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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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1 Introduction

1.1 Tropical forest

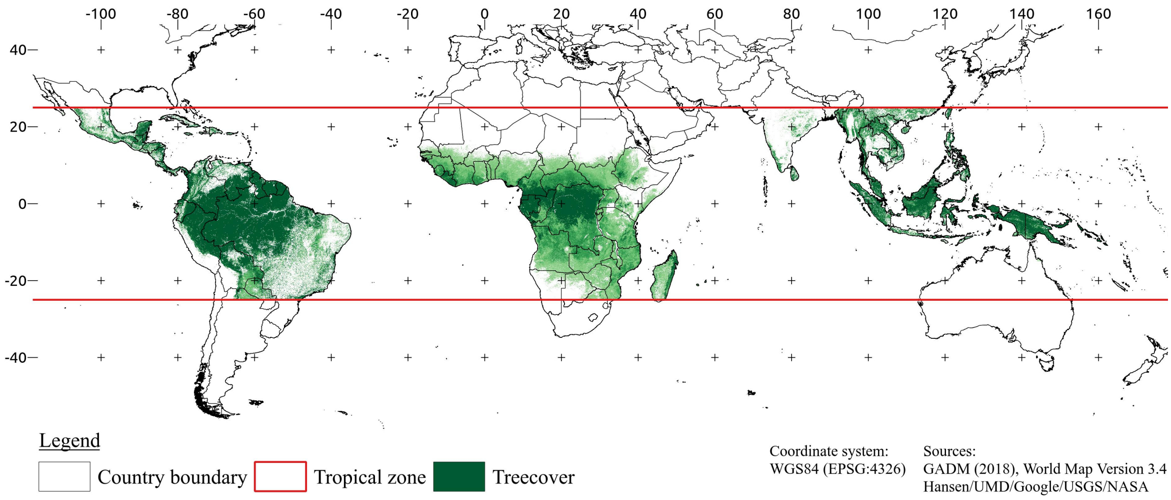

Figure 1.1: Geographic tropical zone framed red and the tropical forest

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

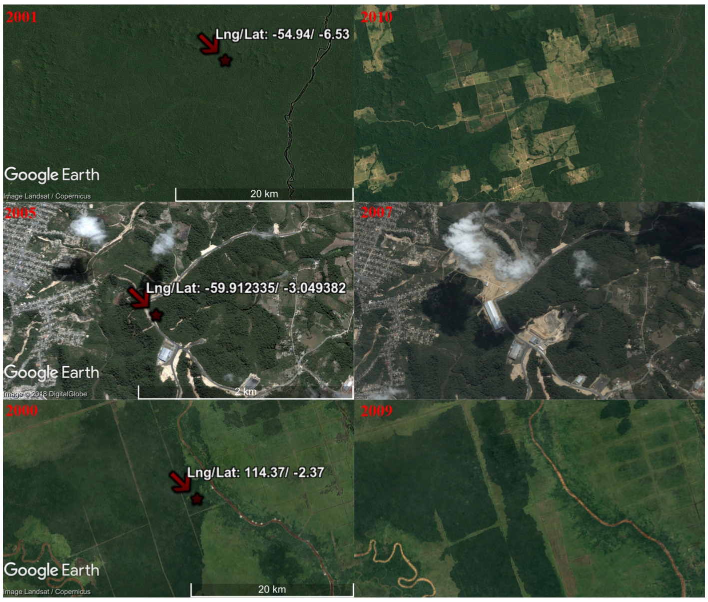

Figure 1.2: Upper Brazil agriculture, middle Brazil urbanization, lower Indonesia large scale palm oil plantations

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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1.2.5 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

Introduction word what follows in this section

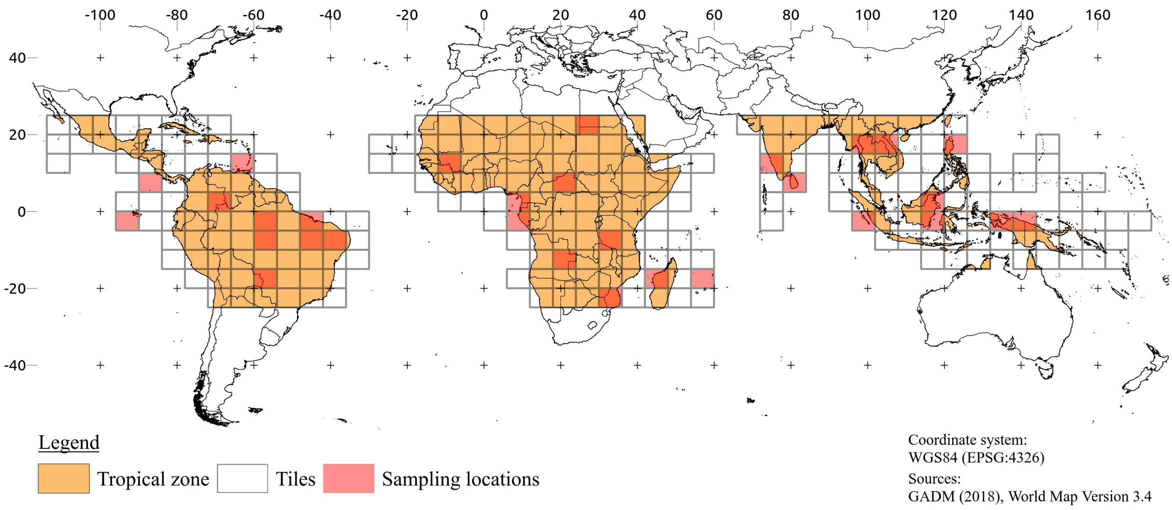

Figure 2.1: Study extent and raster image tiles

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 on the annual global forest cover change between 2000 and 2012 [Hansen et al. 2013a; 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+) at a spatial resolution of 30 meters per pixel [Hansen et al. 2013b]. 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 gain. 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). Furthermore, across the provided 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. Forest loss is defined as a stand displacement disturbance leading from a forest state to a non forest-state. To compute this losses.finish description, accuracy report, acquisition

2.1.1.2 GlobeLand30

GlobeLand30 (GL30) is the first 30 meter 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 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]. 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.

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 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. The homepage

Table 2.1: Classification schema of the GL30 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	Shrub land	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	Bare land	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

2.1.1.3 Intact Forest Landscapes

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2.1.1.4 Aboveground Woody Biomass

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2.1.1.5 Global Soil Organic Carbon

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2.1.1.6 Auxiliary

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2.1.2 Empirical data

2.1.2.1 Soil Organic Carbon

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2.1.2.2 Ecosystem Service Values

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2.2 Methods

2.2.1 Pre-processing

Problem description, all data in different crs, also all data has diferent extent, also some data is vector data must converted to raster data. from each raster data where only tilled data set created a tile mask in target crs projection where stored name of the file an its extent. select a template datasets in our case gl30 2010. intersection compute with mask intersections are selections, now pipeline if more tiles for one needed merge them, after reproject them next clip then, for vector data to raster, software python geopandas and rasterio

2.2.2 Deforestation

2.2.2.1 Forest definition

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2.2.2.2 Land use change driver

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2.2.2.3 Accuracy assessment

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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 $\mathbf{H}$) 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 2.2). 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 2.2.

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

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

polygon clipping 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

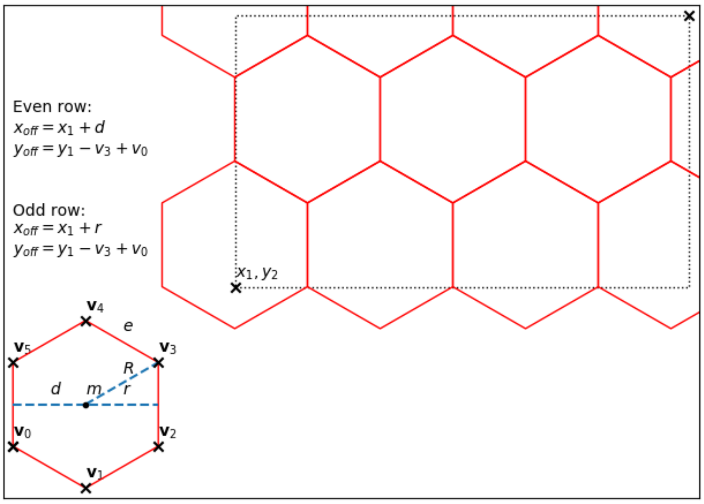

Figure 2.2: Located at the left bottom corner in red a hexagon defined by its geometric properties the 6 vertex vectors $\{v_0,\ldots,v_5\}$ (black crosses), with center vector m, edge length e, R radius of the circumscribing circle, r radius of the inscribed circle and d the length of the short diagonal. 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.

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

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

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

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

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

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

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

3 Results

3.1 Forest definition and accuracy assessment

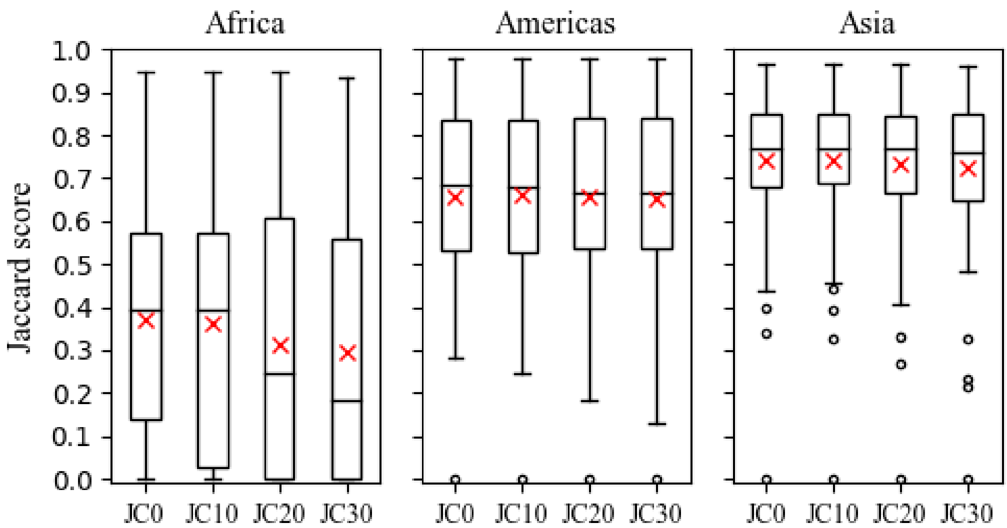

Figure 3.1: Jaccard score to determine tree cover similarity used to develop forest definition

Table 3.1: 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

Table 3.2: 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

3.2.2 Americas

3.2.3 Asia

3.2.4 Africa

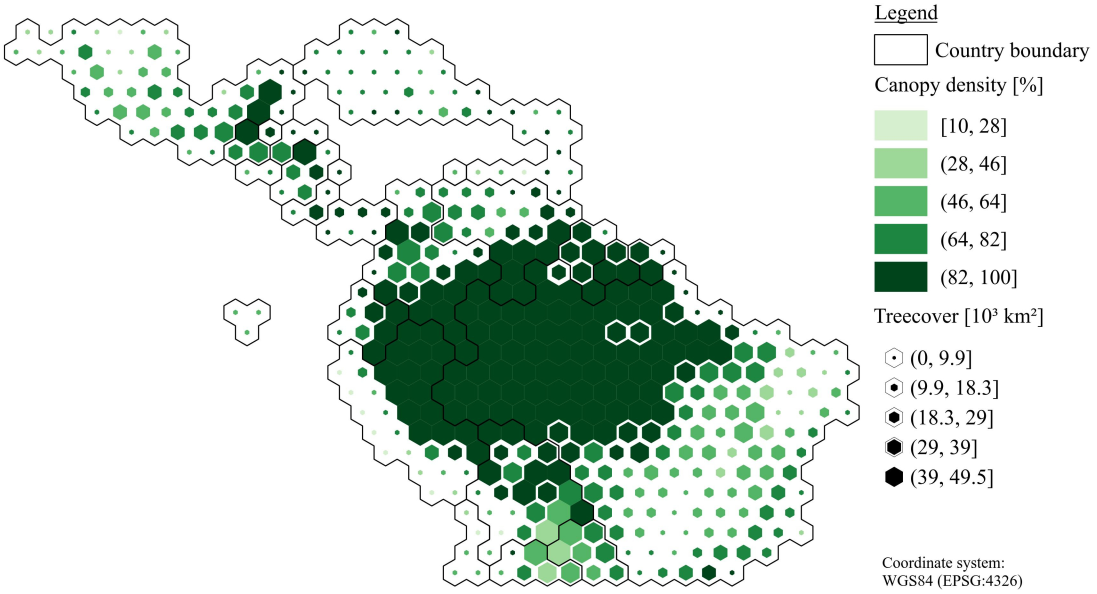

Figure 3.2:

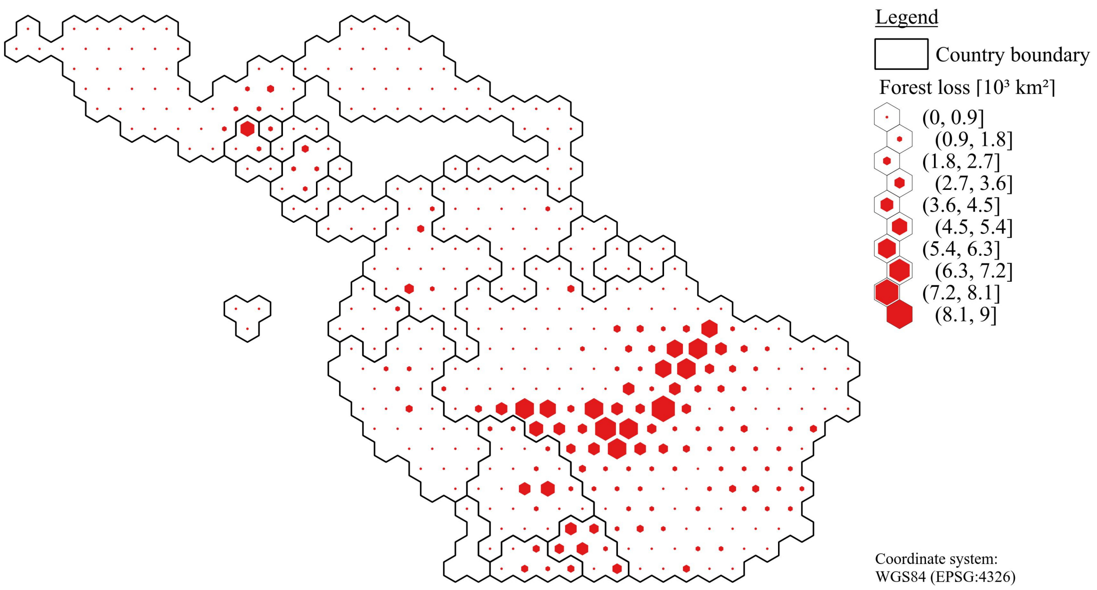

Figure 3.3:

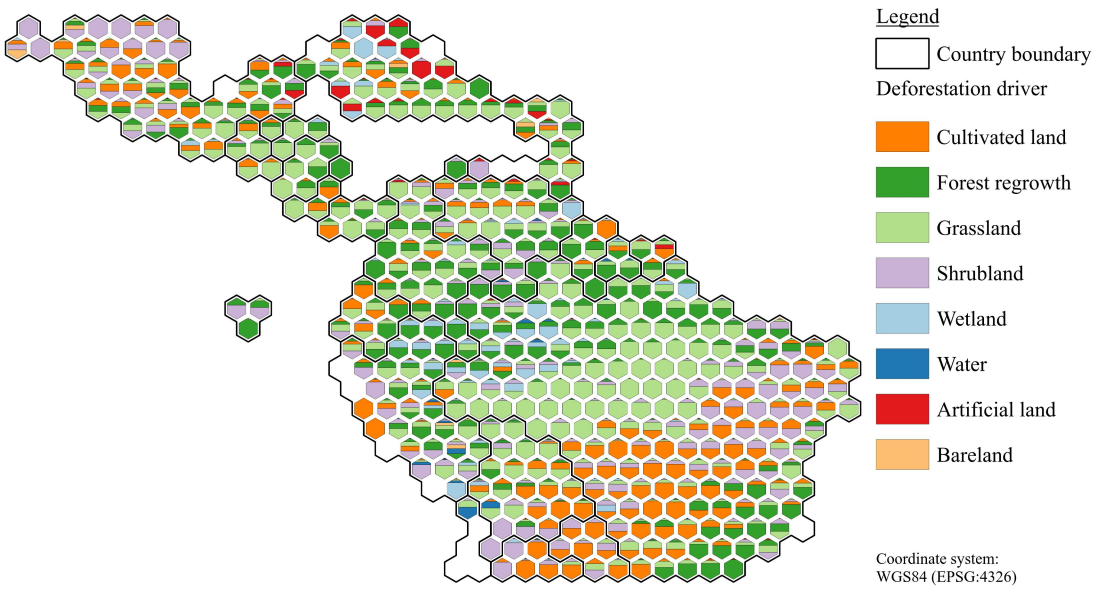

Figure 3.4:

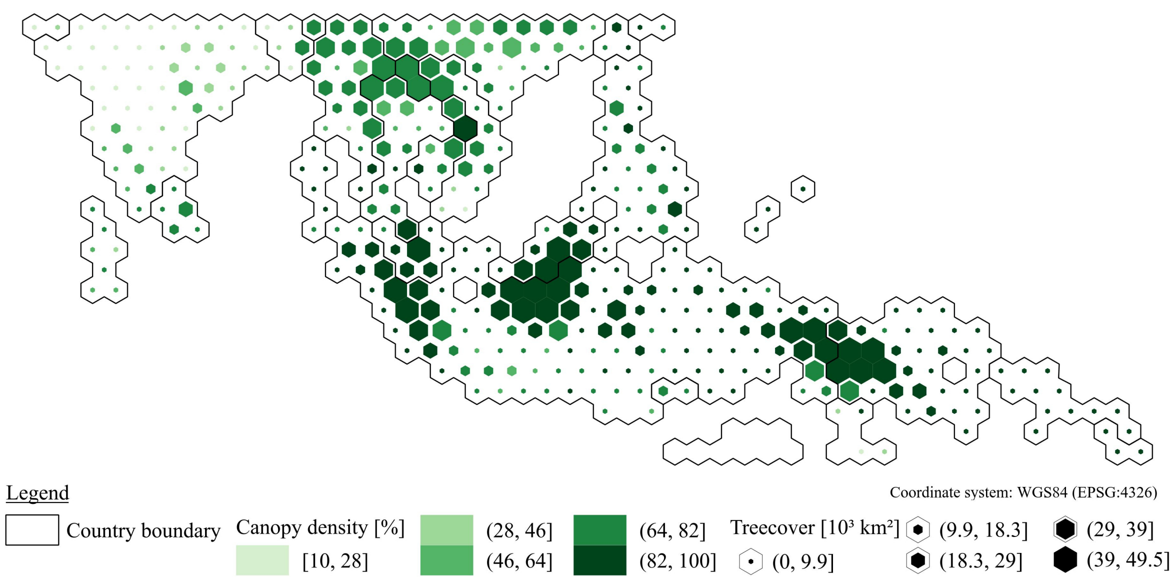

Figure 3.5:

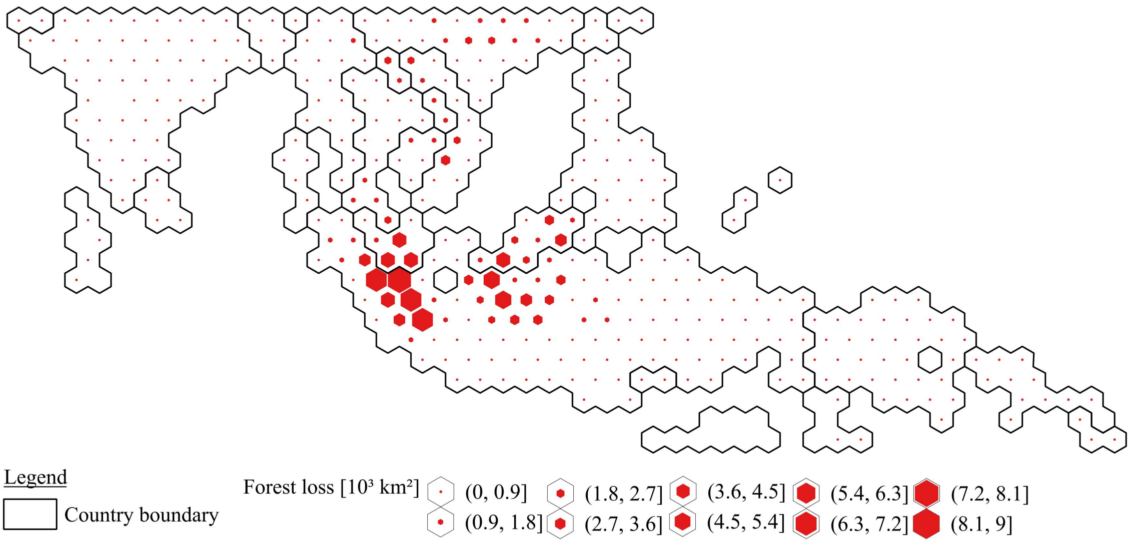

Figure 3.6:

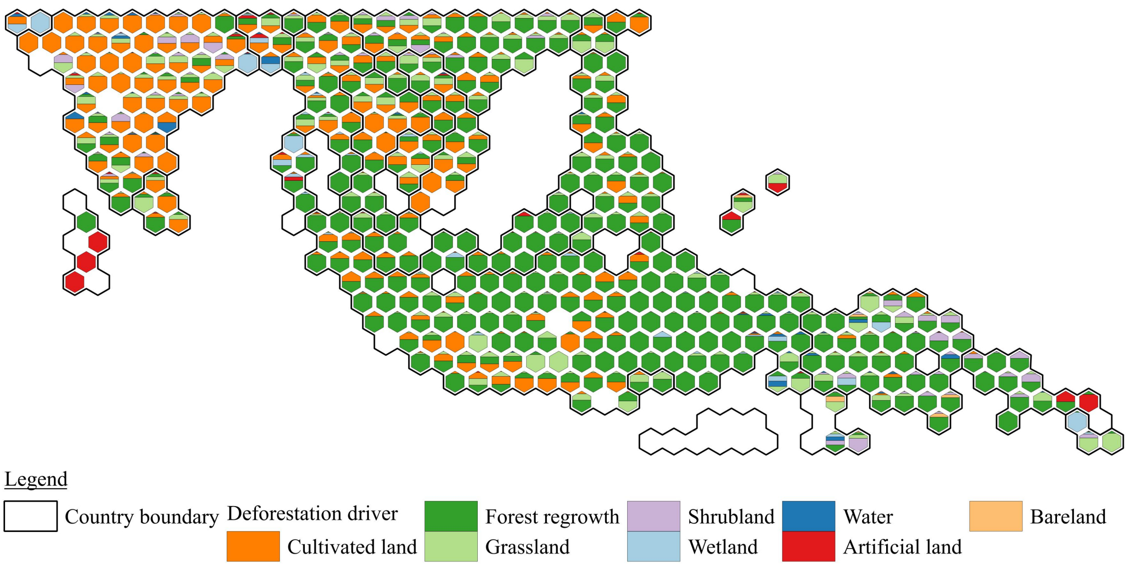

Figure 3.7:

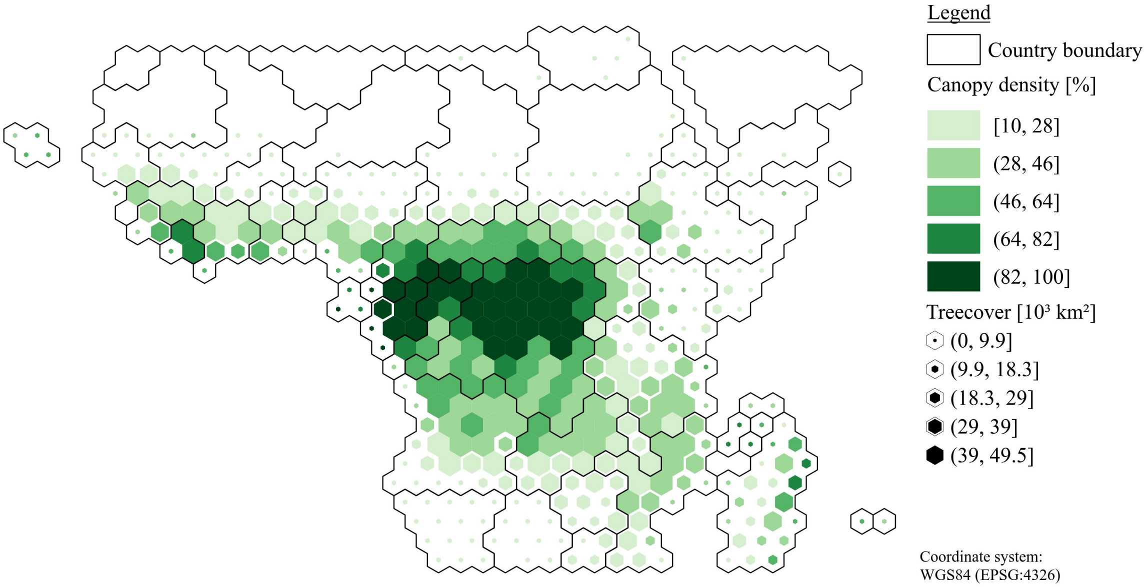

Figure 3.8:

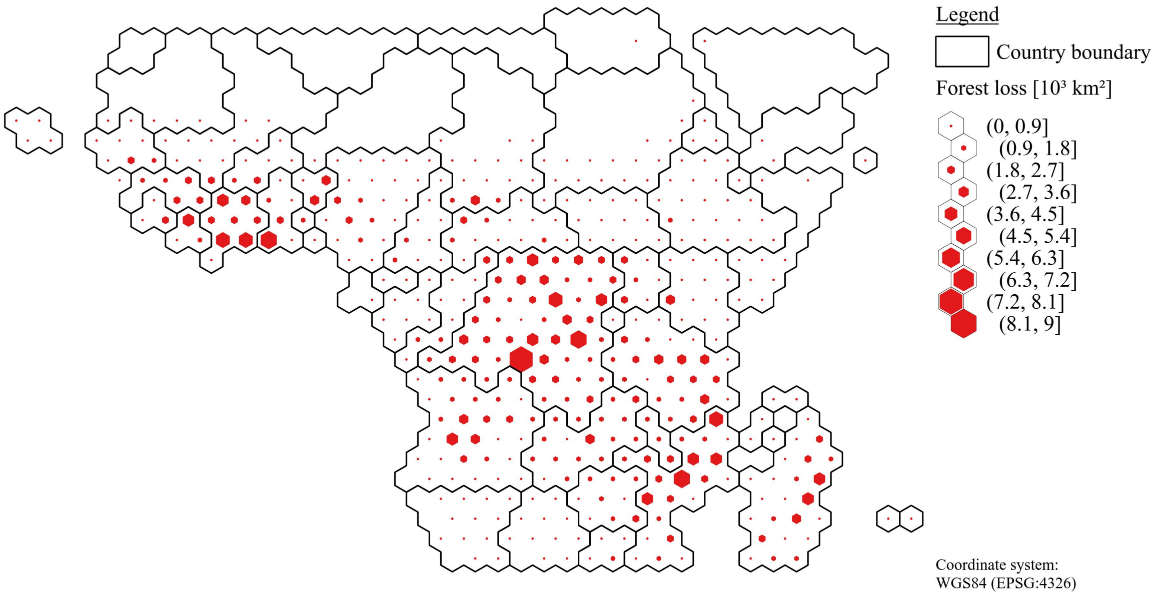

Figure 3.9:

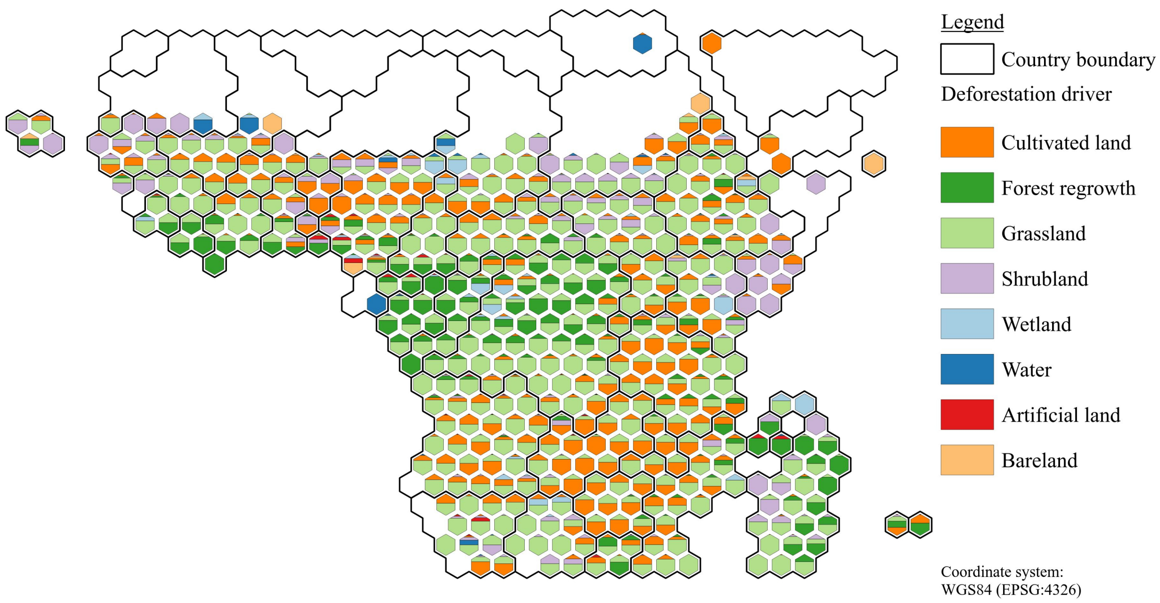
Legend
Country boundary
Deforestation driver
Cultivated land
Forest regrowth
Grassland
Shrubland
Wetland
Water
Artificial land
Bareland
Coordinate system:
WGS84 (EPSG:4326)

Figure 3.10:

3.3 Defore

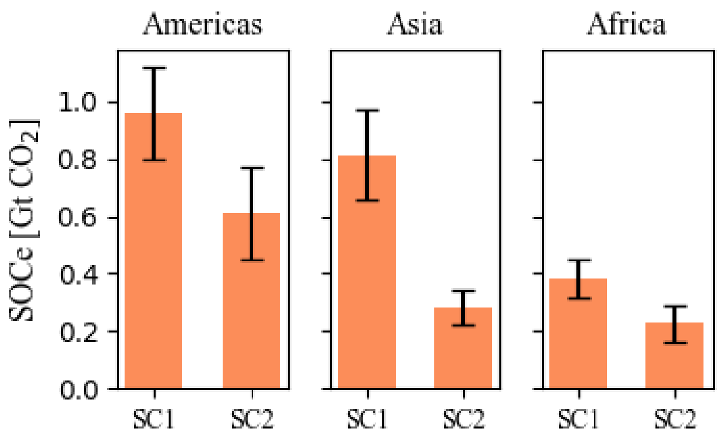

Figure 3.12:

Table 3.3: 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

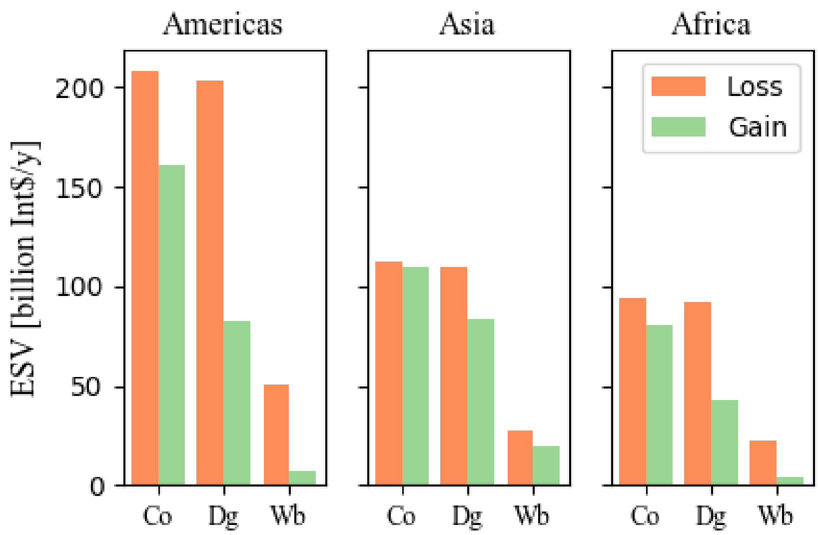

Figure 3.13:

3.4.1 Global

3.4.2 Americas

3.4.3 Asia

3.4.4 Africa

4 Discussion

Acknowledgements

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List of Figures

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List of Abbreviations

FAO	Food and Agriculture Organization of the United Nations
GFC	Global Forest Change
GIS	Geographic Information System
GL30	GlobeLand30
GTiff	Geo-Tiff
IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use/Land Cover
POK	Pixel-Object-Knowledge
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
DT	Decision Tree
SVM	Support Vector Machine
MLC	Maximum Likelihood Classifier

Appendix

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