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RESEARCH ARTICLE

Spatial distribution of single specie dominant forests of *Erythrina fusca* Lour. at the Taiamã Ecological Station, Pantanal, Mato Grosso, Brazil

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Abstract
The Pantanal biome has a great variety of habitats where plant species are distributed according to their particularities. This study aimed at evaluating the spatial distribution of arboreal/shrub vegetation in areas of single specie dominance *Erythrina fusca* forests. An aggregation test (K(t)) for *E. fusca* and spatial dependence tests (K(12)) between *E. fusca* and *Calophyllum brasiliense,* as well as *Alchornea discolor* and *Banara arguta* were performed. The correlation of the distance from the beginning of the plots (riverbank) to the abundance of individuals was tested, and finally, the Kernel density was estimated. We found that *E. fusca* is randomly distributed throughout the area, that the distribution of *C. brasiliense* and *A. discolor* is dependent on *E. fusca*, and that of *B. arguta* is not. The correlation analysis pointed to a decrease in the abundance of the community from the riverbank to the interior of the island, with a smaller reduction in the population of *E. fusca.* The density was higher in the regions close to the river. In addition, sites with a high concentration of individuals close to the elevations created by the roots of *E. fusca* were verified. The distribution of individuals was related to the flood pulse and the adaptive processes of plant establishment, where the flooding selects the species most tolerant to this type of environment, and the formation of higher microrelief in the landscape can increase the dispersion of the species. This points out that any disturbance that may occur in the flood pulse will change the environmental balance.

Keywords Abobral · Establishment · Ramsar · Tolerant · Wetland

Introduction

The Pantanal is a very particular ecossystem, with a great environmental and landscape heterogeneity, such a variety of macro-habitats as rivers, lakes, mountain ranges, forest islands ("capões"), and hill ranges ("morrarias"), with different plant landscapes. These different plant mosaics are composed of aquatic macrophytes, floodable fields, riparian forests, savannas, "cerradão," and deciduous forests (Prance and Schaller 1982; Pott et al. 2009). A substantial part of them are composed, for example, of single species dominant forests of pioneer species.

The understanding of the spatial distribution of arboreal individuals in these communities is essential: as the preferred and/or limiting sites of the species are identified, the knowledge about their ecological niches becomes more precise, contributing to the progress toward the development of forest succession models (Chaves et al. 2018). This allows the researchers to predict how a forest will react to a disturbance or even to microclimatic variations (Pottker et al. 2016). The species distribution at the microhabitat level allows inference about the richness, structure, and composition of the forest. In the Pantanal, for example, the presence of a species in a given environment is influenced by several factors, with individuals occurring in specific locations along a gradient, depending on the soil and climate conditions of each habitat (Gholami and Sayad 2018; Bao et al. 2018).

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From this perspective, it is expected that the distribution of individuals in areas such as the *E. fusca* forests in the Pantanal may be influenced by geomorphological and environmental ranges that are a consequence of geological processes, like sedimentation and erosion, caused mainly by the flood pulse (Junk et al. 2018). In addition, anthropogenic disturbs such advances in agribusiness in the Pantanal region, the Paraguay-Paraná waterway implementation, the hydroelectric plants in operation and construction, among other impacts, can disrupt the intricated flood pulse regulation, directly affecting monospecific plant formations and others elements in the landscape. In this sense, this study aimed to analyze the spatial distribution of arboreal/shrub vegetation in areas of single specie dominance forests of *E. fusca* at the Taiamã E. S., Pantanal de Cáceres, State of Mato Grosso, Brazil and its relationship with the flood regime and association with the most abundant species.

Material and methods

Study area

The study was conducted at the Taiamã Ecological Station (TES) (Fig. 1). The station was established under decree No. 86,061 on June 02, 1981. It is considered a Federal Conservation Unit of Integral Protection, to preserve nature and promote scientific research (Brazil 2000). In 2018, during the 13th Ramsar Convention on Wetlands of International Importance, the TES was granted the title of a Wetland of International Importance, that is, a Ramsar Site (RSIS 2019).

Taiamã Ecological Station (TES) is an island with approximately 11,554 ha. located in the northern region of the Pantanal, in the municipality of Cáceres, Mato Grosso state, Brazil, between the meridians W 57° 24′ and W 45° 40′ and parallels S 16° 48′ and 16° 59′. The station

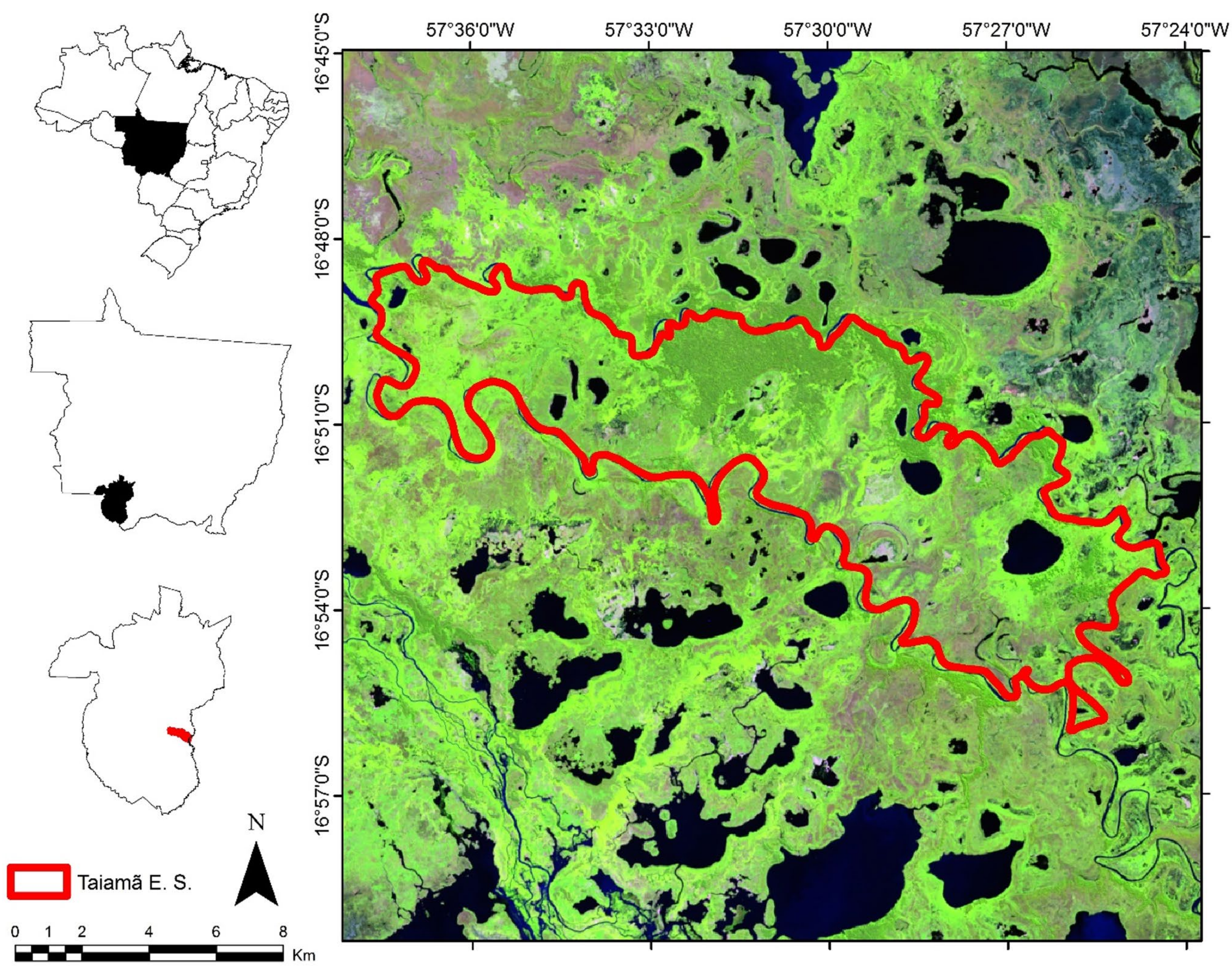

Fig. 1 Delimitation of the Taiamã Ecological Station (Esec Taiamã), northern Pantanal region, Cáceres, Mato Grosso, Brazil

area is delimited by the Paraguay River, which bifurcates into two channels in the region of Taiamã, giving rise to the island (Brazil 2017). The climate of the region is "Aw," according to Köppen's classification (Alvares et al. 2013), which is characterized by tropical vegetation, always with high temperatures and relative humidity (Brazil 2017). The region's relief is predominantly flat, with approximately 25 m in range and between 93 and 118 m in altitude, alternating between small elevations and depressions, and varying between forest environments and flooded fields. The soils of the micro-region are predominantly sandy-clayey and are classified as planosols (Brazil 2017). The macro-habitats of the TES include the aquatic macrophyte fields (occupying 48% of the island), flooded fields (24%), monospecific forests (*E. fusca*), (16%), polyspecific forests (8%), and lakes (4%) (Frota et al. 2017).

Field data collection

We adapted the grid sampling protocols of Brazil's Biodiversity Research Program (PPBio) and RAPELD (Rapid Assessments and Long-term Research) modules (Magnusson et al. 2005) being adopted in four to five-kilometer transects. The transects were installed, along with the station, and one outside of the TES in an area locally known by "the field", due to the landscape, most covered with grasses. In each transect, five modules were installed, with a one-kilometer distance between them (Fig. 2). Each module was made up of five 40 × 50 m plots (40 m wide × 250 m long, from the riverbank into the island), totaling one ha. per module.

In these transects, seven modules with *E. fusca* monospecific forests were identified (transect 1, modules 1, 2, 3 and 4; transect 2, module 1; and transect 4, modules 1 and 3) (Fig. 2). In the seven sampled modules, data on the spatial distribution of specimens were collected from all arboreal and shrubby individuals with a circumference > 10 cm and total height > than 3 m from 1.30 m in height (CAP).

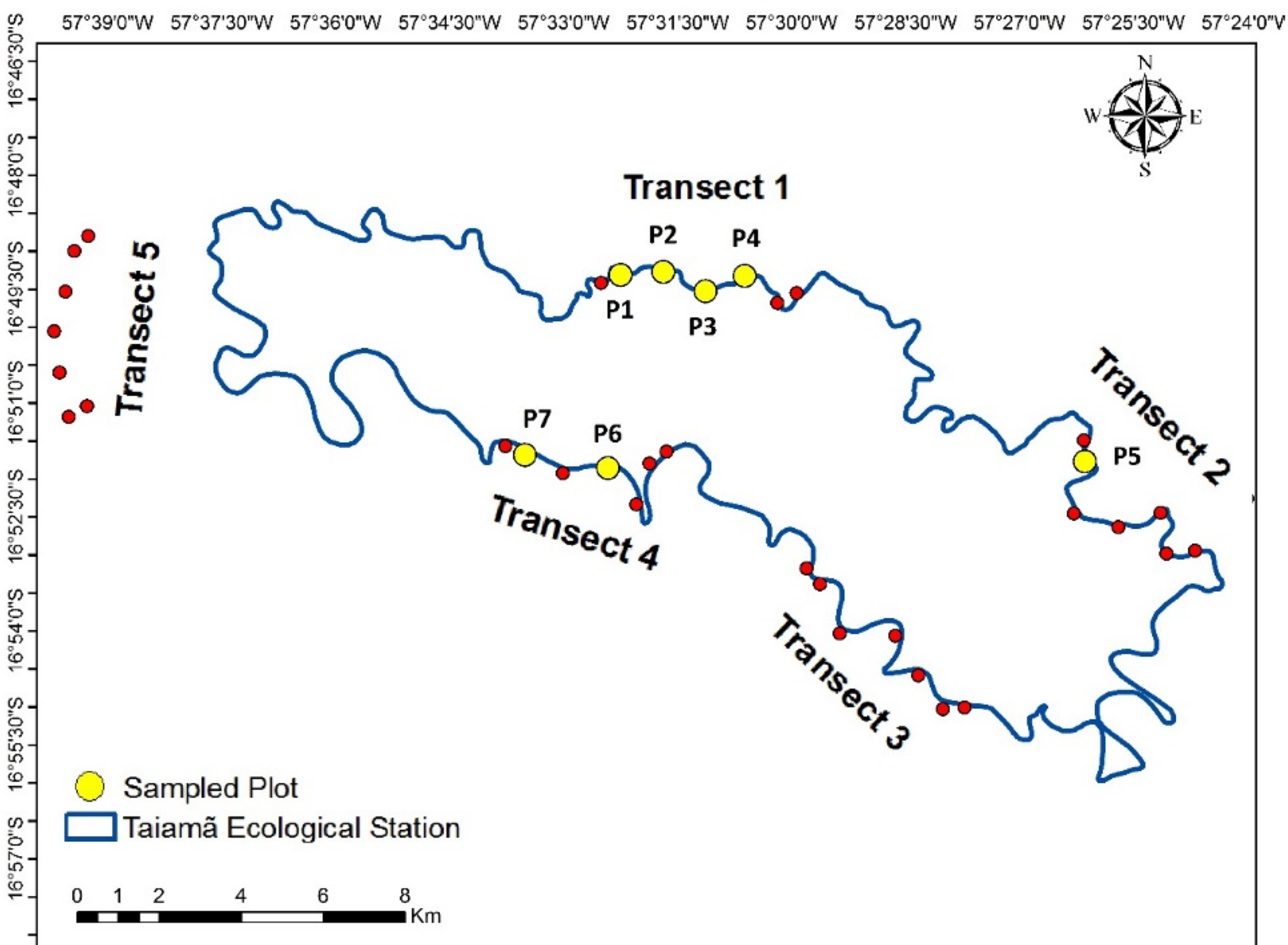

Fig. 2 Distribution of modules and transects of the DARP-Pantanal project, with emphasis on the modules sampled in this study

Dead trees were not considered. The spatial distribution was performed using the axis mapping method. The X-axis was the smallest side of the plot (40 m), and the Y-axis was the largest side of the plot (250 m) (adapted from PPBio) (Magnusson et al. 2005).

Data analysis

A Spearman's test was carried out to evaluate the correlation between the distance from the river (beginning of the plot) and tree abundance, with one test for the general community and one for the population of *E. fusca*. To perform these tests, 1-m classes were created, based on the spatial distribution (X and Y) of individuals in the modules, totaling 249 classes (from 0 to 250 m), and the abundance in each class was estimated. These correlation analyses were performed using the R software (Dessau and Pipper 2008).

With the ArcMap 10.1 software, using X and Y coordinates, distribution maps were constructed, and *Kernel density estimation* (Pranze 1962) was performed, evaluating each module, and considering the total abundance of trees found using the radius of 12.73 m (smallest side of the module (40 m), divided by *Pi*).

The function *K* of Ripley univariate (K(t)) (Aggregation Test) was applied to analyze the spatial distribution of *E. fusca,* and the function *K* of Ripley bivariate (K(12)) (Spatial dependence test) to analyze the spatial associations between the individuals of *E. fusca* with the individuals of the species *Calophyllum brasiliense* Cambess, *Alchornea discolor* Poepp., and *Banara arguta* Briq. that will present themselves with a value of more than five percent in the phytosociological analyses performed for the community. These analyses were performed using the R software (Dessau and Pipper 2008), using a radius of 12.73 m (smallest side of the module (40 m) divided by *Pi*).

Results

Spatial correlation

The Spearman correlation test, performed to investigate the relationship between abundance and distance from the river, showed a negative correlation for the community ($P = 0.000$ and correlation $= -0.44$) and the population of *E. fusca* ($P = 0.007$ and correlation $= -0.19$). This indicates that the abundance of species decreased as we moved away from the river's edge, noting that only the correlation value for the species *E. fusca* was lower than for the general community.

Distribution and density

Concerning the distribution, the community occurs as dispersed and discontinued in the studied modules (Fig. 3). A higher concentration of individuals was observed within the first meters of the plots near the riverbank. When more distant from the riverbank, the species disperse with varying abundance throughout the sampled area, a result in line with the correlation analysis. A difference in distribution was observed: in the modules 1, 2, and 4; the individuals were scattered throughout the area; in the modules 3, 5, 6, and 7, the distribution was discontinuous.

The distribution of *E. fusca* differed between the modules since it was the species that occupied the greatest extent of the areas, and in some modules (5 and 7), it was the only species distributed beyond the first 100 m. The species *C. brasiliense* occurred in all modules with discontinued distribution, with emphasis on its location near the individuals of *E. fusca.* The distribution of *A. discolor* also showed this close relationship with *E. fusca*, although more discontinuous than that observed for *C. brasiliense.* In some modules, *B. arguta* was recorded with a higher occurrence near the river.

Due to this distribution model, the highest densities were recorded near the river and distributed in discontinuous spots along with the studied modules. There was a variation within the modules, from points without trees to areas with high densities. Higher densities were found in most of the modules near the riverbed, except in modules 3 and 6 (Fig. 4).

Aggregation and dependence

By Ripley's K aggregation analysis, the distribution of *E. fusca* was random, since of the seven modules analyzed, there was only aggregation in module 2 (Table 1).

When analyzing the dependence of *C. brasiliense* and *A. discolor* on *E. fusca*, the analyses indicated spatial dependence in both cases. This dependence was shown by small values on the spatial scale, that is, the species occurred close to the individuals of *E. fusca,* with emphasis on the dependence of *C. brasiliense* in all modules. The results also showed that the distribution of *B. arguta* was independent of *E. fusca* in the areas studied.

Discussion

The results indicated that as the distance from the beginning of the plot or riverbank increased, the abundance decreased, except in modules 3 and 6. This area, closest to the river, is also known as a "marginal dike" and has a higher relief than the floodplain (Da Silva and Silva 1999). These areas are formed by sedimentation through river overflow as a

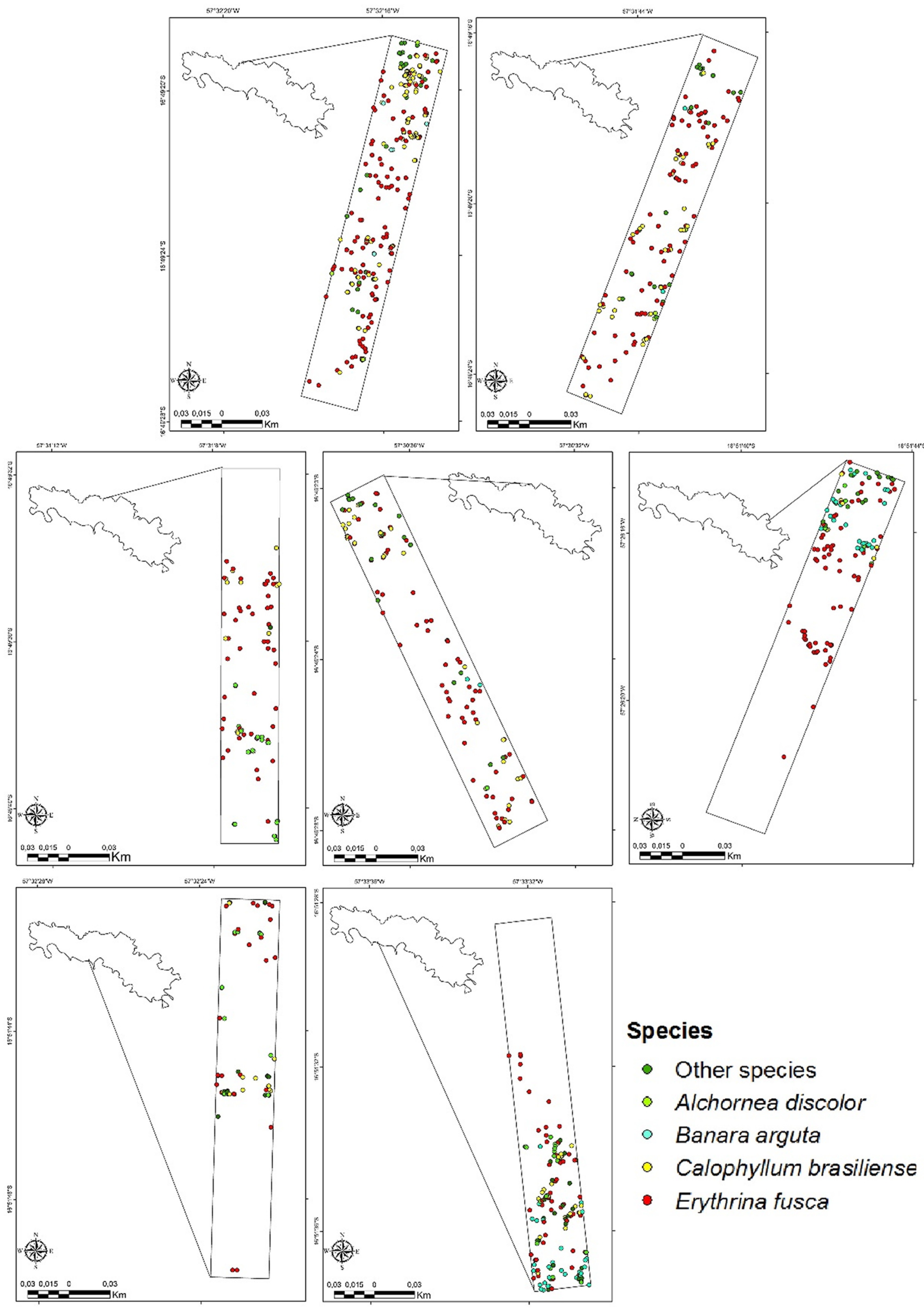

Fig. 3 Distribution of individuals of the species sampled in the modules in a Ecological Station of Taiamã (Esec Taiamã), northern Pantanal region, Cáceres, Mato Grosso, Brazil

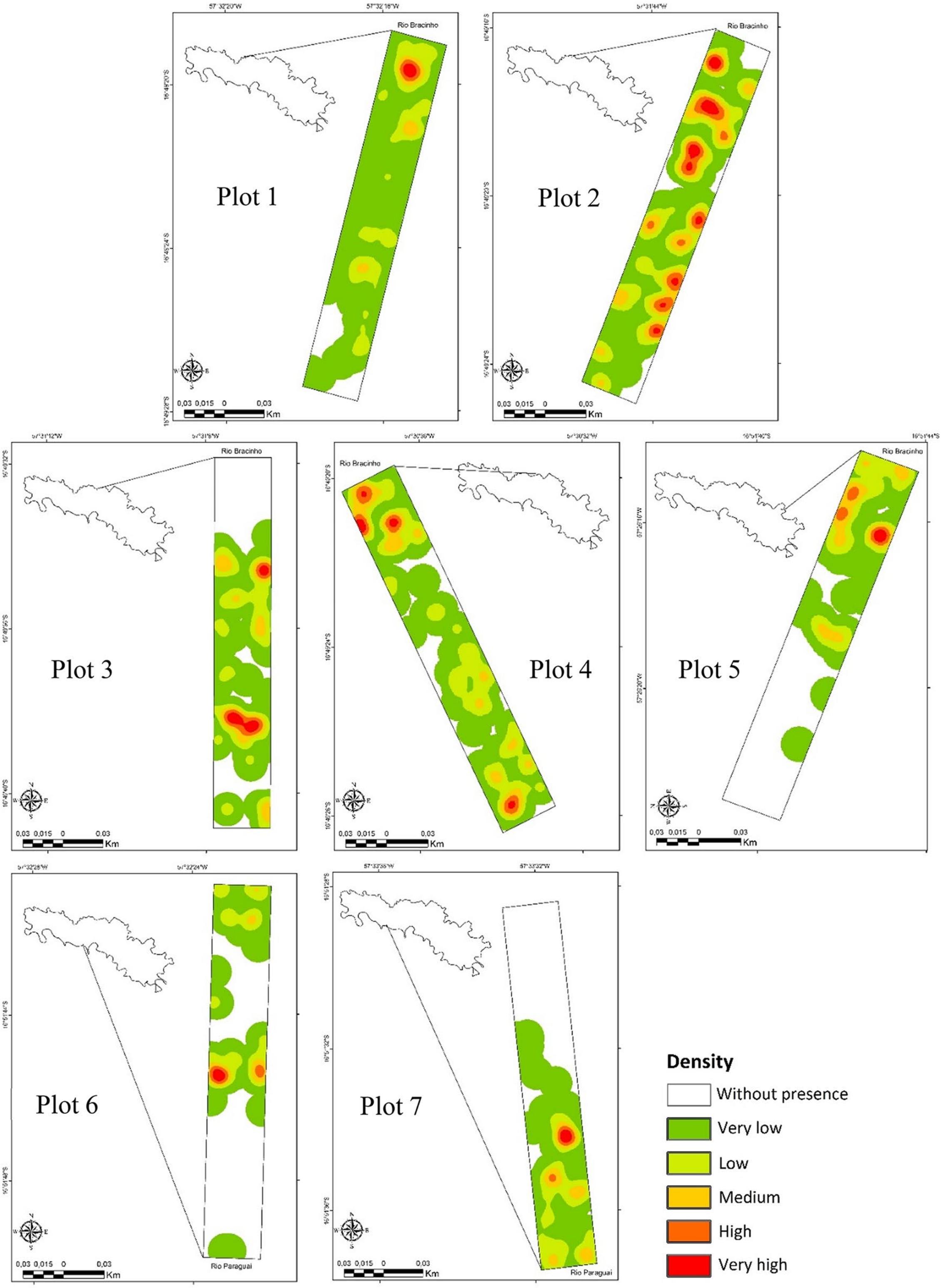

Fig. 4 Map of the Kernel density analysis of the sampled plot in a Ecological Station of Taiamã (Esec Taiamã), northern Pantanal region, Cáceres, Mato Grosso, Brazil

Table 1 Analysis K (t) and K (12) between the Plots and the main species

		K (12) analysis		
	K (t) *E. fusca*	*E. fusca* X *C. brasiliense*	*E. fusca* X *A. discolor*	*E. fusca* X *B. arguta*
Plot 1	Random	0–1.8 Dependent > 1.8 Independent	Independent	Independent
Plot 2	0–1 Aggregate > 1 Random	0–0.5 Dependent > 0.5 Independent	Independent	0–0.5 Dependent > 0.5 Independent
Plot 3	Random	0–2 Independent 2–2.5 Dependent > 2.5 Independent	0–2.5 Dependent > 2.5 Independent	–
Plot 4	Random	0–4 Dependent > 4 Independent	Independent	Independent
Plot 5	Random	Independent	Independent	Independent
Plot 6	Random	0–1.5 Dependent > 1.5–3.5 Independent > 3.5–4.5 Dependent > 4.5 Independent	0–4.5 Dependent > 4.5 Independent	-
Plot 7	Random	0–2 Independent > 2–3 Dependent > 3 Independent	0–3 Dependent > 3 Independent	Independent

result of repeated flood pulse flows that allow them to remain under the effect of flooding for less time, thus allowing the occurrence of arboreal vegetation (Stevaux and Santos 1998; Da Silva and Silva 1999; Umetsu et al. 2011).

Ikeda-Castrillon et al. (2019), when studying islands near the TES, found a positive correlation of species abundance with higher sites. Their results are similar to those of the present study, in which a significant correlation of higher abundance was also observed in higher sites ("marginal dikes"), with a decrease in this parameter in the lowlands ("baixada").

When only the species *E. fusca* was observed, a higher abundance occurred between 50 and 100 m away from the river. This could be a consequence of the increase in its single species dominance since *E. fusca* is more adapted to a higher amplitude and duration of the flood pulse. According to Nunes da Cunha et al. (2007), these areas with single specie dominance sites of E. *fusca* have little elevated "marginal dikes," with a flood level that can reach ≥ 2 m in height.

The distribution of *E. fusca* in the sampled modules was random. The spatial distribution of arboreal individuals in a forest is influenced by abiotic and biotic variables (Connell and Lownan 1989). Among the main abiotic variables are relief, availability of light, nutrients, water, and soil type; among the biotic variables, are intra and interspecific competition, herbivory, occurrence of diseases, phenology, and seed dispersal (Endara and Jaramilo 2011; Da Silva and Rossa-Feres 2017; Chaves et al. 2018). Concerning the *E. fusca* forests, it is possible to observe the influence of some factors, such as the flood pulse and relief. Besides, the species pioneer characteristics (Lamb and Boshier, 2003) is also a positive factor for its dominance, since it allows *E. fusca* to populate areas that other species cannot, thus avoiding competition.

Endara and Jaramilo (2011), when evaluating the distribution of species of *Inga* Mill. (Fabaceae), observed a relationship between distribution, and soil and climate factors. These factors can generate microrelief in small spatial scales that influence the distribution of plants.

Sander et al. (2017) assessed individuals of *Mauritia flexuosa* L.f. in a humid area in the Alta Floresta region, State of Mato Grosso. The authors observed that the distribution of this species was not uniform, but varied from random to grouped. When evaluating *C. brasiliense* in an area subject to the flood pulse in the region of the Guaporé River in *Vila Bela da Santíssima Trindade*, State of Mato Grosso, Morais et al. (2015) found that its distribution was also random. Pottker et al. (2016) concluded that *Ocotea odorifera* (Veil.) Rohwer. was distributed in large clusters and concentrated in the higher regions of the study area due to soil drainage, unlike *E. fusca*, which occurs in high and low areas, and that the species avoids low areas.

Lima-Junior et al. (2012) found that *Vochysia divergens* Pohl. occurred randomly in floodable areas of the Pantanal, as a result of adaptations that allow the species to support flooding. This allows its distribution in both drier areas and places more susceptible to flooding, and is a characteristic that can also justify the random distribution of *E. fusca* in most modules in the present study.

The single species dominant sites of *E. fusca* can be considered as a permanently flooded forest in the lower relief areas. These areas had a surface water table, which remains flooded all year long in the lower areas with average flooding of eight months in the "marginal dike". This is similar to floodable gallery forests, flooded riparian forests, or swampy forests, which remain, all or most of the time, under the effect of flooding throughout the year, thereby limiting the occurrence of some species (Pedreira and Sousa 2011). The dominance of a species is common in this type of forest; that is, there is a smaller diversity in comparison to drier areas. The dominance and, consequently, the distribution of *E. fusca* found in this study could be explained by permanent flooding (Pedreira and Sousa 2011; Brazil 2012).

In the Kernel density estimation, the highest densities were concentrated in the areas closest to the "marginal dike". Umetsu et al. (2011) found that in the riparian forests of the Cuiabá River, the species distribution was also proportional to the elevation of the land. The present results found for the single specie dominance forest of *E. fusca* at TES., which had a higher occurrence in the landscape lowlands ("baixadas"), are in line with the study by Arieira and Nunes da Cunha (2012) for the *Vochysia divergens* forests.

Besides the random distribution of the species, we noted that *E. fusca* forms a small elevation in the ground with its aerial roots. We also observed that other species take advantage of these elevations to establish themselves, a fact also verified by other authors to have been observed in "murundus" fields. These are elevations in the soil, thus increasing the density in lower areas of the modules as a function of the small ground elevations due to roots (Soares and Oliveira 2009; Marimon et al. 2012; Moraes et al. 2014). On these elevations formed by the roots of *E. fusca*, individuals of *C. brasiliense* and *A. discolor* can establish themselves in the area. This positive spatial interaction relationship between *E. fusca* and *C. brasiliense*, and *E. fusca* and *A. discolor* was verified by the K (12) statistical test.

Calophyllum brasiliense showed spatial dependence in all seven modules; this result indicates that this species, even in the driest modules, was distributed near *E. fusca*, and that even if they are distributed in the driest areas of the module, this species can disperse in the lowland regions ("baixada"), as long as it can make use of the roots ground elevations formed by *E. fusca.* This aggregation can be explained by the fact that *E. fusca* is a pioneer species, and that *C. brasiliense* is a secondary species, thus, not so demanding on light (Marques and Joly 2000) for its establishment, and able to take advantage of the elevations formed by the roots of *E. fusca*, surviving nearby. It is worth mentioning that the dispersion of the species *C. brasiliense* occurs mainly by birds and bats, which in turn, can make use of the *E. fusca* trees as natural perches, thereby collaborating with the aggregate occurrence of the species (Mello et al. 2005). *Calophyllum brasiliense* has germination viability of up to three months when submitted to flooding, and their juvenile plants have a good tolerance to hydric stress (Marques and Joly 2000), which allow them to settle in TES, with a preference to occur near *E. fusca* due to the root elevations.

On the contrary, *A. discolor* had a relationship of spatial dependence with *E. fusca* only in modules 3, 6, and 7, and these modules are considered the most related to flooding. Although this species uses the "morrotes" formed by *E. fusca* for establishment, the relationship of spatial dependence did not occur in all the modules. The species *A. discolor* has been reported in studies on humid areas, and therefore has tolerance to flooding (Damasceno-Junior et al. 2005). When observing the dependence of this species on *E. fusca*, it can be assumed that its individuals use the root elevations formed by *E. fusca* to withstand flooding, and to disperse throughout the area.

The relationship of dependence of these species, apart from the flooding conditions of the areas, can be influenced by the type of dispersion, emphasizing that these are plants that can be dispersed by birds and other animals, which in turn use the trees for resting, thus dispersing the seeds near *E. fusca* and contributing to the process of spatial dependence (Da Silva and Rossa-Feres 2017).

The K (12) analysis in the modules where *B. arguta* is present showed that the spatial dependence occurred only in module 2; in the other modules, its distribution was independent of *E. fusca.* The distribution of *B. arguta* was in the higher regions ("marginal dikes"), with its individuals making little use of the root elevations to be distributed in the area; thus, its distribution is probably limited by flooding. Based on the distribution patterns, we can assume that the presence of individuals is related to the duration and intensity of the flood pulse, and also to adaptive processes of species for their establishment in areas where flooding selects the most tolerant species, and higher microrelief in the landscape can provide the conditions for recruitment of individuals of other species, consequently increasing species richness (Arieira and Nunes da Cunha 2006; Marimon et al. 2012).

The pioneer *E. fusca*, through its adaptations, has been enabling other secondary species to establish themselves in the region. Besides the species already mentioned in this study, we also observed, although rarely, *Ficus* sp., *Inga vera* Willd., *Cecropia pachystachya* Trécul., and *Ludwigia tomentosa* (Cambess.) H. Hara. using the root ground elevations for development, probably to overcome flooding (Soares and Oliveira 2009).

These root elevations likely allow the seedlings of these species to withstand the flooding periods, working as protection so that these individuals, when juveniles, are not submerged or remain so for the shortest time possible (Soares and Oliveira 2009). This possibility was also discussed by Soares and Oliveira (2009) in a study on "murundus" (elevation) areas in "paratudal" formations (floodable savanna formations) composed almost exclusively of the plant "paratudo" (*Tabebuia aurea*) in the Pantanal, municipality of Miranda, State of Mato Grosso. According to those authors, if these seedlings withstand the stress caused by flooding, they will develop and serve as accumulators of sediment in these root elevations.

In the areas of the "marginal dikes," besides the higher density previously discussed, the highest richness and abundance of species were also detected. Even though some species can establish themselves in the region using the elevations formed by the roots of *E. fusca,* other species had their distribution limited to the higher areas and did not disperse using these elevations. As discussed by, Moraes et al. (2014), the lower richness in the "murundus" fields was related to the distance between them and the water saturation of the soil, which can limit the species dispersion. Therefore, some species that overcome the flooding in the "marginal dikes" cannot disperse into the lower areas of the land and populate the root ground elevations.

Conclusions

Based on this understanding, it can be inferred that regions where there is a higher deposition of sediments as a function of the flood pulse ("marginal dikes"), tend to have higher richness and abundance of species. Moreover, any change that could occur in the flooding of this region could also change the community structure in these single specie dominance areas. Therefore, the single species dominance in the region is a consequence of flooding, which can regulate the intra and interspecific interactions in the region.

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