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Kompleksowa analiza wylesiania w krajach tropikalnych - bezpośrednie czynniki wylesiania, emisje dwutlenku węgla i równowaga wartości usług ekosystemów

A comprehensive study on deforestation in the tropics - direct deforestation drivers, carbon emissions and ecosystem service value balance

Master's Thesis
on the course of - Forestry

Thesis written under the supervision of
Dr. Prajal Pradhan
Potsdam Institute of Climate Impact Research
Research Domain II - Climate Climate Impacts & Vulnerabilities

Potsdam, 2018

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Contents

1 Introduction

1.1 Tropical forest

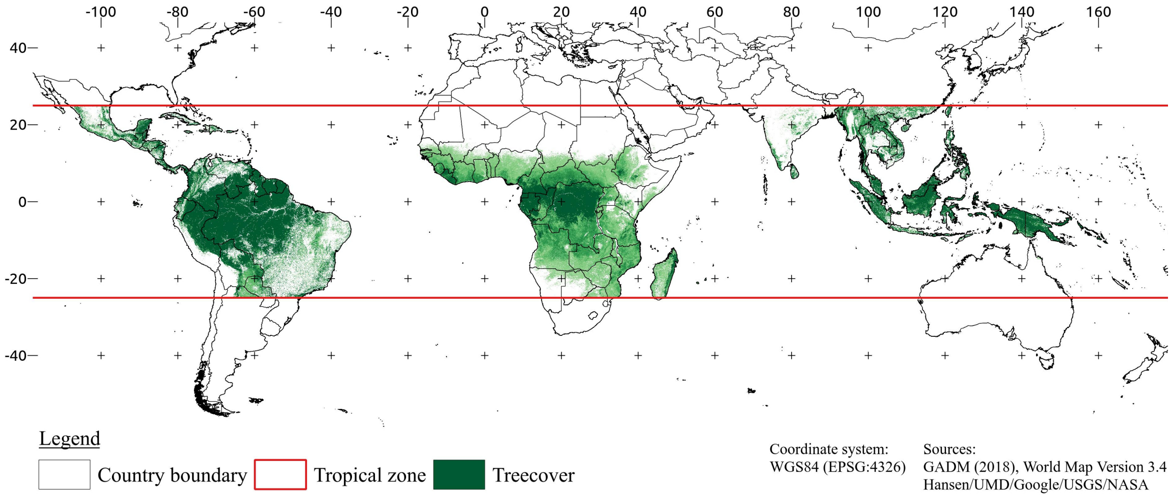

Figure 1.1. Geographic tropical zone framed red and the tropical forest

1.1.1 Current state

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1.1.2 Contribution to climate

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1.1.3 Forest definitions

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1.2 Deforestation

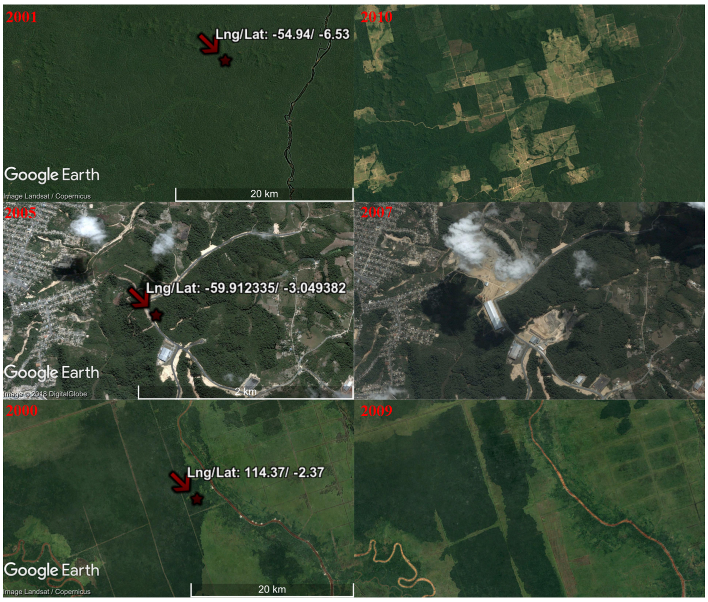

Figure 1.2. Upper Brazil agriculture, middle Brazil urbanization, lower Indonesia large scale palm oil plantations

1.2.1 Land use and land cover change

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1.2.2 Drivers of deforestation

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1.2.3 Emissions trough deforestation

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1.2.4 Removal of AGB

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1.2.5 Soil organic carbon change and soil dynamics

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1.3 Ecosystem services

1.3.1 Ecosystem service values

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1.3.2 Research objective and questions

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2 Data and methods

2.1 Data

2.1.1 Spatial data

2.1.1.1 Global Forest Change

Global Forest Change (GFC) 2000-2012 Version 1.0 is the first high-resolution dataset that provides a comprehensive view of the annual global forest cover change between 2000 and 2012 [Hansen et al. 2013; Li et al. 2017]. The initial GFC dataset released by Hansen et al. is extended by recent releases which encompass the annual forest cover changes between 2000-2013, 2000-2014, 2000-2015 and 2000-2016, respectively. All versions of this dataset have in common, that they are derived from growing season imagery captured by the remote sensing satellite Landsat 7 Enhanced Thematic Mapper Plus (ETM+) enhanced by band metrics of other sensors like Quickbird imagery, existing percent tree cover layers from Landsat data, and global Moderate Resolution Imaging Spectroradiometer (MODIS) percent tree cover [Hansen et al. 2013]. On the satellite imagery, a time-series spectral metrics analysis is applied to gather the global forest extent at 2000 as well as the annual forest loss and the accumulated gain for the period 2001 till 2012. Hence, GFC comprises three independent data layers tree cover, annually forest loss and forest gain divided into 10x10 degree tiles by the geodetic coordinate system World Geodetic System 1984 (WGS84) (EPSG:4326) with a spatial resolution of 1 arc-second per pixel (approximately 900 Km^2 or 30x30 m). Furthermore, across the provided Geo-Tiff (GTiff) layers the pixel data is coded in unsigned 8-bit integers. Hansen et al. defined trees as all vegetation taller than 5 meters for their study. For each pixel covered by trees, a canopy density ranging from 0 t0 100% is computed. Forest loss is defined as a stand displacement disturbance leading from a forest state to a non-forest state (e.g. canopy density >50% to 0%). Tree cover gain is defined as the inverse of loss where the canopy density must exceed 50% to get recognized.

Accuracy

The Hansen et al. GFC dataset is without any constraint publicly available for download. On the version 1.0 dataset homepage you may download "*.txt" files containing the download Uniform Resource Locator (URL) of the tiles for each sub dataset. The spatial location of an image tile can be determined with a tile identifier "{NAME}_{LAT}[NS]_{LNG}[WE]" were latitude (LAT) and longitude refer to the tope left decimal corner coordinates in WGS84 and N or S as well W or E to the orientation on the hemisphere. For this project we needed the subdatasets: Treecover2000, lossyear and gain. The download process is fully automatized with an Python script by using the Standard Library (stdlib) modules urllib, re and threading. First this script downloads the required "*.txt" files and creates an list where each URL is a list element. Next it iterates over the list and extracts the corner coordinates from the file identifier with an Regular Expression (REGEX). This coordinate string is converted to an numeric identifier where latitude coordinates on the northern hemishpere are between $[90,0]$ and on the southern hemisphere between $(0,-90]$. Now a dataset tile is only downloaded if it is within the study extent between [30,-20] latitude. The acquired image tiles are shown in the top panel (green squares) in Figure 2.1. Because we have to download in total 678 images tile the entire download process is parallized by means of multithreading.

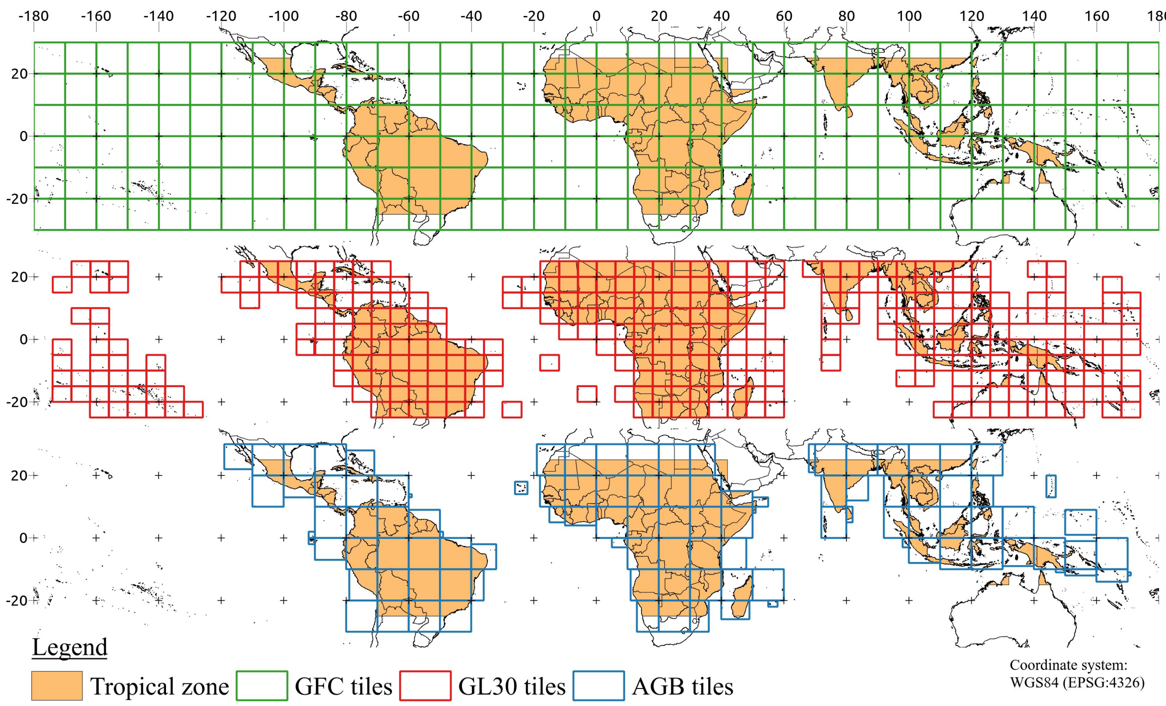

Figure 2.1. Map of downloaded dataset tiles: This map shows the acquired image tiles for this study. From top to bottom in green Global Forest Change (GFC) dataset tiles (Treecover2000, lossyear and gain), the land cover dataset GlobeLand30 (GL30) image tiles in red, and in blue the Aboveground Biomass (AGB) dataset tiles. The orange filled shapes highlight countries within the tropical zone.

2.1.1.2 GlobeLand30

GlobeLand30 (GL30) is the first 30 meter per pixel spatial resolution global land cover dataset that provides a comprehensive view on the distribution of 10 different land cover classes (Table 2.1) over the earth [Chen et al. 2017]. Currently this dataset is for two different time frames available 2000 and 2010 [Chen et al. 2015]. The dataset is coded in unsigned 8 bit integers and as coordinates system it uses WGS84 in Universal Transverse Mercator (UTM) projection and is shipped as GTiff in a tilled manner where each tile covers 6x5 degrees [Chen et al. 2014]. For detection of the 10 land cover classes Chen et al. used a so called Pixel-Object-Knowledge (POK) oriented approach [Chen et al. 2015]. The assigned pixel values and the corresponding land cover class is listed in Table 2.1. They grouped mapping process in different stages where each land cover type is detected separately and deleted from the source satellite image the order is: water bodies, wetland, snow and ice, cultivated land and forest, shrub land, grass land and bare land synchronous. For the detection of a land cover type they used at pixel level one of the following classifiers: Decision Tree (DT), Support Vector Machine (SVM) or Maximum Likelihood Classifier (MLC). After pixel detection they grouped the classified pixel to an object and validated this object by expert knowledge. For their approach they used satellite imagery from Landsat and HJ1 and auxiliary data like MODIS NDVI.

Chen et al. estimates an overall accuracy of 80.33% for the product from 2010 and 78.6% for the product from 2000 (2000 only validated at Shaanxi province in China) [Chen et al. 2015]. Various scientists besides Chen et al. validated the mapping accuracy of GL30 at different regions and scales. Arsanjani et al. estimates an accuracy of 77.9% for Iran and an accuracy >80% for Germany [Arsanjani et al. 2016a,b]. Yang, Cao and Jacobson estimate an accuracy of 82.4%, 80.1% and 83.1% for China, Nepal and East Africa, respectively reference. Unfortunately, there are no estimates for countries regions falling completely in the tropical zone.

Chen funded the GL30 land cover mapping to the UN but it is not barrier less public available. Restriction is registration on the dataset homepage but the author was not able to register at the platform. Fortunately the supervisor of this work had already an account for this page otherwise I would be fucked. To download tiles of this dataset a order application must be filled with the required image tiles identifiers and the the year must be selected. An tile identifier "`[NS]{UTMZONE}_{LAT}`" consist of the hemisphere orientation followed by the top left corner latitude and logitude decimal coordinate (WGS84).Correct: utm zone followed by latidude +6° The homepage provides an interface for selecting the required image tiles but it is broken and buggy, especially the selection of multiple tiles did not work. Fortunately they provide a vector file which contains the dataset tile polygons with assigned identifies. This file was used to select all required tiles within the tropical zone between

Table 2.1. Classification schema of the GlobeLand30 product: The code column is the assigned pixel value, type the corresponding land cover type and definition explains in broad terms which types of surfaces fall into the land cover type [Chen et al. 2017].

Code	Type	Definition
10	Cultivated land	used for agriculture, horticulture and gardens, including paddy fields, irrigated and dry farmland, vegetable and fruit gardens, etc.
20	Forest	covered by trees, vegetation covers over 30%, including deciduous and coniferous forest, and sparse woodland with cover 10-30%, etc.
30	Grassland	covered by natural grass with cover over 10%, etc.
40	Shrubland	covered by shrubs with cover over 30%, including deciduous and evergreen shrubs, and desert steppe with cover over 10%, etc.
50	Wetland	covered by wetland plants and water bodies, including inland marsh, lake marsh, river floodplain wetland, forest/shrub wetland, peat bogs, mangrove and salt marsh, etc.
60	Water bodies	in land area, including river, lake, reservoir, fish pond, etc.
70	Tundra	covered by lichen, moss, hardy perennial herb and shrubs in the polar regions, including shrub-, herbaceous-, wet- and barren-tundra, etc.
80	Artificial surfaces	modified by anthropogenic influence, including all kinds of habitation, industrial and mining area, transportation facilities, and interior urban green zones and water bodies, etc.
90	Bareland	with vegetation cover lower 10%, including desert, sandy fields, Gobi, bare rocks, saline and alkaline land, etc.
100	Snow and ice	covered by permanent snow, glacier and icecap

approxiamtely 23°N and 23°S (WGS84), the selection is shown in red in the middle panel at Figure 2.1. The corresponding identifiers were converted to an single line string and copied to application form. After submitting the form your order will be checked and approved. After one week we received 2 weeks limited access to an password protected ftp server were we downloaded the data. Due to restrictions this process of selecting data and download it could not be automatized with one pipeline only the selection and string conversion was automatized with a throw away script.missing total number of tiles

2.1.1.3 Intact Forest Landscapes

Intact Forest Landscapes (IFL) 2000 is a dataset comprising a mosaic of forest and naturally treeless ecosystems without sings of human activity and large enough to maintain all native biological diversity for the time period 2000 [Potapov et al. 2017]. Due to the fact that IFL comprises different intact natural landscape patterns like primary forests, non-forest ecosystems, temporary treeless areas after a natural disturbance, and water bodies the term is not congruent to the term primary forest defined by the Food and Agriculture Organization of the United Nations (FAO) [FAO 2012]. But as mentioned IFLs includes large patches of primary forests with a minimum extent of 500 Km^2 therefore primary forests can be extracted from the layer. Still there are smaller fragments of primary forest outside of the IFLs. In regards of the extent a IFL has a minimum size of 500 Km^2, a minimum width of 10 Km, and a minimum corridor/appendage width of 2 Km. Further a IFL should not contain any of the following: ecosystem alternation, fragmentation by infrastructure and disturbance, and areas altered or managed trough agriculture, logging, and mining. For mapping and detecting IFLs Potapov et al. used Landsat imagery and several auxiliary data sources like GFC, and national transportation maps. The dataset is may be downloaded as a Shapefile (SHP) with the coordinate reference system WGS84. Each polygon in the SHP represents an IFL patch at a certain location on our planet.

Data acquisition is pretty straight forward the IFL dataset is barrier-less public available for download. As mentioned it is an SHP so you must only download a single compressed archive. This download is realized with an Python script by using the stdlib module urllib.

2.1.1.4 Aboveground Woody Biomass

The Aboveground live woddy Biomass density (AGB) raster dataset is prepared by Global Forest Watch (GFW) with an adapted approach of Baccini et al. [Baccini et al. 2012, 2015, 2017]. For the year 2000, this dataset comprises the aboveground biomass density in Mg C ha^{-1} (mega gram carbon per hectare) per pixel, and a confidence estimate per pixel at a spatial resolution of approximately 1 arc-second (approximately 900 Km^2 or 30x30 m). The dataset covering the global tropical zone as an mosaic of GTiff raster images where each tile has the Coordinate Reference System (CRS) WGS84 and is coded in float. For deriving biomass density GFW used canopy metrics from Geoscience Laser Altimeter System (GLAS) Light Detection and Ranging (LIDAR) footprint and several allometric equations. The resulting GLAS AGB estimates are used to train a Random Forest (RF) model based on Landsat 7 ETM+.

The AGB raster image tiles are public available for download on the homepage of GFW. As mentioned before this dataset covers only the tropical zone therefore no filtering is needed before download. To receive the URL of each image tile the GFW homepage provides an Geographic JavaScript Object Notation (GeoJSON) Application Programming Interface (API). The response of this API if requested is an GeoJSON feature collection containing the URL of the actual biomass layer, the URL of the uncertainty layer, and the rectangular bounds of each image tile. The data acquisition is automatized by a Python script by using the stdlib modules urllib, threading, and the open source library Geopandas. At first the GeoJSON is downloaded via an API call and eventually stored on disk. Next we iterate over each feature of the GeoJSON feature collection and extract the URLs (biomass and confidence) of each tile. These URLs are piped to our multi-threaded downloader and eventually store on disk. Despite mentioning the confidence layers in the dataset description, the server answers with a 404 if the confidence URL is requested. Therefore the confidence layers are not available. In total we downloaded 105 different image tiles, there extent is shown in blue at the bottom panel of Figure 2.1.

2.1.1.5 Global Soil Organic Carbon

The Global Soil Organic Carbon map (GSOCmap) is a joint project between Global Soil Partnership (GSP) and Intergovernmental Technical Panel on Soils (ITPS) to produce a global Soil Organic Carbon (SOC) content map by a country driven approach. This year 2018, the first iteration of this map in version 1.0 was released, and later followed by 1.1 (new country submission by Rwanda) and 1.2 (new country submissions by Chile and Colombia). The mapping project is intended as a long lived dataset which will improve over time and by new country submissions. Till now 67 (approximately 63 % of the global land mass) different countries submitted their SOC estimates. To empower national SOC mappings the International Soil Reference and Information Center (ISRIC) provides several covariate datasets like national Digital Elevation Map (DEM) maps, annual spectral remote sensing data or national soil type grids. Also the contributors can join a mapping training and use the GSOCmap cookbook as guidance for their mapping efforts. As exchange each country shares it own national GSOCmap meeting several criteria: reporting of the Meta-data of national SOC sampling (timeline, depth, bulk density and so on), uncertainty assessment, and the applied methods for estimating and interpolation of the SOC content. As interpolation method the guide organizations suggest the following approaches and more: simple geo-matching, class-matching, Multiple Linear Regression (MLR), RF or SVM. The national maps are aggregated to the final GSOCmap with a target resolution of 30 arc-seconds (approximately 1 Km^2) in the CRS WGS84. The dataset is one GTiff coded in float covering the entire globe where each pixel value is the SOC content in Mg C ha^{-1} at soil depth of 0-30cm [FAO and ITPS 2018].

issue border differences between countries caused by different methodologies and gap filling (if cntry dont use provided mask there is no overlap)

Is public available as geotiff, download at fao hp, download one huge gtiff, acquisition performed by python.

2.1.1.6 Auxiliary

As auxiliary source for country boundaries we used the Global Administrative Areas Map (GADM) [Hijmans et al. 2018].

2.1.2 Empirical data

2.1.2.1 Soil Organic Carbon

Don et al. performed the first study on tropical SOC change for soil depth between 0 and 30 cm. For the study a global meta-analysis is applied by using 358 (153 published an peer-reviewed) different studies to estimate SOC change for 12 major Land-use Change (LUC) types. The base date is derived from 39 different tropical countries covering all continents. Unfortunately Africa and East-Asia are under-sampled whereas South-America has the best data coverage. The meta-analysis is restricted to mineral soils therefore all wet soil types are excluded from analysis. Don et al. considered 5 different Land Use (LU) types for his study: primary forest, secondary forest, grassland, cropland, and perennial crops. Primary forest is defined as natural vegetation without human impacts which includes natural grassland and shrubland. Secondary forest are managed forests and regrown forest after partial destruction of the old stand. Grassland comprises pastures but excludes natural grasslands. Cropland is comprises annual crops like maize or beans and perennial crops could be coffee or sugar cane [Don et al. 2010]. For our study we used only the SOC change estimates for these LUC types which corresponds to the GL30 and IFL classification schema shown in Table 2.2.

Table 2.2. Relative soil organic carbon change for certain land-use change types: The Land-use change columns from and to defines the LUC type with corresponding relative Soil Organic Carbon (SOC) change and the Standard Error of the Mean (SEM) [Don et al. 2010].

LUC type		Relative SOC change	
From	To	[%]	SEM
Primary forest	Grassland	-12.1	±2.3
Primary forest	Cropland	-25.2	±3.3
Primary forest	Secondary forest	-8.6	±2.0
Secondary forest	Grassland	-6.4	±2.5
Secondary forest	Cropland	-21.3	±4.1

2.1.2.2 Ecosystem Service Values

2.2 Methods

2.2.1 Preprocessing

Before we apply further analysis, we have to generalize the used datasets. As introduced in the data section do we use datasets which differ largely in their metadata properties, for example, single-tiled or multi-tiled images, used CRS, spatial resolution, and file type. Therefore, our goal should be to develop a process which creates an image stack of equal meta-data for each location in our study extent. In further descriptions, we will refer to this stack as Aligned Image Stack Mosaic (AISM). As target CRS for our AISM we chose WGS84 and as target extent for the mosaic, we use the bounding box of the GL30-2010 tiles. The following paragraph explains how we developed the alignment algorithm by means of Python and the additional libraries rasterio, geopandas, and shapely.

The first exercise of the preprocessing algorithm is to detect all tiles covering the extent of our template tiles. At first, we create for each multi-tiled dataset a polygon mask as SHP. This mask contains the spatial extent of each tile within a dataset and as attribute the corresponding file identifier. If the dataset tiles are not in WGS84 the extracted bounds are subsequently reprojected to this CRS. During the masking process, we recognized that the raster mosaic bounds of both GL30 datasets (2000 and 2010) generate re-projection errors. These errors showed up as polygons spanning the entire globe but one tile can only fill its UTM zone extent. A further analysis revealed that all tiles located in UTM zone 1 and 60 overflowing the maximum and minimum longitude coordinates of this zones. As solution we excluded all tiles within UTM zone 1 and 60 from further processing, namely: n01_00, s01_00, s01_10, s01_15, s01_20, s60_00, s60_05, s60_10, s60_15, and n53_00. The described steps can be found as well in figure 2.2. Now, as the figure suggests we determine the intersection between these mask layers and group the intersecting tiles by our template tile. Next, we create for the template tile a re-projection profile (warp profile) and apply it subsequently to all intersecting tiles based on the following rules: if from one dataset more than one tile intersects merge them followed by re-projection or if only one tile intersects just re-project it. As introduced the GSOCmap consist only of one single tile with a spatial resolution of approximately 1 Km^2, so it must only re-project and re-sampled by nearest-neighbor approach. We select from the IFL layer all polygons within our template warp profile and convert them to a raster layer where intact forest patches are coded by a one in 8-bit unsigned integer. Last step of the alignment process is the rounding of the AISM bounds to full integer degrees and a subsequent clipping of each tile to this rounded bounds. The entire work flow it pictured in figure 2.2 and results in a AISM shown in figure 2.3. Finally, we create a polygon mask of our AISM and store for each polygon the corresponding dataset tiles. This mask is used as a file index for the next algorithms.

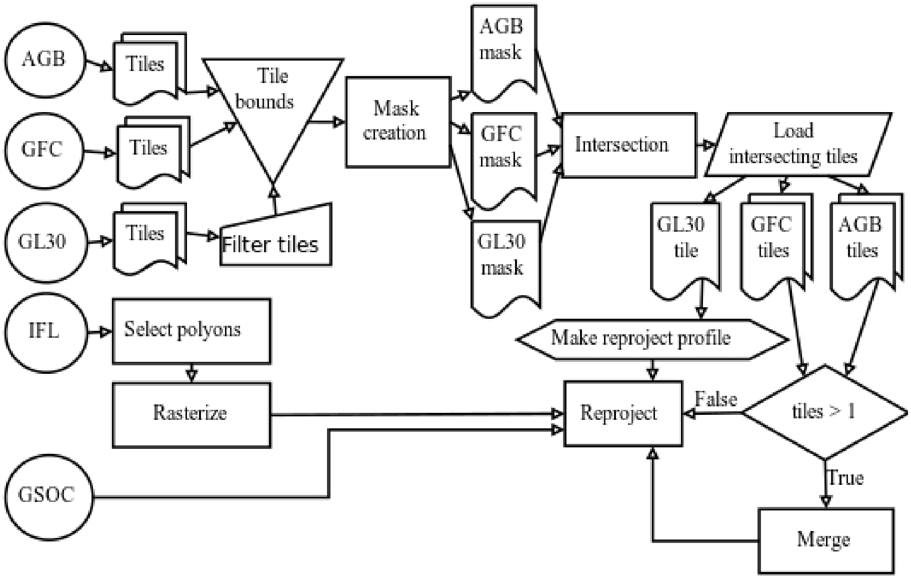

Figure 2.2. Flowchart of tile alignment process: For the multi-tiled datasets (multi-document symbols) a mask is created by extracting the tile bounds. Next, the intersection between theses masks is determined and the corresponding tiles are loaded from disk. GL30 tiles are used as template by creating re-project profile and subsequently applying it to intersecting tiles. From the IFL layer only polygons within the re-project are selected and subsequently converted to a raster layer.

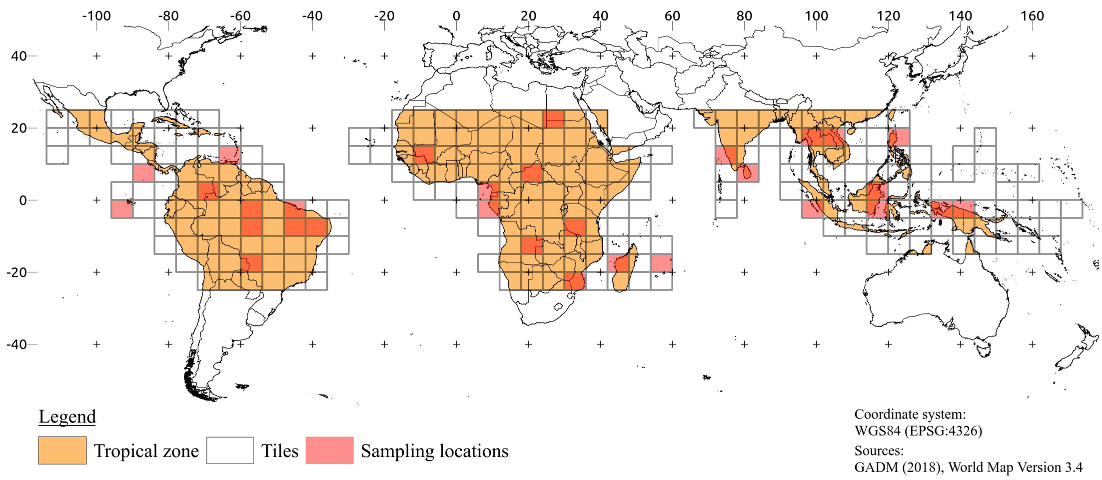

Figure 2.3. Map of aligned data tiles and sampling locations: The map shows the location of the aligned multi-image stack tiles as black-framed square sized polygons, the sampling locations for accuracy assessment in red, and countries within the tropical zone in orange.

2.2.2 Deforestation

2.2.2.1 Forest definition

jaccard index, wilcoxon signed-rank test, gl30 2000, gfc treecover 2000, different canopy densities

2.2.2.2 Land use change driver

cluster based reclassification, select forest loss from 2001 till 2010, in canopy density class of forest definition, gain only considered if on deforested pixels,

2.2.2.3 Accuracy assessment

confusion matrix, java script plattform, random selection of sampling size, sampling algorithm

2.2.3 Emissions

2.2.3.1 Above ground biomass

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2.2.3.2 Soil organic carbon change

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2.2.4 Ecosystem service values

2.2.4.1 Ecosystem service value loss

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2.2.4.2 Ecosystem service value gain

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2.2.5 Binning analysis

The previous sections were focused on the generation of large scale spatial data. Now, a feasible method must be developed for analyzing, aggregating, interpreting and visualizing the output data. To develop a good approach we must formalize the problem domain. At first we are confronted with large N (many samples) which results in many variables (dimensionality) and complexity of relationships among this variables [Carr 1990]. From a visual/analytical perspective georeferenced raster maps can be interpreted as a multivariate scatter plot of large datasets where longitude and latitude represent the x and y coordinate of an data point and the pixel values (in this case nominal scaled) representing the third dimension as an group coloring. Therefore we have a large multidimensional dataset combined with a scatter plot visualization which leads commonly to over plotting issues and hidden point densities [Carr et al. 1987]. Due to the spatial nature of your data we are also confronted with not equal distributed data some regions show high data densities and other regions have sparse to no data. Also a severe problem domain is the frame size of our representation. Goal is to present data on a continental level which intensifies visual problems. Each pixel has a resolution of approximately 30x30m, the continental representation of americas spanning approximately 1200000x120000km2. Therefore small scale isolated changes are hidden and only large scale changes are visual detectable. Which results in hidden details and not perceivable patterns of change.

Goal should be to develop an process who solve this issues and generates satisfying output for our multivariate data. In case of raster data a re-sampling to coarser resolution could solve over plotting and resolution issues as well normalize the unequal distributed data. But the nature of re-sampling (for nominal data a nearest neighbor or majority wins Reference) would negate important spatial patterns as well frequency distributions. Another well known approach is to use binning of the spatial explicit data with a certain kind of regular polygon that is tessellating the plane [Carr et al. 1992]. Polygon tessellations provide numerous opportunities for presenting multivariate statistical summaries. The scaling of the polygon could be used to represent pixel densities within the polygon area, a polygon filling color gradient is applicable to show nominal or ordinal scaled data. Also it is imaginable to use the polygon interior for a pie chart. To use regular tessellation it is important to mention there are only three types of regular polygons tessellate the plane: squares, equilateral triangles and hexagons [Carr et al. 1992]. Square tessellation is the most common approach used for binning in spatial visualization. A raster image is a square tessellation. In a square mosaic each polygon shares 4 edge neighbors and 4 vertex neighbors more explanation error distance disadvantages etc Hexagons properties, advantages disadvantages of both tessellations. Final goal is to show your analysis results of spatial explicit raster data in hexagonal binned form. For bivariate maps we choose a visual representation with scaled hexagons and colorization. For multivariate details we choose a pie chart alike visualization. We split the hexagons horizontal in regards of the presented ratio. The ratios should be ordered descending so that the greatest ratio is south oriented. It is following a general description how we created the hexagon grids and how we tackled the polygon split problem.

To be flexible at hexagon construction we accept 4 different parameters as construction arguments: D long diagonal (Diameter of the circumscribing circle), d short diagonal (diameter of the inscribed circle), A area the hexagon should span and or e the edge length. One selected parameter of these is used to compute R the radius of the circumscribing circle with respect to input parameter as shown in equation 2.1. R is used to calculate the midpoint $< c_x, c_y >$ of the hexagon located in the first quadrant of the cartesian coordinate system Equation 2.2 and 2.3. Equation 2.4 shows the computation of the hexagon anti-clockwise vertex matrix. Whereas the two leftmost vertices (first and last row of the matrix **H**) are located at koordinatenursprung, will sagen auf deutsch korridanten at x=0 und y=value of matrix. In summary equation 2.1 to 2.4 show the creation of an hexagon at the leftmost corner of first quadrant (Figure 2.4). The orientation is important for the subsequent mosaic creation.

$$R = \frac{\sqrt{2A}}{\sqrt[4]{27}} = \frac{D}{2} = \frac{d}{\sqrt{3}} = e \tag{2.1}$$

$$c_x = \frac{R\sqrt{3}}{2} \tag{2.2}$$

$$c_y = R \tag{2.3}$$

$$\mathbf{H} = \begin{bmatrix} 0 & c_x & 2c_x & 2c_x & c_x & 0 \\ R\sin\left(\frac{7\pi}{6}\right)+c_y & 0 & R\sin\left(\frac{11\pi}{6}\right)+c_y & R\sin\left(\frac{\pi}{6}\right)+c_y & 2R & R\sin\left(\frac{5\pi}{6}\right)+c_y \\ 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \tag{2.4}$$

A polygon tessellation needs several polygons to create a grid in case of the creation of one hexagon with the presented algorithm needs approximately benchmark but the creation of several N hexagons needs approximately benchmark. Therefore it is much simpler to create only one hexagon with the presented algorithm and to create the grid polygons by copying the coordinates of the source polygon and translating them to their target position with a affine transformation matrix shown in equation 2.5. To create the grid we get the rectangular bounds of the area to tessellate as a matrix $\mathbf{B} \in R^{2\times 2}$ (equation 2.6), where the first column of the matrix contains the lower left corner and the second column the upper right corner of the image. Each subsequent translation in regards of x_{off} is $x_1 + d$ for even rows and bla bla for odd rows. Y_{off} is computed by bla bla see figure 2.4.

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & x_{off} \\ 0 & 1 & y_{off} \\ 0 & 0 & 1 \end{bmatrix} \circ \mathbf{H} \tag{2.5}$$

$$\mathbf{B} = \begin{bmatrix} x_1 & x_2 \\ y_1 & y_2 \end{bmatrix} \tag{2.6}$$

Binning of raster data is easy we just have a point in polygon problem each points/pixels falling in hexagon are counted and aggregated through a function. In case of drivers of deforestation we count all driver classes per hexagon and compute ratios next we compute the sha describe for each map how you build it As mentioned before for the visualization of the drivers of deforestation map we want to segment the hexagons with horizontal lines and each segment should represent the share of the direct deforestation driver within the tessellated area. To compute the split line for a certain hexagon we need the hexagon R computeable from the area of the hexagon equation 2.7 and the rectangular bounds of the hexagon. We compute the relative share of an deforestation driver per hexagon this relative share can be used to compute the y-axis coordinate of an split line equation 2.8. A regular hexagon can not only be presented in it vertex form as shown above. We can also use functions to define the hexagon shape. A hexagon consist of 2 picewise functions where each function consist of 3 linear functions restricted to an intervall. If we invert these functions we can use these functions to compute the x-coordinate of the split line with the previous computed y-coordinate Equations 2.9 and 2.10. As a results we receive the solution matrix L which represents the horizontal line segment splitting the hexagon at the point where we want (driver ratio share) equation 2.11. The solution matrix can be plugged in to a polygon split function which separates the hexagon polygon in a upper and lower part to do so we iterate over the hexagon vertices and decide if they are above or under the split line and

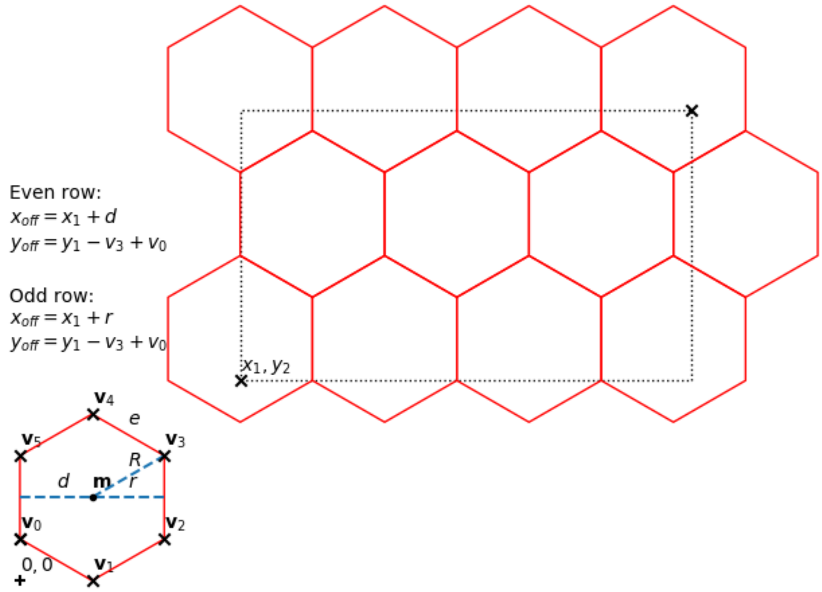


Figure 2.4. Hexagon tessellation: Located at the left bottom corner in red a hexagon defined by its geometric properties the 6 vertex vectors $\{\vec{v}_0, \ldots, \vec{v}_5\}$ (black crosses), with center vector $\vec{m}$, edge length e, R radius of the circumscribing circle, r radius of the inscribed circle and d the length of the short diagonal. Top right black dotted box are the bounds of an area which is tessellated by a hexagon grid in red. Each grid cell is translated from the origin hexagon at its position by computing the x_{off} and y_{off} offset with the presented equations at the left-hand side of the grid.

append to a lower upper polygon. These list are our results explain better split function.

$$R = \frac{\sqrt{2A}}{\sqrt[4]{27}} \tag{2.7}$$

$$y = \frac{P(y_2 - y_1)}{100} + y_1 \tag{2.8}$$

$$f^{-1}(y) = \begin{cases} -\frac{y-y_1}{\tan(\frac{\pi}{6})} + \frac{x_1+x_2}{2} & \text{if } y_1 \leq y < y_1 + R\sin(\frac{5\pi}{6}) \\ x_1 & \text{if } y_1 + R\sin(\frac{5\pi}{6}) \leq y < R(\sin(\frac{5\pi}{6}) + 1) \\ \frac{y-y_2}{\tan(\frac{\pi}{6})} + \frac{x_1+x_2}{2} & \text{if } R(\sin(\frac{5\pi}{6}) + 1) \leq y \leq y_2 \end{cases} \tag{2.9}$$

$$g^{-1}(y) = \begin{cases} \frac{y-y_1}{\tan(\frac{\pi}{6})} + \frac{x_1+x_2}{2} & \text{if } y_1 \leq y < y_1 + R\sin(\frac{5\pi}{6}) \\ x_2 & \text{if } y_1 + R\sin(\frac{5\pi}{6}) \leq y < R(\sin(\frac{5\pi}{6}) + 1) \\ -\frac{y-y_2}{\tan(\frac{\pi}{6})} + \frac{x_1+x_2}{2} & \text{if } R(\sin(\frac{5\pi}{6}) + 1) \leq y \leq y_2 \end{cases} \tag{2.10}$$

$$\mathbf{L} = \begin{bmatrix} f^{-1}(y) & g^{-1}(y) \\ y & y \end{bmatrix} \tag{2.11}$$

3 Results

3.1 Forest definition and accuracy assessment

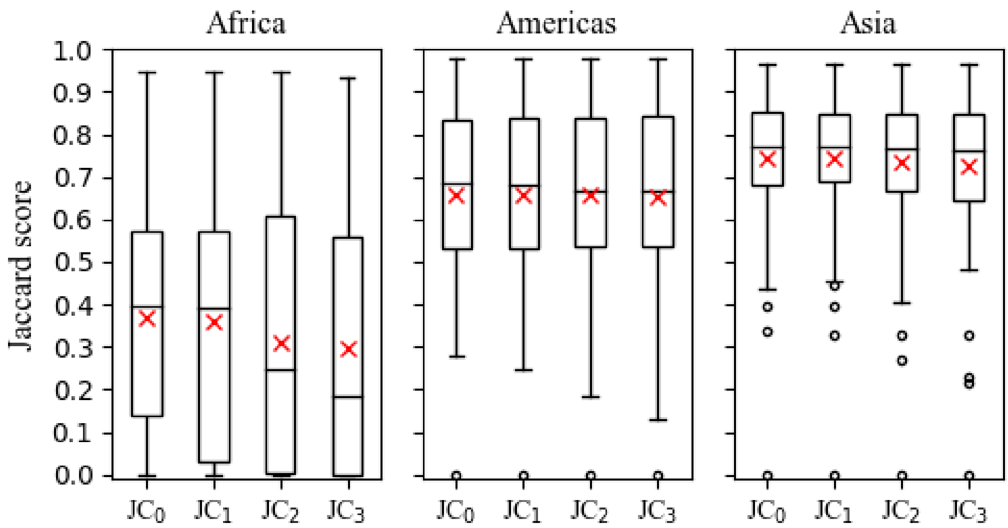


Figure 3.1. Similarity distribution of GFC tree cover vs. GL30 tree cover at 2000: Americas from JC_0 till JC_3: $\bar{x} \approxeq .71, .71, .70, .69$; $\tilde{x} \approxeq .77, .77, .76, .75$; $Q_1 \approxeq .64, .65, .64, .63$; $Q_3 \approxeq .84, .84, .84, .83$; Asia from JC_0 till JC_3: $\bar{x} \approxeq .71, .71, .70, .69$; $\tilde{x} \approxeq .77, .77, .76, .75$; $Q_1 \approxeq .65, .66, .64, .63$; $Q_3 \approxeq .84, .84, .84, .83$; Africa from JC_0 till JC_3: $\bar{x} \approxeq .39, .39, .34, .32$; $\tilde{x} \approxeq .40, .40, .31, .29$; $Q_1 \approxeq .14, .10, .00, .00$; $Q_3 \approxeq .60, .61, .63, .56$

Table 3.1. Two-sided Wilcoxon signed-rank test:

	H_0: $\tilde{x_1} = \tilde{x_2}$											
	Americas				Asia				Africa			
Cls	JC_0	JC_1	JC_2	JC_3	JC_0	JC_1	JC_2	JC_3	JC_0	JC_1	JC_2	JC_3
JC_0	1.				1.				1.			
JC_1	.00	1.			.72	1.			.22	1.		
JC_2	.06	.36	1.		.00	.00	1.		.03	.03	1.	
JC_3	.16	.50	.60	1.	.00	.00	.00	1.	.00	.00	.00	1.

Table 3.2. One-sided Wilcoxon signed-rank test:

		H$_0$: $\tilde{x_1} \leq \tilde{x_2}$											
		Americas				Asia				Africa			
	Cls	JC$_0$	JC$_1$	JC$_2$	JC$_3$	JC$_0$	JC$_1$	JC$_2$	JC$_3$	JC$_0$	JC$_1$	JC$_2$	JC$_3$
H$_0$: $\tilde{x_1} \geq \tilde{x_2}$	JC$_0$	1.	.00	.03	.08	1.	.64	1.	1.	1.	.11	.98	1.
	JC$_1$	1.	1.	.18	.25	.36	1.	1.	1.	.89	1.	.99	1.
	JC$_2$	.97	.82	1.	.30	.00	.00	1.	1.	.02	.01	1.	1.
	JC$_3$	.92	.75	.70	1.	.00	.00	.00	1.	.00	.00	.00	1.

Table 3.3. Confusion matrix for accuracy assessment

		Reference											
	Cls	10	20	25	30	40	50	60	80	90	Tot	UAc	Om
Prediction	10	732	38	62	15	16	2	3	5	0	873	.84	.16
	20	42	751	57	189	31	12	0	17	4	1103	.68	.32
	25	29	202	1155	173	22	10	5	11	4	1611	.72	.28
	30	36	187	32	1466	73	21	0	17	0	1832	.80	.20
	40	14	21	4	41	352	1	1	2	1	437	.81	.19
	50	0	5	3	10	4	50	0	1	0	73	.68	.32
	60	2	1	0	3	0	2	18	2	0	28	.64	.36
	80	3	4	0	1	1	1	0	50	0	60	.83	.17
	90	0	0	0	1	0	0	0	3	5	9	.56	.44
	Tot	858	1209	1313	1899	499	99	27	108	14	6026		
	PAc	.85	.62	.88	.77	.71	.51	.67	.46	.36			OvAc
	Com	.15	.38	.12	.23	.29	.49	.33	.54	.64			.75

3.2 Deforestation drivers

3.2.1 Global

3.2.2 Americas

3.2.3 Asia

3.2.4 Africa

Table 3.4. Absolute in km^2

Type	Class		Americas	Asia	Africa
Agriculture	Cropland	rel.	24.37	18.37	25.01
		abs.	95908	38719	44368
	Grassland	rel.	46.19	8.41	50.46
		abs.	181781	17726	89516
Forestry/Plantations	Regrowth	rel.	14.40	70.27	18.61
		abs.	56671	148111	33014
	Shrubland	rel.	12.69	1.11	3.77
		abs.	49941	2340	6688
Urban/Mining	Artificial	rel.	0.41	0.46	0.71
		abs.	1614	970	1260
	Bareland	rel.	0.10	0.03	0.09
		abs.	394	63	160
Natural	Wetland	rel.	1.50	0.97	1.23
		abs.	5903	2045	2182
	Water	rel.	0.32	0.38	0.13
		abs.	1259	801	231
Forest loss		rel.	3.87	4.68	1.69
		abs.	393550	210774	177400
Forest cover		abs.	10223187	4457940	10496591

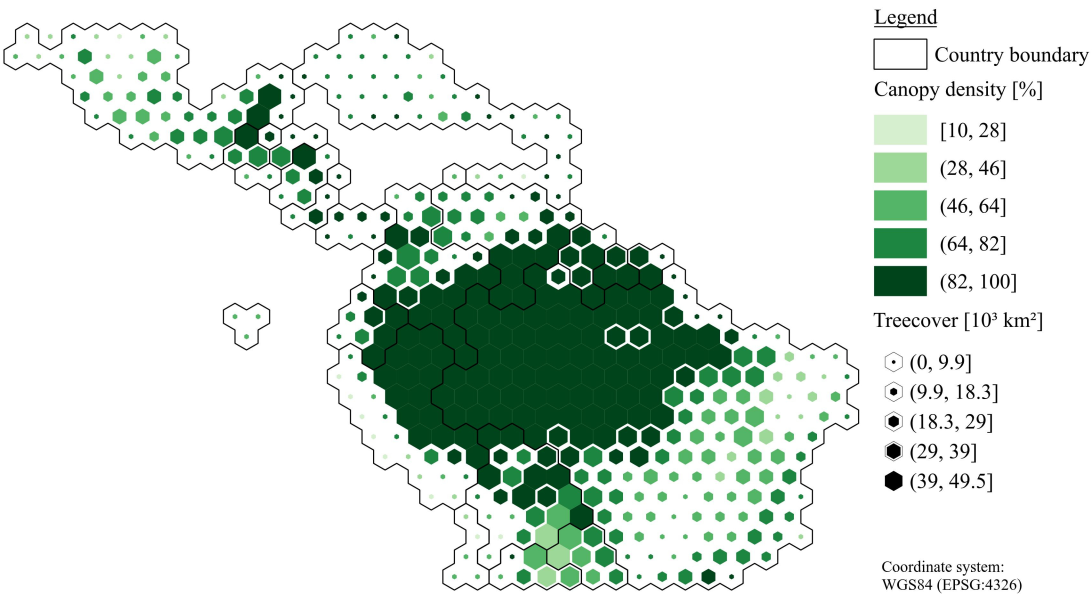


Figure 3.2.

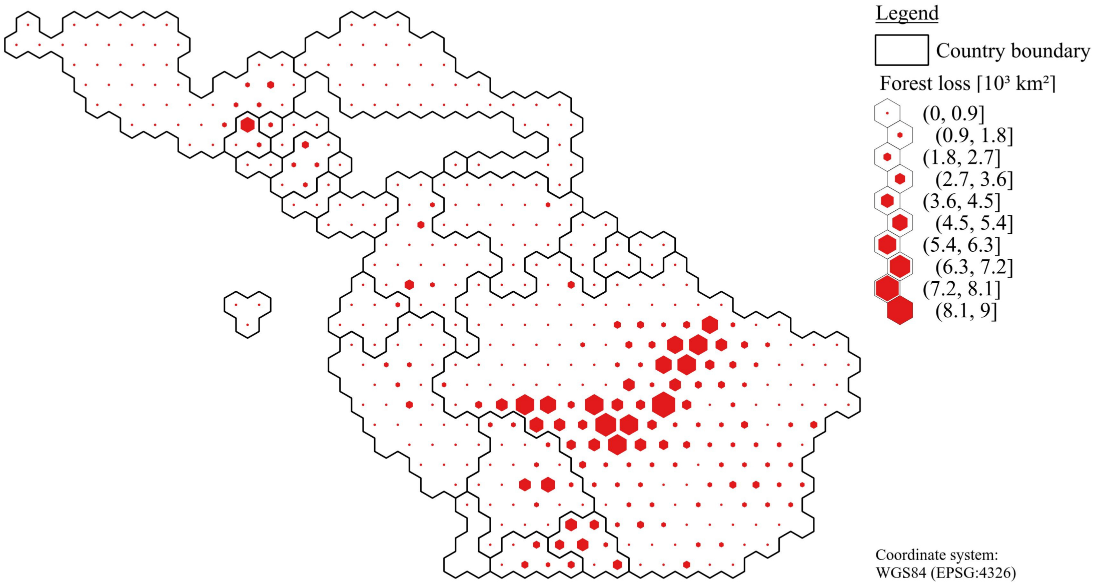
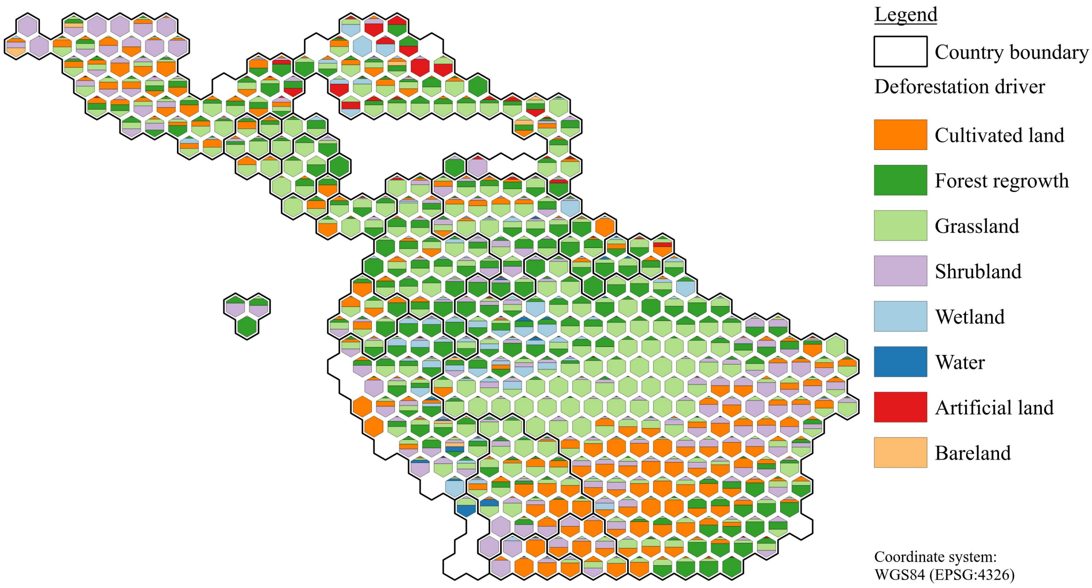


Figure 3.3.



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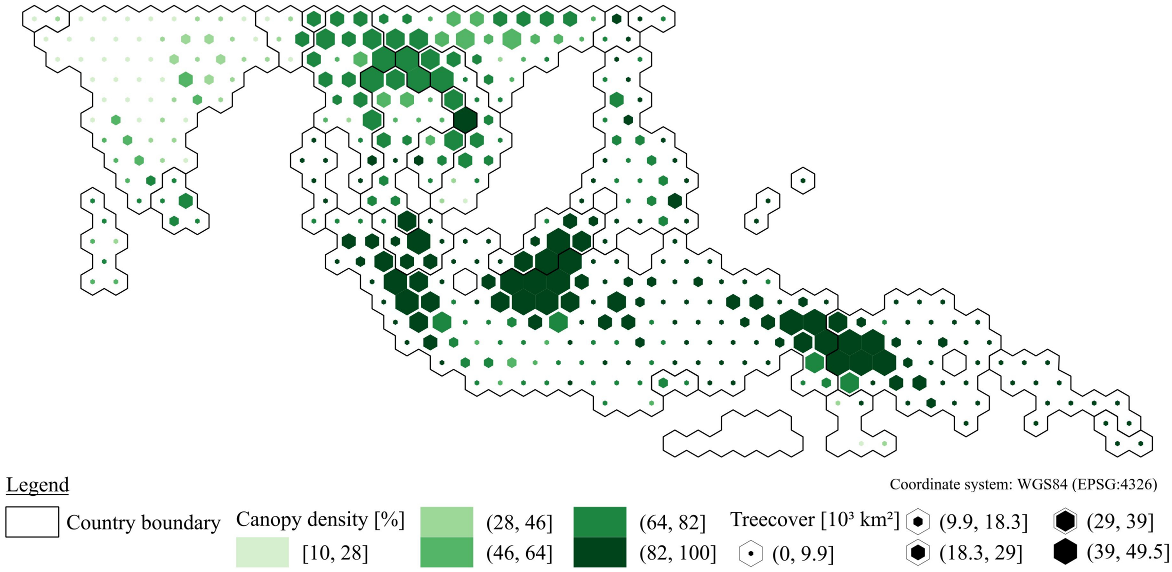

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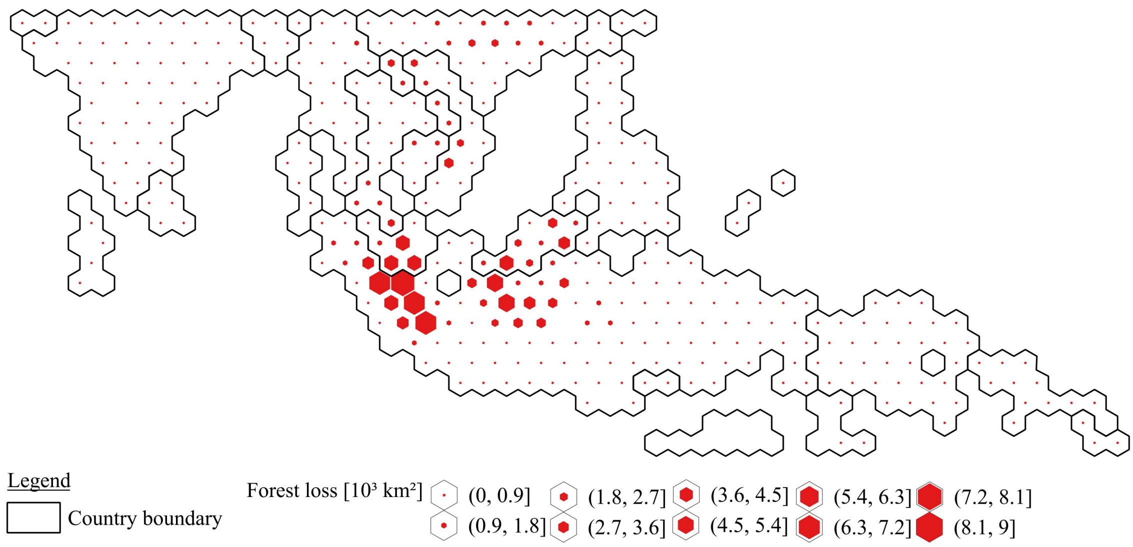


Figure 3.6.

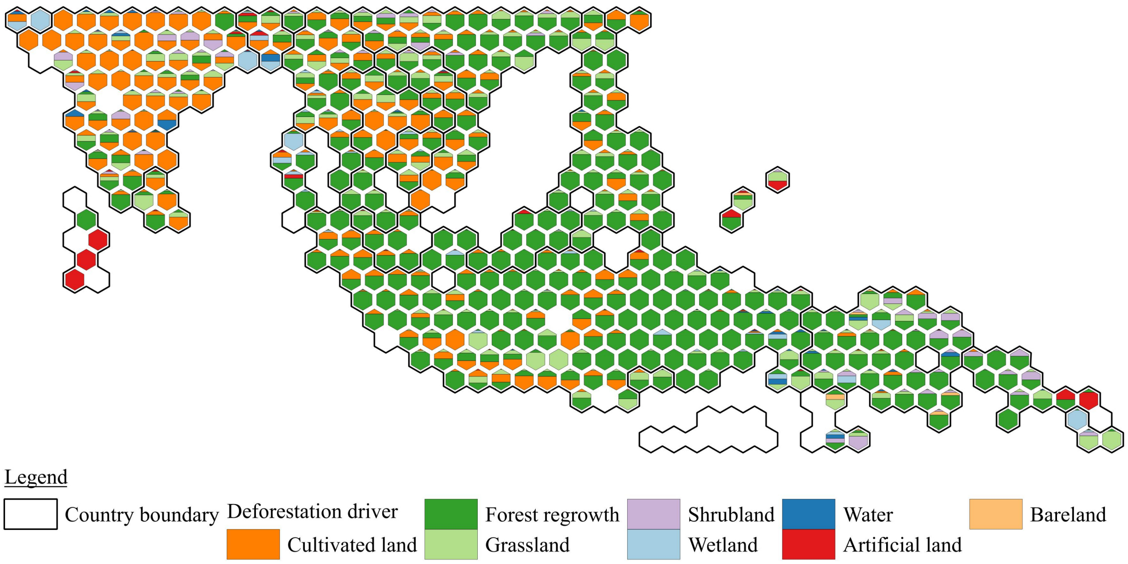
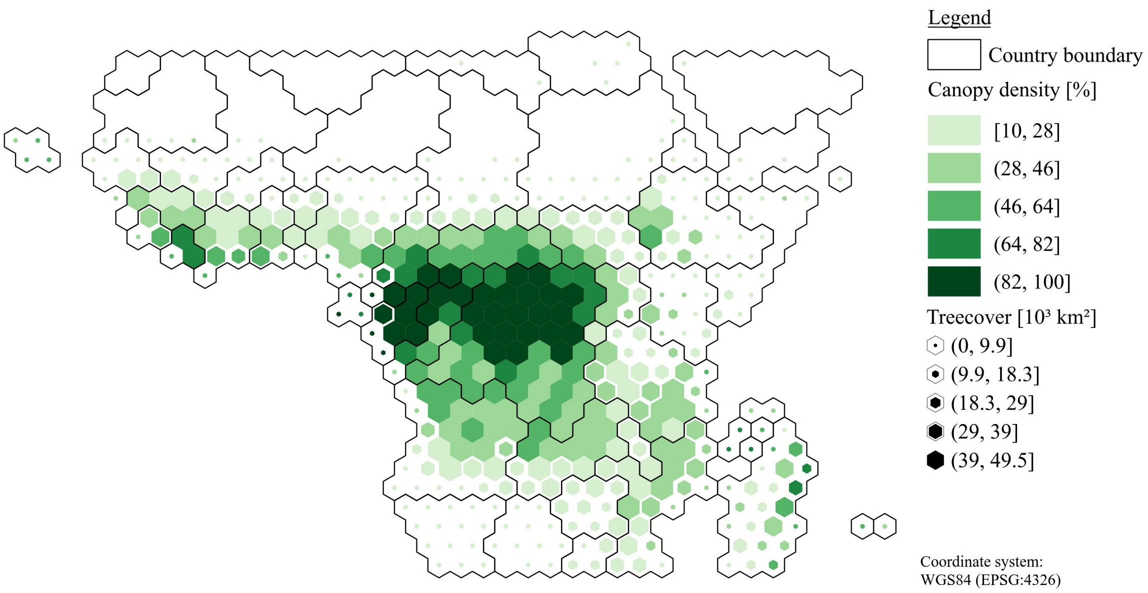


Figure 3.7.



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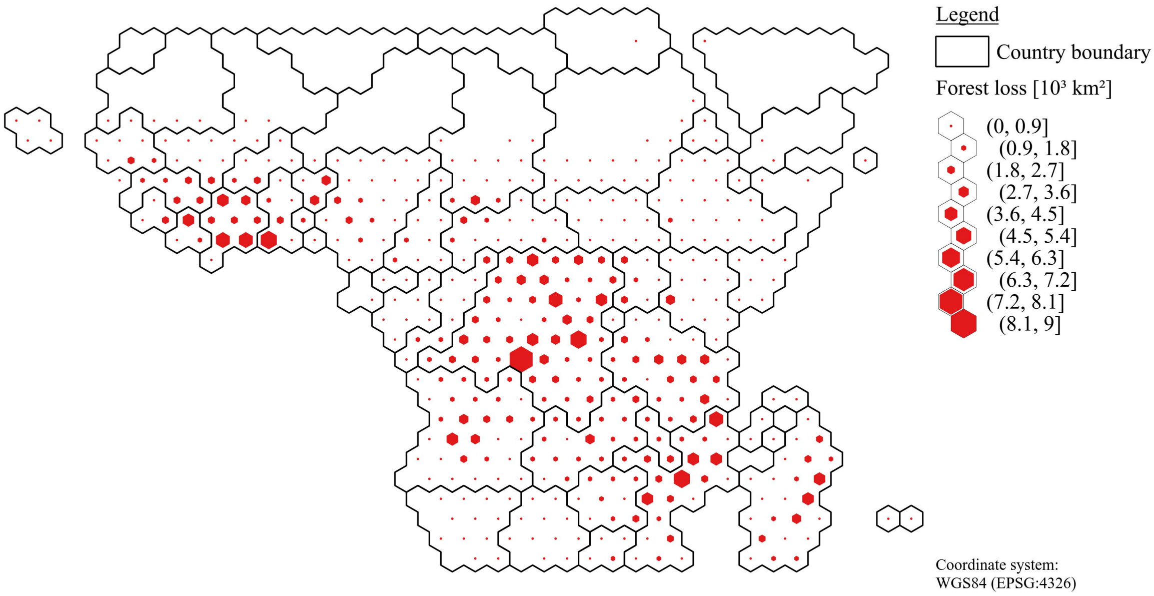

Figure 3.9.

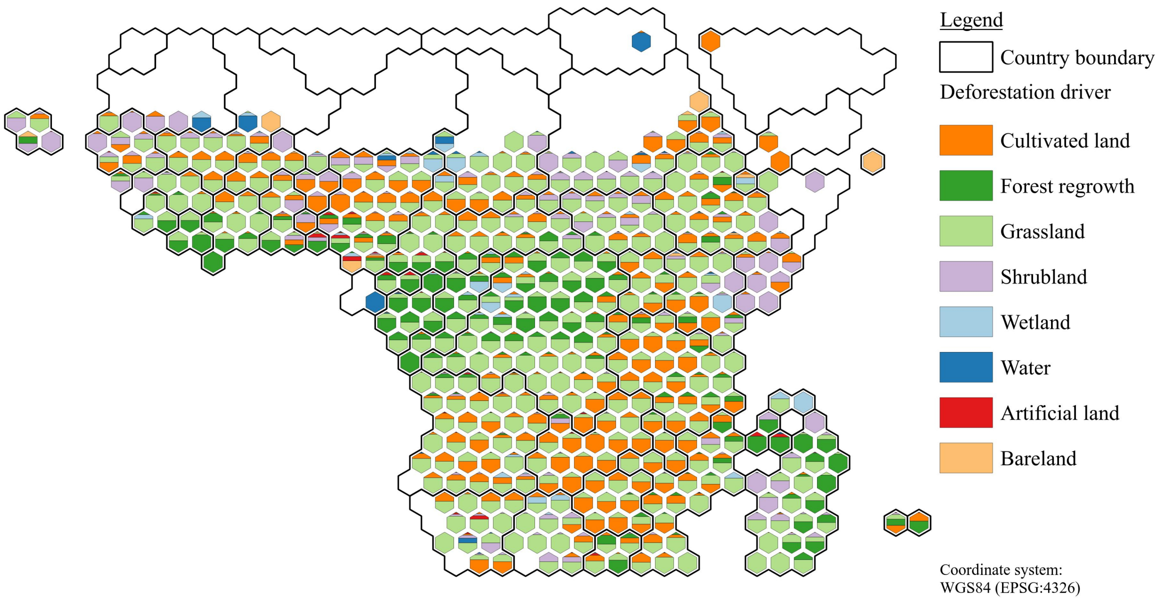

Figure 3.10.

3.3 Defore

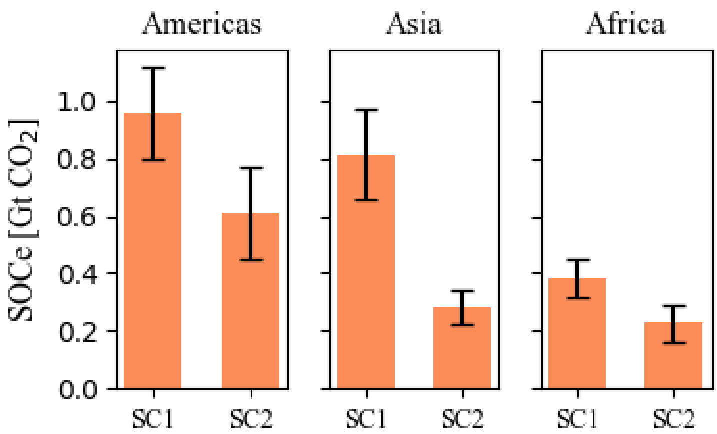

Figure 3.12.

Table 3.5. Soil organic carbon emissions

Region	SC1 [Gt CO_2]			SC2 [Gt CO_2]			SC3 [Gt CO_2]		
	min	mean	max	min	mean	max	min	mean	max
Americas	0.80	0.96	1.12	0.45	0.61	0.77	0.43	0.59	0.76
Asia	0.66	0.81	0.97	0.22	0.28	0.34	0.22	0.28	0.33
Africa	0.32	0.39	0.45	0.17	0.23	0.29	0.16	0.23	0.29

3.3.1 Global

3.3.2 Americas

3.3.3 Asia

3.3.4 Africa

3.4 Ecosystem service value balance

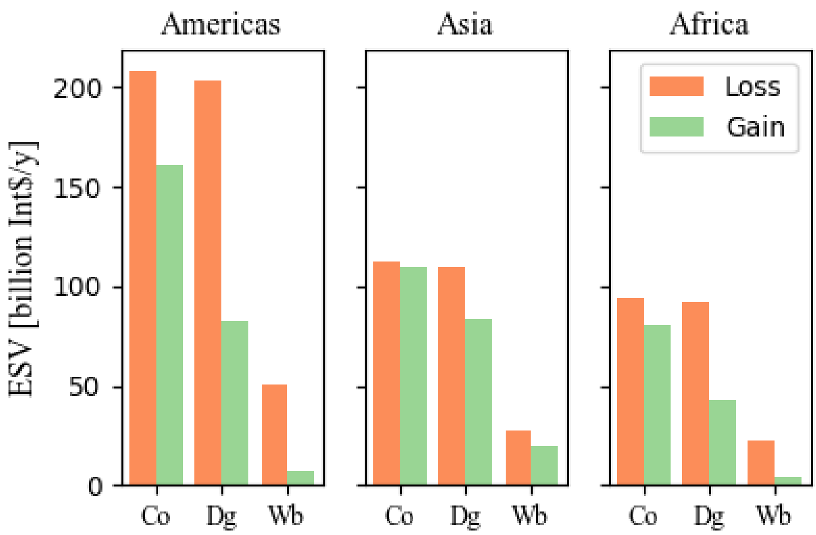

Figure 3.13.

3.4.1 Global

3.4.2 Americas

3.4.3 Asia

3.4.4 Africa

4 Discussion

Acknowledgements

Bibliography

Arsanjani J. J., See L., and Tayyebi A. Assessing the suitability of GlobeLand30 for mapping land cover in Germany. *International Journal of Digital Earth*, 2016a. doi: 10.1080/17538947.2016.1151956.

Arsanjani J. J., Tayyebi A., and Vaz E. GlobeLand30 as an alternative fine-scale global land cover map: Challenges, possibilities, and implications for developing countries. *Habitat International xxx*, pages 1–7, 2016b. doi: 10.1016/j.habitatint.2016.02.003.

Baccini A., Goetz S., Walker W., Laporte N., Sun M., Sulla-Menashe D., Hackler J., Beck P., Friedl M., Samanta S., and Houghton R. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, 2, March 2012. doi: 10.1038/nclimate1354.

Baccini A., Walker W., Carvahlo L., Farina M., Sulla-Menashe D., and Houghton R. Tropical forests are a net carbon source based on new measurements of gain and loss. Online accessed through Global Forest Watch, 2015. URL `https://www.globalforestwatch.org`.

Baccini A., Walker W., Carvalho L., Farina M., and D. Sulla-Menashe R. A. H. Tropical forests are a net carbon source based on aboveground measumeasure of gain and loss. *Science*, September 2017. doi: 10.1126/science.aam5962.

Carr D. B. Looking at large data sets using binned data plots. resreport, U.S. Department of Energy, 1990.

Carr D. B., Littlefield R. J., Nicholson W. L., and Littlefield J. S. Scatterplot matrix techniques for large N. *Journal of the American Statistical Association*, 82(398), 1987.

Carr D. B., Olsen A. R., and White D. Hexagon mosaic maps for display of univariate and bivariate geographical data. *Cartography and Geographic Information Systems*, 19(4), 1992.

Chen J., Chen J., Liao A., Cao X., Chen L., Chen X., He C., Han G., Peng S., Lu M., Zhang W., Tong X., and Mills J. *30-meter Global Land Cover Dataset - Product Description*. National Geomatics Center of China, May 2014.

Chen J., Chen J., Liao A., Cao X., Chen L., Chen X., He C., Han G., Peng S., Lu M., Zhang W., Tong X., and Mills J. Global land cover mapping at 30 m resolution: A POK-based operational approach. *ISPRS Journal of Photogrammetry and Remote Sensing*, 103:7–27, 2015. doi: 10.1016/j.isprsjprs.2014.09.002. URL `http://www.globallandcover.com`.

Chen J., Cao X., Peng S., and Ren H. Analysis and Applications of GlobeLand30: A Review. *International Journal of Geo-Information*, 6(230), July 2017. doi: 10.3390/ijgi6080230.

Don A., Schumacher J., and Freibauer A. Impact of tropical land-use change on soil organic carbon stocks - a meta-analysis. *Global Change Biology*, 17(4):1658–1670, November 2010. doi: 10.1111/j.1365-2486.2010.02336.x.

FAO. FRA 2015 terms and definitions. resreport, Food and Agriculture Organization of the United Nations, 2012.

FAO and ITPS. Global Soil Organic Carbon Map. resreport, FAO and ITPS, 2018.

Hansen M. C., Potapov P. V., Moore R., Hancher M., Turubanova S. A., Tyukavina A., Thau D., Stehman S. V., Goetz S. J., Loveland T. R., Kommareddy A., Egorov A., Chini L., Justice C. O., and Townshend J. R. G. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 342(6160):850–853, November 2013. doi: 10.1126/science.1244693. URL https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.0.html.

Hijmans R., Garcia N., Kapoor J., Rala A., Maunahan A., and Wieczorek J. GADM database of Global Administrative Areas. Online, May 2018. URL https://www.gadm.org. Version 3.6.

Li Y., Sulla-Menashe D., Motesharrei S., Kalnay X.-P. S., Ying Q., Li S., and Ma Z. Inconsistent estimates of forest cover change in China between 2000 and 2013 from multiple datasets: differences in parameters, spatial resolution, and definitions. *Scientific Reports*, 7(8748), August 2017. doi: 10.1038/s41598-017-07732-5.

Potapov P., Hansen M. C., Laestadius L., Turubanova S., Yaroshenko A., Thies C., Smith W., Zhuravleva I., Komarova A., Minnemeyer S., and Esipova E. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances*, 3, 2017. doi: 10.1126/sciadv.1600821. URL http://www.intactforests.org/.

List of Figures

List of Tables

List of Abbreviations

AGB	Aboveground live woddy Biomass density
API	Application Programming Interface
CRS	Coordinate Reference System
DEM	Digital Elevation Map
DT	Decision Tree
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization of the United Nations
GADM	Global Administrative Areas Map
GFC	Global Forest Change
GFW	Global Forest Watch
GIS	Geographic Information System
GL30	GlobeLand30
GLAS	Geoscience Laser Altimeter System
GSOCmap	Global Soil Organic Carbon map
GSP	Global Soil Partnership
GTiff	Geo-Tiff
GeoJSON	Geographic JavaScript Object Notation
IFL	Intact Forest Landscapes
IPCC	Intergovernmental Panel on Climate Change
ISRIC	International Soil Reference and Information Center
ITPS	Intergovernmental Technical Panel on Soils
LIDAR	Light Detection and Ranging
LU	Land Use
LUC	Land-use Change
LULC	Land Use/Land Cover
MLC	Maximum Likelihood Classifier
MODIS	Moderate Resolution Imaging Spectroradiometer
POK	Pixel-Object-Knowledge
REGEX	Regular Expression
RF	Random Forest
SHP	Shapefile
SOC	Soil Organic Carbon
SVM	Support Vector Machine
URL	Uniform Resource Locator
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
stdlib	Standard Library

MLR	Multiple Linear Regression
AISM	Aligned Image Stack Mosaic

Appendix

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