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ANALYSIS OF THE ENVIRONMENTAL FUNCTION OF PERMANENT PRESERVATION AREAS IN ENTERPRISE ASSESSMENT

ANÁLISE DA FUNÇÃO AMBIENTAL DAS ÁREAS DE PRESERVAÇÃO PERMANENTE NA AVALIAÇÃO DE EMPREENDIMENTOS

Priscila Ikematsu

Researcher at Instituto de Pesquisas Tecnológicas (IPT) – São Paulo (SP), Brazil.

Omar Yazbek Bitar

Researcher at IPT – São Paulo (SP), Brazil.

Mariana Hortelani Carneseca Longo

Researcher at IPT – São Paulo (SP), Brazil.

Sofia Julia Alves Macedo Campos

Researcher at IPT – São Paulo (SP), Brazil.

André Luiz Ferreira

Technologist at Instituto Brasileiro de Geografia e Estatística (IBGE) – Rio de Janeiro (RJ), Brazil.

Correspondence address:
Priscila Ikematsu – Instituto de Pesquisas Tecnológicas (IPT) – Av. Prof. Almeida Prado, 532 – Cidade Universitária – CEP: 05508-901 – São Paulo (SP), Brazil – E-mail: priscilai@ipt.br

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ABSTRACT

The analysis of permanent preservation areas (PPAs) is an important step to design technological and locational alternatives for the environmental assessment of enterprises, as well as to support the issuance of environmental licenses. Thus, the aim of the current study is to present the method developed for the environmental assessment of ventures that have direct or indirect effects on PPAs and on their environmental functions. Five steps were proposed for this analysis: the conceptualization of PPAs based on a literature review; technical visit to the study site; analysis of the environmental functions of PPAs; PPA mapping; and evaluation of projects and future uses to be applied to the area. The herein proposed method was effective and efficient in the presented case studies, since it allowed recommending adjustments in the project presented by the entrepreneur and technically supported the selection of the best locational alternative by taking into consideration the environmental legislation requirements.

Keywords: permanent preservation area; environmental assessment; environmental legislation.

RESUMO

A análise de áreas de preservação permanente (APPs) é uma atividade importante na concepção de alternativas tecnológicas e locacionais durante a avaliação ambiental de empreendimentos, bem como para apoiar a emissão de licenças ambientais. Nesse contexto, este trabalho objetivou apresentar o método desenvolvido para avaliação ambiental de empreendimentos com influência direta ou indireta em APP e em suas funções ambientais. Cinco etapas são propostas para essa análise: a conceituação da feição protegida na forma de APP por meio de revisão bibliográfica; visita técnica à área de estudo; análise das funções ambientais de APP presentes; representação cartográfica da APP; e avaliação dos projetos e os usos propostos na área. O método aqui proposto se mostrou válido e eficiente nos estudos de caso apresentados, pois permitiu recomendar ajustes no projeto elaborado pelo empreendedor e subsidiou tecnicamente a definição da alternativa locacional mais viável frente às exigências da legislação ambiental.

Palavras-chave: área de preservação permanente; avaliação ambiental; legislação ambiental.

INTRODUCTION

Brazil has a complex institutional system focused on managing the environment; this system derives from a long discussion process involving different social, political and economic contexts (ALCÂNTARA, 2019). Incorporating environmental feasibility into decision-making processes is a major challenge for planners, as well as for public and private managers, since it means indicating the best technological and locational alternatives for a given work or activity by taking into consideration environmental impacts associated with environment's carrying capacity (SÁNCHEZ, 2006; MONTAÑO; SOUZA, 2008).

Environmental licensing and environmental impact assessment are instruments provided by the National Environmental Policy (Federal Law No. 6.938/1981). Environmental licensing is the administrative process that formalizes environmental control conditions and measures to be respected by entrepreneurs in order to enable the environmental adequacy of activities or ventures. Environmental impact assessment refers to the systematic analysis of environmental impacts deriving from a proposed action (policy, plan, program or project) and of its alternatives. The Public Power is in charge of analyzing the feasibility of venture and activity projects based on environmental resource use, since these projects can be effectively or potentially polluting or even capable of causing environmental degradation (BRASIL, 1981; SÁNCHEZ, 2006; MONTAÑO; SOUZA, 2008; AGRA FILHO *et al*., 2012).

Several normative measures must be taken into consideration at the time to issue environmental licenses. Among them, it is worth emphasizing the Forest Code — Federal Law No. 12.651/2012 (BRASIL, 2012) — , which defines the concept of Permanent Preservation Area (PPA). According to article 3 in this Law, PPAs are protected areas that have the environmental function of "preserving water resources, landscape, geological stability and biodiversity, enabling fauna and flora gene flow, protecting the soil and assuring the well-being of human populations" (BRASIL, 2012). Each PPA category defined in this law has a protection range whose specific restrictions are adopted.

The legal framework supporting PPA protection derived from great concern with areas acknowledged as important sources of environmental goods and services seen as essential to human survival (BORGES *et al*., 2011). During the environmental assessment of projects, the incidence of this type of specially protected area tends to influence project design, technological and locational alternatives, as well as the issuance of authorizations and licenses provided by the Brazilian legislation. It happens because anthropic interventions leading to changes in PPAs' environmental functions are not allowed in urban or rural areas, no matter the existence, or not, of vegetation cover in these environments (BORGES *et al*., 2011; BRASIL, 2012; IKEMATSU *et al*., 2016a). Exceptional cases are explained in article 8 of Federal Law No. 12.651/2012: interventions in APPs are allowed in cases of public utility, social interest and low environmental impact, provided that the inexistence of a technical and locational alternative is proved (BRASIL, 2012).

Therefore, the prohibition on removing the vegetation and on installing any form of use and occupation in APPs implies the analysis of environmental impacts caused by a given project and its alternatives; this process must comprise mapping protected features and analyzing their environmental functions. However, these procedures depend on definitions set in the Forest Code, which are, in some cases, susceptible to questioning due to poor clarity and concept generalization issues; besides, they are not easy to be applied under field conditions. In addition, the definition of the environmental functions and the protection range of each PPA is set by general rules, regardless of elements such as biome, aspects of the physical environment, specific features of watercourses, climate conditions specific to each microbasin, as well as local and regional contexts (IKEMATSU et al., 2016a).

The environmental functions justifying the existence of a given PPA can transcend the length defined in the existing laws because they are part of a system composed of several interdependencies. According to Metzger (2010), the effectiveness of these protection areas depends on several factors such as the ecosystem service type taken into consideration and the width of the preserved vegetation. Thus, the consequences of land use in PPA must be analyzed by having in mind not only the area protected by normative instruments but also the dynamic system that sometimes can hinder quantitative predictions. Lack of consensus about the geographic interpretation of environmental legislations can be a significant obstacle to the maintenance of different ecosystems and their PPAs. Therefore, the ability to properly identify areas where the Forest Code is applicable to and, consequently, areas where it is ignored or disrespected is a necessary precondition to assure compliance with regulations, as well as to support decision-making processes and policies focused on future land use (DITT *et al*., 2008; METZGER, 2010).

Despite these statements, feasibility studies focused on projects based on the analysis of the environmental functions of PPAs remain scarce in the literature. In light of the foregoing, the aim of the present study was to fill this gap by presenting the method developed to enable the environmental assessment of ventures that have direct or indirect influence on PPAs and on their environmental functions (general and specific).

ENVIRONMENTAL FUNCTION OF PERMANENT PRESERVATION AREAS

Environmental functions are associated with the role played by PPAs in maintaining ecological balance and in the natural dynamics of evolutionary processes. Thus, they play an important role in assuring the correct indication of restrictions or permissions to use protected areas. They also work as an important ground to assure more effective and protective ecosystem services in areas with significant environmental attributes. In addition, environmental functions are relevant in terms of internalizing environmental relevance in the set of rights and duties pertaining to intersections between property rights and environmental protection (CARVALHO, 2018). Table 1 presents different PPA categories and their respective delimitation criteria, based on the Brazilian Forest Code.

It is essential understanding the environmental functions of each PPA category in order to provide criteria and information that can be used to support decision-making processes in a given venture based on nature conservation. Thus, a brief discussion about PPA functions is herein presented, both the ones explained in article 3 of Federal Law No. 12.651/2012 (BRASIL, 2012) — herein called general environmental functions — and specific environmental functions directly linked to the evolution of environmental phenomena to be observed at the time to implement or expand a given venture (IKEMATSU *et al*., 2016a).

The general environmental function — “preserving water resources” — unfolds into several specific functions. The following specific environmental functions can be observed in areas located on the banks of rivers and watercourses: receiving and containing sediments from across the basin, mitigating sedimentation in the riverbed and the risks of silting up the watercourse; retaining water in the microbasin; protecting the banks and promoting stability in the edges of the watercourse; assuring natural fluctuation of water levels in periods of intense rainfall and heavy water discharge; and protecting and conserving biodiversity and the associated genetic heritage. These functions directly depend on features of the physical environment where the hydrographic basin is located in, on the incidence of vegetation, on climate and on triggering conditions that generate stress conditions or change materials’ resistance, such as intense rainfall or land use and occupation processes (MELLO, 2005).

The conditions of areas surrounding springs and of their contribution basin are strongly associated with the maintenance of the recharge area, base flow and river flow; with the survival of water sources, mainly in times of rainfall shortage; with freshwater storage with protection against losses due to evaporation; and with the preservation of water quality. It happens because these areas work as natural filter. Thus, interventions made in infiltration and percolation processes tend to change groundwater flow patterns and, consequently, they lead to exfiltration in discharge zones with low water potential. Direct interventions such as groundwater abstraction, or indirect interventions such as recharge area waterproofing in aquifers, change the water volume in water tables and affect water flow produced by springs; consequently, they change the flow of watercourses. In addition, it is worth mentioning the environmental function associated with the contributing hydrographic basin of each spring, since water production and spring features result from processes taking place throughout the contribution area, rather than just in the surrounding area of the spring, a fact that should also be taken into consideration in the process of environmentally assessing these features (IKEMATSU *et al*., 2016b).

Natural lakes and ponds, as well as artificial reservoirs, have the environmental function of storing and retaining water; this function can be associated with different uses (human supply, irrigation, recreation, flood control, transport and navigation, nutrient balance, power generation, among others). In addition,

Table 1 – Permanent preservation areas (PPA) delimitation criteria.

PPA category to be protected	PPA delimitation criterion	PPA range
Peripheral range of watercourse	River width < 10 m	30 m
	River width ranges from 10 to 50 m	50 m
	River width ranges from 50 to 200 m	100 m
	River width ranges from 200 to 600 m	200 m
	River width > 600 m	500 m
Spring/ water source	Classification as spring or perennial water source	50-m radius around the spring
Natural lake and pond	Rural location	100 m
	Rural location with up to 20 ha	50 m
	Urban location	30 m
Artificial reservoir	Range defined in ventures' environmental license.	
Hillside	Areas presenting slope > 45º at the highest slope line	
Hilltop	Areas delimited based on contour line corresponding to 2/3 (two thirds) of the minimum hill height, always in comparison to the base, which is defined as the horizontal plane determined by the adjacent plain or water mirror, or to wavy reliefs, based on the height of the saddle point closest to the elevation in the hills (geomorphological features with minimum height 100 m and mean slope greater than 25º).	2/3 (two thirds) of the minimum hill height, always in comparison to the base
Restinga	Featuring the sandy deposit parallel to the coastline, which has overall elongated shape and is generated by sedimentation processes. This environment hosts different communities presenting marine influence, mosaic-shaped vegetal cover, as well as herbaceous, shrubby and arboreal (the most internalized one) strata depending on the successional stage; being dune fixer or mangrove stabilizer.	The entire *restinga* length
Mangrove	Featuring the coastal ecosystem observed in lowlands susceptible to the action of tides. This ecosystem is formed by recent mud or sand flats, which are mainly associated with the natural vegetation known as mangrove. This vegetation is susceptible to fluvial marine influence, it is typical of muddy soils in estuarine regions and presents discontinuous distribution along the Brazilian coast.	The entire mangrove length
Plateau or mountain range	Strip in horizontal projections measured from the edge of the plateaus and mountain range up to the rupture line of the relief.	Range of at least 100 m
Altitude	Altitude above 1,800 m, regardless of the vegetation.	Range greater than 1,800 m
Vereda	Marginal strip in horizontal projection from the permanently swampy and soaked space.	Range of at least 50 m

Source: based on Brasil (2012).

waterbodies present relevant scenic beauty and host several fauna and flora species. One of the main attractions for tourists looking for fun and relaxation lies on water reserves, whether they are natural or artificial, since these places enable activities focused on promoting health and leisure (sport and recreation), scientific research, education (knowledge about the environment and nature), visual appreciation of its intrinsic beauty, as well as artistic inspiration (FERREIRA; LOPES; ARAÚJO, 2012).

Hillside PPAs stand out for their geological stability function, since these areas are featured by high declivity (equal to, or greater than, 45º) where the weathering mantle, which is not very resistant, presents several planes of possible ruptures (landslide). The steep slope influences the intensity of action by natural erosive agents; consequently, it influences the intensity of surface geodynamic processes of slope retreat (CARVALHO *et al*., 2001). It is worth mentioning the special soil protection role played by vegetation in controlling rainfall-associated erosion in steep declivity areas. Water interception by plant leaves, physical water containment by the root system, sediment filtration, decrease in runoff speed, as well as maintenance of soil porosity and permeability (ARAÚJO; ALMEIDA; GUERRA, 2007), are examples of specific environmental functions associated with hillside PPAs.

Hilltops have the important function of maintaining and regulating the hydrological cycle within hydrographic basins as a whole; they can influence processes such as water infiltration, percolation and runoff. Increased vertical infiltration at hilltops decreases water runoff downstream slopes and increases the geological stability and recharge of aquifers giving rise to perennial or intermittent springs (IPT, 2015).

Restingas' formation process is originally associated with accumulation and deposition of sandy sediments transported by sea water in coastal environments, as well as with their positioning, since they work as barriers to the erosive action of waves; however, their environmental function tends to change over time. It gradually changes from the initial sediment retention phases to favorable conditions to consolidate deposits. Later, these deposits tend to stabilize and incorporate themselves into the coastal landscape due to the establishment of plant and fauna species. Deposits experiencing ecological wholeness tend to make accumulated sediments unavailable by retaining them in their structure and preventing their removal by current and predominantly natural processes. The eventual suppression of the vegetation covering sandy deposits affects the habitat of different species and tends to expose sediments to the erosive action of rainwater and winds, as well as to the impact of waves in open sea or even in lagoons and wide bars, which removes these materials and transport them to other areas. Therefore, it can lead to instability in erosion and sedimentation dynamics, and to accelerated loss of material in one stretch to be accumulated in another location, which can even affect human settlements (IPT, 2008).

Mangroves have purifying action, i.e., they work as biological filters. Aerobic and anaerobic bacteria interact with organic matter and mud in order to fixate and inert contaminating particles (ALVES, 2001). The spatial effect of mangrove's vegetation cover along the coastal zone allows immobilizing heavy metals in plants and in the soil before they reach nearby aquatic ecosystems; thus, this vegetation cover works as a biogeochemical barrier (OLIVEIRA, 2009). Trunks and roots, including pneumatophores, can influence water circulation and lead to the deposition and accumulation of sediments and particulate organic matter (LOVELOCK; ELLISON, 2007 *apud* LIMA; TOGNELLA, 2012). Typical mangrove trees stabilize sediments between their roots and trunks, as well as work as wind barriers to mitigate the effects of storms in coastal areas; besides, they slow down the energy of wave and tidal oscillations capable of resuspending sediments in shallow coastal areas. Thus, they tend to improve the quality of estuarine and coastal waters, since they assure nutrient supply and immobilization in the soil and, at the same time, protect the coastline (SCHAEFFER-NOVELLI *et al*., 2012).

Mangrove structure also acts as a biostabilization unit that helps better conserving the coastal landscape, as protection against flooding by attenuating its energy and the advance of tides, as well as sediment deposit in fluvial marine plains (CAVALCANTI, 2004). Due to the great variety of ecological niches, which results in diversified fauna, and given the incidence of endemic species (visitors or migratory) in this environment, mangroves act as important biological diversity maintainers (ALVES, 2001). In addition, mangroves are essential to the development of socioeconomic activities associated with artisanal fishing and with the sustainable exploitation of coastal renewable resources, which attract human populations that settle in the surrounding areas. Riverside communities are highly dependent on resources provided by mangroves, whose survival depends on the exploitation of the benthic macrofauna as source of food and income, wood extraction, medicines, alcohol, oils and tannins, ecological tourism, navigation and environmental education in this ecosystem (LAMPARELLI, 1998; SEMACE, 2006).

Plateaus and mountain ranges do little to promote surface water flow and allow greater water movement towards the subsurface in order to supply water tables and springs (BORGES, 2008; CPRM, 2013). According to Resende *et al*. (1995), instability in the edges of plateaus and mountain ranges is associated with low soil pedogenesis and erosion ratio. Thus, gravitational movements of mass, rock and falling blocks are the main processes linked to the natural dynamics of plateaus and mountain ranges. In addition, the edges, escarpments, foothill and plateau of flat-topped reliefs covered with vegetation form ecological corridors for fauna and flora, assure the continuous circulation of gene flow from the top to the base and along the plateau, promote ecological connectivity in the landscape and, consequently, help preserving biodiversity. Finally, it is worth mentioning the heterogeneity of habitats that the environment in the edges of plateaus and mountain ranges can provide to regional fauna and flora. This environment is particularly important for some plant species that preferentially colonize these rocky habitats, since they are capable to adapt to water shortage and to poorly developed substrates (POREMBSKI *et al*., 1998). In addition, some fauna species prefer this environment at the time to build their nests and take shelter, like swallows and birds of prey.

Veredas are swampy or wet places presenting hydromorphic soils and typical vegetation (BRASIL, 2012); they are important to local populations due to perennial water availability in regions where this resource is significantly scarce, such as central Brazil. They also play a fundamental role in biodiversity, since they host several Cerrado flora and fauna species; they are true ecological corridors capable of interconnecting Cerrado fragments in order to enable matter and gene flow (GUIMARÃES, 2012).

It is essential maintaining the environmental function of PPAs in order to assure balance in processes associated with them and to prevent the incidence of events capable of affecting the well-being of human populations and ecosystems. Anthropic interventions can lead to changes in environmental processes and, consequently, in the herein addressed environmental functions. Thus, it is important analyzing these interventions at the time to set guidelines to implement projects and to map the area to be protected. Table 2 presents environmental functions (general and specific) that can be taken into consideration in the environmental assessment of projects that can affect PPAs.

MATERIALS AND METHODS

The complexity of the topic at hand, in association with its interdisciplinary nature, indicates the need of combining different methodological approaches capable of completing each other to enable more robust analyses and incisive inferences to help better understanding the cases to be analyzed. Thus, the present study has followed an exploratory methodological approach based on bibliographic research; a quantitative approach based on mappings and on the use of indicators; and a descriptive approach based on case studies (MINAYO, 2000; CRESWELL, 2010). Figure 1 depicts the steps proposed for the evaluation of projects with influence on PPAs and on their environmental functions (general and specific).

The first step of the proposed method lies on the conceptual analysis of the protected feature in the form of PPA, not only within the legal scope, but also according to the available technical-scientific literature. This step is important, since PPA delimitation resulting from direct legislation application is not an easily executable task due to a whole variety of possible interpretations about its meaning, which can lead to different and contradictory results. It is important properly understanding the concepts involved in PPA delimitation to avoid mistakes at the time to apply guidelines deriving from legal documents. Thus, it is necessary searching for reference studies on the WEB and in libraries, based on previously defined keywords, as well as reading

Table 2 – General environmental functions and examples of specific environmental functions of permanent preservation areas (PPA).

General environmental function (Forest Code)	Main specific environmental functions	PPA								
		Water-course range	Spring	Natural lake/ pond/ Reservoir	Hillside	Hilltop	*Restinga*	Mangrove	Plateau and mountain range	*Vereda*
Preserving water resources	Maintaining water flow	X	X	X		X			X	X
	Preserving the natural quality of water	X	X					X	X	X
	Maintaining the recharge area		X			X			X	X
	Assuring the natural fluctuation of water levels	X								
	Acting as natural biological filter of organic matter and enabling heavy metal retention	X						X		X
Preserving the landscape	Maintaining landscape structure and dynamics	X			X			X	X	
	Acting as a mechanical barrier against the erosive action of waves and tides							X		
	Ornamental and landscape effect			X	X			X	X	
Preserving biodiversity; enabling fauna and flora gene flow	Providing fauna feeding and sheltering conditions	X		X		X	X	X	X	X
	Forming and maintaining ecological corridors	X			X	X		X	X	X
	Preserving the genetic heritage of typical hillside fauna and flora				X	X			X	
	Providing habitat for resident migratory species				X			X	X	
Preserving geological stability; protecting the soil	Providing protection against erosion and sedimentation processes	X			X					
	Stabilizing hillsides				X				X	
	Protecting mangrove-adjacent lands from coastal processes							X		
	Water retention (reducing defluvium)	X					X			
	Retaining fine sediments from upstream erosion processes	X			X		X	X	X	
Assuring the well-being of human populations	Providing environmental services (provision, regulation, cultural and support)	X	X	X	X	X	X	X	X	X

technical documents made available by companies, such as environmental impact studies, environmental control plans, specific projects already in place, among others. It is done to identify multiple components, processes and interactions that can be established within the scope of ecosystems, which are likely influenced by the expansion of activities implemented by companies in PPAs. Furthermore, the regional context of PPA is also essential to better understand the physical, biotic and anthropic situation of the venture.

The second step comprises the technical visit to the study site, which must be carried out to enable field recognition of areas to be evaluated as to the presence of environmental functions; this step must cover initial data collection, mapping validation and photographic record procedures.

The third step includes the analysis of the environmental functions of the PPA identified in each case, since the application of Law postulates depends on the clarity about the ecological role played by them, which will be safeguarded by regulatory actions or changed by the intervention in the PPA. The Forest Code only indicates general environmental functions, which are explained in the definition of PPA set in its article 3. Specific environmental functions can be defined given the peculiarity of each case, since such functions are susceptible to periodic measurement and more directly linked to the evolutionary analysis of the environmental phenomena to be observed. The assessment of environmental functions (general and specific), based on the literature about the topic and on the environmental legislation, takes into consideration the interaction among physical environment (geology, geomorphology, geotechnics, hydrology, hydrogeology and surface dynamics processes), biotic (fauna and flora) and anthropic (land use and legislation) aspects.

The fourth step encompasses the cartographic representation of the PPA, which is carried out based on mathematical functions available in the Geographic Information System (GIS) software, on remote sensing and on field work. This procedure is essential to spatially indicate the location of conflicts between intended uses and incident rules. It is important associating GIS techniques and on-site surveys, since PPA demarcation,

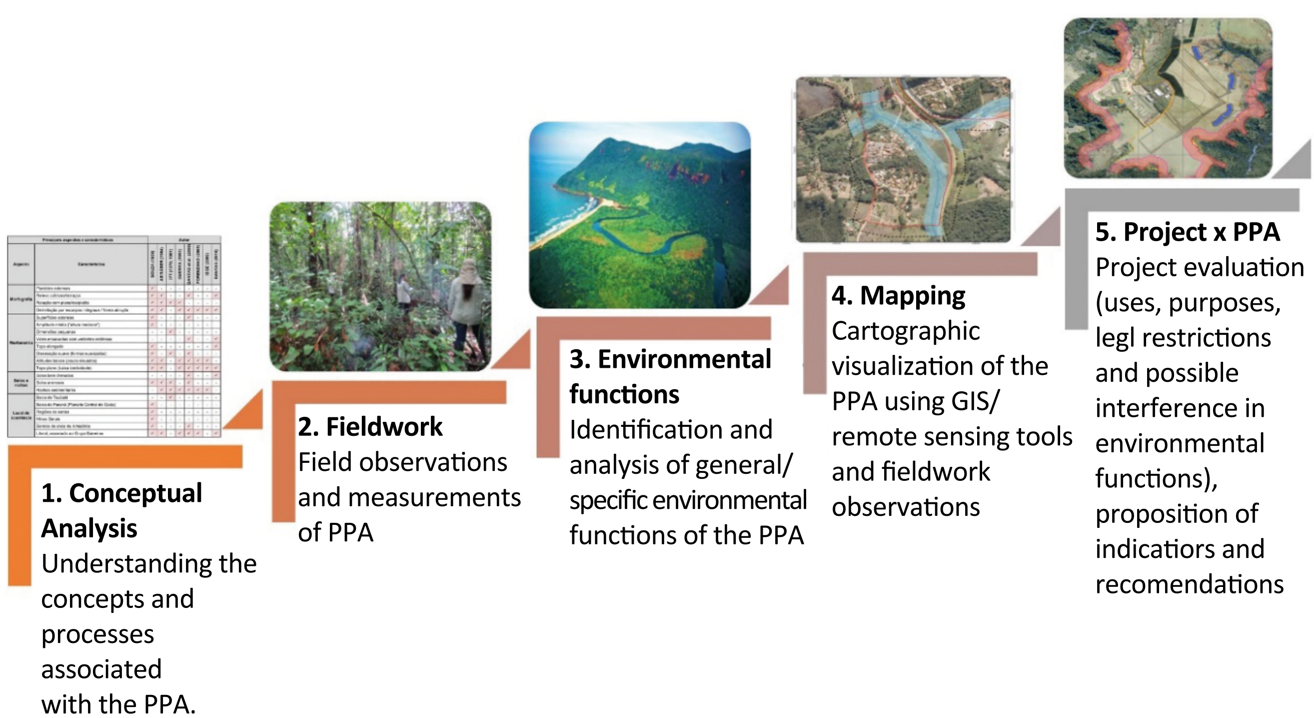

Figure 1 – Steps of the analysis of permanent preservation areas (PPA) environmental functions in the evaluation of projects.

strictly in the field, is conditioned by a series of factors such as access to the area of interest, time of year (dry or rainy), specific instruments (GPS, altimeter, clinometer, topographic maps), study execution time, among others. These factors can make it hard, or even impossible, to recognize the existence, or not, of a given PPA within the desired period, mainly when the study involves large-scale projects.

Finally, the fifth and last step lies on the evaluation of the proposed projects and uses of the area based on legal restrictions and on likely interference in its environmental functions (general and specific). In addition, the influence of anthropic actions on processes associated with the natural dynamics of the environment is addressed, recommendations are made by taking into consideration the compliance with the legislation, the importance of the identified environmental functions and the possible direct and indirect changes that may take place in the region affected by the venture.

RESULTS AND DISCUSSION

Two cases will be used to exemplify the application of the methodology in the evaluation of projects capable of interfering in PPAs and in their environmental functions. Aspects linked to the conceptualization, environmental functions, cartographic representation and environmental assessment process of the venture will be addressed in each case.

The first case analyzed the expansion of activities performed by a company specialized in building agricultural machinery, whose land was in a region presenting flat-topped relief, i.e., with possible influence on PPA in the edges of plateaus and mountain ranges. It was selected to exemplify how the proposed method can contribute to the analysis of project insertion in PPA.

The second case refers to studies carried out in order to expand the waste disposal area in a primary aluminum and alumina production company, which may have effects on the environmental functions of a spring PPA. The method of choice in this study was applied to help selecting the best location alternative for the project.

Permanent preservation areas in the edges of plateaus or mountain ranges

The case study focused on evaluating the project's influence on PPAs in plateaus or mountain ranges consisted of an area designed to expand the activities of an agricultural machinery company in Central-West São Paulo State. The land to be occupied by the new facilities corresponds to a section of the watershed divider of Aguapeí and Peixe rivers; based on the geological-geomorphological perspective, it is regionally located in Paraná Sedimentary Basin and in the morphosculpture of Planalto Ocidental Paulista (São Paulo Western Plateau), more precisely in Marília Residual Plateau (Planalto Residual de Marília), which is featured by the presence of a typical flat-topped relief. Federal Law No. 12.651/2012 (BRASIL, 2012) establishes that PPAs in the edges of plateaus or mountain ranges correspond to a range never smaller than 100 m in horizontal projections up to the rupture line of the relief.

The application of Step 1 of the proposed methodology has indicated that terms such as "plateaus" and "mountain ranges" are similar to terms such as "mesa", "high plain", "ridges" and "*chapadões*". All these terms are used to represent different geoforms of flat-topped relief, although they present some divergences in delimitation criteria. Definitions of these terms, which were presented by different authors (SOUZA, 1939; AB'SÁBER, 1964; IPT, 1981; GUERRA, 1993; FLORENZANO, 2008; IBGE, 2009; DANTAS, 2010), as well as in normative documents (BRASIL, 2002; 2012), have shown that:

- the concept of plateau is overall associated with tablelands and high plateaus;
- plateau tops present smooth dissection and low slope;
- plateaus are described as a hillock relief;
- they are delimited by high and straight slopes in escarpments or steps;
- they present sedimentary rocks and sandy soils;
- plateaus are located at lower altitudes when compared to mountain ranges.

On the other hand, based on the literature (HARTT, 1870; SOUZA, 1939; AB'SÁBER, 1956; GUERRA, 1993; IPT, 1981; CASSETI, [2005]; FLORENZANO, 2008; IBGE, 2009; DANTAS, 2010; BRASIL, 2002; 2012; MARTINS; SALGADO, 2016), the term "mountain range" is overall associated with tablelands and high plateaus, presents sedimentary rocks and horizontal structure, it is abruptly individualized by its high and straight slopes in escarpments or steps, and has low slope at the top. Martins and Salgado (2016, p. 174) have also emphasized that "the name given to this relief results from the process, rather than from its shape", i.e., it is intrinsically linked to the physical and chemical processes marking its evolution. Thus, according to the aforementioned authors, differentiating flat-topped reliefs is a hard task, mainly in the case of plateaus, which present similar evolution linked to the lateral retraction of the slopes.

Features described in the definition of flat-topped reliefs were observed in the study site during the field visit (Step 2). These reliefs presented flat and extensive tops, altitude of approximately 200 m in comparison to the surrounding hills and integrated the surface of Marília Residual Plateau. This configuration was visible on the slopes located to the West, South and Southeast of the venture, where erosive scarps imposed themselves against the broad hills of the lower surface and left typical colluvial deposits in their foothills. Aerial images collected by an unmanned aerial vehicle (UAV) model Phantom 3, equipped with a 4k camera, helped analyzing specific aspects and allowed having regional view of the area to be mapped. The hillsides of the rugged areas located to the Southeast and West of the venture plots presented accelerated dynamics in the lateral retraction of the slopes and favored the notching of drainages in areas located on the opposite side, where linear erosive processes prevail. Such retraction left scars from a recent sliding event on these slopes. Despite being less slopped, since they rarely reach 45° inclination, these hillsides are featured as a sector with high potential to present further escarpments resulting from headward erosion in that section.

According to Step 3, the environmental functions of these geoforms were evaluated in the regional context of the study site, since they are intrinsically linked to its structural configuration. Plateaus and mountain ranges are arranged on horizontal structure lithologies, mainly on the ones of sedimentary origin, which resemble tablelands or elevated surfaces dissected in a hillock relief. Overall, they are composed of flattened and elongated tops of low slope and steep at the edges (straight and sloping sides). They occupy extensive surfaces with medium and low topographic altitude, and they are featured by the presence of sandy, well-drained soils. Thus, their environmental functions lie on maintaining water flow, preserving the natural quality of water, maintaining the recharge area, well as the structure and dynamics of the landscape, stabilizing slopes, ornamental and landscape effects, providing fauna feeding and sheltering conditions, forming and maintaining ecological corridors, among others, as shown in Table 2.

Based on Step 4, plateaus had their extension mapped based on dictates of the Forest Code, on the concept outlined in Step 1 and on information collected in the field visit in Step 2. The cartographic procedure carried out to enable PPA delimitation consisted of the spatialization of a 100-m section from the previously defined rupture line — it was performed with the aid of the buffer tool available in ArcGIS 10.5. The tracing of the rupture line (polyline vector file) characterizing the feature to be protected and determining the lower limit of the PPA in the edges of plateaus or mountain ranges was defined based on planialtimetric survey conducted in the venture area, satellite and radar images, digital orthophotos, topographic sheets, hydrographic network and information collected in the field. The context of the flat-topped reliefs in the study site was assessed based on pre-existing geomorphological maps, which worked as a starting point for further adjustments in the project scale.

Figure 2 shows the approximate delimitation of the rupture line (continuous, red) from where the PPA strip (100-m buffer) is drawn, which presents land use restrictions. Based on the environmental functions of plateaus and mountain ranges identified in Step 3, the erosive escarpment advancement sector (orange dashed line) was included in the final mapping due to its relevance to the planning of future intended uses in the venture area.

The analysis of the project to expand the venture in the mapped PPAs was conducted in the last step. It indicated that the area selected for earthworks (cut/fill) in the project presented by the company did not advance within the limits of the PPA in the edges of plateaus and mountain ranges, if one takes into consideration the locally delimited rupture line. However, there were pre-existing wells in the Northwest section of the venture in the area where the delimited PPA is located in; some of them were very close to the relief rupture line. Another aspect highlighted in the analysis refers to the proximity of the structures designed to temporary accumulate rainwater and to regulate the outflow (detention reservoirs) close to the sector with high potential to present advancement of escarpments. It was possible noticing that two projected structures were outside the PPA in the edges of plateaus and mountain ranges, but they were in an area that requires attention to be given to evolutionary processes of headward erosion advancement in that section. In addition, designed energy dissipators could also have influence on the natural dynamics of physical and biotic components.

In view of the systematized elements, besides the delimitation of local rupture and correlated PPA, it was possible pointing out areas more susceptible to physical environment processes due to escarpment erosion advancement and to the nature of the soil and rocky substrate (sandstone). It was recommended avoiding interventions in these regions — although they did not configure PPAs in the edges of plateaus and mountain ranges, as defined in the legislation — by taking into consideration the environmental fragility intrinsic to the nature of the soil and rocky substrate and the environmental functions of these areas.

Spring permanent preservation area

The analyzed venture and its influence on the spring PPA consisted of expanding a given area for bauxite waste disposal, which could be carried out in two alternative locations. The first alternative, called Scenario 1, kept the PPA preserved, but it required a larger area to store the waste. Scenario 2, on the other hand, had direct influence on the spring and on its respective PPA due to the construction of the disposal area. Scenario

Source: IPT (2016).

Figure 2 – Approximate delimitation of the rupture line (red continuous line) and of the erosive escarpment advancement sector (orange dashed line) in an image captured with UAV model Phantom 3. Note the sliding scars marking the advancement of escarpments due to lateral retraction.

0 was also taken into consideration; it represented the current situation without the project's interference and it was used as a reference parameter for the analysis of environmental functions, since virtually all the future interference area in this configuration was covered with native vegetation. According to Federal Law N. 12.651/2012, the source or "the natural outcrop of the perennial water table that starts a watercourse" (article 2) must be protected at minimum range of 50 m from the water emergence point (BRASIL, 2012).

The analysis carried out in the first step of the proposed methodology has indicated that, despite the notorious environmental importance of springs in geoenvironmental research, studies about them remain scarce; they are mostly focused on making superficial physiological and hydrological descriptions. Theoretical studies specifically focused on springs are rare, a fact that leaves some gaps in the definition of their concept (FELIPPE; MAGALHÃES JÚNIOR, 2013) and reflects on the adopted cartographic procedures. According to the technical-scientific literature (GUERRA, 1993; CUSTÓDIO; LLAMAS, 1996; CALHEIROS et al., 2004; VALENTE; GOMES, 2005; GOMES; MELO; VALE, 2005; SANTOS, 2009; PEREIRA et al., 2011; UNESCO, 2012; BRASIL, 2002; 2012; MAGALHÃES et al., 2012; FELIPPE; MAGALHÃES JÚNIOR, 2013), the incidence of springs is overall associated with:

- groundwater outcrop, either punctual or in zones;
- watercourse origin;
- natural occurrence;
- headland regions;
- surface/groundwater integration.

The concept of spring is approached in different ways, without defined uniformity, since it involves significant environmental complexity. Carmo, Felippe and Magalhães Junior (2014) have emphasized that spring diagnosis must include the geomorphological set of spring and drainage network conformation, exfiltration type (punctual, diffuse or multiple springs), mobility of the emergence place (fixed or mobile springs) and seasonality (perennial, intermittent or ephemeral springs), among other parameters, due to the great heterogeneity of springs. Other elements mentioned in the literature comprise topographic conditions, geological and hydrogeological context (PEREIRA *et al*., 2011; SANTOS, 2009), hygrophilous vegetation incidence areas (CARVALHO; RIOS; SANTOS, 2013) and hydromorphism in soils involving the springs (MAGALHÃES *et al*., 2012).

Field visits made in Step 2 allowed seeing that the expansion project takes place on land with incidence of spring, whose area is distributed over an extensive surface and forms a swamp without free-water surface; some water emergence points form igarapés (watercourses). It was also possible seeing relevant biodiversity, the presence of natural and recovered vegetation cover and watercourses, as well as that the site is an aquifer recharge area.

Environmental functions were analyzed in the third step of the proposed method and correlated to indicators in order to compare changes resulting from the venture in each of the two scenarios presented by the company (Scenario 1 — without interference in spring PPA; and Scenario 2 — with direct intervention in PPA). The selection of indicators was based on the legislation at federal, state and local levels, on specific environmental functions defined in this assessment, on elements that were not addressed in the pre-existing studies made available by the company and on the likely constructive evolution of the work in the territory and in the environmental system (natural and anthropic). The concept of environmental indicator is the integrated representation of a certain set of data, information and knowledge about possible changes in the performance of environmental functions due to the venture. It communicates, in a simple and objective way, the essential features and the meaning of this activity in the progress, or regression, of the environmental condition (PNUMA, 2004). Table 3 presents the environmental functions of PPAs and the indicators in the comparative assessment of the venture's influence on these protected areas.

The fourth step lied on mapping springs and their respective PPAs based on a combination of techniques, geoprocessing tools and field data. Tools available in the GIS software were used to develop the Digital Terrain Model (Topo to Raster function of the ArcGIS 10.5 software), to generate the drainage network in the study site (TerraView Hidro 4.1.0 software), to rank the drainage network (Hydroflow 0.9 software), to extract the initial points of first-order channels

Table 3 – Environmental function (general and specific) of permanent preservation areas (PPA) and examples of indicators for comparative analysis of locational alternatives.

General environmental function (Forest Code)	Main specific environmental functions	Indicator	
		Name	Parameter
Preserving water resources	Maintaining water flow and recharge area	Interference in recharge area and runoff	Waterproofed area due to venture construction (m^2, ha)
		Interference in springs	Waterproofed area in comparison to the total area of the spring contribution basin (%)
			Spring flow ($m^3/s/$; L/s)
			Number of springs whose contribution basins are potentially affected
		Groundwater depth variation	Groundwater depth (m)
	Preserving the natural quality of water	Changes in the quality of water	pH, temperature, turbidity, DO and BOD values
	Acting as natural biological filter of organic matter and enabling heavy metal retention	Changes in the natural biological filter capacity	Physical-chemical composition of sediments and leaf chemical composition in arboreal strata
Preserving the landscape	Maintaining landscape structure and dynamics	Changes in landscape	Changes in land use in the study site (%)
	Ornamental and landscape effect	Changes in landscape	Advancement in rupture line or shoreline (cm, m)
Preserving biodiversity; enabling fauna and flora gene flow	Providing habitat, as well as fauna feeding and sheltering conditions	Vegetation cover index	Proportion of the vegetation cover area in comparison to the total area (%)
		Changes in the edge effect of fragments	Mean shape index of the fragments belonging to class “vegetation cover”, based on the area of fragments
	Forming and maintaining ecological corridors	Isolation of fragments	Mean distance from the nearest neighbor (m)
	Preserving the genetic heritage of typical hillside fauna and flora	Changes in the PPA area	PPA area (m^2, ha)
Preserving geological stability; protecting the soil	Protecting margins from erosion and sedimentation processes	Direct interference in PPA	Changes in land use in the PPA (%)
	Stabilizing hillsides	Incidence of erosive features (furrows, ravines and gullies)	Length, width and depth (m)
			Affected area (m^2 or ha)
			Outcropping water depth (cm, m)
Assuring the well-being of human populations	Providing environmental services (provision, regulation, cultural and support)	Interference in environmental service provision	Changes in the quality of water in the watercourse

DO: Dissolved oxygen; BOD: Biochemical oxygen demand

(Feature Vertices to Points function of the ArcGIS 10.5 software), to validate data in orthogonal view (Global Mapper software) and to delimit the spring contribution basin (Hydrological Modeling function of the TerraView Hidro 4.1.0 software). In addition, the spring contribution basin was mapped, although it did not constitute a PPA, since the 50-m radius makes little contribution to water flow due to its small extension in comparison to the hydrographic basin encompassing it. Thus, the entire contribution area deserves attention as to the environmental functions it represents, notably the ones related to rainwater infiltration capacity (CALHEIROS *et al*., 2004). In cases of intermittent springs, contribution basin protection tends to assure the temporal continuity of rainwater infiltration, percolation, storage and exfiltration processes, depending on the natural rhythm of the system (CARMO; FELIPPE; MAGALHÃES JUNIOR, 2014).

The last step lied on evaluating the project in the spring PPA and its mapped contribution basin. Based on the selected indicators and parameters, it was possible seeing that Scenario 1 tends to require larger vegetation suppression area and larger waterproofed surface, which can lead to changes in surface water runoff and in groundwater dynamics (responsible for recharging aquifers, for maintaining springs and for assuring the continuity of downstream watercourses) with predictions of relatively greater magnitude. Consequently, one can expect greater changes in the flow of watercourses originated by the spring, as well as greater variation in groundwater depth, greater reduction in the self-purification capacity of waterbodies, greater interference in biodiversity, lesser landscape connectivity and greater interference in environmental service provision, mainly the ones directly linked to the availability of environmental resources from forest ecosystems, such as food and wild resource provision (buriti, açaí, palmito-juçara, among others). Thus, Scenario 2 has shown to have lesser influence on the general and specific environmental functions of PPAs than Scenarios 1 and 0.

Results in the current study have technically substantiated the definition of the most viable location alternative, based on the environmental legislation. In addition, a series of recommendations and complementary actions focused on collecting data and information necessary to monitor the defined indicators and parameters was listed, namely: integrated monitoring of watercourse and spring flows that may be affected by the construction of the waste disposal area, as well as the integrated monitoring of the corresponding water levels and rainfall variations; use of collected data for studies about artificial recharge and ecological flow; diagnosis and monitoring of the composition and abundance of native forest and river system species. These actions will enable greater technical basis to help better understanding variables (biotic and abiotic, natural and anthropic) and possible interference in the investigated environmental functions. However, it is important emphasizing that, regardless of the category, PPAs are places whose fragility leads to negative impacts in case of anthropogenic changes in any of their physical and/or biological components; they tend to change their environmental functions in the short, mid or long-term, although sometimes in an indirect way.

CONCLUSION

The herein presented case studies highlight the importance of understanding the regional context of definitions available in the literature and of specific environmental functions of PPAs in the environmental assessment of changes resulting from the implementation of projects. Results have shown that each PPA is part of a system composed of several interdependencies, where consequences must be analyzed not only in the range protected by normative instruments but also in the dynamic and non-linear set they are inserted in. The analysis of ventures in PPAs, based on their environmental functions, allows understanding how these protected areas will be directly or indirectly affected by them and it may indicate the need of expanding the area to be protected beyond the legally established one. In addition, the definition of specific indicators and parameters provides subsidies to compare changing trends due to the socio-environmental of PPAs' functions. It is possible concluding that the proposed method proved to be valid and efficient in the herein presented case studies, since it enabled recommending adjustments to the project prepared by the entrepreneur and technically subsidized the definition of the most viable locational alternative based on the environmental legislation about the functions of PPAs.

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