Carbon Losses due to Tropical Forest Fragmentation - A Forgotten Process in the Global Carbon Cycle

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Tollefson (2013), Nature

IPCC (2007)
Current estimate of global carbon loss due to land use and land-cover change (2000 – 2009): 1.1 (+/- 0.11) Gt C / y

Houghton et al. (2012), Biogeosciences
Tollefson (2013), Nature

Edge effects:

- Altered species composition
- Altered microclimate
- Wind and fire disturbance
- Higher mortality
- Less biomass

Laurance et al. (1997), Science
Laurance (2000), TREE
Laurance et al. (2006), PNAS
Naturally neighbouring ecozone

Anthropogenic land use cover

**Aims**

- Evaluation of the global amount of anthropogenic edge area in tropical forests
- Global estimate of the additional carbon losses due to tropical forest fragmentation
Methods – Fragment Analysis

ESA (2009), GlobCover land cover map

ENVISAT (2013)
Methods – Fragment Analysis

![Map showing tropical forest areas and land use changes](image)

- **Tropical Forest**
- **Naturally Succeeding Land Use Cover**
- **Non-naturally Succeeding Land Use Cover**

*References:
Laurance et al. (1997), Science, Laurance et al. (1998), Forest Ecology and Management, Pütz et al. (2011), Ecological Modelling*
Methods – Fragment Analysis

Uncertainties

- Fraction of lost above-ground biomass: 10% - 70%
- Edge depth: 100m – 300m


Laurance (2000), TREE

ESA (2009), GlobCover land cover map
Results – General Aspects

- More than 2,000,000 tropical forest fragments world wide
- Distributed over more than $10^9$ ha forested area
- Mean fragment size: 550 ha
- Three largest fragments (63% of forested area):
  - Amazon River Basin – Congo rainforest – Borneo Island

![Fragment Size Distribution](image-url)
Edge depth = 100 m:

Total edge area: 111 billion ha ≈
   10% of the total forested area

Anthr. edge area: 93 billion ha ≈
   8% of the total forested area ≈
   84% of the total edge area
Results – Carbon Losses

- Estimated total Carbon stock in tropical forested area: 183 Gt C
  (from GlobCover 2009 & mean biomass values from Pan et al. (2011), Science)

- Carbon stock in anthropogenic edge area (d = 100m): 15 Gt C

- Total losses: 7.7 Gt C
  ≈ 4.2% of the estimated total above-ground Carbon stock in tropical forests

$\varepsilon = 0.5$

$d = 100$

$d = \text{Edge Depth [m]}
\varepsilon = \text{Fraction of Lost Carbon [#]}$
• Time Frame for Carbon Losses from Edge Areas:

10 to 50 years

Laurance et al. (1998), Forest Ecology and Management
Pütz et al. (2011), Ecological Modelling

• 7.7 Gt C emitted over 30 years:

0.25 Gt C / y

\( \approx \) 20% of the yearly Carbon emissions due to land use cover change

GEOCARBON (2013)
• 10% of tropical forested area within 100 m vicinity of forest edges

• 84% of tropical forest edges created by human activities

• 0.25 Gt C / y emissions from tropical forest fragmentation

...a forgotten process in the global Carbon cycle?
References

<table>
<thead>
<tr>
<th>Unit</th>
<th>America</th>
<th>Africa</th>
<th>Asia &amp; Austr.</th>
<th>World</th>
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</thead>
<tbody>
<tr>
<td>Number of fragments</td>
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<td>874,102</td>
<td>375,025</td>
<td>763,341</td>
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<tr>
<td>Total forested area</td>
<td>(\times 10^6 \text{ ha})</td>
<td>714</td>
<td>216</td>
<td>176</td>
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<td>Mean fragment size</td>
<td>[ha]</td>
<td>816</td>
<td>575</td>
<td>231</td>
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<td>Total edge length</td>
<td>(\times 10^6 \text{ km})</td>
<td>5,554</td>
<td>2,554</td>
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<td>Human induced edge length</td>
<td>(\times 10^6 \text{ km})</td>
<td>4,605</td>
<td>1,700</td>
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<td>Total edge area</td>
<td>(\times 10^6 \text{ ha})</td>
<td>50</td>
<td>23</td>
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<tr>
<td>Total edge area / total forested area</td>
<td>[%]</td>
<td>7</td>
<td>11</td>
<td>22</td>
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<tr>
<td>Anthropogenic edge area / total edge area</td>
<td>[%]</td>
<td>83</td>
<td>63</td>
<td>95</td>
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<tr>
<td>Mean above-ground carbon stock*</td>
<td>[t/ha]</td>
<td>170</td>
<td>155</td>
<td>163**</td>
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<td>Total above-ground carbon stock</td>
<td>[Gt]</td>
<td>121</td>
<td>33</td>
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<td>Total carbon losses</td>
<td>[Gt]</td>
<td>4</td>
<td>1</td>
<td>3</td>
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</table>

* year 2007

** value only referring to Asia; Australia (year 2000): 120 t/ha

Pan et al. (2011),
Ruesch & Gibbs (2008)
<table>
<thead>
<tr>
<th>Value</th>
<th>GlobCover global legend</th>
<th>Tropical Forest</th>
<th>Nat. Succeeding LUC</th>
<th>Non-Nat. Succeeding LUC</th>
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</thead>
<tbody>
<tr>
<td>11</td>
<td>Post-flooding or irrigated croplands</td>
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<td>14</td>
<td>Rainfed croplands</td>
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<tr>
<td>20</td>
<td>Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)</td>
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<tr>
<td>30</td>
<td>Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)</td>
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<td>40</td>
<td>Closed to open (&gt;15%) broadleaved evergreen and/or semi-deciduous forest (&gt;5m)</td>
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<td>Tropical Forest</td>
</tr>
<tr>
<td>50</td>
<td>Closed (&gt;40%) broadleaved deciduous forest (&gt;5m)</td>
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<td>60</td>
<td>Open (15-40%) broadleaved deciduous forest (&gt;5m)</td>
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<td>70</td>
<td>Closed (&gt;40%) needleleaved evergreen forest (&gt;5m)</td>
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<tr>
<td>90</td>
<td>Open (15-40%) needleleaved deciduous or evergreen forest (&gt;5m)</td>
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<td>100</td>
<td>Closed to open (&gt;15%) mixed broadleaved and needleleaved forest (&gt;5m)</td>
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<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>110</td>
<td>Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)</td>
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<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>120</td>
<td>Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)</td>
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<td>Non-Nat. Succeeding LUC</td>
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<td>130</td>
<td>Closed to open (&gt;15%) shrubland (&lt;5m)</td>
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<td>Non-Nat. Succeeding LUC</td>
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<td>140</td>
<td>Closed to open (&gt;15%) grassland</td>
<td></td>
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<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>150</td>
<td>Sparse (&gt;15%) vegetation (woody vegetation, shrubs, grassland)</td>
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<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>170</td>
<td>Closed (&gt;40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Fresh water</td>
<td></td>
<td></td>
<td>Tropical Forest</td>
</tr>
<tr>
<td>180</td>
<td>Closed to open (&gt;15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water</td>
<td></td>
<td></td>
<td>Nat. Succeeding LUC</td>
</tr>
<tr>
<td>190</td>
<td>Artificial surfaces and associated areas (urban areas &gt;50%)</td>
<td></td>
<td></td>
<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>200</td>
<td>Bare areas</td>
<td></td>
<td></td>
<td>Non-Nat. Succeeding LUC</td>
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<tr>
<td>210</td>
<td>Water bodies</td>
<td></td>
<td></td>
<td>Nat. Succeeding LUC</td>
</tr>
<tr>
<td>220</td>
<td>Permanent snow and ice</td>
<td></td>
<td></td>
<td>Non-Nat. Succeeding LUC</td>
</tr>
</tbody>
</table>
Didham’s and Ewers’ core area model

\[
SI = \frac{P}{2\sqrt{\pi} TA}
\]  
(1)

size index SI []
perimeter P [m]
total patch area TA [m²]

\[
EA \approx dP - SI^2 \pi d^2
\]  
(2)

edge area EA [m²]
depth of edge effect d [m]

only valid for \( d \leq r \), for \( d > r \): \( EA = TA \)

\[
C_{loss} = \lambda \times EA \times AGC
\]  
(3)
Small Fragments

Minimum Mapping Unit ~ 9 ha

Total forested area correct
Edge area underestimated

Estimate distribution of small fragments (area conservancy)

- Option 1: Neglect smaller fragments
- Option 2: Assume equipartition
- Option 3: Assume power law distribution
Edge Depth = 100 m

Numbers: anthropogenic edge area / total forested area [%]

Total edge area: 111 billion ha ≈ 10% of the total forested area
Anthr. edge area: 93 billion ha ≈ 8% of the total forested area

Range: 1.7% - 91.7% edge area per fragment