration (days) & dry season intensity (moisture deficit) BCI 1931-2006

moisture loss with no rain and PET=-6.6/day

fitted line

1957

2005
1957 dry season
BCI

-1029 mm drought

157 d

2005 dry season
BCI

-637 mm drought

157 d
Panama Canal Authority rainfall gauges
Dry season intensity
Tree inventories
Estimated dry season intensity at each
Tree inventories
Estimated dry season intensity at each
Tree distributions across the gradient in drought
Lecointea amazonica plots and inventories
Manilkara bidentata plots and inventories
Maranthes panamensis plots and inventories
32 species wet-forest species reach the odd Laguna site
104 wet forest species reach C. Jefe-C. Azul but no drier
Frequent climatic limits of wet forest species
Unusual climatic limits of wet forest species

Just 5 species reach limits at Sherman and BCI
50 Pacific coast species reach Sherman but not beyond
87 Pacific species reach C. Campana but not the very wet sites.
48 species are restricted to the driest climate
Lacistema aggregatum plots and inventories

99 species span the entire gradient, dry to very wet
Range limits of species from the driest area of the Canal region

Panama City

BCI

Sherman

C. Campana

wet forest
Species accumulation toward drier climate illustrates dry end of range limits.

- ~wet forest limit
- C. Jefe
- C. Campana

The graph shows the decrease in the number of species with increasing dry season intensity, indicating a transition from wet forest to drier conditions.
Species accumulation toward drier climate

Illustrates dry end of range limits at the "wet forest limit".

Singletons show the dry end of the range limits.
Species accumulation toward wetter climate

illustrates wet end of range limits

~wet forest limit

C. Campana

C. Jefe

singleton

wetter

dry season intensity

number of species
Species accumulation toward wetter climate illustrates wet end of range limits

- wet forest limit
- C. Campana
- C. Jefe
- singletons

Dry season intensity
Singletons

167 species in wet forest

35 in central zone

15 in Pacific forest
### Tree species richness near the Panama Canal

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<tr>
<th>Habitat Type</th>
<th>Species Count</th>
<th>Percentage</th>
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<tr>
<td>Confined to wet forest</td>
<td>276</td>
<td>26%</td>
</tr>
<tr>
<td>Not restricted</td>
<td>432</td>
<td>41%</td>
</tr>
<tr>
<td>Confined to mid to dry</td>
<td>121</td>
<td>12%</td>
</tr>
<tr>
<td>Singleton (wet forest)</td>
<td>166</td>
<td>16%</td>
</tr>
<tr>
<td>Singleton (mid to dry)</td>
<td>51</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1046</strong></td>
<td></td>
</tr>
<tr>
<td>(other not included)</td>
<td>50</td>
<td></td>
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**Source pool for tree species (with singletons):**

- Wet forest: 874 (and more to be found)
- Moist forest: 604 (few to be found?)
Species diversity per hectare

- 166 species
- 73 species
- 93 species
- 87 species
- 116 species
- 52 species

Tree species > 10 cm diameter in 1 ha plots
Experimental drought tolerance: survival rate without water

Tree inventories

tree water availability from Kursar et al. (2 sites)

99 species span the entire gradient, dry to very wet. Niche model from dry season duration.
Niche model from dry season duration

Tabernaemontana undulata

Laguna high H₂O low nutrient
Experimental and geographic climatic response
Soil phosphorus in tree plots

Engelbrecht et al., B. Turner unpub.
Soil nutrients
19 sites
Ben Turner (unpub)
Conclusions

- Inability to survive drought limits ranges
- More species adapted to wet forest conditions
- Experiments on species responses suggest more than drought is involved
- Only a minority of species have ranges limited by poor dispersal