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Human Accessibility Modelling Applied to Protected Areas Management

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Abstract

Natural protected areas in tropical regions are considered important refuges for flora and fauna, and the only remaining habitat for many species. However, these areas still suffer from numerous human impacts, whether by illegal hunting, logging or tourism. Mapping areas of greater human access and its potential effect to wildlife should be considered as strategy for management in protected areas. This study aimed to generate a human accessibility map for the Anchieta Island, for purposes of zoning and management. We evaluated the impact of human presence (tourism) on the occurrence of wildlife at Anchieta Island by using the concept of human accessibility. Accessibility model was correlated with estimated travel-time using Pearson's Correlation and showed significant positive relationship ($r = 0.714$) between accessibility model and travel time observed in the field. Thus, the accessibility methodology can be a valuable tool to analyze human impacts on wildlife through hunting and logging in protected areas.

Key words: Tourism, Cost-Distance, Anchieta Island State Park, Accessibility, Zoning.

Introduction

Human activities have direct impacts on vertebrate wildlife populations and influence species conservation (Beale & Monaghan 2004). Therefore mapping areas of greater human access and its potential effect to wildlife needs to inform potential strategies for managing protected areas. The ease of access to these areas in tropical countries encourages the development of illegal activities such as hunting, smuggling, fishing, logging and extraction of natural products for trade (Joppa *et al.* 2008).

The increase of tourism in Brazil has attracted tourists to protected areas in recent years (Kinker 2005). Many authors argue that negative impacts are inherent to recreational use in these parks (Vickery 1995; Leung & Marion 2000). Even the most alert tourists leave marks and disrupt the ecosystem without realizing it. Thus, for proper management of protected areas it must reconcile both the public demands and the prevention of undesirable impacts on wildlife and their habitat (Hammitt & Cole 1998).

The impacts of tourism can have socio-cultural, economic or environmental dimensions (Mason 2008). Regarding environmental impacts, its nature and severity in protected areas vary by the type of recreation and can be direct or indirect, or even synergistic or compensatory (Newsome *et al.* 2005). We summarized the main effects of recreational use in protected areas on Table 1.

Human accessibility has been proposed as a way to analyze the human impact on the distribution of vertebrate populations (Carver *et al.* 2002). This impact is measured by the distance of the closest point of access, and considering also the access difficulties (*e.g.* barriers or other landscape features).

The literature presents a lot of definitions for the term accessibility and in general it depends on the focus of the study. The term accessibility means "capable of being

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Table 1. Main effects of recreation and tourism on biotic and abiotic factors of protected areas.

Ecological components	Activity				
	Trails (hiking, construction and maintenance)	Camping	Swimming, diving, use of water transports	Inappropriate disposal of wastes	Vehicles inside and outside park boundaries
Soil	Soil compaction and sterility (Newsome *et al.* 2002)	Loss of organic mulch (litter) (Newsome *et al.* 2002)	Changing of river/lake banks (Newsome *et al.* 2002)	Reservoir of solid waste (disease transmission) (Cole 2002)	Compaction and erosion (Liddle 1997)
	Loss of organic mulch (leaf litter) (Ceballos-Lascurain 1996)	Increased soil compaction and reduced porosity (Cole 2002)		Change in concentration of soil chemicals (Cole 2002)	Sediment and nutrients runoff (Newsome *et al.* 2002)
	Erosion and alteration of microbial activities (Cole 2002)	Change in concentration of soil chemicals (Cole 2002)			Waterproofing and porosity reduction (Liddle 1997)
Vegetation	Reduction of leaf area / plant biomass and exposure of roots and damage to tree trunks (Liddle 1997)	Increased fire risk (Cole 2002)	Change in the composition of aquatic and riparian species (Newsome *et al.* 2002)	Change in the composition of aquatic species (Newsome *et al.* 2002)	Reduction in vegetation cover (Liddle 1997)
	Trampling of seedlings and changes in reproduction (Cole 2002)	Exposure of roots and damage to tree trunks (Cole 2002)	Elimination of macrophytes from water by direct contact (Buckley 2009)		Spread of weeds and exotic plants (from tires etc.). (Pigram & Jenkins 2006)
	Introduction of exotic species and spread of weeds and fungal spores (Buckley 2009)	Change of species composition (Newsome *et al.* 2002)			Risk of fire (Pigram & Jenkins 2006)
Wildlife	Changing the distribution pattern of some species (Newsome *et al.* 2005)	Habitat loss (Newsome *et al.* 2002)	Degradation of coral reefs and mortality of fish and other organisms (Liddle 1997)	Alteration of aquatic biota (*e.g.* coral bleaching) (Edington & Edington 1986)	Death from run over (Edington & Edington 1986)
	Offensive disturbance of wildlife (Liddle, 1997)	Modification of normal activities because of noise, light etc. (Newsome at al. 2005)	Destruction of habitats and resources (e.g. nests on rocks) (Newsome *et al.* 2002)	Modification of normal activities, for habituation, aggression, etc. (Orams 2002)	Destruction of nests, holes and shelters (Buckley 2004)
	Habitat alteration and creation of new micro-habitats (Liddle 1997; Cole 2002)	Impact of pesticides in birds and other animals in the trophic chain (Newsome *et al.* 2002)	Disturbance by noise (Liddle 1997)	Composition change (attraction of opportunistic species) (Newsome *et al.* 2005)	Modification of normal activities because of noise, visual impact etc. (Buckley 2009)
Water	Changes in the drainage system (rupture of water courses) (Cole 2002)	Pollution (Buckley 2009)	Pollution and change in water quality (Mason 2008)	Increase the amount of pathogenic bacteria (Newsome *et al.* 2002)	
			Water turbulence and increased turbidity (Newsome *et al.* 2002)	Excessive growth of algae (eutrophication) (Edington & Edington 1986)	
			Decreased concentration of oxygen dissolved in water (Hammitt & Cole 1998)	Increased nutrients and suspended solids reducing the health of aquatic ecosystems (Pigram & Jenkins 2006)	

reached", implying a measure of the proximity between two points (Ingram 1971). Methods to measure accessibility are well developed in public service (*e.g.* Harris 2001; Weber & Kwan 2003) and also in the evaluation of land use change (*e.g.* Nagendra *et al.* 2003; El-Geneidy & Levinson 2007). These methods are, however, rarely used directly in the planning of wildlife conservation and most of them focus only on landscape connectivity and animal dispersion (Lin 2009; Pinto & Keitt 2009). The accessibility model takes into account the distance covered from an origin point, going by the available areas for the human movement by through the access/path of smaller resistance (Theobald *et al.* 2010).

The distance that separates the destination from the origin point affects the degree of relative accessibility. Factors in addition to distance can be included, such as slope, land cover, presence of road or trail, etc. These information can be combined with distance, which can allow us to explore cost-distance based effects (Theobald 2009). Land cover may have different cost values according to vegetation density and soil substrate, thus influencing human movement in the landscape (Adriaensen 2003; Jobe & White 2009). Cost-distance is also called the effective distance, because it presents a more realistic measure of movement. It considers the resistance of the landscape and not only the extent in straight line (Euclidian distance; Lin 2009).

The growth of ecotourism in tropical areas has attracted tourists for protected areas but these public parks are poorly prepared to attend the demand conciliating recreation and conservation goals (Terborgh & Van Schaik 2002). The measurement of human physical accessibility is fundamental concerning conservation strategies. According to Vickery (1995), the growing interest in outdoor recreation and the resulting increase in visitation in protected areas can cause considerable degradation and environmental disturbances. The author recommends that the permission for access to these sites should only happen with careful planning.

Furthermore, accessibility could be incorporated as conservation strategy through parks spatial zoning system, allocating areas for specific levels and intensities of human activities and for protection (Eagles *et al.* 2002). Fennell & Dowling (2003) considers the environmental zoning of protected areas as a key tool in planning and managing these areas. For this, zoning must consider all activities that occur within the park boundaries, such as land cover, recreation and tourism. Conservation objectives can reach better results if recreational activities are concentrated in certain areas of the park. The provision of facilities such as tables and showers may encourage the tourists' permanence in these areas and thus reduce the pressure in sensitive areas (Vickery 1995). This practice of releasing human access to certain areas of the park and restrict the use of some sensitive sites may be crucial to conserve rare and endemic species to the region.

Our overall goal was to create a model of human physical accessibility using Anchieta Island State Park (PEIA) as a study area. This model can be used to estimate the impacts of human influence on vertebrate population, for instance, and can be applied to other protected areas.

Material and Methods

The PEIA is located in Ubatuba municipality, north coast of São Paulo state, Brazil (45° 02' 20" to 45° 04' 59" W; 23° 31' 31" to 23° 33' 40" S ; Figure 1). The park covers 828 ha, has a long history of human occupation and held a prison in the 1930s. All its area belongs to Anchieta Island State Park (PEIA), created in 1977. The island vegetation is composed of coastal Atlantic rainforest and some areas of disturbed vegetation are occupied by ferns. To prevail guidelines for management and conservation of PEIA's natural resources, balancing tourism development, four different zones of use were adopted in the Management Plan (Guillaumon *et al.* 1989): 1) intangible zone; 2) extensive use zone; 3) recovery zone and 4) intensive use zone.

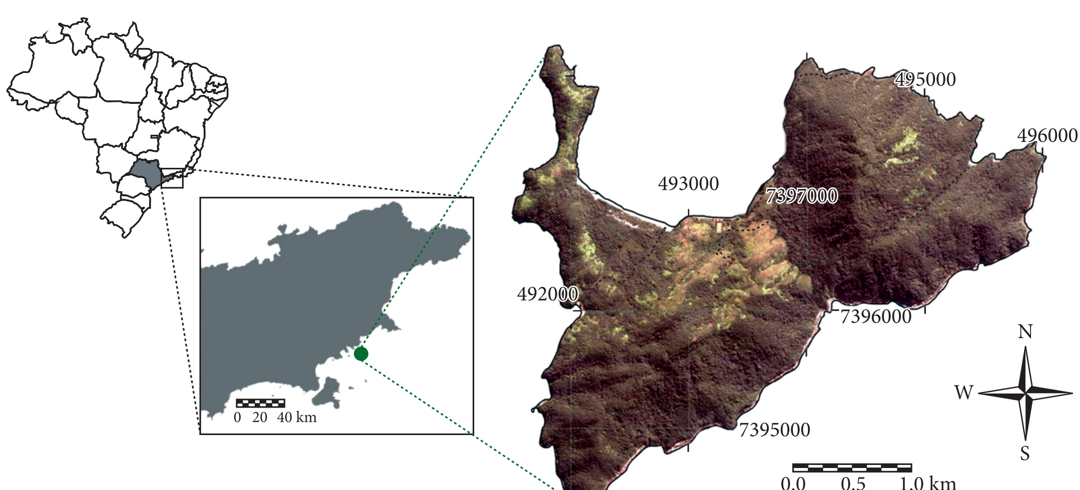

Figure 1. Image of Anchieta Island, São Paulo State, Brazil. Dashed lines indicate the trails of the park.

The influence of human presence at Anchieta Island was evaluated through accessibility concept, based on cost-distance in GIS environment (ArcGIS 9.2). Accessibility model takes into account the distance from an origin point, passing through available areas for human movement for the access/path of least resistance. Low cost values represent low effort to reach the aimed site. High values represent the high cost of human physical effort to reach these areas, influenced by natural barriers (topography) or anthropogenic (constructions).

The calculation of accessibility based on cost-distance in GIS environment requires raster input maps: 1) a file of resistance/friction map which specifies the cost of movement between cells (*e.g.* slope map) and 2) a file of the origin location(s), from which the cumulative cost of moving to each target cell is measured. The algorithm function of the cost-distance uses the resistance file and calculates a value for each cell, which is the lowest cumulative cost from this cell to the closest source cell (Theobald 2009). This function calculates the cost of moving from the center of one cell to another, computed as (Mitchell 1999) (Equation 1):

$$C_i = \left(c_i \times \frac{R}{2}\right) + \left(c_j \times \frac{R}{2}\right) \quad (1)$$

where C_i equals the cost-distance value of the cell i, c_i is the cost value (from resistance file) of the source cell of the movement i, c_j is the cost value (from resistance file) of the source cell of the movement j and R equals the cell size or resolution. The construction of the accessibility model considers that a person likely will travel some distance along a road or trail (DTT) and then travel certain distance off trail (DTOT) to reach the target location.

In this study the accessibility model was built taking into account the distance of the closest point of access (park trails and buildings) and the access difficulties (slope and land cover with 5 m cell resolution). The steps to construct the accessibility model were the following (Figure 2): 1) the DTT cost-distance was calculated considering the trails as access routes to park areas and the area occupied by buildings as the input source. There are no paved roads on the park, and they are all considered walking trails. As the tracks have different degrees of difficulty along the way due to type of soil substrate, steepness, etc., we set weights for each track, following the concept of Analytical Hierarchy Process (AHP) (Saaty 1977). AHP is a systematic method to assist in making complex decisions and in the comparison of alternatives, justifying the choice. A matrix was assembled by comparing the tracks, according to a scale of degrees of difficulty (Table 2). The final weight obtained for each track was calculated as the sum of weights from each class, divided by the total sum (all classes), multiplied by 20 and converted to integers. High weight or resistance signifies low permeability.

The second step (2) was to allocate cost values of the trails (weighted) to all adjacent areas within PEIA, using Cost Allocation function; (3) in DTOT maps of land cover (based on Aranha 2011) and slope of PEIA were combined. Because each class of land cover map embraces different degrees of difficulty along the way, we set weights for each cover type. The land cover classes considered in this study were the following: a) *Restinga*, b) Ferns, c) Beach, d) Miconia vegetation, e) Initial stage forest of succession, f) Intermediate stage forest, g) Advanced stage forest, h) Buildings, i) Rocky coast and j) Wetland. Similarly, a

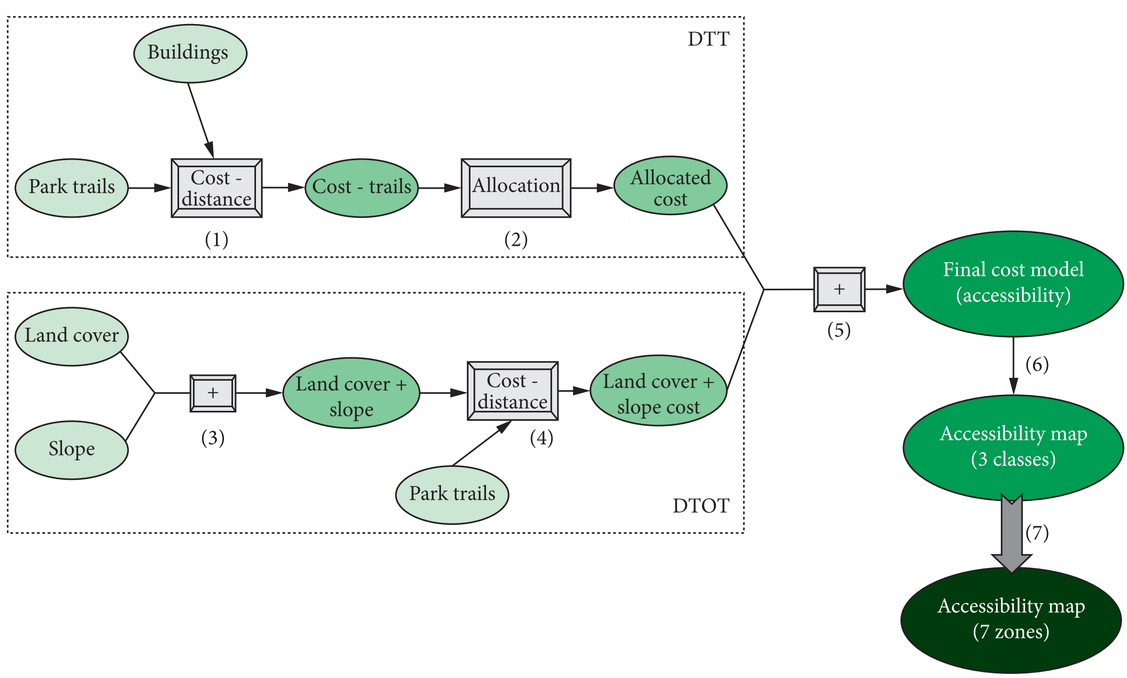

Figure 2. GIS procedures to obtain the accessibility model of Anchieta Island, SP, with steps from 1 to 7 detailed in the text.

Table 2. Decision-making matrix adopted for park trails and land cover weights in PEIA.

Land cover class	Final weight	Park trail	Final weight
Restinga	3	Saco Grande	1
Ferns	8	Sul	1
Beach	1	Pedra do navio	5
Miconia	2	Leste	10
Initial stage forest	7	Represa	3
Intermediate stage forest	5		
Advanced stage forest	4		
Buildings	1		
Rocky coast	8		
Wetland	3		

matrix was assembled (Table 2) through a comparison between classes of land cover, according to the degrees of difficulty (AHP ; Saaty 1977); (4) from the resulting map we calculated the cost-distance by considering the park trails as source of access; (5) the maps of cost allocated in DTT, and cost of land cover and of slope in DTOT were then combined to generate the accessibility gradient map for PEIA, with areas of greater and lesser access throughout Anchieta Island; (6) the final accessibility map was then classified according to three levels considering the same range of values: short hike (1-2 hours), day hike (2-4 hours) and long hike (>4 hours); (7) because each access level has different types of vegetation the island was divided into seven zones, considering the degree of access and vegetation type.

To validate the accessibility model in the field, we recorded the travel-time by starting from the main park entrance of tourists (building areas) to 18 random points distributed within PEIA. The location of the random points were chosen according to vegetation classes and distance from origin in order to cover all classes of accessibility (10 points in short hike, 5 in day hike and 3 in long hike). The course was carried out firstly over the park trails and then off trails to the mentioned points. Pearson's correlation analysis was performed including the travel-time to the specific sites distributed on the island and its cost-distance values.

Results

The output values for the accessibility model for PEIA comprised values of physical costs ranging from 2 to 16. We reclassified the accessibility map into seven zones (Figure 3), which showed that the areas of easier access correspond with those most degraded. The class with the largest area is the one of day hike (309 ha), followed by long hike class (280 ha) and short hike (213 ha).

Each access zones presented distinct characteristics in altitude, slope, land cover and vegetation composition. The first zone represents the touristic entry of the island and is the most accessible site (short hike), characterized by flat terrain and low elevation areas. It is also the most heterogeneous in vegetation composition, encompassing *restinga* vegetation, forest in advanced and intermediate regeneration stage, and disturbed vegetation (ferns). The day hike zones comprise different regeneration stages and fern fields, with average slope and higher elevations. The long hike zones are steeper, with average elevation. The latter comprise the most homogeneous vegetation composition, with dense forest and some fern spots. Recommendations and conservation objectives proposed for each zone described in this study are shown in Table 3.

Our analysis showed positive significant correlation between accessibility model and travel-time observed in the field ($r = 0.714$; $n = 18$; $p < 0.01$). The higher the value of cost in the model presented, the greater the time taken to access the desired location. For instance, the minimum time computed to reach a low cost local on the island (average 3.1) was six minutes and the maximum time to reach a place of high cost (average 7.2) was 39 minutes, which implies that higher cost values takes more travel-time than lower cost values.

Discussion

The results corroborate and emphasize the success of the model adopted for representation of the human real accessibility at the Anchieta Island. The accessibility model presented in this study can be a valuable tool to assess the human impact in protected areas, and it has considerable implications for wildlife conservation (hunting) and deforestation (logging) (Chin & Bennett 2000; Peres & Lake 2003). The fact that areas of easier access in PEIA correspond with those most degraded can be linked to the disturbance history of the island, starting from Indigenous occupation and mainly during the period of the prison operation (for 25 years). Today the use of the park by visitors has to be the primary focus of management planning, presenting the objectives of the protected area, as well as involving the tourists in the conservation strategy.

Areas with extensively disturbed vegetation (anthropogenic field and forests in early stages of succession) could be recovered from habitat restoration with native seedlings or seeds, when located in areas with steeper slopes (to prevent soil erosion) (Gandolfi & Rodrigues 2007). Forest regeneration is also indicated in flat areas with heavy traffic

Table 3. PEIA zoning described in the present study with their respective management recommendations.

Zones (PEIA)	Human access	Recommendations	Aims
1	Long hike	• Intense and effective enforcement against illegal hunting and habitat destruction because it is an area of difficult access and full recovery of the vegetation. • Conduction of natural regeneration, since there is less disturbance and ecological processes are still active (Gandolfi & Rodrigues 2007).	(1) Preservation of ecosystem and genetic potential, working as a matrix of repopulation, (2) Isolation of the area from disturbing factors, (3) Area used only for research and monitoring purposes.
2	Long hike	• Conduction of natural regeneration is also the most suitable, since there are fewer disturbances and it is able to maintain the conditions for self-perpetuation (seed and seedling banks). • In areas occupied by ferns, with low potential for regeneration, reforestation is recommended (seed planting and nucleation techniques) (Reis *et al.* 2003; Gandolfi & Rodrigues 2007).	(1) Site dedicated solely to research and monitoring, (2) Recreational activities limited to the beach area, (3) Wildlife hunting protection (effective monitoring by trail and sea), (4) Isolation of the area against disturbing factors.
3	Day hike	• Intensified surveillance of the zone, since there was also found of traces hunting in this area. • In areas with intermediate and advanced forest stage, we recommend self-perpetuation (e.g. seed and seedlings bank), along with park trail isolation. • In areas occupied by ferns, with low potential for regeneration, it is recommended reforestation (seed planting and nucleation techniques) (Reis *et al.* 2003; Gandolfi & Rodrigues 2007).	(1) Preservation of ecosystem and genetic potential (forests) to act as a matrix of repopulation, (2) Restricting use of trails by visitors, with permission only accompanied by capable monitors, (3) Protection against wildlife hunting.
4	Day hike	• As this is an area of medium access, natural regeneration is not impaired by tourist traffic. In areas with low regeneration and without forest cover, it is recommended seed planting or nucleation techniques (Reis *et al.* 2003).	(1) Isolation of the area from disturbing factors, (2) Prevention of soil erosion.
5	Day hike	• Measures to allow natural recovery, without direct intervention in forested areas are recommended. • In areas with low regeneration and without forest cover, it is recommended the seed planting or nucleation techniques (Reis *et al.* 2003).	(1) Isolation of the area from disturbing factors, (2) Protection of the soil against erosion.
6	Short hike	• This is the zone of intense human activity and the most degraded as well. Therefore, we recommend reforestation (seed planting or nucleation techniques) in areas of low regeneration, with management of fern fields. • In forested areas we suggest natural regeneration, because dispersers are present in these areas. It is also necessary to isolate the recovery areas by fencing or firebreaks (Gandolfi & Rodrigues 2007).	(1) Proper management of park trails, (2) Recreational activities limited to beaches, monitored trails and historical-cultural buildings, (3) Isolation of the area from disturbing factors, (4) Conservation of the rivers.
7	Day hike	• Conduction of natural regeneration in forested areas, since the ecological processes are still active. • In areas of low regeneration we advise reforestation (seed planting or nucleation techniques), as in the fern fields (Reis *et al.* 2003).	(1) Isolation of the area from disturbing factors, (2) Exclusive destination for research and monitoring.

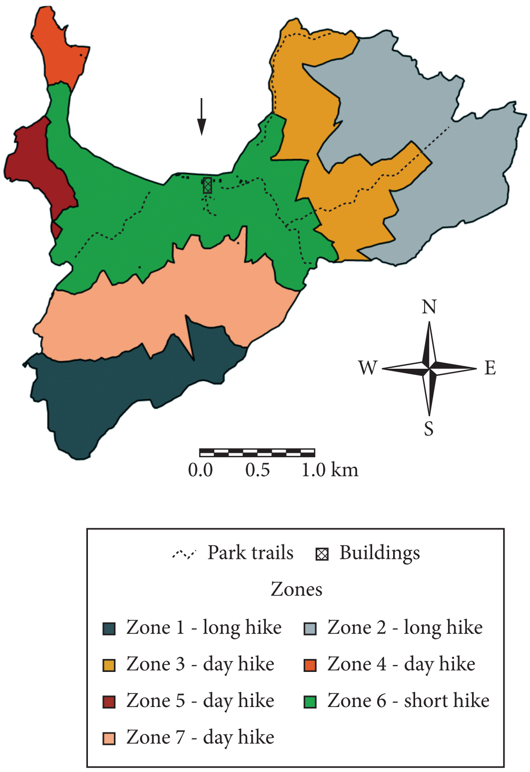

Figure 3. Zoning of the Anchieta Island, SP, classified into seven accessibility areas, detailing the construction area (old prison) and park trails. The dark arrow indicates the location of PEIA entrance.

of tourists for speeding up regeneration. The problem with soil erosion is generally lower in these flatter areas. Thus, the implementation of measures to enable natural regeneration would be more appropriate because, besides the lesser financial cost, the movement of tourists in specific areas of the island is already restricted. In zones with less disturbed vegetation and with more advanced stage of regeneration, the restriction of tourist access when necessary is appropriate to preserve the ecosystem.

Zone 6 presents areas requiring more protection due to easy access (short hike zone). Those areas are coincident to most visited sites in PEIA. Since 1998, the landing site, the entry and length of stay of visitors are controlled. Even so, there is still the need to develop standards for the park, allowing the structure of ordered visitation, to restrict specific areas to be restored and monitored permission for interpretative trails.

It is important to consider that zoning would be enhanced with the inclusion of vegetation communities mapping of more vulnerable and the most sensitive animal species. An example would be restricting access to potential nesting sites. In addition, zoning allows the temporal or seasonal access to certain areas, depending on the dynamics and behaviour of species (Vickery 1995). In times of PEIA's visitation peak, December and January, access to some areas of the park would be narrower to ensure the preservation of some species.

The accessibility model created for the Anchieta Island allowed identifying more appropriate measures of management and protection, in function of local physical characteristics of the area, of current land cover and of the use of those areas for tourism. As PEIA management program dates 20 years ago, the data obtained by this study on accessibility in the Island should be considered in its review. Our results should serve as base for the development and implementation of strategies for environmental conservation, and effective recommendations that complement the park's management processes. Furthermore the model presented in this study can be applied in other tropical protected areas, as a form of supporting in future management strategies of these parks, according to the particular characteristics of each one.

The impact of human presence was analyzed in this study by accessibility, especially considering tourism, which is the most common factor in PEIA. Still, accessibility models can also be used to analyze other human impacts on protected areas, such as gaming and logging, for example.

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