A cross-border deforestation index to understand underlying drivers of deforestation

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This paper considers a preliminary investigation involving the development of a Cross-Border Deforestation Index (CBDI), which is an attempt to quantify the differences in deforestation between two countries or potentially any two administrative units. In this study, the focus was on countries. For each pair of bordering countries, a 50 km buffer zone was drawn and the average value of the Vegetation Continuous Field (VCF) was calculated for each country in the pair. The ratio of these two averages is the CBDI. Values of 1 indicate similar levels of forest cover but values greater than 1 point towards dissimilar land use policies within countries and/or sub-national administrative levels. This index was calculated for all pairs of bordering tropical countries in South and Central America, Asia and Africa. In addition, a visual analysis of the spatial variation of the VCF was undertaken to show how this can complement the CBDI. The results showed that countries such as Argentina, Brazil, Chile, El Salvador, Laos, Thailand and DR Congo, in combination with different neighbouring countries, all have CBDI values differing from 1. These areas are worth examining in greater detail in order to understand what types of drivers are behind these outlying CBDI values. These drivers could include land use policy, population pressure, accessibility, etc. Future work will include the addition of environmental factors. By computing the CBDI for so called Homogeneous Response Units (HRU: areas of similar or identical environmental conditions in terms of soil, altitude and slope), we will be able to examine the changing effect on the CBDI. This work is still ongoing and will be expanded to consider HRU for all country pairs. In addition, regression of the CBDI with different drivers of deforestation will be attempted in order to help identify these underlying causes.

Keywords: deforestation, Vegetation Continuous Field (VCF), GLC-2000, Homogenous Response Units (HRU)

Introduction

Tropical forests are one of the Earth's most essential resources. Over the last century a substantial increase in human activity in the tropics has resulted in deforestation. According to the Food and Agriculture Organization (FAO), the definition of deforestation refers to a change of land cover with depletion of tree crown cover to less than 10 percent (FAO, 2006). The importance of the resource coupled with the lack of knowledge on the distribution, processes and influences of deforestation has led to a number of research activities (Achard et al., 2004; INPE, 2005; Lepers et al., 2005). Specific cases exist around the globe (although they are more apparent in the tropics) where political borders are visible from satellite data and satellite derived products. In these cases, it appears that a land use policy (or lack thereof) in one country has allowed/encouraged deforestation activity to occur right up to the border while in the neighboring country no activity is taking place. In particular, it is interesting to see that along country borders, forest cover in one country is either degraded or is entirely deforested whereas in the other country forest it is entirely intact. In order to shed light on these differences and to be able to quantify the actual difference of deforestation between two countries or regions, we have developed a Cross-Border Deforestation Index (CBDI). The datasets used in the development of the index are described in the next section along with the methodology

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for extraction and calculation of the index at two different scales. Finally, the CBDI has been evaluated using the Global Land Cover 2000 dataset.

Materials and Methods

Study Area and Datasets

The study area includes all tropical countries that have sufficient border coverage with other neighbouring countries. Therefore, all island countries have been excluded from this analysis. The main dataset used in this study is the Vegetation Continuous Fields (VCF) product, which has been derived from all seven bands of the MODIS sensor on NASA's Terra satellite (Hansen et al., 2003; 2007). This product contains proportional estimates of vegetation cover including woody vegetation, herbaceous vegetation and bare ground and is available at 500m and 1km resolution. The source for this data set was the Global Land Cover Facility (http://www.landcover.org).

Development of a Cross-Border Deforestation Index

A list of neighbouring countries was first determined from a basic country dataset and a 50 km buffer was then drawn around each border. The choice of 50 km was made because it provides enough area along the border to determine differences in forest cover on both sides. The buffer was then overlaid on the VCF data and the average was calculated for each country in the neighbouring pair. This was repeated for all pairs of neighbouring countries. An example of this process is provided in Figure 1 which shows the process for Brazil and Bolivia. The CBDI is the ratio of the average VCF for two neighbouring countries as follows:

$$\text{CBDI} = VCF_i / VCF_j \qquad (1)$$

where i is the average VCF for the first country and j is the average VCF value for a neighbouring country. An index of 1 indicates no variation across the border while values of the index greater than 1 indicate increasing variation between the two countries.

Visual Analysis

To complement the CBDI, it is possible to calculate the spatial variation of the VCF across the border using a kernel approach. Circles of 10 km were systematically moved across the VCF image and the standard deviation across the area was calculated at each point. By applying this technique to the VCF border data it is possible to see where the largest cross border variations are occurring. It can be assumed that the kernel will produce lower standard deviations when contained entirely within a single country and increase as it moves across the border if there are differences between the two countries.

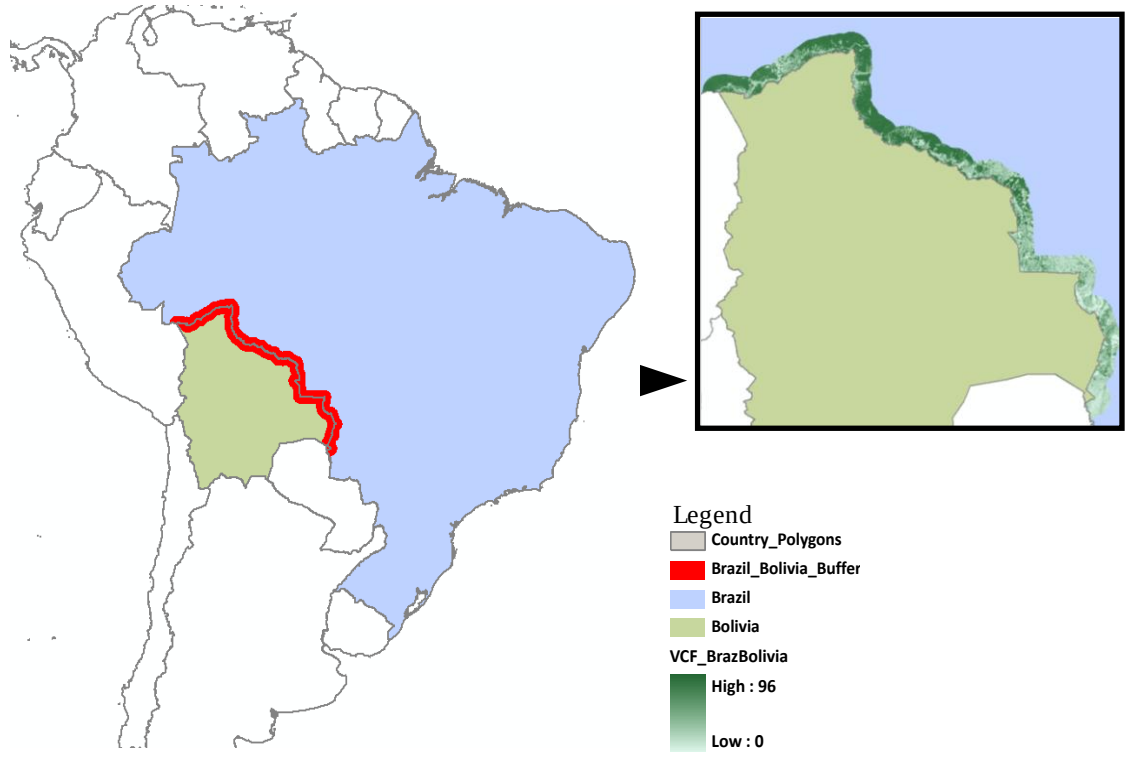

Figure 1: Data extraction along the borders of Brazil and Bolivia

Results and Discussion

CBDI Results

Table 1 contains the CBDI results in descending order for all neighbouring countries in South and Central America, Asia and Africa. The values of most significance are those furthest away from 1. In South America, it is clear that Argentina, Brazil and Chile all have different practices than some of their neighbours while El Salvador, Guatemala and Dominican Republic are also identified in Central America as differing from their bordering countries. In Asia, Laos and Thailand consistently stands out from their neighbouring countries.

Table 1. The CBDI for all neighbouring countries in a) South America; b) Central America; and c) Asia ranked from highest to lowest values.

South America

Neighbouring Countries	CBDI
Argentina/Brazil	1.73
Paraguay/Brazil	1.55
Chile/Argentina	1.50
Uruguay/Brazil	1.38
Bolivia/Brazil	1.37
Argentina/Paraguay	1.21
Suriname/Brazil	1.17
Argentina/Uruguay	1.12
Guyana/Brazil	1.09
Venezuela/Colombia	1.07
Panama/Colombia	1.07
Ecuador/Colombia	1.05
French Guiana/Brazil	1.05
Guyana/Venezuela	1.05
Argentina/Bolivia	1.04
Chile/Bolivia	1.03
Suriname/Guyana	1.03
Peru/Bolivia	1.02
Peru/Colombia	1.01
Colombia/Brazil	1.01
Peru/Ecuador	1.01
French Guiana/Suriname	1.00
Paraguay/Bolivia	1.00
Peru/Brazil	1.00
Brazil/Venezuela	1.00

Central America

Neighbouring Countries	CBDI
Dominican Republic/Haiti	1.78
Belize/Guatemala	1.25
El Salvador/Guatemala	1.24
Honduras/El Salvador	1.21
Costa Rica/Panama	1.14
Nicaragua/Costa Rica	1.10
Mexico/Guatemala	1.05
Mexico/Belize	1.05
Honduras/Nicaragua	1.00
Honduras/Guatemala	1.00

a) Asia

Neighbouring Countries	CBDI
Laos/Thailand	1.61
Laos/Viet Nam	1.39
Malaysia/Thailand	1.38
Cambodia/Thailand	1.34
Timor/Indonesia	1.25
Myanmar/Thailand	1.24
Cambodia/Viet Nam	1.22
Laos/Myanmar	1.11
Malaysia/Indonesia	1.07
Laos/Cambodia	1.03

Table 2 contains the CBDI for African countries, again ranked from highest to lowest values. There was no domination of any one country in particular when it came to outliers, although DRCongo, Tanzania and Burkina Faso are all represented in the top 10 outliers.

Table 2. The CBDI for all neighbouring countries in Africa ranked from highest to lowest values

Neighbouring Countries	CBDI	Neighbouring Countries	CBDI	Neighbouring Countries	CBDI
DRCongo/Rwanda	1.80	Tanzania/Rwanda	1.19	DRCongo/Tanzania	1.09
DRCongo/Burundi	1.64	Tanzania/Kenya	1.19	Namibia/South Africa	1.08
Ethiopia/Sudan	1.52	DRCongo/Zambia	1.18	Benin/Togo	1.07
Kenya/Somalia	1.49	Ethiopia/Kenya	1.18	Congo/Central AR	1.07
South Africa/Zimbabwe	1.46	DRCongo/Uganda	1.18	Ghana/Burkina Faso	1.07
Tanzania/Malawi	1.45	Rwanda/Uganda	1.17	Ivory Coast/Mali	1.07
Congo/Angola	1.40	Senegal/Mauritania	1.16	Mozambique/Tanzania	1.07
Benin/Burkina Faso	1.38	Liberia/Sierra Leone	1.16	EqGuinea/Cameroon	1.06
Ethiopia/Eritrea	1.35	Liberia/Guinea	1.16	Mali/Senegal	1.06
Ivory Coast/Burkina Faso	1.34	Guinea/Mali	1.15	Equatorial Guinea/Gabon	1.05
Sierra Leone/Guinea	1.31	Tanzania/Burundi	1.15	Central AR/Sudan	1.05
Nigeria/Chad	1.30	Mali/Burkina Faso	1.14	Rwanda/Burundi	1.05
Burkina Faso/Niger	1.29	Chad/Sudan	1.14	Ghana/Ivory Coast	1.05
Kenya/Sudan	1.29	Cameroon/Nigeria	1.13	Togo/Burkina Faso	1.05
Tanzania/Uganda	1.28	Gabon/Congo	1.13	Nigeria/Niger	1.04
Guinea/Senegal	1.28	South Africa/Swaziland	1.13	Malawi/Zambia	1.04
Mozambique/Malawi	1.26	DRCongo/Sudan	1.13	DRCongo/Central AR	1.04
Zambia/Tanzania	1.26	Togo/Ghana	1.12	Kenya/Uganda	1.04
Sudan/Uganda	1.25	Liberia/Ivory Coast	1.11	Zambia/Namibia	1.04
Zambia/Zimbabwe	1.25	Zimbabwe/Botswana	1.11	Angola/DRCongo	1.04
Guinea-Bissau/Senegal	1.24	Guinea-Bissau/Guinea	1.11	Gambia/Senegal	1.04
Central AR/Chad	1.24	Mali/Mauritania	1.10	Ethiopia/Somalia	1.03
Mozambique/Zimbabwe	1.24	Ethiopia/Djibouti	1.10	Angola/Namibia	1.03
Lesotho/South Africa	1.23	Zambia/Botswana	1.10	Nigeria/Benin	1.02
Mozambique/South Africa	1.23	Swaziland/Mozambique	1.09	Congo/Cameroon	1.01
Ivory Coast/Guinea	1.23	DRCongo/Congo	1.09	Central AR/Cameroon	1.01
Benin/Niger	1.22	Angola/Zambia	1.09	Cameroon/Chad	1.00
Mozambique/Zambia	1.22	Eritrea/Sudan	1.09	Gabon/Cameroon	1.00
South Africa/Botswana	1.20	Botswana/Namibia	1.09	Djibouti/Somalia	1.00

Figure 2 contains a graph of CBDI showing the main outliers, i.e. values greater than 1.3. Chile and Peru, and El Salvador and Nicaragua are the top two outliers, with representatives from across all the four regions.

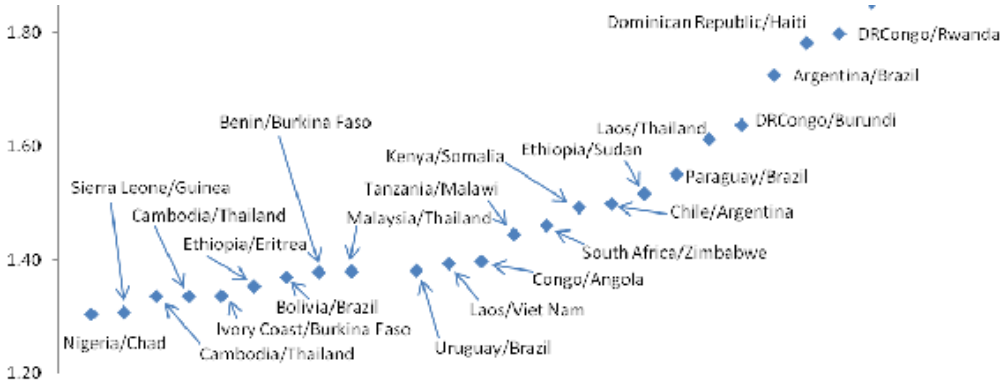

Figure 2: Graph of CBDI values for all areas illustrating the main outliers

Visual Analysis

Figures 3 and 4 show the results of the spatial variation across selected neighbouring countries in South America. Figure 2 illustrates a high variation in the vegetation cover between Argentina and Brazil, and Argentina and Paraguay, i.e. values of CBDI greater than 1.

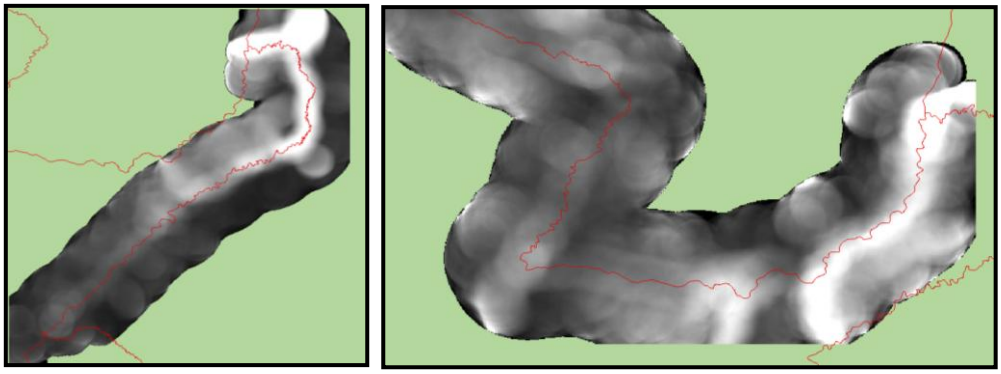

Figure 3: The spatial variation across the Argentina/Brazil and Argentina/Paraguay borders. Lighter colours show higher values of variation.

Figure 3 illustrates an example of where there is low variation away from the border but along the border itself, there is evidence of higher variation or lighter colours are evident. The CBDI for these two neighbouring countries is almost 1, which shows the effect of averaging over a 50 km buffer but the visual analysis indicates that some variation does exist near the border. Moreover, the patterns along the Columbia/Brazil border also show a different cross-border effect as a result of a road network, for example, that requires further investigation.

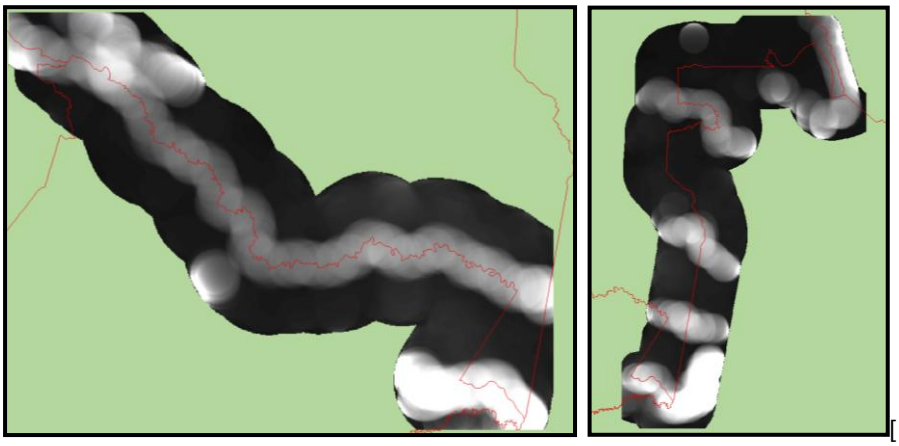

Figure 4: The spatial variation across the Columbia/Peru and Columbia/Brazil borders. Lighter colours show higher values of variation

.Conclusions

Remotely sensed data clearly shows patterns of deforestation and forest cover that differ between neighbouring countries. This paper represents an initial attempt at showing how these differences can be quantified as a cross-border index of deforestation. The CBDI was evaluated for the tropical countries that span Central and South America, Asia and Africa. The results clearly identified occurrences of low or high CBDI, indicating areas where one country has a greater amount of deforestation or forest cover than its neighbour. This index therefore allows us to highlight areas that are worth examining in greater detail in order to understand what type of drivers produce these values such as differences in land use policy, population pressure, accessibility, etc. Future work will look at these drivers in more detail, including a regression analysis to see how much of the variation in the CBDI can be explained using drivers such as those identified in Geist and Lambin (2001).

One current flaw with the CBDI as calculated entirely from the VCF is that the variation of environmental conditions from one side of the border to the other is not considered. A dataset of Homogeneous Response Units (HRU), developed as part of the Geo-Bene project (http://www.geo-bene.eu/?q=node/1754), could be used to account for those characteristics of landscape that remain relatively stable over time, i.e. altitude, slope and soil. It is planned to recalculate the CBDI for each HRU occurring in the buffered border zone to create a better representative CBDI in the future. Varying the size of the buffer and focusing on sub-national zones as well as collecting additional potential drivers of deforestation represent other avenues for exploration in the future.

Such an index may also be useful as a monitoring device if repeatedly applied over time. It would be interesting to determine to what extent the CBDI was an indicator of within country deforestation. This could also be a useful tool in the detection of illegal logging, which is likely occurring along some of these country borders, and is most prevalent in tropical forests (Kinnaird et al., 2003).

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