Land-use change analysis in the *Sete de Setembro* Indigenous Land (Rondônia & Mato Grosso, Brazil) using multi-temporal Landsat images classification between 2000 and 2009

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Abstract. Indigenous Lands that are under high risk of deforestation are good candidates for REDD (Reduction of Emissions from Deforestation and Forest Degradation). REDD proposes to reduce deforestation and forest degradation through remuneration of carbon benefits. To estimate avoided greenhouse gas (GHG) emissions, the calculation is usually based on the most plausible expected amount of deforestation/degradation based on a Land-Use and Land-Cover Change (LULCC) reference scenario. One of the core methodological steps of a LULCC reference (or baseline) scenario is to evaluate the quantity of LULCC that occurred in a historical period, and to identify the drivers of these changes in order to understand how LULCC would evolve in a future period. The objective of this study was to map annual land-cover/use classes in the *Sete de Setembro* Indigenous Land (in Rondônia and Mato Grosso) between 2000 and 2009, and to extract LULCC rates to serve as the basis for the Suruí Forest Carbon Project LULCC reference scenario. We applied a Maximum-Likelihood supervised classification of multi-temporal Landsat-TM images to distinguish five land-cover subclasses: 1-burned areas, 2-bare soil, 3-secondary vegetation, 4- forest and 5-water, and we then grouped these subclasses to obtain three land-cover/use classes. In 2009, 3416.5 ha were vegetation in equilibrium, 240.033 ha were forest and 230 ha were secondary vegetation. Applying a subtraction calculation between consecutive land-cover/use maps, we obtained an annual average of 154.7 ha of deforestation and 88 ha of secondary vegetation clearing. Forest-cutting represents, on average, 72% of LULCC, whereas secondary-vegetation clearing represents 28%.

Keywords: Protected areas, Deforestation, REDD, Change detection, Áreas Protegidas, Desmatamento, REDD, Detecção de mudanças.

1) Introduction

With 1,086,950 km^2, indigenous lands represent 21.7% of the Brazil's nine-state Legal Amazon region (Veríssimo et al., 2011). The large geographical extent of these protected areas and their demonstration of historical retention to deforestation indicate that, together with conservation units, these areas are important in maintaining the Amazon forest.

However, protected areas that are currently under high anthropogenic pressure, especially in the “Arc of deforestation,” have experienced increasing deforestation and degradation inside their boundaries (Soares-Filho et al., 2010; Veríssimo et al., 2011; Vitel et al., 2009). Both internal and external factors are threatening their role in conservation. First, the scarcity of forests in the areas surrounding indigenous lands that are situated in high-pressure zones, as in the state of Rondônia, is worrying because neighboring-agent invasions have already been observed in some indigenous lands (e.g., the indigenous lands of the Xavante tribe in Mato Grosso and of the Uru-Eu-Wau-Wau in Rondônia), where pastures and agricultural fields have expanded into areas of conserved forest. Other risks to protected areas in Rondônia are advances of external agents who log, hunt, fish and mine. Internally, other factors could influence the evolution of forest conversion. Indeed, greater proximity of indigenous lands to cities favors access to markets and consuming centers; the greater contact with Brazilian society has progressively modified traditional practices and ways of life of forest populations, influencing the redistribution of family labor to economically profitable activities that generate products in response to market demand. These include cattle ranching, logging and agriculture. Additionally, the observed demographic growth in indigenous lands (IBGE, 2010) could accelerate the expansion of economic activities that cause environmental impacts in these areas.

A way of limiting the disappearance of forest cover in inhabited protected areas is to avoid the development of activities that have a heavy impact on the environment, such as extensive cattle ranching. Ways are needed to reinforce and maintain sustainable production systems to feed the local population, such as traditional agricultural practices, and to favor activities that generate economic return in ways that are less impacting in terms of forest-cover loss, for example by promoting handicraft manufacture or agro-forest systems. The REDD mechanism intends to use carbon payments to stimulate forest-management activities that guarantee both forest conservation and a livelihood for the traditional population. This is the case for the Suruí Forest Carbon Project (PCFS), which is the first REDD project to be implanted in a Brazilian indigenous land through the voluntary REDD mechanism. The objective is to avoid the advance of the deforestation process that has spread during the last decade, mainly for establishment of pastures and coffee plantations. To calculate the financial credits that could be obtained with REDD in areas under high risk of deforestation (as is the case for the majority of indigenous lands in Rondônia), a possibility is to calculate the GHG emissions associated with expected deforestation and/or forest degradation that would occur without REDD, basing the calculation on a future time period. This is the “flow method,” which is different from the “stock method” that would remunerate the preservation of an initial carbon stock. The most plausible LULCC (Land-Use and Land-Cover Change) scenario on which REDD projects can be based is also called the LULCC “reference scenario” or “baseline.”

The first step to understanding how LULCC would evolve in the future in areas where deforestation and degradation processes have already advanced, or have either only just started or would soon start, is to analyze the historical LULCC of the area. Analyzing historical LULCC means characterizing the dynamics of human activities in a given space and analyzing their impacts on forest cover and structure. One possibility is to combine socioeconomic data (surveys, ground observations and bibliography) with satellite imagery to define land-cover/use classes and characterize the transitions between these classes over a historical period. It is important to determine if a clear trend exists in LULCC. The use of satellite imagery permits observing certain scars that human-induced activities have left on the forest cover, but the observation also depends on the scale or spatial resolution used in defining forest cover and on the characteristics of the satellite image. In this study, we evaluated the LULCC of the *Sete de Setembro* Indigenous Land over the historical period from 2000 to 2009 using multi-temporal Landsat 5-TM imagery. This analysis resulted in annual land-cover/use maps, after which the application of post-classification change detection permitted calculation of the trends in forest-cutting and secondary-vegetation clearing rates.

2) Methods

2.1) Study area and satellite images

The study area is the *Sete de Setembro* Indigenous Land (SSIL), which is located in the western Amazon region straddling the border between the states of Rondônia and Mato Grosso (Figure 1). The area of 247,850 ha encompasses parts of the municipalities of Cacoal, Espigão do Oeste in Rondônia and Rondôlandia in Mato Grosso. The SSIL is situated 40 km from Cacoal.

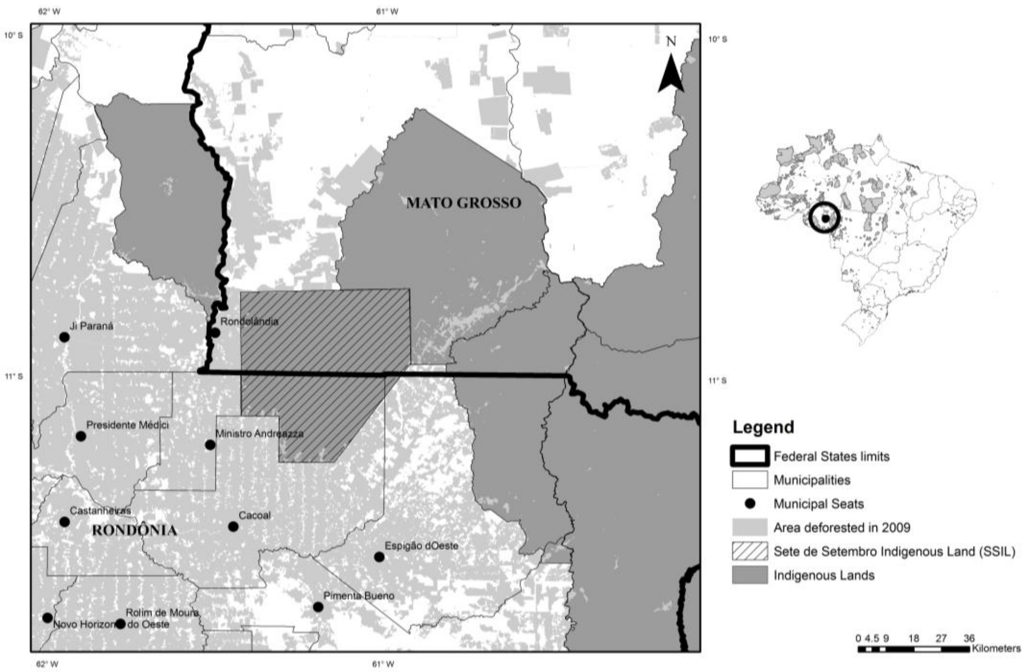

Figure 1- Study area location.

In the 1970s and 1980s, Cacoal underwent an accelerated deforestation process (Fearnside, 1986, 1989) that resulted in the loss of 65% of the municipality forest cover by 2011. Pasture and agriculture predominate in the deforested areas. The indigenous tribe that inhabits this land is the Suruí, which had a population of 1231 in 2009 (Metareilá, 2010). Twenty-six villages are scattered around the limits of the reserve; this settlement pattern has been created as a means of defending against invasions and against incursions to steal timber. The predominant land cover of the SSIL is tropical rain forest vegetation. Dense sub-montane ombrophylous forest represents about 70% of the total area, and the rest of the territory has small patches of non-forest vegetation (Savanna) and open sub-montane rain forest (RADAMBRASIL, 1978). Soils are predominantly red-yellow podzolic (Ultisol and Acrisol). The predominant topography is gently undulating with slopes between 3% and 12%.

We used satellite images between 2000 and 2009 from the Landsat 5-TM optical sensor for the 230/68 (Path/Row) scene to analyze the evolution of land-cover/use in the SSIL. The 2000-2009 period was chosen because of field observations reported by the Metareilá Association of the Suruí People indicating a modification of land-cover/use due to forest degradation associated with illegal logging and due to deforestation associated with pasture and coffee-plantation establishment since 2000. The only image that was not available on the

INPE website is the one for 2002. We therefore did not map land-cover/use for this year, but instead, we calculated land-use changes between 2001 and 2003. Spatial resolution is 30 m. We used the same definition of forest as Brazil adopted in the context of the UNFCCC (United Nations Framework Convention on Climate Change): a forest area must be at least one hectare in area and it must have a minimum tree crown cover of 30% and a minimum tree height of 5 m. Landsat images are able to detect landscape features at this scale (Arino et al., 2011). We considered deforestation to be a transition between forest and non-forest classes.

The 230/68 Landsat scene covers more than 95% of the SSIL. The portion covered by the contiguous 230/67 scene (5%) is only composed of forest, and no other land-cover class was found in this area either through visual interpretation in the images between 2000 and 2009 or from observations during the over-flight carried out by IDESAM in 2010. We mainly used images obtained during the dry season (May to September), which is the period that has the least cloud cover.

2.2) Pre-processing of image data and maximum-likelihood classification

The methodological steps used to map land-cover/use classes and annual changes are diagrammed in Figure 2. Images were geometrically corrected using a first-degree polynomial model and a nearest-neighbor re-sampling technique with NASA Geocover images from the year 2000 (available at https://zulu.sec.nasa.gov/mrsid). The root-mean square (RMS) of positional errors varied between 0.2 and 0.4.

The set of images has been corrected for atmospheric interference effects using an automatic method in the Claslite 2.2 program (Asner et al., 2009), which is based on the atmospheric radiative transfer 6S (Vermote et al., 1997). Calibrated reflectance data images were transformed to floating-point format in the ENVI software with the objective of normalizing the spectral signature data in images of different years. To avoid confusion between non-forest vegetation (savanna) and bare soil originating from anthropogenic activities like cattle ranching or agriculture, a mask for savanna was applied based on the Amazon Cartographic Base[1] (scale 1:100,000).

We used the supervised Maximum-Likelihood classifier in the ENVI software with the option to classify 100% of the pixels. To train the classifier, we used 105 pixel samples that had spectral signatures for five land-cover classes; these pixels corresponded to control points collected during the field visits in 2010 and 2011 using a manual GPS. We initially defined the following five land-cover classes: 1) forest, 2) burned areas from slash-and-burn in forest and from clearing secondary vegetation, 3) areas of bare soil prepared for agro-pastoral practices and habitations, 4) secondary vegetation, and 5) water (major rivers and water bodies). We then defined four classes of land-use/cover by grouping land-cover sub-classes 2, 3 and 4 from the previous classification to obtain the following new classes: 1) forest, 2) anthropic vegetation in equilibrium, 3) non-forest, and 4) water.

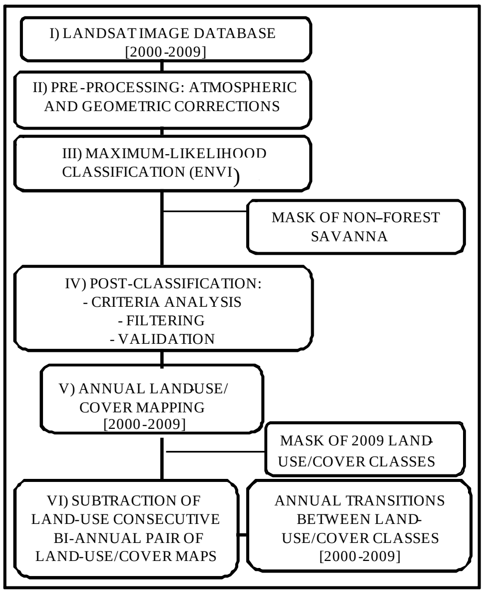

Figure 2- Flowchart showing the phases of the methodology.

[1] Ministry of the Environment 2010.

The forest class includes different vegetation types of tropical rain forest as described. This class includes all areas classified as forest in 2009 that did not change class between 2000 and 2009. However, it is known that there has been selective logging in the SSIL. The field surveys, reports of the indigenous residents, satellite images and an over-flight indicate that almost the entire area has been logged, although it was not possible to specify exactly what proportion of the area this has affected. The class "anthropic vegetation in equilibrium" combines classes of bare soil from productive areas (pasture and agriculture fields), habitations, secondary vegetation (originating from abandoned productive activities) and recently burned areas.

2.3) Post-classification

After classification of the images, the classes obtained in raster format were transformed into shapefiles in the ENVI software. Later, map algebra was used in the ArcGis software and all polygons with areas less than one hectare were removed in accord with the Minimum Mapping Unit (MMU) defined in the study. Since there are several hilltops in the SSIL (where the dominant topography is undulating), we removed all of the pixels classified as secondary vegetation in the altitude range of 344-478 m because PRODES[2] data for the same period had shown that no deforestation had occurred in this altitude range between 2000 and 2009. We therefore attributed the "forest" class to these pixels.

The classification was validated using 337 control points, using GPS points and visual interpretation of high-resolution imagery (QuickBird) for the year 2010. The objective is to test the accuracy of the classification by comparing estimated and observed classes; this is why we based our analysis on information from around the same period of time. In choosing the locations in the classified image where accuracy would be analyzed, we used a systematic sample by constructing a grid in which 338 points were distributed.

2.4) LULCC post-classification analysis of consecutive land-cover/use maps

After classifying the land-cover/use of the SSIL for each year from 2000 to 2009 (excepting 2002), we derived LULCC through a methodology of algebraic map applying an arithmetic subtraction operation between maps of consecutive years (e.g., 2004/2005). For this, we used the raster calculation in the modeler component of the ERDAS software, and applied GIS algebra in the ArcGis program. The transitions of interest were forest clear-cutting (from the "forest" class to the "vegetation in equilibrium" class, which corresponds to deforestation) and re-use of secondary vegetation ("secondary vegetation" to "deforested areas[3]"). We applied a mask corresponding to the class "vegetation in equilibrium" for the year 2009, which is the most recent classified image in the historical period, to concentrate our analysis on areas that were considered to be human-induced, reducing the dimension of data to be analyzed. Additionally, we considered that a deforested area was not considered to return to primary forest during the period analyzed (2001-2009). In order to isolate the changes in any given year, a mask of cumulative deforestation in previous years was applied in the analysis. For example, when the changes between the years 2004 and 2005 were analyzed, a mask of the deforestation that occurred between 2001 and 2004 was applied to the 2005 map; as a result, only the changes between 2004 and 2005 were identified in the analysis. We only considered changes relative to the MMU of one hectare and removed all changes in areas smaller than this minimum. For the transition "re-use of secondary

[2] Amazon Forest Monitoring by satellite of INPE- National Institute for Space Research. Available at <http://www.obt.inpe.br/prodes/index.php>. Minimum Mapping Units of 6.25 ha.

3 The land-cover class "deforested areas" has only been used to calculate the secondary vegetation clearing rate. This class grouped the two previous sub-classes "bare soils" and "burned areas".

vegetation," we only applied a mask corresponding to the previous annual clearing because a vegetation-regeneration area must be at least one year old to be cleared again.

3) Results and Discussion

We obtained an accuracy of 88% and a Kappa of 0.8 for the classification of the 2010 Landsat image. There was little confusion between forest and cleared areas in the classification. The largest errors were attributed to the "secondary vegetation" class being confused with the "forest" class.

At the beginning of the PCFS project, 3416.5 ha of forest were considered to have been deforested before this date (Figure 3-A).

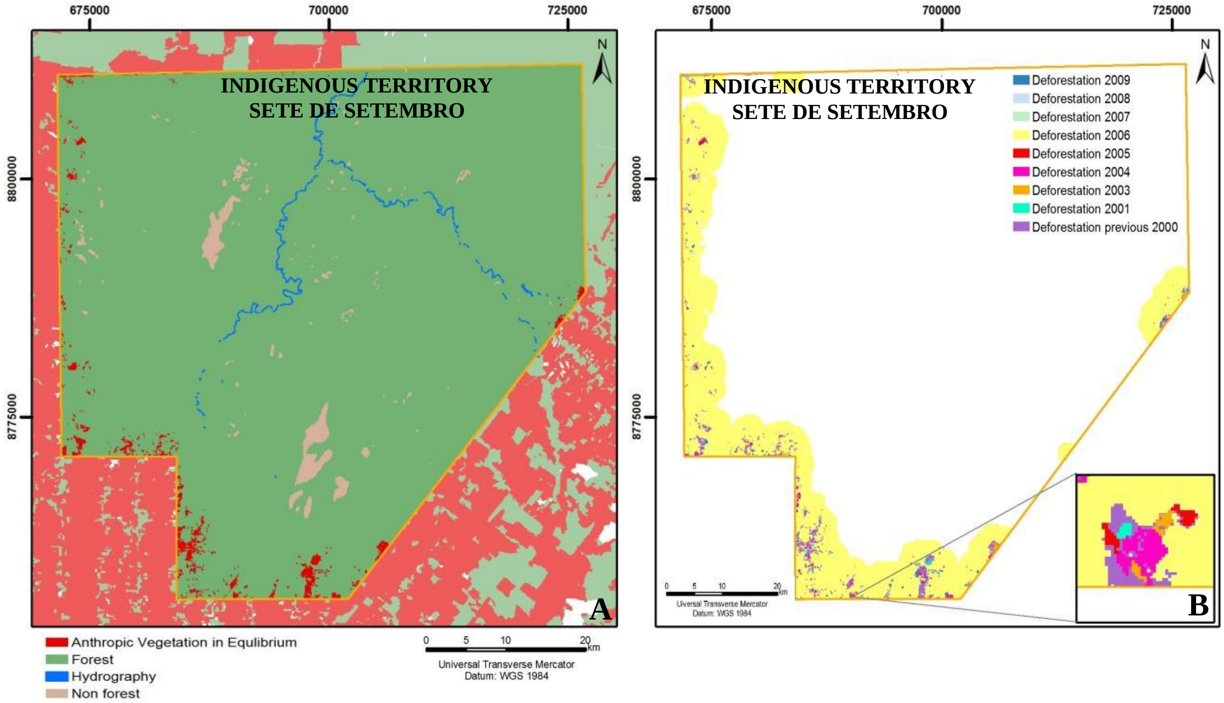

Figure 3- Land-cover/use of the SSIL in 2009 (A) and LULCC between 2000 and 2009 (B).

The analysis of LULCC resulted in a cumulative area of 1415.8 ha of forest cutting between 2001 and 2009, which corresponds to an average annual deforestation rate of 157.4 ha between these dates (Figure 3-B). Forest cutting represents 72% of annual changes, whereas clearing of secondary vegetation represents 28%. A total of 792 ha of secondary vegetation was cleared, which corresponds to an annual average of 88 ha during this period.

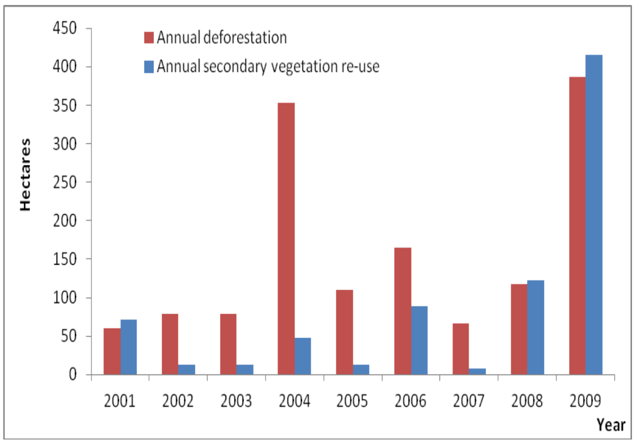

Figure 4- LULCC rates between 2001 and 2009.

We did not find a significant statistical trend in the evolution of LULCC since 2000 (Figure 4) despite observing an increasing annual rate of deforestation. According to the surveys of agents and of socioeconomic activities (Cenamo et al., 2011; Metareilá, 2010), the recent increase in deforestation is linked to the reduction of revenues from illegal logging: part of the Suruí population converted forest areas to cattle ranching and coffee production in order to compensate for economics losses. Among the needs for understanding future course of logging is better knowledge how it will be influenced by the structure of the current forest (tree diameters and recruitment state).

Table 1-Land cover/use classes and evolution of LULCC between 2000 and 2009. Areas in hectares.

Data	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
LAND-USE/COVER CLASSES – MAXVER CLASSIFICATION										
Vegetation in equilibrium	1,200.8	994.6		1,288.5	1,728.1	1,781.0	1,845.4	1,893.9	2,446.6	3,416.5
Forest	242,249	242,455		242,161	241,721	241,669	241,604	241,556	241,003	240,033
Water	327.4	327.4		327.4	327.4	327.4	327.4	327.4	327.4	327.4
LULCC – POST CLASSIFICATION ANALYSIS METHOD										
Forest clear-cutting		60.5	78.7	78.7	353.6	110.3	164.5	65.9	117.4	386.3
Re-use (clearing) of secondary vegetation		72	12.3	12.3	47.3	12.5	88.7	8.4	122.9	415.8
Total area of changes		132.5	91.0	91.0	400.9	122.9	253.3	74.3	240.2	802.1
% Forest-cutting		46%	86%	86%	88%	90%	65%	89%	49%	48%
% Clearing of secondary vegetation		54%	14%	14%	12%	10%	35%	11%	51%	52%

Landsat 5-TM images were sufficient to calculate deforestation rates in the SSIL over the historical period of 2000-2009 at a scale of one hectare. Deforested areas are in this case a mix of uses: productive activities (cattle ranching and agriculture) and habitations. However, with the use of Landsat images, we were not able to distinguish the different productive uses, especially separating pastures from agricultural fields (i.e., the coffee plantations occupy most of the Suruí agriculture fields). Nevertheless, in other studies, Landsat images have been used to map coffee in different stages (see Lamparelli et al., 2011), but in our study the 30-m resolution of Landsat imagery would not permit mapping of this kind because agricultural areas do not have such a regular pattern and their areas are not sufficient (average of 1.73 ha per Suruí household), and because coffee plantations are mixed with patches of subsistence agriculture (average of 0.57 ha per household), which makes identification difficult. However, mapping productive areas is an important concern for REDD projects; indeed, to reduce demand for forest cutting for new productive areas, several projects propose to improve the profitability of activities that have already led to deforestation. Combining the mapping of productive areas with household socioeconomic surveys improves the accuracy of information on productive systems. To do so, it would be necessary to invest in higher-resolution images to observe more detailed characteristics such as the texture, geometry and reflectance of areas of productive activities in order to better distinguish their areal extents. Another concern is the MMU of one hectare: this definition of forest is not sufficient to capture small patches of deforestation linked to traditional agriculture, which are generally smaller than one hectare. Since the Suruí possess, on average, an agriculture subsistence area of 0.57 ha per household, it is possible that we did not capture all of the cleared areas associated with this activity in our analysis.

4) Conclusion

The analysis of LULCC that was conducted in the *Sete de Setembro* Indigenous Land indicated increasing deforestation rates since 2000, except for the year 2006, when the deforestation rate decreased. For REDD, an important concern, in addition to historical LULCC analysis, is to identify factors that could induce a modification of the evolution of land use in the future. In the *Sete de Setembro* case, one of the principal factors indentified is economic: the decreasing revenues from illegal logging could favor greater use of economic alternatives such as cattle ranching.

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