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Insular streams integrity in Ilhabela, Brazil

Summary

Riparian zones are fragile, dynamic, and complex habitats, especially insular ones. We developed an approach relating 71 environmental variables from the rivers of Ilhabela (Brazil) through a rapid assessment protocol adapted to the rivers and their adjacent environments. The prominent disturbances were related to changes in the physical structure of the riparian ecotone. Height and type of riparian vegetation, stability of riverbanks, sediment deposition, and silting of the bed were the factors that most determined the state of the environment. We evaluated 20 rivers from the eight hydrographic basins of Ilhabela, of which 7 presented excellent conditions, 10 in good condition, and 3 in regular condition. The environments in the most populous portion of the island indicated more critical situations, given the anthropogenic impacts. Riverine management must consider the need for stricter observance of laws and occupation and zoning plans, aiming at environmental conservation and biodiversity.

Keywords: rapid assessment method, watershed, environmental integrity, biodiversity, islands

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Introduction

Environmental isolation strengthens communities' dependence on ecosystem resources on islands, while occupation increases around streams.[1] The linear nature of streams, continuity, and connectivity contribute to the formation of ecological corrido.[2] being relevant to improving water quality, as they filter pollutants and nutrients, in addition to being sources of organic matter for aquatic communities and promote the diversity of Inter-river habitats.[3,4,5,6] Small riparian zones process and recycle material from the entire drainage basin, thus forming essential corridors for biodiversity conservation.[5-9] Of the 35 *hotspots* defined by *Conservation International*, 20 correspond to islands and insular components.[10] which makes it necessary to be concerned about the effects of human impact.[11] The Atlantic Forest biome is home to one of the most critical biodiversity groups, with about 20,000 plant species (6.7% of all species in the world), of which 8,000 are endemic in Atlantic Forest Conservation Units.[12,13] Biodiversity loss is more intense on islands in tropical regions.[14] their occupation increases the tendency for situations of vulnerability.[15] and it is imperative to use strategies with an integrated understanding of ecological processes.[16,17] Wetlands are some of the most threatened ecosystems globally; their rates of degradation increase are higher than anywhere else.[18-22] Thus, river ecology has focused on ecotones between the terrestrial and aquatic domains to which riparian zones belong.[6,23] as the removal of riparian vegetation causes significant changes in aquatic environments.[24] as well as the removal of mangroves along coastlines, which affects water quality and biodiversity.[25]

Although generally not very large, these transition areas (ecotones) are of fundamental importance in conservation, providing simultaneous contact or coexistence of plant and animal species, with different plant formations being important corridors for many populations.[26]

We know that studies seek to assess the levels of anthropogenic impact in stretches of watersheds.[27] however, it is necessary to review practices and introduce improvements to characterize these habitats.[28] Among these, we can mention the Rapid Assessment Methods (RAMs) as the tools to support us in assessing riparian habitats for environmental characterization and their diagnosis.[28-30] These methods assess deviation from current conditions by comparing the natural or reference state, as they establish a scoring system that assesses existing differences.[31,32] Based on this information and knowing that there is little knowledge in Brazil about these transition areas, it is essential to develop research on the apprehension of data from these ecotones since the maintenance of riparian habitats on the islands is perhaps the most crucial management strategy for the conservation of the biodiversity in these locations.[33]

Goal

To assess the integrity conditions of riparian habitats in watersheds on São Sebastião Island, Ilhabela, Ilhabela São Paulo State, Brazil, using a Rapid Assessment Method (RAM).

Material and methods

São Sebastião island houses the municipality of Ilhabela (23°46'28" S; 45° 21'20" W) and is one of the most oversized insular Atlantic Forest conservation units in South America. Being of volcanic origin, it is 3 km from the South American continent and has an area of 348.3 km², of which 84% are inside conservation units. It has humid forests on the slopes and a humid tropical climate.[34] with abundant watersheds and streams with waterfalls. Alkaline rocks and topography are mountainous.[35] It houses different conservation units, with the legal overlapping of Indigenous Lands, including areas with slopes above 45 degrees, close to watercourses and mangroves.[36] The sampling sites are in the lower middle part of the 20 rivers belonging to the island's eight watersheds (Figure 1).

Sampling took place in the first half of July 2017. The application of the protocol took approximately 50 minutes at each point. The first part of data collection took place in the main channel and its surroundings, followed by data from two transverse transects along 50 meters of the watercourse. We used 71 environmental parameters to evaluate perturbation degree. We evaluated the characteristics of the environments in which the metric, hydrological, geomorphological and ecological attributes were considered, using indicators outlined in a field record sheet. The following information: relief, land use, vegetation, conservation status, vegetation strata present, adjacent land use, riparian cover, local soil impact, valley and channel shapes, width, and depth. Also, we took vegetation heights, shading and slopes, runoff conditions, sediment deposition, leaves, branches, trunk accumulations, sand, silt, gravel, pebbles and boulders, soil texture, stability, and ravine cover. We used habitat, water, and

aquatic vegetation information to apply scores (0 to 5) according to the preservation conditions Table 1 using field observations as a basis. Those with the highest score (5) represent optimal environmental conditions, while lower scores represent decreasing conditions. Subsequently, the scores were added to determine the degree of fragility of each sampled habitat, where the lowest score is the more exposed to greater vulnerability.

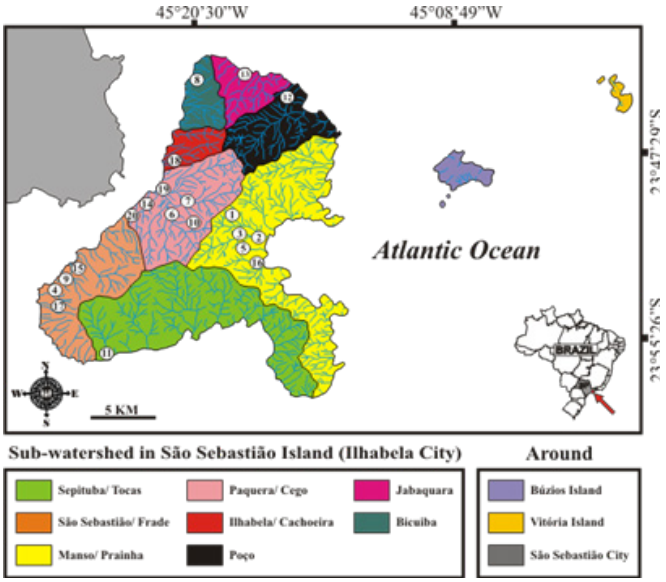

Figure 1 Hydrographic map of Ilhabela with pinpoints of the 20 sampling sites.

The value of the sum of the scores of each sampled location was compared with the ranges of stress gradient values, thus attributing the final condition. The optimal conditions vary between 101 and 120 points, representing attributes of the sampling site in natural conditions without threats to its functioning. Good conditions range between 81 and 100, with most of its attributes under elevated conditions. However, they require protective measures to avoid impact and estimate measures to achieve complete integrity. The median conditions (between 31 and 80) are present moderately altered attributes, requiring recovery measures and the elimination and reduction of impact pressure to the maximum. In addition, the worst conditions are up to 30 points; they have altered riverside environments in need of rehabilitation.

We carried out a principal component analysis (PCA) to verify which parameters significantly influenced the results (*loads analysis*).

Results

We obtained three blocks of integrity conditions: optimal, good, and worst. Table 2 shows the results according to the conditions we found them. Our results ranged from 101 - 116 for optimal conditions, 81 - 89 for good conditions, and 64 - 78 for worst conditions (Table 2).

Thirty-five percent of the sampling sites were in excellent condition, against 15% regular and 50% good. In other words, 65% no longer fully present their natural condition.

Being surrounded by Ilhabela State Park, basin 33 presented the most considerable amount of riverside environments with excellent conditions. The primitive vegetation was predominant in these places. In 50% of the places, conditions were good (R8 to R 17), even in different basins. Sampling sites R18 to R20 (basin 30) represented 15% of the total sampling with regular conditions and were located within the limits of the urban center, in the densest and most anthropized region of the island. In these places, fifty percent of the riparian vegetation was highly disturbed or almost absent in many places.

Table 1 Scores attributed to observed parameters

Parameter	5 Points	4 Points	3 Points	2 Points	0 Points
Relief	Mountain	-	Hill	Flat Land	-
Preservation	Primitive	Slightly Deforested	Heavily Deforested	Deforested	Urban Occupation Graze
Vegetation Present	Native Forest	Mangrove Or Swamp	Marshy / Transitional Forest	Shoal / Brushwood	
Soil Use	Slope Forest	Reforestation	Agricultural	Urban	Industry And Mining
Adjoining Soil Use	Forest Reserve	Slightly Deforested	Agricultural	Urban	Road
Present Strata	Arboreal - Shrubs - Herbaceous	Arboreal - Shrubs	Shrubs - Herbaceous	Bushy	Herbaceous
Riparian Cover	Native Trees, Bushes, Ferns, Rock, Stone	Trees, Shrubs, And Ferns	Trees, Rock, And Stone Structural Floors	Native, Rock, Stone, Exotic	Exposed Soil
Shading%	> 75%	51-75%	26-50%	25%	0
Estimated Vegetation Height	Higher Than 10	Between 6 - 10	Between 3 - 6	Between 0.5 - 3	Less Than 0.5
Width Of The Flooded Channel	Wider Than 20	Between 11 - 20	Between 6 - 10	Between 3 - 5	Less Than 1
Greater Height In Left Ravine	Higher Than 5	Between 2 - 5	Between 1.1 - 2	Between 0.6 - 1	Lower Than 0.5
Lower Height In Left Ravine	Higher Than 5	Between 2 - 5	Between 1.1 - 2	Between 0.6 - 1	Lower Than 0.5
Greater Height In Right Ravine	Higher Than 5	Between 2 - 5	Between 1.1 - 2	Between 0.6 - 1	Lower Than 0.5
Lower Height In Right Ravine	Higher Than 5	Between 2 - 5	Between 1.1 - 2	Between 0.6 - 1	Lower Than 0.5

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Table Continued...

Parameter	5 Points	4 Points	3 Points	2 Points	0 Points
River Depth (M)	Deeper Than 1.2 M	0.91 - 1.2 M	0.76 - 0.9 M	0.6 - 0.75 M	0 - 0.5 M
Valley Shape	Scattered	Box	In Steps	In V Or U Shape	Artificial
Habitat Type	Waterfall	Stream	Rapids	Side-Channel	Reserve Or Tranquil
Flow Condition	High & Continuous	Normal	High With Pulses	Low With Drastic Pulses	Low - Stagnant
Declivity	> 30th	-	< 30°	-	-
Margin Stability	Vegetation - Rocks - Roots - Logs	Rocks - Roots - Logs	Roots	Logs	Ravine / Exposed Soil
Velocity	Turbulent Water With Bubbles	Altered Surface	Noticeable, No Surface Change	Slightly Altered Surface	Stagnant
Substrate Present	Leaves - Branches - Silt - Boulders	Leaves - Silt - Trunk - Gravel	Silt - Pebbles - Gravel - Boulders	Gravel - Pebbles - Sand	Sand
Sinuosity	More Than 21%	11-20%	6-10%	1-5%	0%
Interferences	None	Bridge / Passage	Course Deviation / Canalization / Capture	Tracks / Fires / Deforestation	Bridge Barrage

Table 2 Local codes, scores, environmental stress conditions in rivers, their classification order, and location in the Ilhabela watersheds

Local Code	sub-basin	Sampling Site	score	Stress Conditions
R1	33	Castilians Montante Água Branca	116.0	optimal
R2	33	Quilombo Castilians	114.0	optimal
R3	33	Castilians Trail 1	110.0	optimal
R4	31	Sul Veloso Waterfall	105.0	optimal
R5	33	Castilians Trail 2	104.0	optimal
R6	30	Kingdom Center	103.0	optimal
R7	30	Water Mill Center	101.0	optimal
R8	28	North Bicuiba Stream	99.0	Good
R9	31	South Ribeirao Sao Sebastiao	99.0	Good
R10	29	waterfall center	98.0	Good
R11	32	South Sepituba	96.0	Good
R12	34	North Well	95.0	Good
R13	27	North Jabaquara 1	87.0	Good
R14	30	Itaquanduba Center	86.0	Good
R15	31	South Friagem Stream	82.0	Good
R16	33	Castilians Beach	81.0	Good
R17	31	Sul Veloso	81.0	Good
R18	30	Córrego da Flirt Center	78.0	Worst
R19	30	Perequê Mangue Center	69.0	Worst
R20	30	Itaguaçu Marina Center	64.0	Worst

However, according to the scores, a portion of the 20 rivers sampled showed some impact. Although the sites R 15, R16, and R17 have received a good score, their conditions are closer to the median, characterized by the dense and specific presence of the traditional and summer population, with some commercial and ecotourism activities. . In the R5, R6, and R7 (best) locations, the scores are closer to good. There are minor urban points in these areas with irregular occupation around the main point of water collection to supply the municipality, also counting on ecotourism activities.

Regarding the impact on local land use, we observed that 55% of the sites are still natural and preserved. Of the remaining 45%, 20% are residential, 10% are for recreation, 5% with the presence of garbage, and 10% with passages or bridges. Of the samples collected, 35% are in mountainous regions, 20% in flat areas, and 45% in hills. Differentiated topography was seen at each sampling site and in all evaluated sub-basins. Hillside forests were predominant as adjacent vegetation in 65% of the samples; 15% in the transitional forest, 10% mangrove, and 5% swamp forest (Figure 2).

Figure 2 Riparian environments in Ilhabela: silting, rubble, invasive and exotic plants.

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When performing the multivariate analysis, the results of the variance-covariance relationship pointed to the fact that the first two components explain 70% of the analysis according to the study of the principal components. Data readings showed the groups that had a positive and negative influence on the results. Based on the loads of the principal components that were analyzed using the 71 parameters evaluated as a base, we identified that only 13 (Table 3). were responsible for 77.91% of the data variance.

Table 3 Codes of parameters analyzed in this study were considered relevant for the loading analysis

Acronym	Meaning	PC 1	PC 2
ESH	Estimated height	0.9349	0.1272
RIPC	Riparian Cover	-0.0607	0.1157
ILS	Impact on Local Soil	-0.0755	-0.0241
FCW	Flooded Channel Width	-0.0290	0.4266
RW1	River Width 0-5m	-0.0219	0.4132
RW3	River Width 31-35m	0.0385	0.6702
HRM	Greatest Right Ravine Height	0.2462	-0.2402
GLRH	Greatest Left Ravine Height	0.1805	-0.2922
LRRH	Lowest Right Ravine Height	0.0664	-0.0874
LLRH	Lowest Left Ravine Height	0.0655	-0.0979
T1RMS	Right Margin Stability	0.0623	-0.0135
ASU	Adjacent Soil Use	-0.0236	-0.0572
AQUV	Aquatic Vegetation	-0.0860	-0.0647

Sites R2, R3, R9, and R10 (light blue color) formed a group at the positive end of the graph and were related to the parameters of estimated height (ESH) and river width of 31-35m (RW3) (Figure 3). On the other hand, another group with the sites R4, R6, R12, R17, and R20 (orange color) were linked to the local soil impact (ILS), aquatic vegetation (AQUV), and adjacent land use (ASU). A group emerged that was composed of R5 and R8 locations (green color) concerning right bank stability (T1RMS), right lower ravine height (LRRH), higher right ravine height (GRRH), and left greatest ravine height (GLRH).

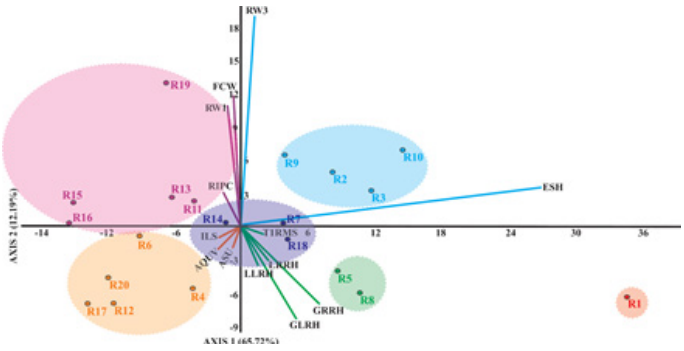

Figure 3 Principal Components Analysis (PCA) using the 13 main parameters as assessed herein. Captions on Table 02.

Discussion

The results indicate that the riparian habitats of Ilhabela signal attention, especially in places affected by the destruction and fragmentation of the vegetation surrounding the floodplains. A high concentration of people occupies the areas with the worst ecological quality. It suggests that assessments of the riverside environments of the islands and their management are urgent for the recovery and conservation of the analyzed site. This study demonstrates the prevalence of human pressure on the analyzed environments on the islands and the conflicts arising from conservation management and local public policies.[37]

In the rivers to the north of the island, the water speed is faster due to the slopes and the presence of larger stones, with the mountainous topography with a very different slope between the places, imprinting characteristics of occupation and preservation that are also different. In these, we saw less vegetation in the riverbeds, but there were lots of roots and trunks in high, stable gorges with tall vegetation, and the riparian zone is denser, while to the south, there is lower slope vegetation as well as less shading and stones. The riparian zone is less dense, and there is a greater penetration and incidence of sunlight in it with edges and fragmentation, affected by heat stress during the summer months.[38] We verified that these local characteristics of Ilhabela are related to the impacts suffered according to land use and occupation.

Rivers in mountainous regions, which are closer upstream to the state park, are broader and deeper, with rapids or waterfalls and the formation of pools between larger rocks. Its ravines are very high and stable, and the vegetation is the highest on the entire island. Dense Ombrophiles Forest is predominant with high shading and slopes that alternate with flatter areas composing the vegetation of the riverside zone. In these locations, the environments are in optimal conditions.

However, we observe high urbanization along the riparian zone; degradation is present in rivers and mangroves, caused by direct anthropic impact. There we can observe the low vegetation and invasive and exotic species in these environments that deprive the natural forest of its characteristics, including the low fluidity of the water and the presence of sand and silt. The hydrographic basins of Ilhabela persist due to the exuberance of their forest composition and riparian forest. It is a fact that tropical forests play a fundamental role in the ecological and climatic balance of the planet, and their riparian vegetation is relevant for the maintenance and conservation of these areas.[39,40] The low continuity between patches of habitat caused by the fragmentation of ecological landscapes represents the greatest threat to biodiversity conservation. Its maintenance is only possible through preservation and recovery processes, both for vegetation and rivers.[41] In addition, different tree height ranges indicate specific conservation problems in Brazilian Atlantic forests.[42] Analysis and monitoring schemes for this biota and ecosystems are urgently needed.[43]

The accumulation of biomass by the aerial part of the vegetation in the soil from plant structures can represent up to 90% of the net primary productivity of terrestrial ecosystems.[15,39] Degradation of natural ecosystems and inadequate land management reduce water supply with acceptable quality standards for different uses, exacerbating conflicts in the face of scarcity.[44,45]

Riparian forests are the most dynamic landscape areas and are called riparian zones.[36] Riparian forests play several other roles.[46] therefore, there are many relationships between terrestrial and aquatic systems. They have extraordinary roles in the dynamics of aquatic ecosystems. It is worth mentioning: the formation of habitats and shelters, migration corridors, breeding sites, thermal constancy, regulation of inputs and energy production, supply of organic matter, containment of ravines, reduction of sediment ingress, shading and regulation of flow and current to influence on the concentration of chemical elements in the water. Pressure on water resources from population growth and climate change requires assessment to support ecosystem maintenance while benefiting.[47] The discharge of effluents causes several ecological damages to these ecosystems.[48]

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However, poor water quality exposes ecosystems and human health to risks.[49] The World Health Organization recognizes evidence of the association of health problems with exposure levels in degraded environments.[50] By defining natural units and their degrees of fragility, better definitions for planning, public policies, and guidelines for zoning and management of areas to preserve environmental balance.[51]

According to the diagnosis, we observed two rivers in the study, six and seven (basin 30) - considered anthropized - are in optimal conditions. This difference can be explained by its location, far from the dense belt and closer to a spring protection area where high-impact activities are absent, even in adjacent areas. With so many risk factors for the conservation of riverine environments, it should be noted that the terrestrial environment around them affects rivers; therefore, all these factors must be understood to understand their dynamics.[52]

There is an impact on the riparian zone, mainly due to anthropogenic factors. Habitat quality is associated with the intensity of human activity and land-use types in surrounding areas.[53] In this sense, it is worth mentioning that the intangible area of the island has 72% in the form of slopes above 30%. Of these, 94% are in places with steep slopes and cliffs that tend to erode due to their susceptibility. Removing vegetation cover can destabilize and trigger ravines, furrows, laminar erosion, and mass displacement.[54] Thus, understanding how stressors interfere with and affect the ecological status and ecosystem services is essential for developing Basin Management Plans and creating future environmental policies.[55]

Master Plan for Socio-environmental Development of Ilhabela Municipality.[56] indicates the preservation, protection, and recovery of the environment's hydrographic basins and water resources. According to this instrument, the most impacted area is classified as an Urban Area of Low Restriction, which comprises reliefs with predominant slopes from 0 to 30%, close to the administrative, commercial, and services center. Intense urbanization along the island's beaches has led to higher rates of coastal erosion.[57]

It is challenging to distinguish natural changes from human activities, specifically on islands.[58] The resilience and resistance of existing vegetation and the attributes and types of existing species have important implications for mitigating changes that will affect the biotic composition of island ecosystems.[41] The analysis we carry out in these environments also considers external processes as primary determinants of the structure and operations of river environments. In recent years, anthropogenic activity has facilitated the invasion of ecosystems by non-native species and natural hazards, which has led to the worsening of several environmental problems, including the degeneration of ecosystem services and the sharp decline in biodiversity.[59] Among other factors, impacts on aquatic ecosystems are caused by deforestation of native vegetation, physical changes in ecosystems, removal of riparian vegetation, and loss of ecosystem goods and services offered by rivers.[60]

Areas of dense and sparse occupation characterize the island's territory. Dense areas are along the continuous urban area characterized as a priority for urbanization purposes within the Special Economic Zones included in the master plan, and sparse areas are those with low densification characteristics. Environmental protection should predominate, aiming at its perpetuation and sustainability.[56]

There is a trend toward expanding activities driven by local economic growth. Although Ilhabela tourism is the primary source of income for island communities, it contributes to the impact on the environment. It directly interferes with the availability of drinking water, which is a predominant activity among services in Ilhabela.[35] thus representing 80% of employment rates and total local income.[61] There is a greater vulnerability in the region close to the coastal part that faces the São Sebastião Channel, the most anthropized region.[62] The lack of treatment structures, dumps, and domestic sewage is a conservation problem, especially in irregular occupations.

In order to contain the advance of the deterioration of water and vegetation cover, policies for the preservation and control of the use of environmental resources must strictly comply.[63] Although surface water quality presents a favorable scenario for most water bodies in UGRHI 3, the rivers that cut through the most densely populated urban points gradually lost water quality.

Brazil has numerous public policy instruments for biodiversity conservation, especially for protected areas.[64] The Municipality's Atlantic Forest Conservation and Recovery Plans are essential for carrying out actions that can only be implemented through the guidelines established here.[65] To address today's sustainability challenges, recognizing dependence on human well-being and natural capital is essential.[66] The environmental issue related to water requires the participation of various social actors, and the management of water resources must occur in an integrated manner.[67]

Thus, characterization makes it possible to establish a relationship between parameters measured in a basin and its conditioning factors to assess its vulnerability.[68] The introduction of monitoring and control instruments as indicators of environmental integrity allows the measurement of conditions in these ecosystems.[69] One challenge is to apply the proposed protocol to many islands and archipelagos and to attract collaborative work to achieve conservation goals.[70]

According to Bebbington et al., it is necessary to find models, metrics, and tools to articulate how current activities are unsustainable. In this sense, a multivariate analysis was used to assess the strength of the critical variables in the set of variables.[71]

However, indicators can simplify, quantify, analyze, and communicate complex information to conceptualize phenomena and assess and identify trends in hot spots.[72]

Conclusions

This work alerts the need for studies and conservation of the islands, especially the preservation of the environments of the riparian islands, the maintenance of available water resources, and the natural environments and biodiversity.

It was possible to verify the vulnerability and the conservation conditions in each habitat assessed through the stress gradient. The approach proposed by the protocol was influential in the diagnosis and monitoring of riparian environments, which aimed to maintain their habitats and biodiversity. It also aims to contribute to valuing and safeguarding this legacy, which is unique in the world's oceanic islands.

This methodology intends to support research and public conservation and management policies. It is necessary to suggest a study for the recovery of designated areas, which are in regular conditions and located in sub-basin 30, which has less municipal and administrative protection.

We recommend that public bodies responsible for the environment and water resources take note of the situation and promote the adoption of measures for the recovery of the degradation processes that have been observed to ensure the preservation of biodiversity and the sustainable use of water and natural resources.

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None

Conflicts of interest

All authors declare that there is no conflicts of interest.

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