Land tenure, road and deforestation patterns in southeast State of Acre - Brazil

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Abstract. This paper analyzes land tenure, road, and deforestation linkages in the southeastern part of Acre-Brazil. This region has been integrated by the Inter-Oceanic Highway, which has been paved in Acre and will link Brazil to markets in the Pacific via Peru. Highway paving will facilitate the extraction and transport of forest products and increase cattle ranching through improved access to formerly remote areas. However, land tenure arrangements are diverse in eastern Acre, so it is likely that deforestation will vary among different lands along the Highway. This paper evaluates deforestation over time among lands with different use rules along the Inter-Oceanic Highway in eastern Acre. A five years time series analysis of Landsat Thematic Mapper (TM) imagery were employed to evaluate the spatial and temporal distribution of deforestation. Results show that deforestation estimates of the selected lands by time of completed paving status have accelerated after highway paving; almost all segments show an exponential increase in deforestation estimates. In addition, all three explanatory factors – time since paving, distance from highway, and land tenure – are important for understanding where deforestation is greater. However, the acceleration in deforestation is a generalized phenomenon, and occurs in all lands considered, regardless of their time since paving, distance to highway, and land tenure type. This acceleration is cause for concern, because recent deforestation estimates are nearing legal limits in some tenure types and have exceeded limits in others. This raises policy questions concerning land use rules alongside initiatives for regional development via highway paving.

Palavras-chave: remote sensing, pacific highway, rural settlement, image processing, sensoriamento remoto, estrada do pacifico, assentamento rural, processamento de imagem

1. Introdução

Tropical deforestation is considered to be one of the most significant types of land-cover changes underway globally (Myers 2000). It also has a substantial effect on climate change through burning and release of CO_2 into the atmosphere (Fearnside 2008). Deforestation and climate change are expected to result in considerable water shortages and other forms of resource scarcity (Rayner and Malone 2001). These concerns raise questions about the spatial distribution of deforestation, which influences the locations where many negative environmental consequences are likely to result. Information about the spatial distribution of deforestation is necessary to estimate the impacts of habitat destruction and fragmentation on biological diversity (Skole and Tucker 1993).

No region of tropical deforestation has drawn more concern than the Amazon basin, especially the Brazilian Amazon. The Amazon forest plays an important role in both moderating temperatures and in recycling water into the atmosphere during the dry season, on local and regional levels. Consequently, large-scale deforestation in the Amazon may result in warmer and drier conditions in the region (Malhi et al. 2008). Deforestation in Amazonia has historically followed the extension of roads (Perz et al. 2008) and the consequent expansion of logging, cattle ranchers and agricultural frontiers. Roads facilitate access to natural resources, raising land values and attracting population and investment. In forested regions, improvements in access may lead to the onset or acceleration of deforestation over time. That said, simple models of accessibility incorrectly predict deforestation insofar as land tenure rules vary from one place to another. Theoretical frameworks to explain land cover change highlight the importance of institutional factors, notably land tenure rules, since institutions define use rules that in turn can determine whether and where deforestation and other land use may occur (Geist and Lambin 2006). Hence lands with similar accessibility but different tenure rules may nonetheless exhibit very different deforestation rates and patterns.

In the Amazon, highway paving as well as tenure diversification have proceeded apace. It is therefore likely that any accounting for deforestation in the Amazon requires attention to both factors. In this study, I consider the importance of highway paving, distance from highway and land tenure for deforestation in eastern Acre, Brazil. Acre is a very useful study case because it has incurred high-profile infrastructure investments as well as serving as a policy laboratory for several innovative land tenure models, including some which have since diffused to other parts of Brazil. The analysis focuses on comparisons in deforestation over time and across space in eastern Acre using a time series data set of Landsat images from 1986 to 2005. The imagery span the period of highway paving in eastern Acre, and an area that encompasses locations close to and far from a key highway, along with numerous lands with different tenure rules.

2. Methodology of the Study

The state of Acre covers an area of 164,220 km^2. It is located in the western Amazon (7^o 07´ - 11^o 08´ S and 66^{o}30´- 74^o 00´W), along the southeast and northwest boundaries of the state of Amazonas, west and south of Peru, south and southeast of Bolivia, and southeast of Rondônia state. I focus on eastern Acre because it encompasses the Inter-Oceanic Highway route thru Acre and it contains numerous different land tenures types. (Figure 1).

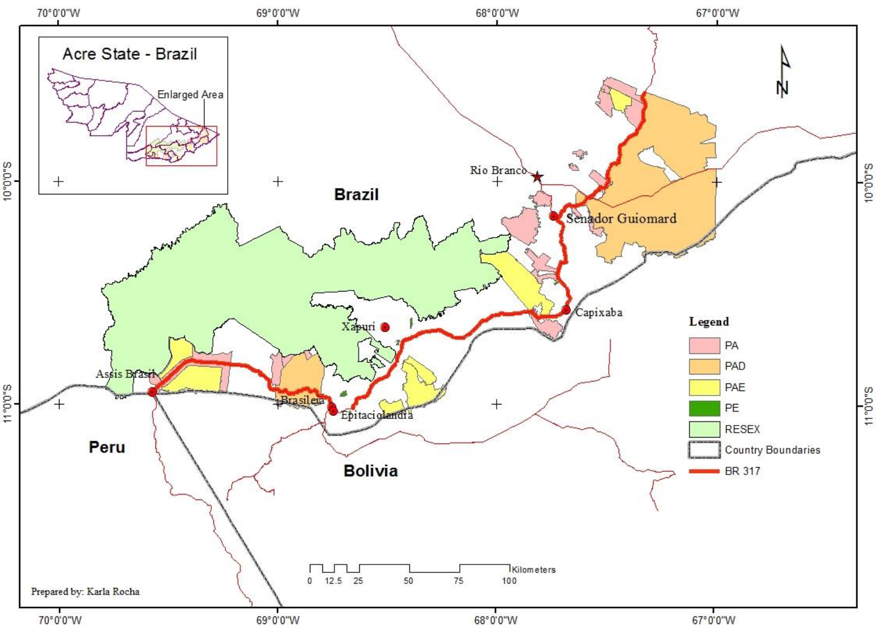

Figure 1. State of Acre and its different land tenures category.

The analysis uses Landsat imagery for 1986, 1991, 1996, 2000 and 2005. Landsat ETM and TM images were acquired from the University of Florida. I focus on the dry-season imagery, specifically July, with relatively cloud-free images. The Landsat data were radiometrically calibrated, geometrically registered (image to image rectification), normalized for precipitation differences (when necessary), and mosaicked. Following processing, I pursued classification techniques in order to transform the spectral data into earth surface information through the extraction of thematic features (deforestation, land-use and land-cover change). It was removed clouds, shadows and water from each image before classification. A forest and non-forest trajectory image was created from the classifications. Image. Change trajectories are defined as sequences of successive changes in land cover types providing information on changes between two or more time periods of an area or region. For the purpose of the analysis, I divided the study area into 5 segments based on the timing of highway paving, distance from highway, and land tenure type. Figure 2 provides a visual overview of these various divisions.

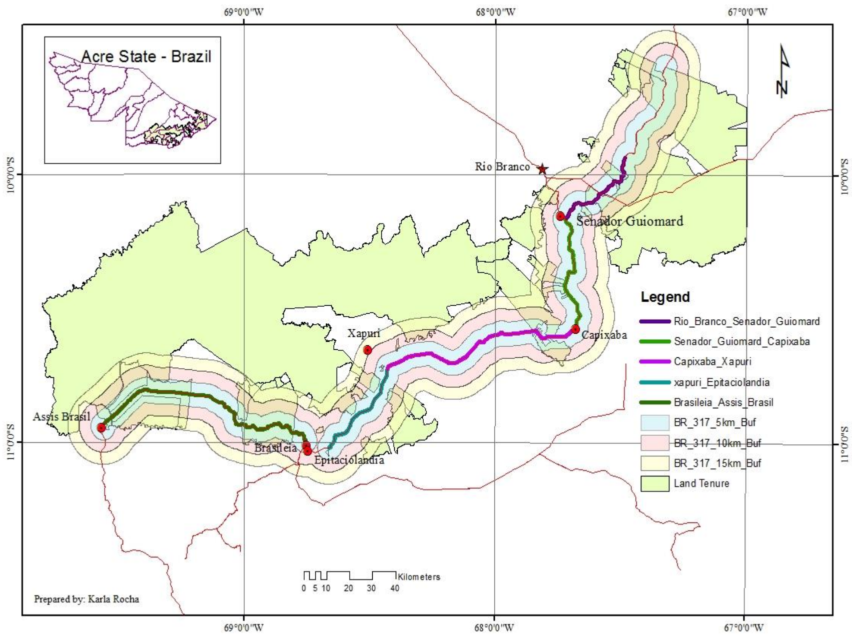

Figure 2. Road segment according to paving status, buffer and land tenure category.

Figure 3 shows the road segments and deforestation by time periods. To permit evaluation of the effects of distance from the highway, I created distance buffers along the BR-317 corridor. I defined three distance intervals: 0-<5 km, 5-<10 km, and 10-<15 km. While one might define other buffers, these distinctions permit comparisons of lands closer to and farther from the highway. This permits a spatial analysis of deforestation. Finally, I conduct the land tenure analysis by comparing lands with different use rules and deforestation limits.

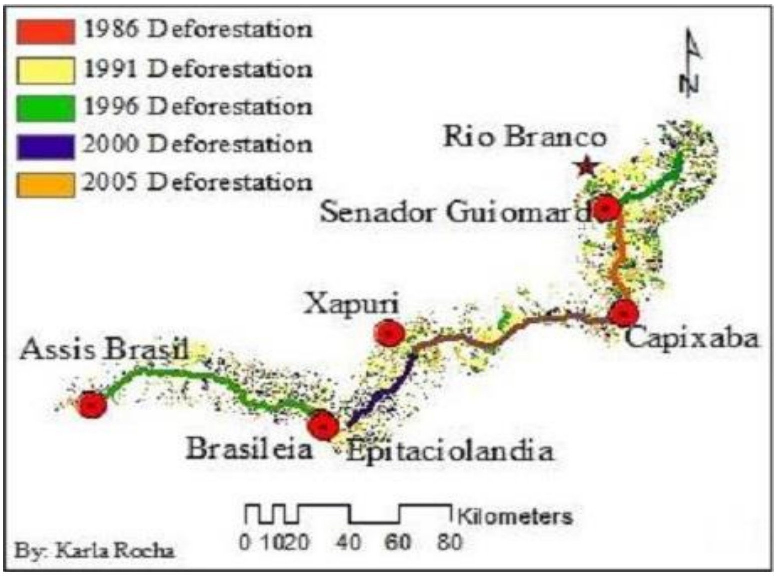

Figure 3. Deforestation through 1986 to 2005 by paving status.

3. Results and Discussion

3.1. Time of Paving and Deforestation

Figure 4 presents findings for deforestation in the selected lands in eastern Acre from 1986-2005, broken down by time of highway paving. Overall, deforestation rose from roughly 4% in 1986 to approximately 28% in 2005. The trajectory of deforestation shows non-linearities, with an increase from 1986-1991, a deceleration from 1991-1996, and an acceleration from 1996-2000 and especially during 2000-2005. The accelerations during the last two periods coincide with a major effort to complete paving of the Inter-Oceanic Highway in Acre during the late 1990s and early 2000s. In general, areas with earlier paving have more deforestation. The Rio Branco-Quinari (Senador Guiomard) segment, which was paved by 1984, exhibits the highest deforestation percentages. Moving south and west along the Inter-Oceanic Highway, road segments were paved more recently, and each progressive segment exhibits lower deforestation percentages. Rio Branco-Quinari has a higher deforestation percentage than Quinari-Capixaba, which exhibits more proportional deforestation than Capixaba-Xapuri, and so on. The one exception to this pattern is the last segment, Brasiléia-Assis Brasil, which has a higher deforestation percentage than many of the other segments. Hence the gradient holds in most but not in all cases.

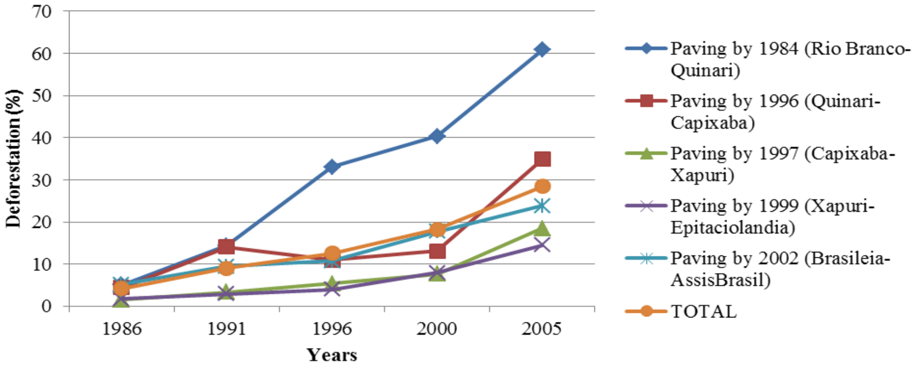

Figure 4. Deforestation thru time by highway paving status, selected lands along the Inter-Oceanic highway in Acre, Brazil 1986-2005.

Another way to evaluate highway paving and deforestation in Figure 4 is to compare deforestation percentages before and after paving by road segment. For Rio Branco-Quinari, the highway was paved before the first observation in 1986. I note that deforestation in 1986 was low (under 5%) but it rose very rapidly thereafter, exceeding 60% by 2005. Hence in this segment, there was little deforestation by 1986 but rapid forest loss after road paving. The question then is whether other road segments also exhibit little deforestation before paving and rapid forest loss afterwards as well. Here the findings are somewhat mixed. The Quinari-Capixaba segment was paved by 1996, and exhibits little deforestation up to 1996 (roughly 11%), but there is little response up to 2000; however, deforestation there jumped to almost 35% by 2005. The next segment, Capixaba-Xapuri, exhibits a similar pattern of a delayed jump in deforestation after paving. Xapuri-Epitaciolândia also had little deforestation by 2000, by the time paving was completed, and deforestation rises faster thereafter. Brasiléia-Assis Brasil received paving by 2002, but deforestation was already rising in the late 1990s. These findings do suggest a correspondence in the timing of paving and accelerated deforestation, but they also suggest that other processes are also at work, since some segments have delays in the acceleration of deforestation while others exhibit rising deforestation during paving rather than only afterwards.

If the timing of paving only partly accounts for deforestation patterns, it is also possible that the effects of the Inter-Oceanic Highway reflect proximity of land to the highway itself. I therefore compare lands at different distances from the highway, in buffers with 5 km intervals. Figure 5 presents deforestation along the Inter-Oceanic Highway in eastern Acre from 1986-2005 by the distance buffers. There is considerable prior literature on land use and land cover change, including for the Amazon, which emphasizes the importance of accessibility for forest loss, and consistently shows greater forest loss closer to highways. Figure 5 is therefore surprising, because it shows rather similar deforestation percentages among the buffers out to 15 km from the Inter-Oceanic Highway. Initially, deforestation shows a U-shaped distance curve, but with time, the standard distance gradient emerges, such that deforestation is greater closer to the highway by 2005. Nonetheless, there is not a large difference between the 5-10 km and 10-15 km buffers. For the most part, access to land is not easy far from the highway; secondary roads in rural areas of Acre remain unpaved and virtually impassable during the rainy season. One reason the deforestation percentages at 10-15 km appear high is that the capital city of Rio Branco falls within that buffer as the Inter-Oceanic Highway passes around the center of town.

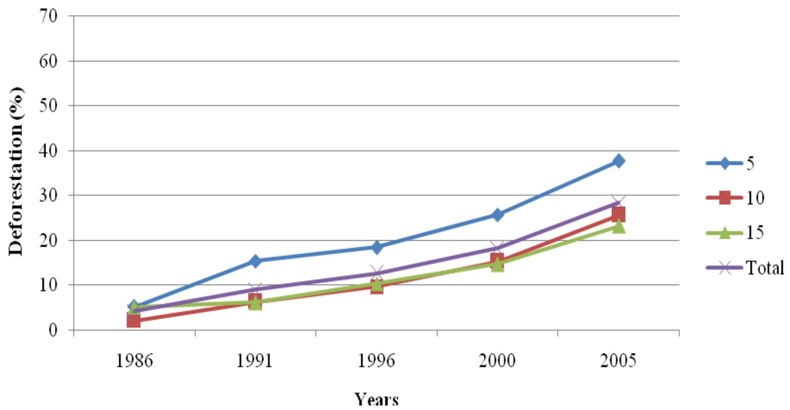

Figure 5. Deforestation thru time by distance from highway, selected lands along the Inter-Oceanic highway in Acre, Brazil 1986-2005.

Rio Branco-Quinari segment exhibits higher deforestation percentages in the buffers more distant from the Inter-Oceanic Highway. This is true of all time points, and is consistent with the interpretation that the higher deforestation percentages in the most distant buffer are due to urban growth of Rio Branco. By contrast, the other road segments all exhibit deforestation distance gradients that correspond to previous work on accessibility and land cover change. Further, the distance gradients become stronger as one moves farther from Rio Branco. Whereas the distance gradient is weak in the Quinari-Capixaba segment it is stronger in all three of the other highway segments, and in each of those segments, the distance gradient appears at all time points. Hence distance gradients in deforestation do have a relationship with time since paving, but the relationship is distorted in the study region due to the routing of the Inter-Oceanic Highway around Rio Branco.

3.2. Land Tenure Type and Deforestation

Figure 6 presents deforestation estimates for lands in the tenure categories. I expect deforestation to be highest in the agroforestry poles (PEs) which lack deforestation limits, followed by the PAs and PADs (which have 20% deforestation limits), and then the PAEs and the CMER (which have 10% deforestation limits). It also shows large differences in deforestation percentages among the tenure categories, as well as distinct deforestation trajectories over time. The higher rates of deforestation in the PAs and PADs are explained by the expansion of cattle pasture. Crop prices in Acre have fluctuated over time, whereas cattle prices have proven relatively stable or rising. At the same time, PEs exhibited deforestation fluctuations, notably a decline after 1991 before a rise after 2000, in part due to instabilities in crop marketing opportunities. Families in PAs and PADs faced the same difficulties, but had more land that permitted pasture expansion. That said, Figure 6 also indicates that at least in lands close to the Inter-Oceanic Highways in PAs and PADs, deforestation exceeds the legal limits. This may be due to properties under 100 ha, which are exempt from the 20% rule, or "grandfathering" in older PADs which existed before the 20% rule.

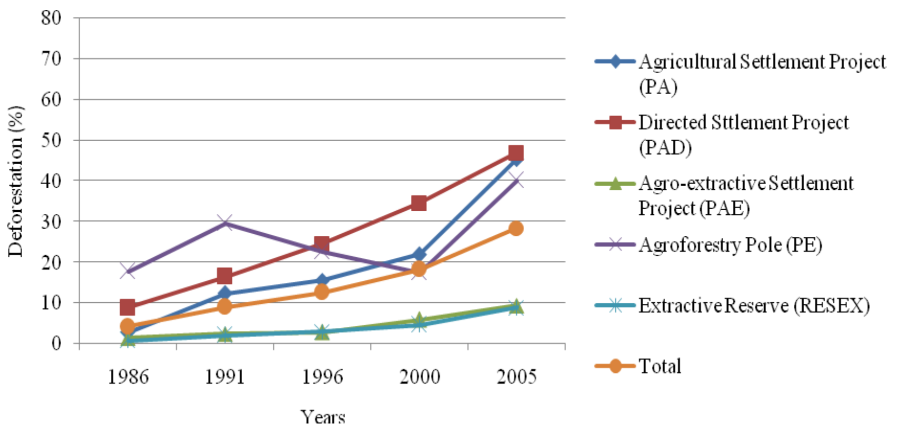

Figure 6. Deforestation thru time by land type, selected lands along the Inter-Oceanic highway in Acre, Brazil 1986-2005.

In any event, there are lower estimates among PAE and the CMER. This does not change over time. That is not to say that deforestation does not increase over time in these tenure categories; both exhibit deforestation of roughly 1% in 1986 and 9% in 2005. What is remarkable is how similar the trajectories of the two categories are; both have 10% limits and both have virtually identical trajectories. Further, both types remained under their legal deforestation limits as of 2005. Overall, deforestation estimates decline as one move from highway segments with earlier paving to later paving, regardless of land tenure type. This applies to the PEs as well as the PAs and PADs, and also the PAEs and the CMER.

There are however some non-linearities. For example, among the PAs, deforestation is relatively high in the Rio Branco-Quinari segment, low in the Quinari-Capixaba segment, and moderate in the segments beyond. One explanation for this is that in some cases, there are older settlements in areas with more recent paving, and settlement age may be countering the effects of paving recency. Among the PAs, near Capixaba, there has been an emergent agribusiness enterprise for sugar cane. Investment for sugar cane processing began in 1989 with the creation of Brazilian Alcohol S/A, (ALCOBRAS), which was linked to Brazil's National Alcohol Program, PROALCOOL. The PAs and PADs tend to occur in older segments closer to Rio Branco, and the PEs, PAEs and the CMER are located in newer segments farther away. This might lead one to suspect that tenure differences are actually due to these different spatial distributions of the tenure types, as where PAs and PADs have more deforestation merely because they are in areas with older paving than PAEs and the CMER.

Comparing deforestation percentages over time among land tenure types and distance from the Inter-Oceanic Highway. We know that because the highway passes around Rio Branco, the distance gradient in deforestation does not appear there; and we know that PAs and PADs tend to occur in highway segments closer to Rio Branco. Hence it is not surprising that deforestation either does not decline much by distance (PAs) or it actually rises (PADs). Conversely, distance gradients in deforestation do appear for the other tenure types that tend to occur along other highway segments, as for PEs, PAEs, and the CMER. Hence observation of gradients in deforestation by distance from the Inter-Oceanic Highway is affected by the route of the road and thus road segment, more than land tenure per se.

4. Conclusion

Several key conclusions arise from the foregoing analysis. First, deforestation along the Inter-Oceanic Highway has risen over time, and accelerated around the time that paving concluded in Acre. There is some evidence of non-linearities, with a slowdown in the early 1990s, followed by an exponential acceleration in the late 1990s and early 2000s. This finding applies regardless of time of paving, distance from the highway, or land tenure type. The acceleration is likely to be related to the conclusion of paving of the highway corridor, but paving by itself is unlikely to be a sufficient explanation; more generalized economic expansion is also key, with the paved highway facilitating new land use and marketing.

That said, there are spatial differences as well as temporal dynamics at play in land cover change in eastern Acre. All three of the explanatory factors I considered – time since paving, distance from the highway, and land tenure type – exhibit important effects on deforestation percentages. Lands along highway segments with earlier paving, closer to the highway, and with tenure rules including higher deforestation limits (or no limits at all) all exhibited higher deforestation percentages. Further, with one exception, there were not strong interactions among these explanatory variables. For example, lands along highway segments with earlier paving had higher deforestation regardless of distance from the highway; and lands along segments with older paving also had greater deforestation regardless of land tenure type. The interaction concerned highway segment and distance from the highway, and arose due to the route of the Inter-Oceanic Highway, which skirts around the city of Rio Branco. As a result, the distance gradient disappears or even reverses in highway segments with earlier paving, but in segments farther from Rio Branco, the gradient appears normal, with less deforestation farther from the highway. Overall, the analysis confirms the importance of time since paving, distance from highway and land tenure type, and suggests that interactions among these factors are not strong, with an exception based on the route of the highway.

Hence there are important temporal non-linearities in deforestation in eastern Acre, as well as substantial spatial differences in deforestation. Future research can further inquire into these temporal dynamics and spatial patterns. For one thing, it will be important to know if the acceleration in deforestation since 1996 continues beyond 2005. If that is the case, it is likely that several land tenure types will exhibit deforestation beyond their legal limits. PAs and PADs, or at least the portions thereof included in this analysis, already exceeded their deforestation limits in 2005; PAEs and the CMER were nearing their limits by then as well.

Another issue would be to expand the distance buffers to consider lands farther out from the Inter-Oceanic Highway. This analysis went out to 15 km, but previous research suggests that road impacts extend to 50 km. Hence future research could increase the buffers out to 50 km, or even beyond. This would expand the land areas under analysis, but come at the cost of having many more distance buffers to compare. It would also be useful to identify the urban area of Rio Branco and mask that out from the analysis, since the deforestation analysis is primarily concerned with rural land use. However, this is only likely to partially correct for the impact of the state capital; even beyond the urban boundaries but close to town, land use is likely to be intensive and forests are likely to be scarce. A key policy implication of this analysis concerns land tenure and regional integration via highway paving. Clearly, land tenure matters for deforestation levels, suggesting that landholders at least try to follow established land use rules.

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