Assessing global land change in support of biodiversity monitoring

Quantifying global land cover
DeFries et al., 1994

Mixed forest
DeFries et al., 1998

8km AVHRR

Mixed forest

Evergreen needleleaf forest
Loveland et al., 2000
Hansen et al., 2000 *
Bartholomé et al., 2005

1km AVHRR

Mixed forest
Evergreen needleleaf forest
Deciduous broadleaf forest
Woodland
Wooded grassland
Grassland
Cropland
Urban and built-up
30m Landsat

Hansen et al., 2013 *
Kim et al., 2014
Data requirements for large area land monitoring

- Systematic global acquisitions
- No/low cost
- Easy access
- Minimal pre-processing required
The Landsat Data Archive

- 30-m TM/ETM+/OLI data
- MSS data


Total archive of 30-m observations, average number of images per year per scene

- Systematic global acquisitions
- Free of charge
- Easy access
- Minimal pre-processing required

Data is free since 2008
Indonesia, Riau province

Image Process
- Raw Digital Numbers
Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
Indonesia, Riau province

Image Process
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing
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Compositing...
Indonesia, Riau province

Image Process
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

Cloud-free mosaic
- 92 images total
- more than 20 per path/row
- 3 years of data!
Landsat 5-4-3
2000 best pixel composite
2000 to 2013 tree cover extent and forest loss and gain
Global forest cover change 2000-2014

Gross forest cover loss 2000-2014 within tropical countries

Annual forest loss, million ha

Brazil

Indonesia

DRC

Annual loss shown using 3-year mean filter
15.7Mha of mapped gross forest cover loss
14.4 ± 2.0Mha of reference gross forest cover loss

6.2Mha mapped primary forest loss
7.5 ± 2.2Mha of reference primary forest loss

10.7Mha of forest loss from MoF

Annual primary forest loss disaggregated by landform for Indonesia as a whole, and the island groups of Sumatra, Kalimantan and Papua. Dashed lines are linear fits to the data.
Primary forest loss
Global forest cover change 2000-2014

Annual % forest loss and annual loss area per country within Congo basin

Cameroon (0.16%)

Gabon (0.08%)

Republic of Congo (0.11%)

CAR (0.08%)

DRC (0.28%)
Forest cover loss due to fire

Forest cover change factor attribution, 2000-2012
Landsat 2010 tree height
30m
GEDI LIDAR

**Science Objectives**

- What is the carbon balance of the Earth’s forests?
- How will the land surface mitigate atmospheric CO2 in the future?
- How does forest structure affect habitat quality and biodiversity?

**Quantity**

- Forest Biomass
- Disturbance and Recovery
- Carbon Sequestration Potential
- Vertical Forest Structure and its Relationship to Biodiversity

**Science Implementation**

- Multi-beam waveform lidar
  - NIR, 20 m footprint
- 14 ground tracks provide 15 billion land surface observations per year
  - Canopy height metrics and profiles
- Deployed on ISS JEM-EF in 2018
- 1 year nominal mission
- Led by University of Maryland and GSFC

**Sampling Pattern**

**Higher Order Data Products**

<table>
<thead>
<tr>
<th>Level 4 Product</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Empirical Model Outputs</strong></td>
<td></td>
</tr>
<tr>
<td>Aboveground Carbon</td>
<td>25 m / 500 m</td>
</tr>
<tr>
<td>Aboveground Carbon Change (2000-2018)</td>
<td>500 m grid</td>
</tr>
<tr>
<td><strong>Ecosystem Model Outputs</strong></td>
<td></td>
</tr>
<tr>
<td>Aboveground Carbon and Carbon Flux</td>
<td>500 m grid</td>
</tr>
<tr>
<td>Carbon Sequestration Potential</td>
<td>500 m grid</td>
</tr>
<tr>
<td><strong>Enhanced Resolution from Fusion</strong></td>
<td></td>
</tr>
<tr>
<td>High Resolution Height and Carbon from LandSat</td>
<td>30 m</td>
</tr>
<tr>
<td>Height, Structure and Carbon from Tandem-X</td>
<td>Variable</td>
</tr>
</tbody>
</table>
Intact Forest Landscapes

[Map showing the distribution of intact forest landscapes globally, with areas shaded green for IFL 2013 and red for IFL loss between 2000-2013.]
Republic of the Congo – High loss of IFL within FSC-certified concessions

glad.geog.umd.edu/forest-alerts
FSC HCVF
Policy motion #65 requires 80% of IFL's within certified concessions to be set aside for protection.
Russian Far East alert implementation
Pan-tropical forest carbon stock strata:
1—low cover (45MgC/ha);
2—medium cover short (53);
3—medium cover tall (74);
4—dense cover short (89);
5—dense cover short intact (102);
6—dense cover tall (141);
7—dense cover tall intact (151).

Tyukavina et al., 2015, Aboveground carbon loss in natural and managed tropical forests from 2000 to 2012, Environmental Research Letters
Stratified sampling for estimating area of natural versus managed forest loss

Forest loss in natural and managed forests. Sample locations classified as reference loss within natural and managed forests for each of the seven forest type strata (see previous figure): 1 – low cover; 2 – medium cover short; 3 – medium cover tall; 4 – dense cover short; 5 – dense cover short intact; 6 – dense cover tall; 7 – dense cover tall intact.
Validation data used for sample block interpretation. Upper part – available Landsat image composites (band combination SWIR-NIR-red). Cloud or shadow contaminated pixels were removed. Sample pixel is outlined in red (location 24.4101 E, 55.1556 N). The graph at the bottom shows annual profiles of SWIR band reflectance (red line), TCC (green line) and minimal NDVI (white line) for this sample pixel. In this sample, forest cover was lost in 2007.
<table>
<thead>
<tr>
<th></th>
<th>Gross forest cover loss</th>
<th>Natural forest cover loss</th>
<th>Gross AGC loss</th>
<th>Natural forest AGC loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (Mha)</td>
<td>Difference between sample and map estimates (%)</td>
<td>% of sample gross forest loss estimate</td>
<td>Annual (TgC/yr)</td>
</tr>
<tr>
<td></td>
<td>Map (Hansen et al., 2013)</td>
<td>Sample estimate</td>
<td></td>
<td>Area (Mha)</td>
</tr>
<tr>
<td>1 DRC</td>
<td>5.9</td>
<td>9.7 ± 3.1</td>
<td>↑ 65</td>
<td>4.3 ± 1.9</td>
</tr>
<tr>
<td>2 Humid Tropical Africa</td>
<td>5.1</td>
<td>9.8 ± 6.2</td>
<td>↑ 92</td>
<td>1.2 ± 0.8</td>
</tr>
<tr>
<td>3 The rest of Sub-Saharan Africa</td>
<td>9.7</td>
<td>17.4 ± 6.2</td>
<td>↑ 79</td>
<td>9.0 ± 3.4</td>
</tr>
<tr>
<td></td>
<td>Africa total</td>
<td>20.7</td>
<td>36.9 ± 9.2</td>
<td>↑ 78</td>
</tr>
<tr>
<td>4 Brazil</td>
<td>34.4</td>
<td>37.6 ± 3.0</td>
<td>↑ 9</td>
<td>25.1 ± 3.8</td>
</tr>
<tr>
<td>5 Pan-Amazon</td>
<td>9.0</td>
<td>10.8 ± 1.8</td>
<td>↑ 21</td>
<td>7.5 ± 2.1</td>
</tr>
<tr>
<td>6 The rest of Latin America</td>
<td>14.9</td>
<td>18.8 ± 4.1</td>
<td>↑ 27</td>
<td>11.6 ± 3.6</td>
</tr>
<tr>
<td></td>
<td>Latin America total</td>
<td>58.3</td>
<td>67.3 ± 6.1</td>
<td>↑ 5</td>
</tr>
<tr>
<td>7 Indonesia</td>
<td>15.7</td>
<td>14.4 ± 2.0</td>
<td>↓ 8</td>
<td>7.5 ± 2.2</td>
</tr>
<tr>
<td>8 Mainland South and Southeast Asia</td>
<td>12.3</td>
<td>16.3 ± 2.8</td>
<td>↑ 32</td>
<td>10.3 ± 2.2</td>
</tr>
<tr>
<td>9 Insular Southeast Asia</td>
<td>6.1</td>
<td>5.5 ± 1.3</td>
<td>↓ 8</td>
<td>2.7 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>South and Southeast Asia total</td>
<td>34.2</td>
<td>36.4 ± 3.8</td>
<td>↑ 6</td>
</tr>
<tr>
<td>10 Pan-tropical total</td>
<td>113.1</td>
<td>140.5 ± 11.6</td>
<td>↑ 24</td>
<td>77.5 ± 8.8</td>
</tr>
</tbody>
</table>
Disaggregation of 2000-2012 forest cover loss by land cover land use change dynamic.

<table>
<thead>
<tr>
<th>Category</th>
<th>From field and image</th>
<th>From field data only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All loss</td>
<td>loss&gt;=3 pixels</td>
</tr>
<tr>
<td>Permanent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>1.4%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Corn</td>
<td>3.2%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Plantation crops</td>
<td>3.4%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Sugar Cane</td>
<td>0.9%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Pasture</td>
<td>8.1%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Subtotal</td>
<td>17.0%</td>
<td>18.3%</td>
</tr>
<tr>
<td>Rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow</td>
<td>27.5%</td>
<td>29.5%</td>
</tr>
<tr>
<td>Corn</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Pasture</td>
<td>24.9%</td>
<td>26.7%</td>
</tr>
<tr>
<td>Logging</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Burned area</td>
<td>22.8%</td>
<td>24.5%</td>
</tr>
<tr>
<td>Hurricane</td>
<td>0.6%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Subtotal</td>
<td>76.1%</td>
<td>81.7%</td>
</tr>
<tr>
<td>Subtotal</td>
<td>Indeterminate</td>
<td>6.8%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Percent bare ground times-series
Berlin

2000-2013 bare ground gain
Cottbus

2013 TM/ETM+ 5-4-3 r-g-b
Cottbus

2000-2013 bare ground gain
Kikwit, Bandundu, DRC
Northern coast of Java – February surface water
Northern coast of Java – April surface water
Northern coast of Java – June surface water
Northern coast of Java – r-g-b of Feb/Apr/Jun
Southern Africa – annual Landsat composite
Southern Africa – February surface water
Southern Africa – April surface water
Southern Africa – June surface water
Land use change

Row crops
Grassland
Other land cover
Dense tree cover
Water
Forest loss to row crops
Pre-2005 forest to row crops
Post-2005 forest to row crops
Monitoring and Forecasting Chimpanzee Habitat Health

Dynamic habitat suitability modeling

Modeling reflects disturbances in chimpanzee (*P. troglodytes*) habitat in a logging concession in Republic of Congo 2003-2012. Red areas show highest habitat suitability. Yellow areas show decreasing suitability over time.

Image time-series

Landsat per-pixel time-series data analysis and compositing

SWIR normalized surface reflectance

- Clouds
- Land observations
- Shadows

2011 2012 2013 2014
Spatial resolution

Nadir temporal revisit

Public

Constellations

Landsat 7 + 8
(systematically acquired, freely available)

Landsat + Sentinel 2

MODIS, MERIS, VIIRS, PROBA V, AVHRR, VEGETATION
(systematically acquired, freely available)

Operational global land monitoring using multi-spectral data
Some conclusions

• Operational earth observing systems with open data policies are required for long-term monitoring of land change and consequent impacts on biodiversity
  • Landsat + Sentinel will offer sub-weekly cadence

• From-to change of cover type/condition, as well as change factor (primary forest -> mechanical clearing -> palm oil) are a priority
  • Generate per pixel land use histories
  • Differentiate ephemeral from permanent change dynamics

• Land change could be integrated with in situ monitoring of biodiversity
  • Preliminary results for chimpanzees with JGI are promising

• Operational time-series should leverage other data as warranted
  • Lidar for calibration of structure, radar for overcoming limitations of optical data

• Continuous measures, such as percent tree cover, are preferred, with land use a categorical overlay
May

100km
October

100km
March

100km
Surface water change, 2000 to 2014
White = all protected areas
2000 to 2013 tree cover extent and forest loss and gain