ENVIRONMENTAL PROTECTION IN BRAZIL: WHERE THE TRUTH LIES

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Abstract. The rates of deforestation in Brazil show that having one of the most advanced environmental legislations is not enough for effectively protecting its forests from being converted to food crops or pastures. Delineation of permanent preservation areas, according to the new Brazilian Forest Code, is imperative and may be the last chance to revert this scenario. A substantial portion of the current agricultural production fields is likely to be in protected areas. An integrative approach of SRTM data and digital hydrography Brazilian datasets was developed to produce a hydrographically correct digital elevation model for the Crepori River watershed, a major tributary of Tapajos River, belonging to the Amazon basin. The main objective was to assess the potential and the bottlenecks of using the SRTM data for supporting a countrywide automated delineation of natural preservation areas, a condition sine-qua-non for law enforcement.

Introduction

In the present study we developed an integrative approach using Shuttle Radar Topography Mission (SRTM) data from National Aeronautics and Space Administration (NASA), and digital hydrography Brazilian datasets, from Brazilian Institute for Geography and Statistics (IBGE), to produce a hydrographically correct digital elevation model (HC-DEM), the foundation for automating the process of delineating protected areas, for the Crepori river, a major tributary of Tapajós river located in the Amazon basin. This river was chosen because of the recent expansion of soybean cultivation and gold mining in this region (COLLISCHONN, 2006). Historically the delineation of protected areas and subsequent enforcement of land use restrictions within them has been hampered by a difficulty in determining the physical boundaries of these areas currently expressed only in policy. This research represents a first step in addressing this problem through the development of a method by which these areas can be accurately mapped from existing geospatial data sources for use in the enforcement of existing Brazilian legislation.

Enacted four decades ago, the Brazilian Forest Code (BFC) was conceived and written by visionaries. Even without sophisticated mapping technology, the authors of the BFC managed to create a masterpiece of environmental protection based on solid ecological grounds. This legislation was envisaged to protect the precious ecosystems of Brazil by regulating human impacts on native hilltop vegetation, along ridgelines and riparian zones, and on upland catchments. The protected areas, defined by law as natural preserves, were meant to create a vast network of ecological corridors, connecting all biomes and effectively shielding their biodiversity. Once established, the preserves would lead to healthier watersheds, protecting their soils from erosion and improving water quality and quantity (RIBEIRO, 2004).

The country has a wide-ranging system of protected areas, which form part of the National Protected Areas System (RYLANDS & BRANDON, 2005; BENJAMIN, 1998). The 1965 Brazilian Forest Code, law nº 4771, defined two categories of protected forests: 1) **Legal Reserves**, which require that every property keep reserves of at least 20% of land covered with natural vegetation, increasing to 80% reserves for areas in the Amazon region, and 2) **Permanent Preservation Areas**, whose definitions are based on key geographic watershed features such as divides, riparian areas, hilltops and steep hillsides. While the forests that make up a **Legal Reserve** may be managed – but never clear-cut – for timber production, the Permanent Preservation Areas distinction precludes all direct economic uses of the forested area that falls within their bounds. The permanent preservation area within a private property cannot be used to meet the requirements of its legal reserve. The Brazilian National Council for the Environment (CONAMA), in its Resolution nº 303/2002, defines the following types of Permanent Preservation Areas:

1) on hilltops, comprising the upper-third of hills and mountains;
2) along watershed divides, encompassing the upper-third of the hillsides;
3) on upland catchments, so defined by the contributing area of any given spring;
4) on the margin of natural lakes and lagoons;
5) on riparian zones, whose width depend on the extent of their floodplains;
6) on areas with slopes equal to or greater than 100%; and
7) on any areas situated above 1,800m.

The broad category of Permanent Preservation Areas still contain provisions for protecting environmentally sensitive areas such as those used for nesting or refuge by migratory birds, including beaches, mangroves, salt marshes *(restingas)*, permanent swamp areas dominated by palm trees *(veredas)*, habitats of endangered species, and dunes.

Seen as a cornerstone, the Brazilian law nº 6938/1981, known as the National Environmental Protection Act, did much more than establish a contemporary environmental policy framework; it provided the regime of a strict liability standard for environmental damage. This law defines as crime, subject to imprisonment, all conduct that poses serious risk to human life, to health or to the environment, even when covered by a valid permit. Subsequently, the Brazilian Congress passed law nº 7347/1985, extending to non-governmental organizations standing to sue in environmental affairs. Later, the Constitution of 1988 clearly denoted Brazilian society's concerns for environmental protection:

> **Article 255**: *All persons are entitled to an ecologically balanced environment, which is an asset for the people's common use and is essential to healthy life, it being the duty of the Government and of the community to defend and preserve it for present and future generations*.
>
> ...
>
> - **§ 2**: *Those who explore mineral resources shall be required to restore the degraded environment according to the technical solution required by the proper government agency, according to the law*.

Among other legal penalties, the offender — be it an individual or a legal person, including corporate management — are permanently precluded from signing contracts with the government, receiving tax incentives or any kind of benefit, and taking part in any public bids. Furthermore, its activities can be partially or even totally suspended (BENJAMIN, 1998). Despite all the progress made on the legal apparatus since the promulgation of the Brazilian Forest Code, these accomplishments exist only on paper as their enforcement has yet to be fully realized.

Historically, the lack of appropriate topographic datasets and the expertise needed for manually mapping the preserves, made it virtually impossible to enforce the Brazilian Forest Code over an area of 8.5 million km^2, such as the preservation area around the Tapajós river. As a result, the essence of the environmental legislation gradually faded away, paving the road for a generalized fragmentation of natural habitats in areas that should be preserved (HIRAKURI, 2003).

Recent technological advances in the acquisition of satellite imagery have enabled fast and accurate measurements of deforestation over large geographic extents. With the advent of geographic information systems and the increasing availability of worldwide high-resolution digital imagery, we are finally able to understand the full scope of the Brazilian environmental legislation. Furthermore, we are also able to recognize how deeply integrated the concept of the watershed as the primary planning unit is, in regards to resource management (BENTRUP, 2001; SLOCOMBE, 1993). Nevertheless, even with the new technology, the fact that the forestlands are still being destroyed to provide more room for food crops and pastures, indicates that the ongoing monitoring programs such as the SIPAM project (System for the Protection of the Amazon), PRODES (Program for the Estimation of Deforestation in the Brazilian Amazon), DETER (Real Time Deforestation Detection System) and SIAD (Integrated System for Alert of Deforestation), aren't enough to protect the last of the fragile Brazilian biomes (ASNER *et al.*, 2005). Astonishingly, as remote sensing emerged as a prominent mapping technology, the environmental damage in Brazil increased at an alarming pace. In the last 25 years 15% of the Amazon jungle was cut down. The expansion of the agricultural frontier towards *cerrados* (savanna woodland), an ecosystem that rivals the rainforest for biodiversity, caused the removal of nothing less than 50% of its original 2 millions km^2 (HENRIQUES, 2003; RATTER *et al.*, 1997).

A substantial portion of the current agricultural production fields and commercial forest plantations is likely to lie in Permanent Preservation Areas (WERTZ-KANOUNNIKOFF, 2005), which constitute crimes against the environment, according to the Brazilian laws. The bill 1364/2003, currently under analysis by the Brazilian Congress, obliges all landholders to delineate the natural Permanent Preservation Areas located in their lands and to rehabilitate conflicting areas, using native species, within a timeframe of 5 years. Such a task would definitely benefit from the methodology presented here.

Objective

The main objective of this research is to show the viability of performing an automated delineation of natural preservation areas for the Amazon basin using the SRTM data, hence providing sufficient conditions for imposing the Brazilian Forest Code to the fullest extent of the law.

Methods

Study area. The Crepori River basin drains an area of 13,578km^2 in the southwest region of the State of Pará, Brazil (**Figure 1**). Elevations range from 52m on its confluence with the

Tapajós river to 495m above sea level in the uplands to the south, having an average elevation of 250m (±68m). Its terrain consists of a highly complex network of numerous small rivers that cut through ground with slopes ranging from 0% to 250%, with an average value of 13% (±9%). Annual rainfall in this area is just over 2 meters and the average temperature is 28°C.

Figure 1. Location of the study area in the State of Pará, Brazilian Amazon.

Data. The most recent version of SRTM data, version 2, also known as the finished version, was released by NASA for South America in October 2005. Although available at 30m (1 arc-second) in resolution for the United States, data for areas outside were degraded to 90m (3 arc-seconds). The corresponding datasets are sometimes referred to as SRTM1 and SRTM3 respectively. These data can be freely downloaded from the Land Processes Distributed Active Archive Center's ftp site (ftp://e0srp01u.ecs.nasa.gov), being organized into 1° x 1° tiles of geographic coordinates (latitude, longitude).

The digital stream network dataset, provided by the Brazilian Institute for Geography and Statistics (IBGE), was created by scanning and vectorizing its 1:250,000-scale maps.

Preprocessing. In order to ensure that the divides of the selected target watershed would be accurately depicted in the final digital elevation model (DEM), an 8km buffer was defined around its hydrography, resulting in a total of 6 SRTM3 tiles to cover the entire area. These tiles were then mosaicked to form a continuous 90m cell-size DEM. To preserve map accuracy during subsequent spatial analyses, this DEM was projected to UTM coordinates, zone 21S, keeping the same datum (WGS84) of the original SRTM data. The next step was to convert its cells to a point dataset, each point lying in the center and carrying on the elevation value of the respective cell.

Given the requirements for creating a HC-DEM, centerlines were derived for double-line streams and connected to the remaining of the hydrography. This dataset was then checked for connectivity and downstream orientation of all its arcs (HUTCHINSON, 1989; SAUNDERS, 1999). The projection of the original dataset was Albers, datum SAD69 with coordinate units in kilometers, so it had to be re-projected to UTM zone 21S, datum WGS84 and its coordinates to meters.

The analysis was performed using the software ArcGIS 9.1 running on Windows Server 2003. However, due to a 512Mb undocumented limit imposed by the Topo_To_Raster routine to the size of the resulting DEM, the interpolation process had to be done in TOPOGRID, available in Arc/INFO workstation, which can handle DEMs of up to 1Gb. The cell size of the output DEM was set to 30m, compatible with the precision of the digital hydrography dataset (25m).

Postprocessing. The removal of spurious sinks was performed on the DEM generated by TOPOGRID using the Fill command, available in ArcToolbox, to get rid of any eventual depression that would otherwise block downstream flow. Even using TOPOGRID with drainage enforcement, the digital hydrography does not always coincide with the bottom of the valley, creating peaks and sinks on the vertical profile of the stream network. Drastic changes in elevation values may occur as a result of applying the traditional stream burning techniques to correct the vertical profile of the rasterized stream network (SAUNDERS, 1999). In order to minimize the changes in the original DEM surface values along the hydrography cells, we modified the method proposed by HELLWEGER (1997). Initially the vector hydrography was rasterized and the resulting grid was thinned to 1-cell wide using the shortest path algorithm to connect the cells associated to the springs to the cell of the basin's outlet. Next, the vertical profile of this raster hydrography was extracted from the depressionless DEM and then inverted. The cells associated with the springs were assigned

NODATA and a 1-cell buffer along all the hydrography received zero as elevation value. This raster was then filled to remove any spurious sinks which, in fact, promoted the removal of eventual spurious peaks along the stream network because of its inversion. The resulting hydrography profile was inverted again, bringing it back to the correct vertical position. The spring cells received their original elevation values and a large value (5,000m) was subtracted from all stream cells. The fill procedure was executed once more, this time getting rid of the spurious sinks. The maximum difference between these results and the previous stream profile, minus 0.5m, was calculated and added to all the stream cells, assuring that none of them would be higher than the bordering ones.

The DEM surface within a 5 cell buffer along each side of the hydrography was then replaced by ramps mathematically created between the borders of the buffer and the stream network's cells. The overlapping of some buffers occurred whenever the distance between any two streams was less then 10 cells. Such situations, not contemplated in the Hellwerger's method, are usually found in meandering rivers, leading to miscalculation of the elevation values for the associated ramps. To avoid this problem, it was necessary to identify the centerlines of the areas of superimposition, keeping their original elevation values.

Flow direction is vital for deriving subsequent hydrographic information about a surface and therefore, this dataset should be as accurate as possible given the input data. The derivation of the flow direction grid for the reconditioned DEM required three steps, each one for a different region: (1) for cells lying outside the buffer, the flow direction was derived using the depressionless DEM values converted to millimeters and then to integer, (2) for cells inside the buffer but not belonging to the hydrography, their flow directions were imposed towards the closest river cell using the CostBackLink command, and (3) for cells belonging to the stream network, their directions were forced to follow the shortest path to the basin's mouth, also using the CostBackLink command. This strategy was conceived to guarantee that the surface runoff within the buffer would converge to the stream cells and, once there, it would flow towards the outlet.

Analysis approach. Specific routines for automatically mapping each one the 7 subtypes of protected areas, as previously described, were developed using ModelBuilder.

1) On hill tops: the hills were isolated by inverting the reconditioned DEM. The cell associated with the peak of each hill was a sink and the basis of its hill was defined

by the boundary of respective watershed. The minimum and the maximum elevation values of each hill were calculated and the cells corresponding to its upper third were flagged as protected areas (**Figure 2**).

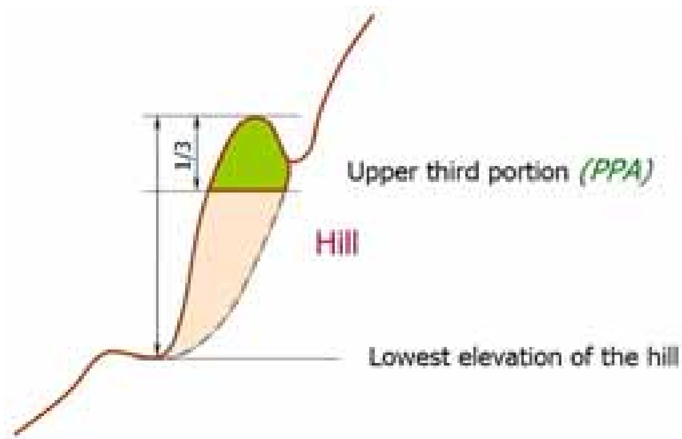


Figure 2. Delineation of Permanent Preservation Areas on hilltops.

2) Along divides: the areas to be protected encompass the upper third of the hillsides. In order to map them, for every cell in the landscape one needs to know what is the elevation of its closest cell to the divide (upper bound) and also what is the elevation of its closest cell to the hydrography (lower bound). These three cells must lie along the same flow path in order to find the relative vertical position of a given cell in respect to its base. Only after that it is possible to select the cells belonging to the hillside's upper third (**Figure 3**).

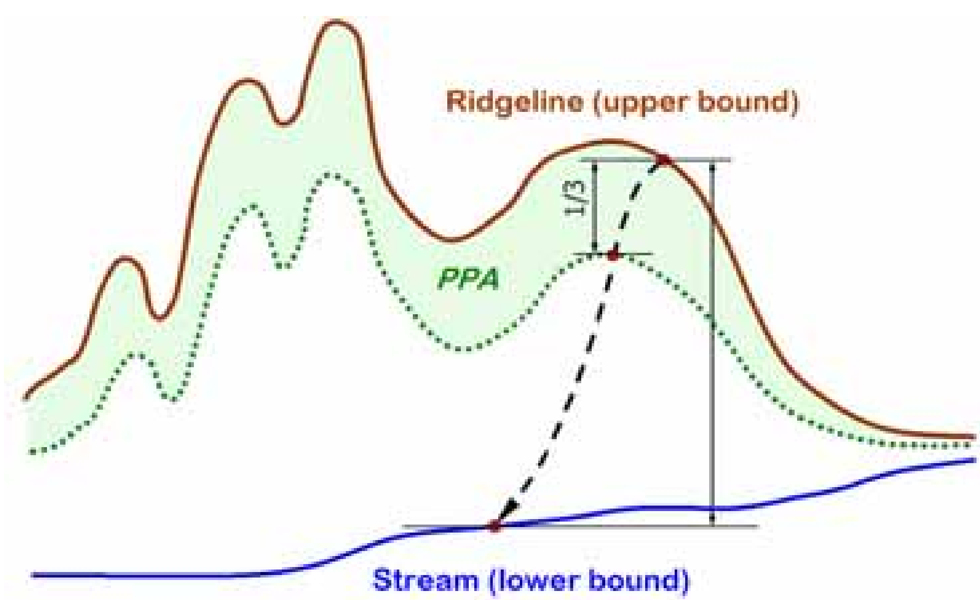


Figure 3. The upper third portion of a hillside.

3) On upland catchments: this category of permanent preservation area combines the area within a minimum radius of 50m of each spring with the respective contributing area (**Figure 4**). A grid containing only the cells associated to the springs was used as input to the WATERSHED command in order to derive the contributing area as well as to define a 50m-radius buffer around them.

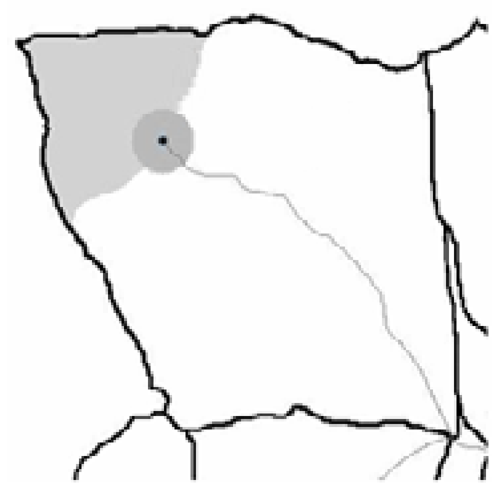


Figure 4. A 50m-buffer around a spring overlaid (dark gray) on its drainage area (gray) compose the area to be protected.

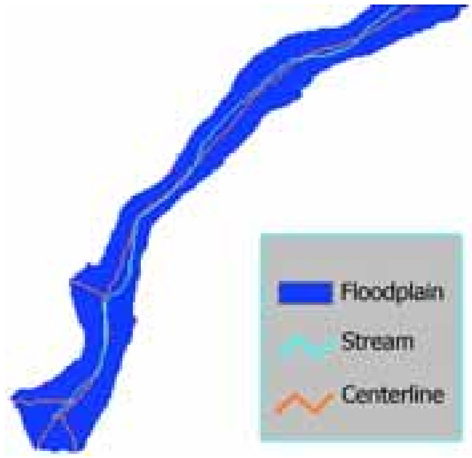
4) Bordering natural lakes and lagoons: the extent of the protection zone adjoining lakes and lagoons varies according to their area, being it 50m for areas up to 20 ha (200,000m^2) and 100m otherwise.

5) On riparian zones: the delineation of protected areas along streams relies on determining the width of the floodplains associated to their highest water levels reached at the peak of the raining season.

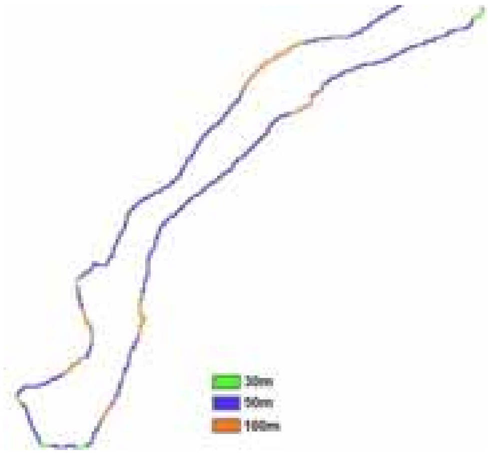
Table 1. Riparian zones' width according to the extent of the floodplain.

Floodplain's width [meters]	Riparian zone's width [meters]
< 10	30
10..50	50
50..200	100
200..600	200
> 600	500

The challenge of finding the floodplain's width lies in the delineation the centerline of the inundated area. Our approach can be summarize in the following steps: (1) identify the floodplain's extent either from radar imagery interpretation or by comparing the DEM surface elevations with simulated water levels from hydraulic models developed for the stream network under analysis, (2) identify the cells lying on the borders of the floodplain and convert them to a point dataset, (3) create a Thiessen polygon dataset for those points, (4) clip the Thiessen lines with the polygon portraying the floodplain extent, (5) remove the Thiessen lines touching the border of the floodplain polygon, to further reduce the amount of lines to work with, (6) manually select the centerlines and save them into a separate dataset (we suggest to use the shortest path algorithm to connect the initial segment to the final one of each major centerline to speed up this process, which tends to be very tedious and labor intensive), (7) rasterize the centerline dataset and generate an Euclidean-distance surface from these cells, (8) extract the distance of each borders' cell to the closest cell of the centerline and multiply the results by two, (9) reclassify the resulting grid using the ranges shown in Table 1, (10) convert those cells to a point dataset and create buffers for them according to the respective riparian width values, (11) rasterize the buffer polygon dataset and finally merge the resulting grid with the floodplain one in order to produce the map of the Permanent Preservation Areas. The main steps of this process are depicted on **Figure 5**.



(a)



(b)

(c)

Figure 5.(a) Comparison between the original stream location and the centerline derived for its floodplain, **(b)** buffer's width as a function of the floodplain's width, **(c)** outline of the riparian zones to be protected bordering the floodplains.

6) On steep slopes: any portion of the terrain whose slope is greater than 100%, which is equivalent to an angle of 45°, is protected under the Brazilian Forest Code. One must ensure that the Z units match the dataset coordinates in order to generate the correct results when applying the SLOPE command; if not, a proper Z factor must be applied.

7) On high elevations: any area situated at more than 1,800m above sea level constitutes a protected area.

Once derived, all seven categories of vegetation protection grids were mosaicked to produce the final map of the permanent protect areas for the Crepori river basin.

Results

Using a cell size of 30m, the rasterization of the Crepori stream network resulted in 2,911 stream links. The total length of the main river was equal to 438km. The original 1:250,000-scale vector hydrography dataset contained no lakes and, since the highest elevation within that watershed was 495m, there were no protected areas for their associated subtypes. The results of the delineation of the protected areas, performed for each one of the 2,911 corresponding catchments, are shown in **Table 2**.

Table 2. Permanent Preservation Areas for the Crepori river basin.

Category	Area [km^2]	Percentage of basin's area
Upland catchments	289	2%
Along ridgelines	2,273	17%
Riparian zones	3,060	23%
Hilltops	4	---
Steep slopes	1	---
Overall protection	**5,383**	**40%**

The overall protection value presented on **Table 2**, being lower than the total sum of all individual categories' values, indicates the occurrence of some overlapping.

Locations used for nesting or refuge by migratory birds and the habitats of endangered species should be added to the Permanent Preservation Areas. However, these sensitive areas cannot be automatically mapped, and are beyond the scope of the present study.

A map of extent of the overall protection provided by the Brazilian Forest Code for a small portion of the Crepori basin is illustrated in **Figure 6**.

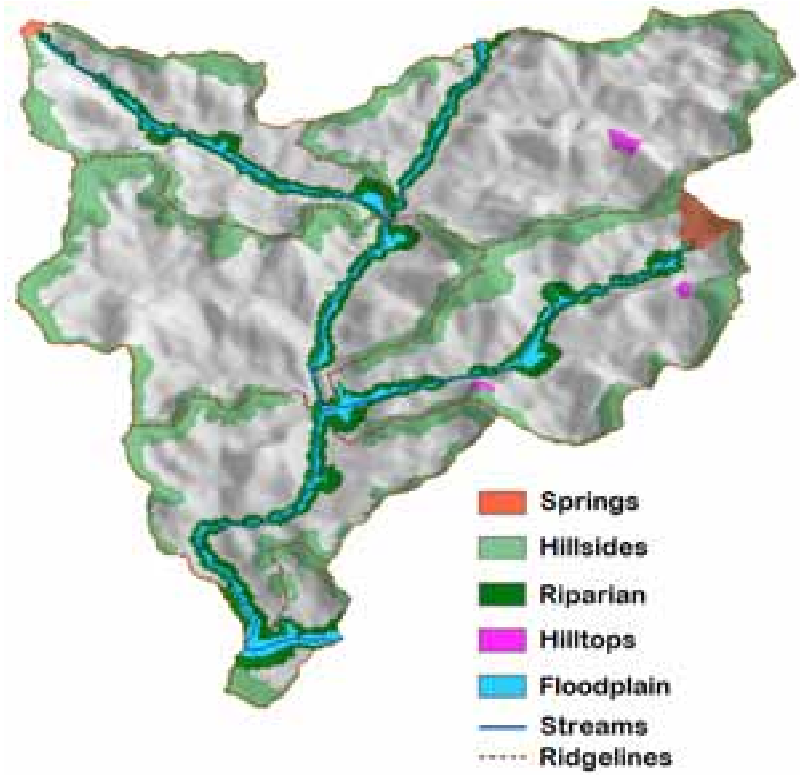


Figure 6. Spatial distribution of the Permanent Preservation Areas.

Conclusions

The results of the present study confirm that the Brazilian Forest Code creates an intriguing mosaic of environmental protection areas strategically distributed over different strata of the watershed toposequence. Contrary to popular belief, even for gently undulated landscapes, such as those of the Crepori river basin, the Permanent Preservation Areas would account for more than 1/3 of the watershed's total area.

Two categories of natural corridors emerge from the visual inspection of **Figure 6**: one formed along the catchments' divides, and another bordering the floodplains. Unsurprisingly, this figure also points out that the protection of hilltops (**Figure 2**) does create fragments in the landscape. The gaps observed on the corridors along ridgelines stem from defining hills as a *"land rise with base-top height between 50m and 300m, having hillsides with slopes of at least 30% along its steepest descent", according to the BFC.* So, hills lower than 50m in height, or even with heights up to 300m but having majority slopes lower than 30%, are exempt from having their upper third portion protected. In addition to fragmenting these corridors, this criterion also produces a major drawback in connectivity of the Permanent Preservation Areas as it impedes them from being naturally connected to riparian zones, a situation highly desirable from an ecological point of view (RYLANDS & BRANDON, 2005). Eventually these two classes of protected areas may coalesce on the upland catchments' protection zones but this is hardly a solution to this problem. Connecting the fragments of the Permanent Preservation Areas to neighboring corridors, may be a rationale for prioritizing the spatial allocation of Legal Reserves. This would produce a vast arrangement of ecological corridors, linking all biomes and effectively protecting their biodiversity.

Low levels of environmental compliance often result from inadequate law enforcement by governmental agencies or the lack of information available about protected areas (HIRAKURI, 2003; BENJAMIN, 1998). This means nothing less than illegal appropriation of public goods for the sole benefit of individuals or corporations. The methodology presented here provides a foundation for conducting a countrywide automated delineation of natural preservation areas, a *conditio sine-qua-non* for environmental compliance to the fullest extent of the law.

If any land use change of Permanent Preservation Areas is an environmental felony, so are the products originated from them. Allowing the trade of these goods is an unfair competition, representing an extreme case of governmental subsidy. Environmental barriers, one of the most important non-tariff mechanisms, along with chain-of-custody certificates, can be much more effective than the traditional practices adopted in international trade agreements to deal with this situation. Environmental law enforcement will dramatically reshape not only the Brazilian but also the global agribusiness market in coming years. Mapping land use conflicts is crucial for a robust assessment of the level of compliance with the Brazilian Forest Code, pointing out the economic vulnerability of the Brazilian agribusiness and ongoing forest certification initiatives.

When overlaid to current land use maps, the outcomes will provide distinct, measurable and perhaps more stifling, a visual representation of illegal clearing in Permanent Preservation Areas that was previously non-existent. The results from our study will offer ample information to government officials, illuminating the reality of political willingness to either enforce land use designations or cater to the illegal motivations of individual, government and corporate interests. That is where the truth lies...

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