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Seasonality of Gross Primary Production in the Atlantic Forest of Brazil

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ABSTRACT:

The approach to carbon sequestration by ecosystems is critical to mitigating the damage and consequences of their effects at regional and global levels. Thus, this study was based on the hypothesis that Atlantic Forest regions have a relevant capacity of atmospheric carbon absorption. For this purpose, the Gross Primary Production data provided by the Moderate Resolution Imaging Spectroradiometer sensor onboard the Earth-orbiting platform and its relationship with the climatic variables of the Itatiaia National Park were analyzed. The year 2015 presented the highest means of Gross Primary Production for the dry and rainy period when compared to 2005 and 2010, with values ranging from 7 g C m^{-2} d^{-1} to 8 g C m^{-2} d^{-1}. The highest negative trends were for temperature in the dry season of 2005 ($Z = -0.29$), rainfall in the dry period of 2010 ($Z = -0.36$) and 2015 in the annual and dry season ($Z = -0.23$ and -0.38). There was no significant trend of Gross Primary Production in the Itatiaia National Park. The land use and occupation classes that stand out with the highest values of mean Gross Primary Production are Dense Ombrophylous High-Montane Forest (9.98 g C m^{-2} d^{-1}) and Dense Montane Forest (9.09 g C m^{-2} d^{-1}). Temperature is the environmental factor of greatest variation among the seasons in the Itatiaia National Park region. The results of this study present relevant importance and contribution to the sustainable management of the Itatiaia National Park and subsidize programs that help in the recovery of uncharacterized areas of the Atlantic Forest.

Keywords: climate change, carbon stock, remote sensing, forest biomass, Conservation Units.

1. INTRODUCTION

In the context of climate change, the focus for carbon sequestration by forest ecosystems is critical to mitigate damage and its consequences at regional and global levels (Sharma et al., 2013). The main process involving carbon sequestration by ecosystems is called Primary Production. This production is processed from the conversion of light energy into phytomass. Gross Primary Production (GPP) refers to photosynthesis at the ecosystem level and is one of the key processes controlling the exchange of carbon dioxide (CO_2) between the biosphere and the atmosphere and is important to offset anthropogenic CO_2 emissions (Beer et al., 2010).

Changes in carbon storage in vegetation and/or soil may have significant implications for the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHG) in the atmosphere, as a function of the burning and/or decomposition resulting from the withdrawal of forests and hence contribute to regional and global climate change (Lung and Espira, 2015). In this sense, tropical forests represent a large part of the carbon in the form of biomass, characterized by a high rate of primary production, and can be attributed to these forests a large fraction of global production (Sharma et al., 2013). However, tropical forests are under great anthropic pressure, especially in Brazil (Metzger et al., 2009).

The Brazilian biome Atlantic Forest is considered one of the most biodiverse areas of the planet and has an original composition characterized by a mosaic of vegetation classified as Dense, Open and Mixed Ombrophylous Forests; Deciduous and Semidecidual Seasonal Forests; Altitude Fields, Mangroves, and Sandbanks (IBGE, 2012). However, this biome has been undergoing a significant reduction of its original cover (FUNDAÇÃO SOS, INPE, 2011), and currently, most of its remnants occur in the form of small fragments, isolated and composed by secondary forests in different successional stages (Metzger et al., 2009). Therefore, all these characteristics gave the Atlantic Forest biome a status of global Hotspot for conservation (Mittermeier et al., 2005).

Given the above, it is evident the need for research related to the monitoring of carbon in areas of the Atlantic Forest biome. However, there is a need for representative areas of the Atlantic Forest for studies related to changes in the landscape and carbon stock. Inserted in this context, the Integral Protection Conservation Units (SNUC, 2000), such as the Itatiaia National Park (PNI) present potential for research related to the monitoring of the atmospheric carbon of the Atlantic Forest biome. The PNI presents several phytophysiognomy of the Atlantic Forest in different successional stages and different areas at different levels of anthropization (Barreto et al. 2013). However, in order to evaluate the real contribution of vegetation to atmospheric carbon fixation, it is essential to integrate tools capable of quantifying this element in the atmosphere (Gibbs et al., 2007; Bustamante et al., 2016; Graham et al., 2017).

The National Aeronautics and Space Administration (NASA) and Earth Observing (EOS) generate every eight days, Gross and Net Primary Production images of terrestrial ecosystems around the globe with a spatial resolution of 1 km (Heinsch et al., 2003; Running et al., 2004). These organizations provide free data for various educational and research institutions. With this data, many works were carried out using remote sensing and geoprocessing in the monitoring of atmospheric carbon. However, these papers emphasis on the Amazonian biome (Santos and Costa, 2003; Aguiar et al., 2006; Keller et al., 2006; Vourlitis et al., 2008; Sendall et al., 2009; Vourlitis et al., 2011; Souza et al., 2014) and little attention to the Atlantic Forest (Paiva and Fernandes, 2015; Ribeiro et al., 2015).

Among the tools integrated into the studies of Primary Production, the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the AQUA and TERRA platforms represent an important technological advance for the climatic and atmospheric carbon studies. The MODIS sensor becomes a promising tool in the 21st century to attempt to analyze the global carbon cycle and its relation to climate change in terrestrial ecosystems (Zhou et al., 2017; Shi et al., 2017; Shi et al., 2018). Despite its limitation in GPP estimates in some ecosystems such as tropical biomes, due to their high heterogeneity and high carbon concentration (Kimball et al., 2017), the GPP derived from the MODIS sensor must still be studied at a local scale in an attempt to use an improved resolution of land use and coverage and local climatic data such as the presence of flux towers for validation (Madani et al., 2017).

In this perspective, it is evident the need for research related to the carbon fixed in areas of the Atlantic Forest biome. Consequently, generating new structural information is essential to mitigate the possible anthropic impacts, to plan actions of the Conservation Units and to promote efficient management techniques that allow us to assist in the conservation of ecosystems.

Thus, this research was based on the hypothesis that forests of the Atlantic Forest have significant Gross Primary Production compared to other tropical forests. Therefore, the objective of this study is to analyze seasonally the Gross Primary Production and compare with the meteorological variables in the Itatiaia National Park.

2. MATERIAL AND METHODS

2.1 Characterization and location of the research area

The Itatiaia National Park is located in the southeastern region of Brazil, between the parallel 22°22'31"S and the meridian 44°39′44″. The park is located in the Serra da

Mantiqueira, between the States of Minas Gerais and Rio de Janeiro, close to the border with the State of São Paulo. Its boundaries reach parts of the municipalities of Itatiaia and Resende in the State of Rio de Janeiro, and Itamonte and Bocaina de Minas in the State of Minas Gerais (Barreto et al., 2013) (Figure 1).

Figure 1

The PNI was the first Conservation Unit (UU) in Brazil, established in 1937. The creation of the PNI was driven by abiotic and biotic elements of extreme relevance such as rare water resources, animals, and plants. These elements are distributed in its current 28,084 hectares of the protected area (Barreto et al., 2013).

Being part of the Serra da Mantiqueira, the predominant relief of the PNI presents a topographic feature that varies from mountainous to steep. The elevations range between 540 m at the southern end and 2,791.55 m at the Pico das Agulhas Negras in the central region of the PNI. Slopes range from 30% for mountainous regions and 50% for steep ones (Barreto et al., 2013).

Due to the mountainous and rugged relief, the PNI presents mostly shallow and young soils. The predominant soil class is the Typical Dystric Humic Cambisol that occurs widely on the slopes. The highest and/or most pronounced slopes dominate the pedological units of the typical Dystric Litolic Neosol. Thicker soils such as Oxisols and Ultisols occur preferentially in slopes and talus deposits (Barreto et al., 2013). In addition, the occurrence of Folic and Fibric Histosols in marshy depressions above the 1,200 m from the PNI (Soares et al., 2016).

The relief, geomorphology and soil characteristics influence the distribution of land cover classes of the PNI. The natural classes of Rocky Outcrop, Altitude Fields, Mixed Ombrophylous Montane Forest, Dense Ombrophylous High-Montane Forest and Montane Forest are mostly settled in difficult to reach region with high altitudes and steep slopes. The soils associated with the Altitude Fields are the Folic and Haplic Histosols in marshy depressions and typical Lithic Leptosol. The Ombrophylous Forests are established in Oxisols, Ultisols and Humic Cambisol. Rocky Outcrops are distributed in the central region where little density of rupiculate plant individuals is observed. Together, these natural classes account for about 83% of PNI coverage. On the other hand, anthropic classes such as agriculture, livestock, urban area, and forestry are located in more accessible regions such as those in slopes and are usually associated with the Oxisols and Ultisols orders (Barreto et a., 2013; Soares et al., 2016).

According to the Köppen-Geiger classification (Alvares et al., 2013), the PNI climatic domain is composed of two mesothermal types. The mesodermal type Cwb presents summer mild and rainy season in the summer, occurring in the elevated parts of the landscape, generally above 1,600 m of altitude. The mesothermic Cpb presents summer mild without a dry season, occurring in the lower regions of the relief (Barreto et al., 2013).

2.2 MODIS Product

The MOD17A2 product related to gross primary production is a cumulative composite of GPP values based on the concept of the efficiency of solar radiation utilization by vegetation (ε). In this logic, primary production is linearly related to the absorbed photosynthetically active radiation (APAR), according to Eq. 1. The APAR can be calculated as the product of the incident photosynthetically active radiation (PAR), in the visible spectral range from 0.4 μm – 0.7 μm assumed as 45% of the total incident solar radiation and the fraction of absorbed photosynthetically active radiation by the vegetation cover (FAPAR) (Monteith, 1972; 1977; Heinsch et al., 2003).

$$GPP = \varepsilon * PAR * FPAR \quad (1)$$

One of the major challenges in the use of such models is to obtain the efficiency of using "ε" light in a large area, due to its dependence on environmental factors and the vegetation itself. One of the solutions consists in relating "ε" according to its maximum value (ε_{max}), plus the environmental contributions synthesized by the minimum air temperature ($Tmin_{scalar}$) and the status of water in the vegetation (VPD_{scalar} - water vapor pressure deficit) (Field et al., 1995), according to Eq. 2:

$$\varepsilon = \varepsilon_{max} * T_{minscalar} * VPD_{scalar} \quad (2)$$

In this study, we used the MODIS GPP: 5.0 version with seasonal images for the years 2005, 2010 and 2015. Pixels values referring to the digital numbers of the MODIS images were converted into biophysical values (Kg C m^{-2}) through multiplication by the scale factor (0.0001) (Heinsch et al., 2003) (Eq. 3). The GPP values were also transformed from the accumulated value every 8 days to mean values every 8 days and converted from Kg C m^{-2} day^{-1} to g C m^{-2} day^{-1}.

$$GPP\_1km = \frac{\text{Biophysical Pixel (kg C m}^{-2})}{8} \quad (3)$$

2.3 Meteorological variables

Temperature and rainfall data were obtained from the Resende-RJ Conventional Weather Station (EMC), OMM code: 83738, provided by the National Institute of

Meteorology – INMET (2005, 2010 and 2015). After preliminary data analysis, the mean temperature was calculated and the occurrence and volume of rainfall (mm) was determined for the respective Julian days in the respective years.

2.4 Statistical methods

For the trend analysis of air temperature, rainfall and estimated GPP (orbital) series, daily air temperature and rainfall data were considered and converted into the annual scale, dry and rainy periods. The GPP was calculated every 8 days and also converted into the annual scale, dry and rainy periods, and these data were submitted to the non-parametric Mann-Kendall (MK) test. The MK test considers that, under stability of a time series, the succession of values occurs independently, and the probability distribution must always remain the same (random series) (Mann, 1945; Kendall, 1975). Based on the Z statistics, a decision can be taken to accept or reject Ho, that is, the hypothesis of data stability cab be accepted or rejected in favor of the alternative hypothesis (existence of a trend in the data). The sign of the Z statistics indicates whether the trend is increasing ($Z> 0$) or decreasing ($Z < 0$). Significance level adopted is $\alpha = 0.05 = 5\%$ for the MK test. If the probability p of the MK test is less than the α level, $p <\alpha$, a statistically significant trend exists, whereas $p> \alpha$ confirms an insignificant trend. For samples where there are no trends, the Z value is close to zero (Mann, 1945; Kendall, 1975; Caúla et al., 2016).

With the information of the climatic variables temperature and rainfall and the GPP value on the respective Julian days, multivariate cluster analysis was performed by the Two-Step Cluster and Principal Component Analysis methods. Statistical analysis was performed using the SPSS 15.0 and R 3.2.1 software.

2.5 Land Cover

According to the PNI survey with the help of IKONOS high-resolution images (1 m - Panchromatic and 4 m - Multispectral), the Itatiaia National Park has seven land use classes. In this study, these data were clustered into 7 classes according to their similarity (Table 1). The classification of soil use and the cover was performed by manual method (visual) and confirmed in the field. The date of the images is July 2011 (HIPARC, 2011). In this case, the ArcGIS 10.2 software was also used to read the data, and through the tool *selected by attributes,* the number of areas in each class was quantified and the GPP value was extracted for each class in a spreadsheet.

Table 1

3. Results and Discussion

3.1 Spatial analysis of the GPP for the years 2005, 2010 and 2015

In the analysis of the dry season (Figure 2a) there was a concentration in almost all PNI areas with a mean value of 6 g C m^{-2} d^{-1}, the highest values were found in the Northeast region of the park, where the predominance was of F and G classes. Based on the images, the rainy season was the one with the highest mean values of approximately 6 g C m^{-2} d^{-1} (Figure 2b). The highest and lowest GPP values found in the dry season for the year 2005 (7 g C m^{-2} d^{-1} and 1 g C m^{-2} d^{-1}) were concentrated in the Northeast portion and a small strip in the South, where the predominance is of F and G classes. For the rainy season, the lowest values were concentrated in the central portion of the

PNI (A and D), the highest values in small portions to South and North with a predominance of B, F and G classes.

Figure 2

The dry period was characterized by a high GPP of approximately 7 g C m^{-2} d^{-1} in almost all PNI areas (Figure 3a) very close to the values found in the rainy season. In 2010 the rainy season had the highest mean values above 7 g C m^{-2} d^{-1} (Figure 3b). The South, Northwest and Northeast regions obtained the highest GPP values, where B, F, and G classes are concentrated. The intermediate values of approximately 5 g C m^{-2} d^{-1} are concentrated in A, C and H classes, respectively.

Figure 3

The year 2015 (Figure 4a and b) presented the highest means for the dry and rainy period when compared to 2005 and 2010, with values ranging from 7 g C m^{-2} d^{-1} to 8 g C m^{-2} d^{-1}. This year's dry season for almost all PNI areas presented values close to 7 g C m^{-2} d^{-1} and in the rainy season, the highest values were concentrated in the southern portion with values higher than 8 g C m^{-2} d^{-1}. In the dry and rainy period, the F class had the highest GPP.

It should be noted that the higher GPP values in the rainy season are associated with the combination of high solar radiation, high vegetation index and high evaporative fraction, factors present in Rio de Janeiro especially in the summer, which was characterized with the highest GPP for both years and the land use and cover in the state. The results obtained were similar to those found by Sjöström et al. (2013), where the authors reported that the MOD17A2 responded better to humid conditions than dry places in Africa. Seasonal pattern of GPP found in the study accompanies the highest rates of solar radiation. Another fact was that the results obtained agree with Peng et al. (2013), who mentions an increased growth of chlorophyll content in crops closely linked to the high rates of GPP. Another important result found here is that the wetter PNI regions (rainy period) allocate more carbon than drier regions (dry period), results similar to those found in the Amazon region by Araujo-Murakami et al. (2014). Other important results should be considered as those found by Yang et al. (2018), where for the same period studied in the Amazon region, they concluded that due to the drought in this period, the forest grew and there was an increase of green areas in the Amazon, in contrast to SIF (solar-induced chlorophyll fluorescence) reduced. Another important conclusion is that if the frequency of events such as El Niño associated with severity of extreme droughts in this region would result in loss of productivity, which would lead to an increase in carbon emissions in the Amazon region (Yang et al., 2018).

Figure 4

3. The trend of the meteorological variables and GPP for the years 2005, 2010 and 2015

In this study, it was observed (Table 2) that the temperature trend was significant for the dry season in the year 2005 with decreasing Z= -0.29. However, in 2010 for the rainfall variable, the reduction in the dry period was observed (Z = -0.36). In the year 2015 in both analyzed conditions of rainfall trend, there was annual and dry decrease (Z = -0.23 and -0.38) and increasing trend of 0.35 in the rainy season, respectively (Table 2). There were no significant trends in GPP. The results of rainfall decrease in the dry period can be compared to studies in other locations in Brazil, where the authors highlight two of the largest droughts of the century in the Amazon region in 2005 and 2010 (Bi et al., 2016). In 2015 there was a reduction of rainfall in both dry and rainy periods in the PNI, this phenomenon was observed and discussed at large and regional scale in Brazil by Cavalcanti et al. (2017). Reductions in rainfall in 2015 also lead to increased transport of aerosols to the atmosphere and loss of biomass from fires (Aouizerats et al., 2015). The decreased occurrence of rainfall in the dry periods as found in this study can cause an increase in the number of fires and emissions of greenhouse gases to the atmosphere (Margono et al., 2014). The authors also conclude that the growing loss of primary forests has significant implications for climate change mitigation and biodiversity conservation efforts.

Table 2

3.3 Land Cover and GPP para os anos 2005, 2010 e 2015

A gradual increase in GPP was observed over the selected years with a mean value above 6 g C m^{-2} d^{-1} (Figure 5). The lowest annual GPP mean was 7.42 g C m^{-2} d^{-1} for 2005, differing statistically from the subsequent years (2010 and 2015) with values of 6.7 g C m^{-2} d^{-1} and 7.2 g C m^{-2} d^{-1}. However, it is possible to perceive a greater amplitude of GPP values for the rainy season, ranging from 6 g C m^{-2} d^{-1} in 2005, 6.78 g C m^{-2} d^{-1} and 7.2 g C m^{-2} d^{-1} for 2015 (Figure 5).

Figure 5

The highest GPP values for the years studied in both periods (dry and rainy) were for F class, with the highlight for the year 2010 in the rainy season with 10.65 g C m^{-2} d^{-1} (Figure 6). The lowest GPP found was for the H class in the dry period in 2005 of approximately 3.36 g C m^{-2} d^{-1} (Figure 6). These results become important since they can serve in the future for modeling and knowledge of the dynamics of this ecosystem. The work carried out by Tramontana et al. (2015) emphasizes the importance of using the GPP by satellite, since the scale would become wider, which would avoid the uncertainty of the modeling performed by point data. The results of this study may be associated with the zenith angle and even the canopies architecture as discussed and reported in the work carried out by Cheng et al. (2015). The PNI has a high altitudinal variability, which may in some way influence the results of higher or lower GPP in some land uses.

Figure 6

3.3 Cluster and principal component analysis

In order to better understand the dynamics of the climatic conditions, air temperature, and rainfall, a cluster analysis was performed according to the seasons, where it was observed that the seasons influence the climatic conditions of the PNI (Figure 7).

Figure 7

Statistical significance was observed in both clusters (rainy season and dry season) for temperature in all years, however, for rainfall, the significance was only observed in the year 2010 for cluster 2 (dry season) (Figure 8). For the GPP, no significant differences were observed.

The patterns of the dynamics of the environmental variables observed in Figure 8 show that temperature is the environmental factor of greatest variation among the seasons in the PNI region, which makes it a climatic variable essential in determining the GPP pattern.

Figure 8

To understand the PPG dynamics relative to seasons and land use, a Principal Component Analysis (Figure 9) was performed, where it was observed that the GPP values are influenced by seasons and there are a greater correlation among GPP values and F and G land use classes.

Figure 9

4. CONCLUSION

The highest GPP values were found in the rainy season in the Itatiaia National Park for both years. Land use and occupation classes that stand out are Dense Ombrophylous High-Montane Forest and Dense Montane Forest.

In relation to the Mann-Kendall test, there was a decrease in temperature in 2005 and a reduction in rainfall in the PNI in 2010 and 2015. GPP did not have significant trends.

A better understanding of surface data is needed to validate the results obtained. It is necessary the comparison with other orbital sensors of high spatial resolution and a greater temporality of the GPP, rainfall, and air temperature data series in the Itatiaia National Park.

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TABLES

Table 1. Land use and cover of the Itatiaia National Park.

Class	Land Cover
A	Rocky Outcrop
B	Agriculture. Anthropic Field and Other Fields
C	Urban Area
D	Vegetational Refuge
E	Planting Areas
F	Dense Ombrophylous High-Montane Forest
G	Dense Ombrophylous Montane Forest
H	Dense Ombrophylous Sub-Montane Forest

Table 2. Trend analysis by the Mann-Kendall test. * = statistically significant trend.

Year	Statistical Parameters	GPP			Temperature			Rainfall		
		Yearly	Dry	Rain	Yearly	Dry	Rain	Yearly	Dry	Rain
2005	Z	-0.07	-0.07	-0.03	0.18	-0.29	0.12	-0.03	-0.16	0.18
	p-values	0.52	0.65	0.87	0.25	0.06*	0.46	0.81	0.36	0.25
2010	Z	-0.03	0.06	-0.17	0.01	0.13	0.06	-0.10	-0.36	0.04
	p-values	0.75	0.69	0.26	0.91	0.40	0.73	0.35	0.05*	0.79
2015	Z	-0.01	0.12	-0.20	-0.11	-0.19	0.01	-0.23	-0.38	0.35
	p-values	0.90	0.43	0.20	0.28	0.22	0.98	0.04*	0.02*	0.03*

Legend: Z = Mann-Kendall test statistical analysis.

FIGURES CAPTIONS

Figure 1. Geographical location and land use and occupation (A) Rocky Outcrop, (B) Agriculture, (C) Urban Area, (D) Altitude Fields, (E) Planting Areas, (F) Dense Ombrophylous High-Montana Forest, (G) Dense Ombrophylous Montana Forest and (H) Dense Ombrophylous Sub-Montana Forest.

Figure 2. Spatial analysis of Gross Primary Productionin the Itatiaia National Park for the dry (a) and rainy (b) in 2005.

Figure 3. Spatial analysis of Gross Primary Production in the Itatiaia National Park for the dry (a) and rainy (b) in 2010.

Figure 4. Spatial analysis of Gross Primary Production in the Itatiaia National Park for the dry (a) and rainy (b) in 2015.

Figure 5. Gross Primary Production for dry and rainy periods in the Itatiaia National Park.

Figure 6. Gross Primary Production for dry and rainy periods by by land use and cover in the Itatiaia National Park.

Figure 7. Representativeness of clusters in the data set (a) and clusters significance test (b).

Figure 8. Clusters significance tests in function of climatic variables. Temperature 2005 (a), 2010 (b) and 2015 (c) and rainfall 2005 (d), 2010(e) and 2015(f).

Figure 9. Principal Component Analysis.

Figure 1

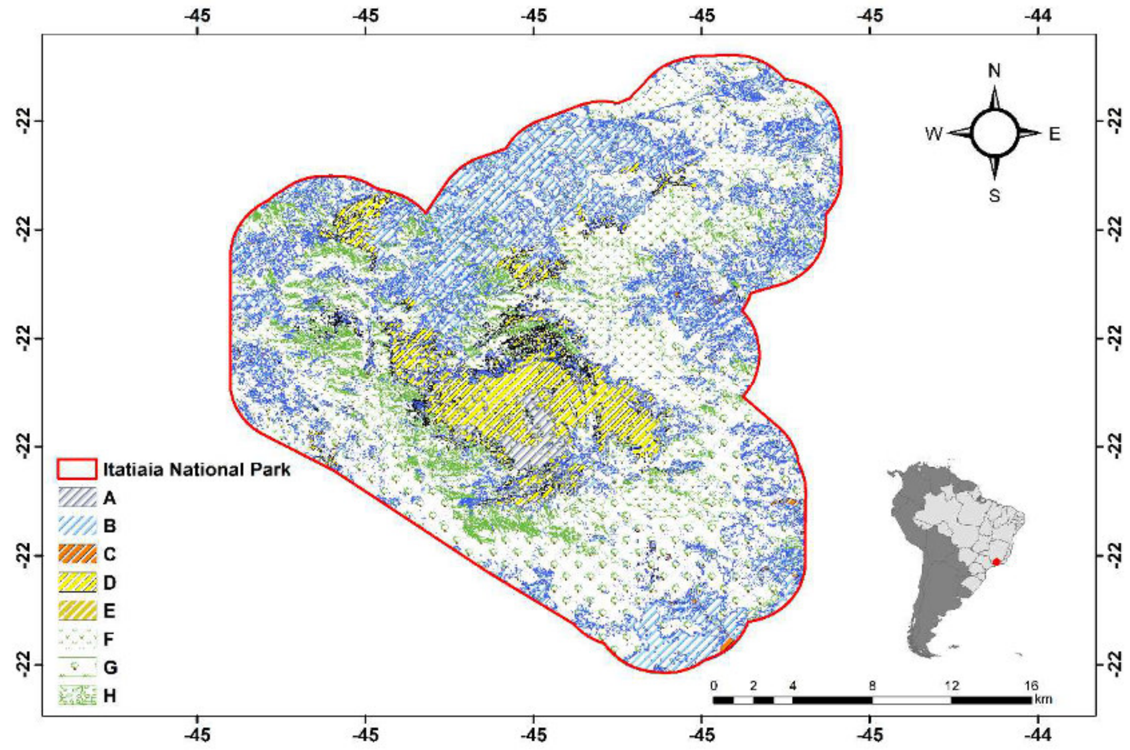

-45
-45
-45
-45
-45
-44
-22
-22
-22
-22
-22
-22
N
W
E
S
Itatiaia National Park
A
B
C
D
E
F
G
H
0
2
4
8
12
16
km

Figure 2

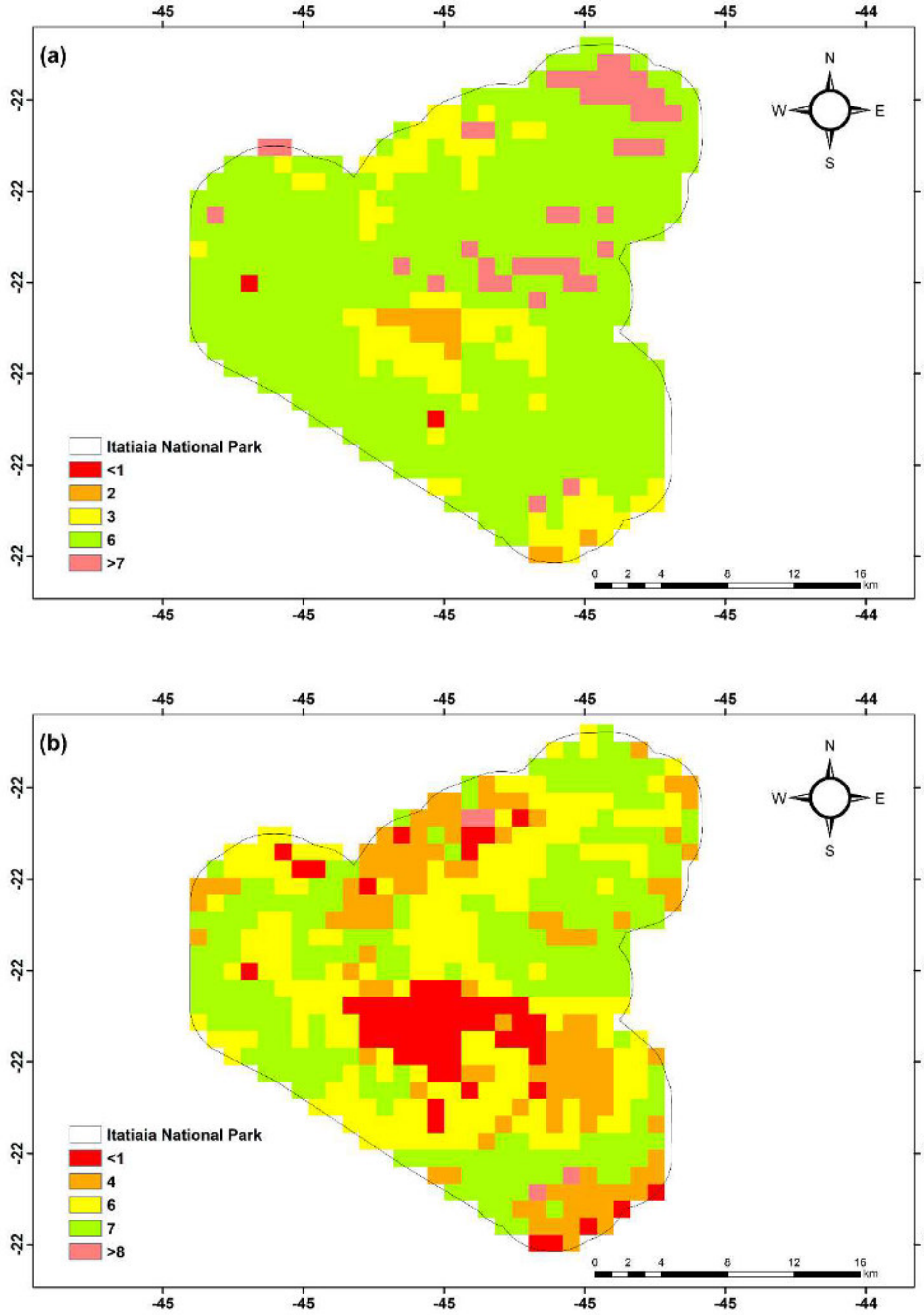
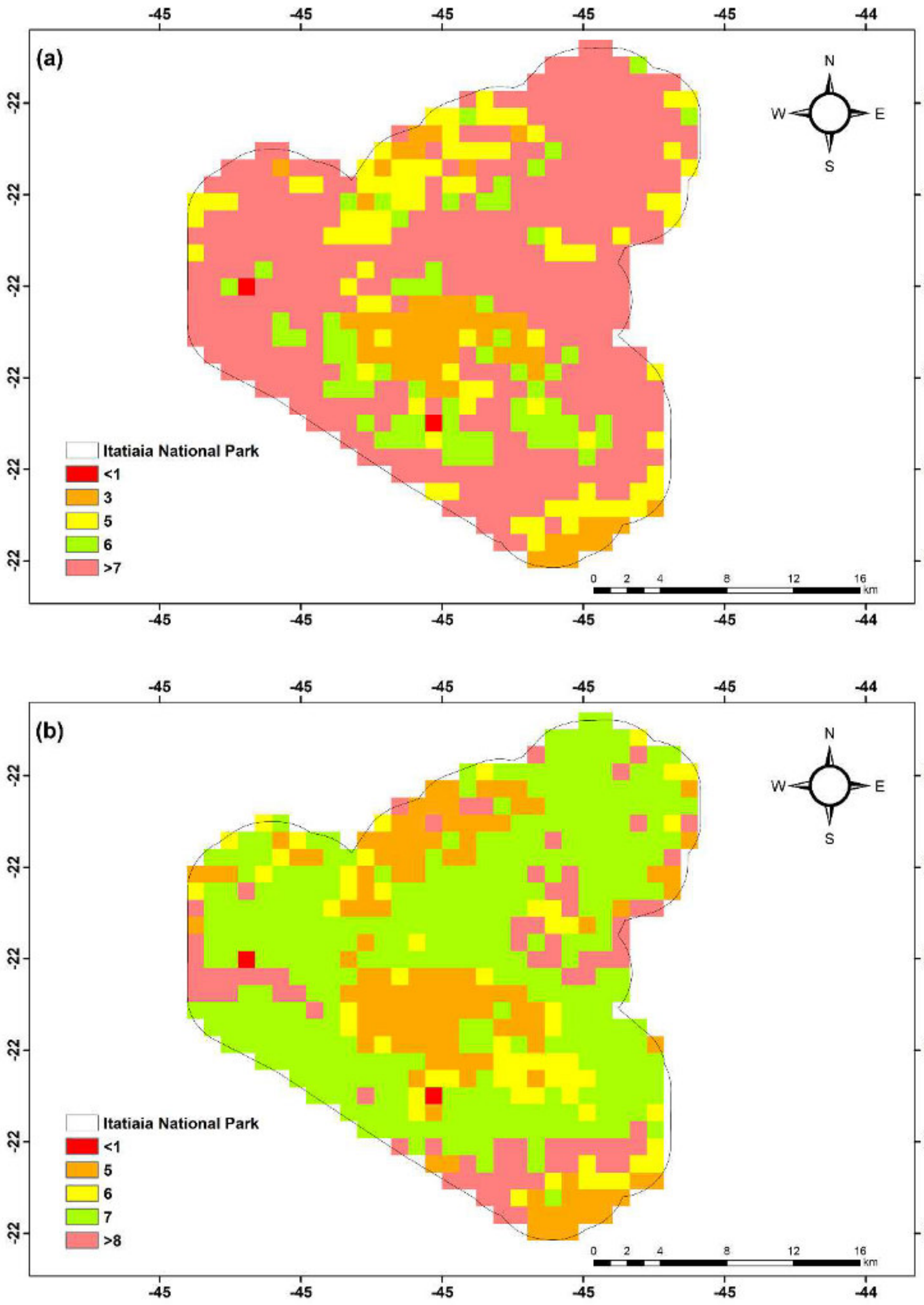

(a)
Itatiaia National Park
<1
2
3
6
>7
(b)
Itatiaia National Park
<1
4
6
7
>8
N
S
W
E
-45
-44
-22
0
2
4
8
12
16
km

Figure 3


(a)
Itatiaia National Park
<1
3
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>7
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W
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8
12
16
km
-45
-44
-22
(b)
Itatiaia National Park
<1
5
6
7
>8

Figure 4

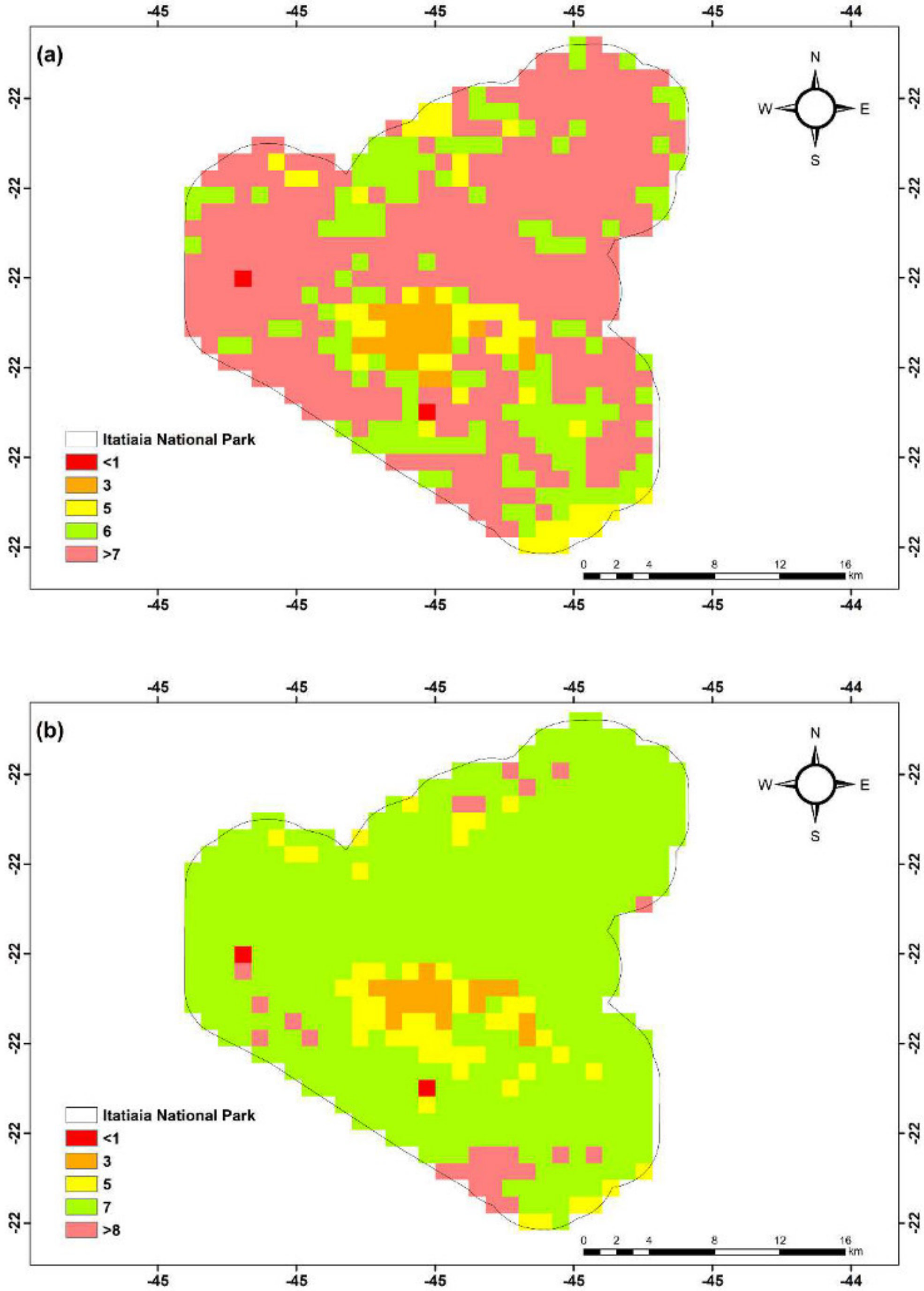

(a)
Itatiaia National Park
<1
3
5
6
>7
(b)
Itatiaia National Park
<1
3
5
7
>8
N
W
E
S
0 2 4 8 12 16 km
-45
-44
-22

Figure 5

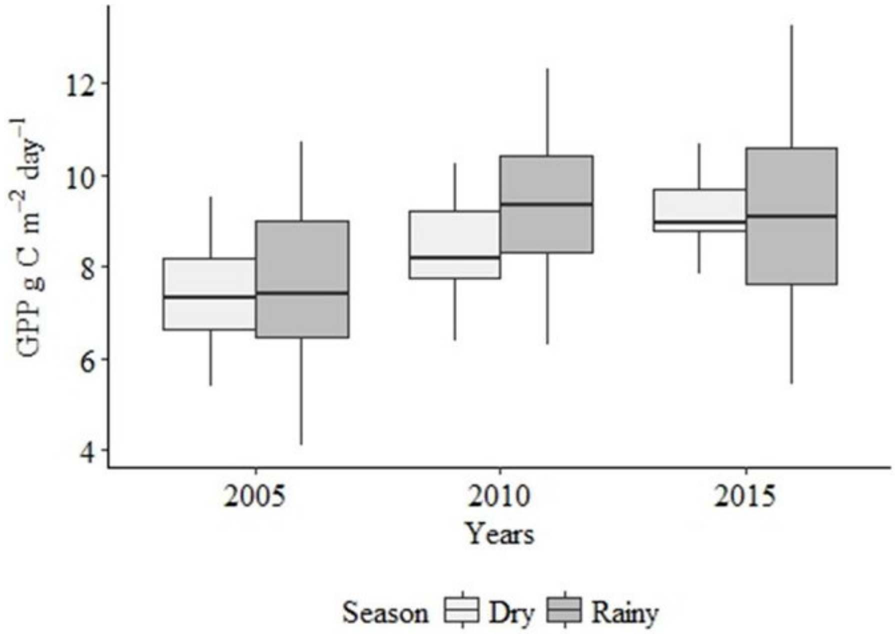


Figure 6

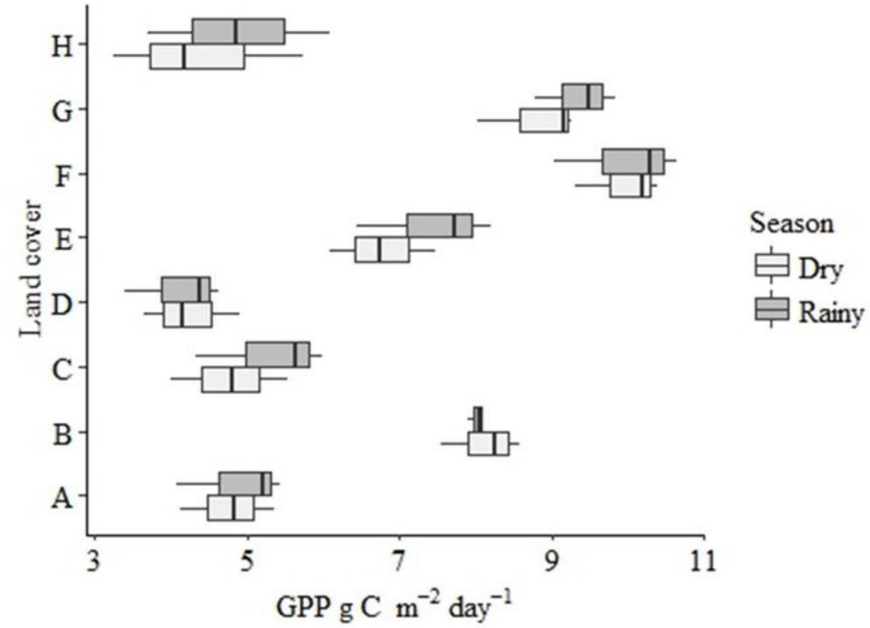


Figure 7

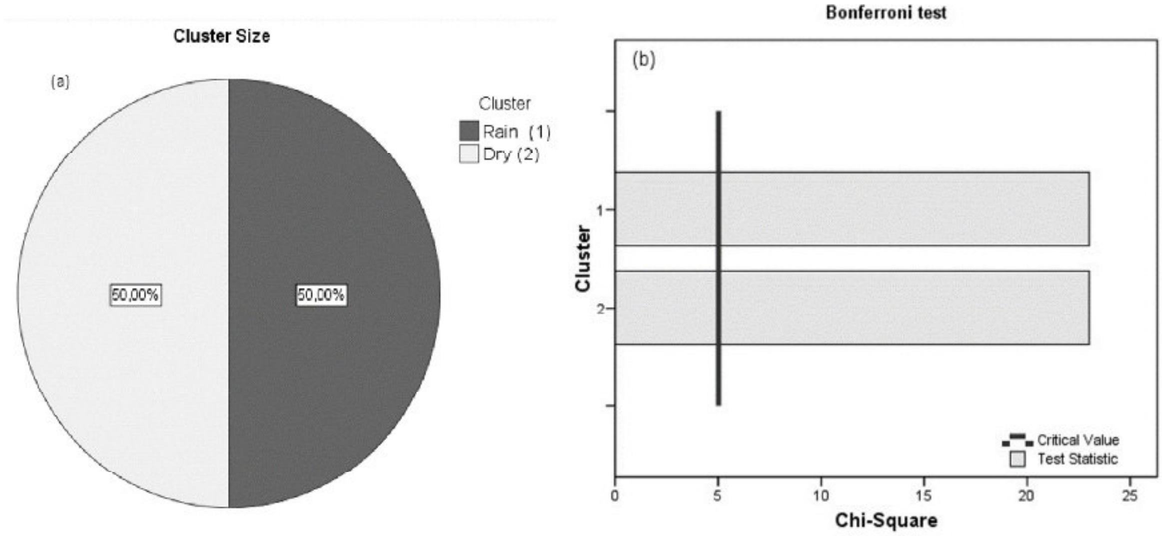

Cluster Size
(a)
Cluster
Rain (1)
Dry (2)
50,00%
50,00%
Bonferroni test
(b)
Cluster
1
2
Critical Value
Test Statistic
0
5
10
15
20
25
Chi-Square

Figure 8

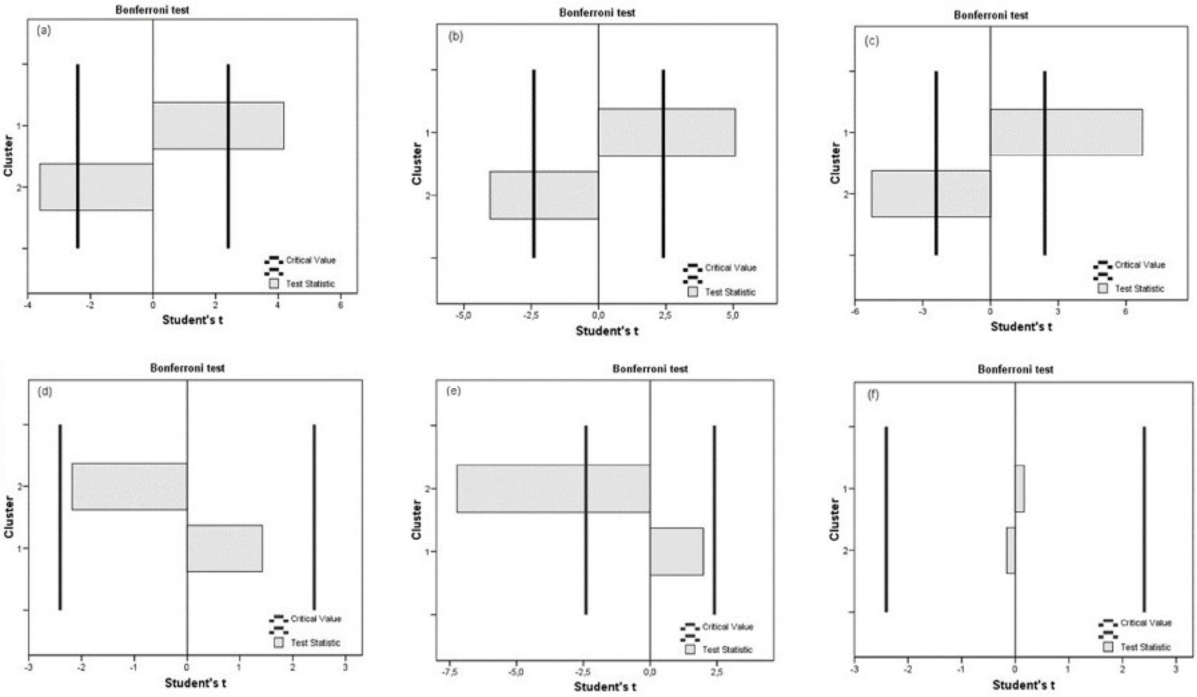
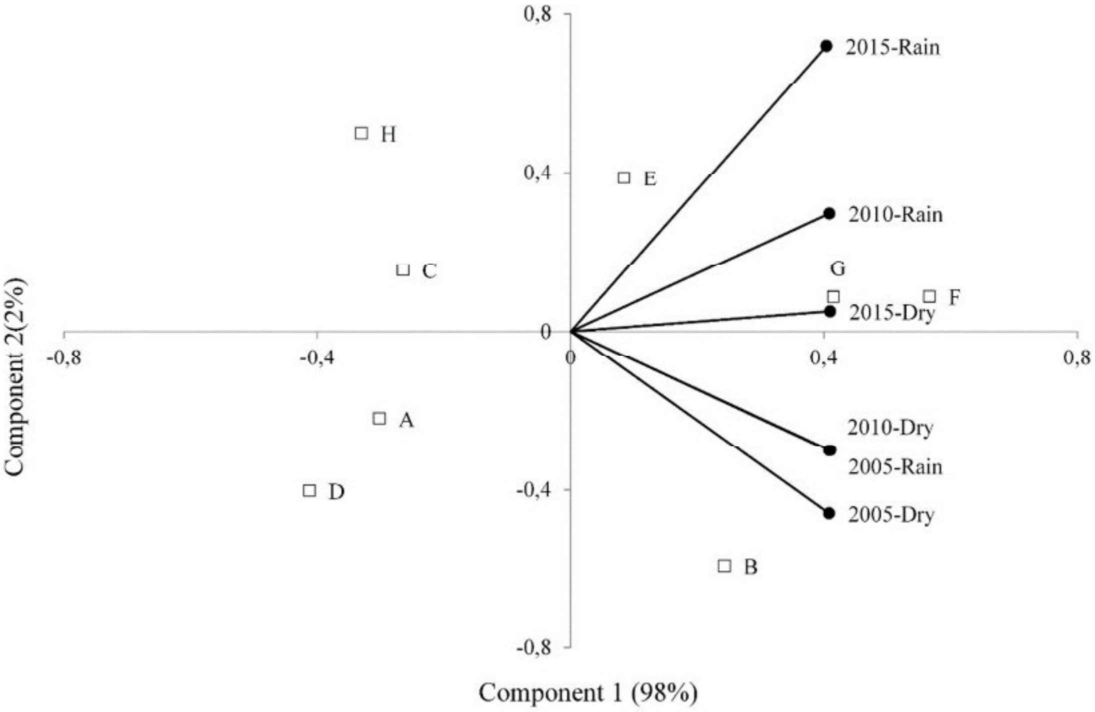

Bonferroni test
(a)
Cluster
1
2
Critical Value
Test Statistic
-4
-2
0
2
4
6
Student's t
Bonferroni test
(b)
Cluster
1
2
Critical Value
Test Statistic
-5,0
-2,5
0,0
2,5
5,0
Student's t
Bonferroni test
(c)
Cluster
1
2
Critical Value
Test Statistic
-6
-3
0
3
6
Student's t
Bonferroni test
(d)
Cluster
2
1
Critical Value
Test Statistic
-3
-2
-1
0
1
2
3
Student's t
Bonferroni test
(e)
Cluster
2
1
Critical Value
Test Statistic
-7,5
-5,0
-2,5
0,0
2,5
Student's t
Bonferroni test
(f)
Cluster
1
2
Critical Value
Test Statistic
-3
-2
-1
0
1
2
3
Student's t

Figure 9


0,8
0,4
0
-0,4
-0,8
-0,8
-0,4
0
0,4
0,8
2015-Rain
2010-Rain
G
2015-Dry
F
2010-Dry
2005-Rain
2005-Dry
H
E
C
A
D
B
Component 2(2%)
Component 1 (98%)

Highlights

Atlantic Forest regions have relevant capacity of atmospheric carbon absorption

There was no significant trend of Gross Primary Production in the Itatiaia National Park

Temperature is the environmental factor of greatest variation among the seasons in the Itatiaia National Park region.