# Forest Carbon Edge Effect Model

## Summary

The InVEST carbon edge model extends the approach of the InVEST carbon model to account for forest carbon stock degradation due to the creation of forest edges. It applies known relationships between carbon storage and distance from forest edge to calculate edge effects in carbon storage, and combines these estimates with carbon inventory data to construct the overall carbon map. This model maps above-ground carbon only, because edge effects have not been documented for the other carbon pools.

## Introduction

Effects of future land-use change on carbon storage or sequestration can be modeled by applying carbon storage estimates found in the literature for different habitat types to each habitat found in a landscape (e.g., Nelson et al. 2010). However, this approach assumes that all habitat is equivalent in its quality of carbon storage, regardless of where it occurs, despite the fact that there is substantial evidence that fragmentation can play a dramatic role in altering carbon storage and sequestration rates in tropical forests (Broadbent et al. 2008, Dantas et al 2011, Laurance et al. 1997, 2000, 2001, 2002). For example, core forest has been shown to store more than three times the carbon of edge forest in Brazilian Atlantic forests (Dantas et al. 2011). Chaplin-Kramer et al. (REF) investigated this pattern for the entire pantropics using remotely sensed data on biomass (Baccini et al 2012) and associated land cover (Friedl et al. 2011) and found a continuous relationship of carbon storage degrading gradually toward a forest edge, which varies substantially from region to region. This model accounts for these documented edge effects in tropical forests, assigning carbon storage based on the distance of a pixel to the nearest forest edge. This can improve the overall accuracy of carbon storage estimates by 20% relative to forest inventory approaches, and better captures the impacts of forest degradation from fragmentation, beyond merely the area of habitat lost.

## The model

The InVEST carbon edge model is an update to the InVEST carbon model, which incorporates the degradation of carbon storage that occurs due to edge effects in tropical forests. The user designates which land cover classes are forest, and then the model uses pregenerated regression results to predict the carbon throughout a forest parcel based on its distance to the nearest forest edge. These results are combined with the carbon assigned to non-forest classes through traditional inventory methods (IPCC 2006) used in the InVEST carbon model, to generate a map of above-ground carbon storage for all land cover classes. It is important to note that unlike the InVEST carbon model, the InVEST carbon edge model only maps above-ground carbon stocks because edge effects have only been detected for above-ground biomass. To include the other three carbon pools (below-ground, soil, and standing dead matter) the InVEST carbon model can be run with 0’s for above-ground carbon and the results summed with these results for a full picture of carbon including edge effects.

### How it works

This model follows the methodology described in Chaplin-Kramer et al. (REF), which constructs a series of regression models between forest biomass density (Mg/ha) and distance from forest edge (km) for 100 km x 100 km grid cells throughout the pantropics. In grid cells where the majority of pixels were from forest biomes, three candidate regression models are considered to represent the relationship between biomass density and distance to forest edge:

1. Asymptotic:
2. Logarithmic:
3. Linear:

Then, for each grid cell, the candidate with the highest r2 value is used to best represent the relationship between density and distance to forest edge.  Models (2) and (3) were deemed as suitable (and more simplistic) alternatives in cells where higher distances were generally not observed and as a result the forest core was not firmly established. In the vast majority of grid cells, model (1) was optimal.

The results of these regressions can be found in the carbon edge regression parameter shapefile (forest\_carbon\_edge\_regression\_model\_parameters.shp) in the core dataset that ships with the InVEST carbon edge model. For any forest pixel within the study region, the model calculates the distance of that pixel from forest edge then calculates biomass to a predefined number of nearest regression models which is then aggregated to a single result using a distance linear interpolation scheme. The model then converts biomass to carbon with a user provided conversion factor, defaulted to 0.47 (IPCC 2006). The user can designate the number of local models used in the interpolation scheme which is defaulted to 10 but can range anywhere from 1 (only closest point) to 2635 (every regression model on the planet). Note that a selection of 1 may result in artificially large differences in carbon when moving from one pixel to the next where they fall in different regression grid cells. The higher the number of regression grid cells selected, the smoother the transition from one pixel to the next. The user may wish to select the number of grid cells overlapping the entire study region in order to eliminate any artifacts of model selection. This can be determined by examining the intermediate\_outputs\local\_carbon\_shape.shp geometry overlaid on the area of interest. The linear interpolation scheme for biomass b on pixel p is given below

Where,

* is the interpolated biomass on pixel p
* n is the number of nearest models to interpolate from, a value provided by the user
* i is the ith nearest biomass model from pixel p
* di is the distance from pixel p to the centroid of the ith biomass model.

The carbon calculated for non-forest classes follows the methodology from the InVEST carbon model, assigning values based on forest carbon inventory data designated in the biophysical table. The carbon maps following this inventory approach and the edge effects approach are merged into the final carbon map, such that the forest land covers exhibit edge effects and all other land covers will not.

## Data needs

The model uses 6 forms of input data. Five are required and one is optional.

1. Land-use/cover map (required). A map of the different types of land uses or land cover (LULC) for the study region, classified into different categories.

Name: file can be named anything (carbon\_edge\_lulc\_demo.tif in the sample data)

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a column labeled ‘value’ that designates the LULC class code for each cell (integers only; e.g., 1 for forest, 10 for grassland, etc.)

1. Biophysical table (required). A table providing information about which classes in the land-use/land-cover map (input 5) are considered forest and should have the edge effect regression applied, and carbon density per ha for the land cover classes that are not forest.

Name: file can be named anything (edge\_carbon\_lu\_table.csv in sample data)

Type: \*.csv

Columns: the columns must be named as follows:

* + 1. lucode
    2. is\_forest
    3. c\_above
    4. Description

*Example (data for Brazil)*:

|  |  |  |  |
| --- | --- | --- | --- |
| lucode | Is\_forest | c\_above | Description |
| 0 | 0 | 0 | Water |
| 1 | 1 | n/a | Evergreen Needleleaf Forest |
| 2 | 1 | n/a | Evergreen Broadleaf Forest |
| 3 | 1 | n/a | Deciduous Needleleaf Forest |
| 4 | 1 | n/a | Deciduous Broadleaf Forest |
| 5 | 1 | n/a | Mixed Forest |
| 6 | 0 | 10.51 | Closed Shrublands |
| 7 | 0 | 4.51 | Open Shrublands |
| 8 | 0 | 20.12 | Woody Savannas |
| 9 | 0 | 4.42 | Savannas |
| 10 | 0 | 31 | Grasslands |
| 12 | 0 | 0.253 | Croplands |
| 13 | 0 | 0 | Urban/Built-up |
| 16 | 0 | 0 | Barren or sparsely vegetated |

Source: (1) Miranda, Sabrina do Couto, et al. Regional variations in biomass distribution in Brazilian savanna woodland. Biotropica 46.2 (2014): 125-138. (2) Saatchi, Susan S., et al. Distribution of aboveground live biomass in the Amazon basin. Global Change Biology 13.4 (2007): 816-837. (3) Fearnside, Philip M. Greenhouse gases from deforestation in Brazilian Amazonia: net committed emissions. Climatic Change 35.3 (1997): 321-360.

1. Carbon edge regression parameter (required, included in base data): this dataset was derived from a pantropical analysis of the relationship between forest biomass and distance from forest edge (Chaplin-Kramer et al. REF). The rows contain the coefficients of the unique parameters for each 100 x 100 km subregion across the tropics. This information need not be altered unless you have run a separate regression for your region and have better or updated information.

Name: carbon\_edge\_regression\_model\_parameters, in the “core data” folder included in the carbon edge model installer

Format: shapefile

1. Number of nearest model point to average: used when calculating the biomass in a pixel. This number determines the number of closest regression models that are used when calculating the total biomass. Each local model is linearly weighted by distance such that the biomass in the pixel is a function of each of these points with the closest point having the highest effect. Default value is 10. Higher values smooth the variation in the edge effect detected in the different grid cells (seen in the carbon edge regression parameter shapefile, input 3) to a greater degree.
2. Carbon conversion factor: enter the number by which to multiply forest biomass to convert to carbon. Default value is 0.47 (according to IPCC 2006). This pertains to forest classes only; values in the biophysical table for non-forest classes should already be in terms of carbon, not biomass.
3. Service areas of interest (optional): If a summary of the carbon value is desired, a vector dataset containing the area(s) of interest, either as a region area or partitioned into subregions (e.g., ecoregions, districts, etc.) can be included.

Name: file can be named anything (demo\_servicesheds in the sample data)

Format: a vector (polygon) file

## Running the model

The model is available as a standalone application accessible from the install directory of InVEST (under the subdirectory invest-3\_x86/invest\_carbon\_edge\_effect.exe).

### Viewing Output from the Model

Upon successful completion of the model, a file explorer window will open to the output workspace specified in the model run. This directory contains an output folder holding files generated by this model. Those files can be viewed in any GIS tool such as ArcGIS, or QGIS. These files are described below in Section Interpreting Results.

## Interpreting Results

### Final Results

Final results are found in the *Workspace* folder specified for this module.

* **carbon\_edge\_effect-log**: Each time the model is run, a text (.txt) file will appear in the *Output* folder. The file will list the parameter values for that run and will be named according to the service, the date and time, and the suffix.
* **carbon\_map\_<suffix>**: a map of carbon stock for the region, with the amount in forest derived from the regression based on distance to forest edge, and the amount in non-forest classes according to the biophysical table.
* **aggregated\_carbon\_stocks**: If an AOI is provided by the user, this summarizes the total carbon and mean carbon per ha in the areas of interest defined in that AOI.

### Intermediate Results

You may also want to examine the intermediate results. These files can help determine the reasons for the patterns in the final results. They are found in the intermediate\_outputs folder within the *Workspace* specified for this module.

* intermediate\_outputs\**local\_carbon\_shape**: this is the regression parameters reprojected to match your study area
* intermediate\_outputs\**edge\_distance\_<suffix>**: the distance of each forest pixel to the nearest forest edge
* intermediate\_outputs\**forest\_edge\_carbon\_stocks\_<suffix>**: a map of carbon in the forest only, according to the regression method
* intermediate\_outputs\**non\_forest\_carbon\_stocks\_<suffix>**: a map of carbon in the non-forest classes only, according to the carbon inventory listed in the biophysical table

## References

Baccini, A., S. J. Goetz, W. S. Walker, N. T. Laporte, M. Sun, D. Sulla-Menashe, J. Hackler, P. S. A. Beck, R. Dubayah, M. A. Friedl, S. Samanta, and R. A. Houghton. 2012. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. Nature Climate Change 2:182–185.

Chaplin-Kramer, R., I. Ramler, R. Sharp, N. M. Haddad, J. S. Gerber, P. C. West, L. Mandle, P. Engstrom, A. Baccini, S. Sim, C. Mueller, and H. King. (n.d.). Degradation in carbon stocks near tropical forest edges. Nature Communications.

Dantas de Paula, M., Alves-Costa, C., Tabarelli, M., 2011. Carbon storage in a fragmented landscape of Atlantic forest: the role played by edge-affected habitats and emergent trees. Tropical Conservation Science 4, 349–358.

Friedl, M. A., D. Sulla-Menashe, B. Tan, A. Schneider, N. Ramankutty, A. Sibley, and X. Huang. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing of Environment 114:168–182.

Intergovernmental Panel on Climate Change (IPCC). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use.

Laurance, W. F., 1997. Biomass Collapse in Amazonian Forest Fragments. Science 278, 1117–1118.

Laurance, W.F., 2000. Do edge effects occur over large spatial scales? Trends in ecology & evolution 15, 134–135.

Laurance, William F., Williamson, G.B., 2001. Positive Feedbacks among Forest Fragmentation, Drought, and Climate Change in the Amazon. Conservation Biology 15, 1529–1535.

Laurance, W., Lovejoy, T., Vasconcelos, H., Bruna, E., Didham, R., Stouffer, P., Gascon, C., Bierregaard, R., Laurance, S., Sampaio, E., 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. Conservation Biology 16, 605–618.

Nelson, E., et al. 2010. Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. PLOS One 5: e14327