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Dendrophysiological plant strategies of *Poincianella pyramidalis* (Tul.) L.P. Queiroz after wood herbivory in semiarid region of Paraíba - Brazil

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ABSTRACT. The increase in *Equus africanus asinus* Linnaeus population in semiarid areas of Northeast Brazil had significant impacts on wild and rural areas. The objective of this work was to analyze the herbivory of *E. africanus asinus* on *Poincianella pyramidalis* (Tul). L.P. Queiroz and determine the dendrophysiological strategies *P. pyramidalis* used during and after damage caused by *E. africanus asinus*. The selected areas have significant populations of *P. pyramidalis* with amplified importance value higher than 50%. Two areas were established: one control and another experimental, with presence of *E. africanus asinus*. The study was carried out from 2001 to 2015. The evaluated variables of *P. pyramidalis* were: sap flow, basic density, diameter, volume, biomass and leaf area index. The increase of abandoned *E. africanus asinus* in semiarid areas resulted in impact and responses from *P. pyramidalis*. This plant species compensates for biomass losses and physiological activities reduction with two strategies: i) increase in the belowground biomass stock, and ii) increase in sap flow in undisturbed branches.

Keywords: ecological interactions, ecophysiology, survival strategies.

Estratégias dendrofisiológicas em *Poincianella pyramidalis* (Tul.) L.P. Queiroz depois da herbivoria no tronco em regiões semiáridas na Paraíba - Brasil

RESUMO. O aumento da população de *Equus africanus asinus* Linnaeus em áreas do Semiárido do Nordeste brasileiro teve um impacto significativo sobre as áreas silvestres e rurais. O objetivo desse trabalho foi analisar a herbivoria de *E. africanus asinus* sobre a espécie vegetal *Poincianella pyramidalis* (Tul). L.P. Queiroz e quais as estratégias dendrofisiológicas que essa espécie (*P. pyramidalis*) utilizou no momento e depois do dano causado pelo *E. africanus asinus*. As áreas selecionadas possuem significante presença populacional de *P. pyramidalis*, com valor de importância ampliada maior do que 50%. Duas áreas foram estabelecidas: uma controle e outra experimental com a presença de *E. africanus asinus*. O estudo foi realizado de 2001 a 2015. As variáveis avaliadas de *P. pyramidalis* foram: fluxo da seiva, densidade básica, diâmetro, volume, biomassa e índice de área foliar. O aumento da população de *E. africanus asinus* abandonados em áreas do Semiárido resultou em impacto e respostas na espécie *P. pyramidalis*. Essa espécie vegetal compensou suas perdas dendrométricas e redução nas atividades fisiológicas com duas estratégias: i) aumento no estoque de biomassa abaixo da superfície do solo; e ii) aumento do fluxo de seiva nos ramos não impactados.

Palavras-chave: interações ecológicas, ecofisiologia, estratégias de sobrevivência.

Introduction

Changes in consumption behavior modified the rural life with some negative results to nature in emergent countries: deforestation and fragmentation of wildlife, excessive extraction of natural resources, and proliferation of exotic species (Biswas & Roy, 2015). In Brazilian Northeastern, for example, the mode of transport and workforce were substituted from animal to motorcycle in small farm areas. This has led to increased number of abandoned individuals, which, in turn, increased significantly their populations (e.g. *Equus sp.*) (*Instituto Brasileiro de Geografia e Estatística* [IBGE], 2015).

It is estimated 0.6 million of *Equus* sp. head in the Brazilian Northeastern, and, of this, 50 thousand were abandoned. This total of abandoned *Equus* sp. 96% are *Equus africanus asinus* Linnaeus (Equidae) (Food and Agriculture Organization [FAO], 2015). This species is used as transportation and workforce because of its resistance and adaptation to climate of the Semiarid: hot and dry areas (> 25°C annual mean and < 800 mm annual total). Abandoned individuals of *E. africanus asinus* refuges in wild areas and, when hungry and thirsty, they eat plant tissue (leaves and branches) to get food and water of native plant species (Freeland & Choquenot, 1990; Carrion, Donlan, Campbell, Lavoie, & Cruz, 2007).

Constant damage to plants caused by animals (herbivory) results in biological responses from plants. These biological responses could be semi deciduousness (loss of plant tissue), beginning of senescence, modification of plant tissue, or changes in physiological habits (Levitt, 1980). *E. africanus asinus* bites branch but do not fully destroy the plant individual. This behavior was described in the literature, the animal takes resources from the plant but do not kill it (Carrion et al., 2007).

In the Caatinga, tree species with more damage caused by *E. africanus asinus* herbivory was *Poincianella pyramidalis* (Tul.) L.P. Queiroz (Fabaceae). This plant species has a good adaptation, it occurs from Cambisol with deciduous shrubby height (until 2 m) to Gleysol with perennial tree height (until 16 m) (Lorenzi, 2011). *P. pyramidalis* is mainly used for fencing and as firewood, popular medicine, urban afforestation and restoration of degraded areas (Sampaio, Pareyn, Figueirôa, & Santos Junior, 2005).

Researches have reported that herbivory reduces physiological activities (e.g. transpiration and photosynthesis) and changes carbon accumulation strategies (dendrometric effects). For example, in plants with reduced transpiration, low will be the photosynthesis and low will be vegetal growth (Cunningham, Pullen, & Colloff, 2009). The study of physiological variables that explain the water flow (sap flow), dendrometric variables that explain tree growth (diameter, basic density, volume and biomass) and other biometric variables (leaf area index) would clarify dendrophysiological strategies of plant against herbivory, over time. Thus, the objective of this work was to analyze the herbivory of *E. africanus asinus* on *P. pyramidalis* and determine the dendrophysiological strategies *P. pyramidalis* used during and after damage caused by *E. africanus asinus*.

Material and methods

The study was carried out in Semiarid area (BSh, Köppen-Geiger classification) (Peel, Finlayson, & McMahon, 2007) (Figure 1A), with significant presence of *Poincianella pyramidalis*. This species has 60% of amplified importance value (AIV = sum of relative frequency, relative density, relative dominance, sociological position and natural regeneration) (Finol, 1971). In this area (7°49'25"S and 36°32'57"W), the density of *P. pyramidalis* individuals was 801 ind ha^{-1} of a total of 1,818 ind ha^{-1}, all individuals with circumference at the base greater than 9 cm and total height greater than 100 cm (Rodal, Sampaio, & Figueiredo, 1992). Two areas were studied, one hectare each, denominated Control Area and Experimental Area. These areas are near 300 meters, and they were divided in 20 subplots of 0.05 ha (without physical limits). All areas occur on Yellow Oxisol 1 (LAx-1), with environmental mean annual temperature of 29°C, approximately, annual rainfall of 650 mm, approximately, and vapor pressure deficit of 1.4 kPa, approximately (mean from April 2000 to April 2015) (*Instituto Nacional do Semiárido* [INSA], 2015). In Experimental area, from 2006 to 2010, presence of *E. africanus asinus* was permitted with density of 28 ind ha^{-1} (Figure 1B), all delimited by fencing.

The dendrophysiological variables measured were sap flow (g m^2 s^{-1}), diameter (cm), aboveground individual volume (m^3), basic density (g cm^{-3}) and leaf area index, of all individuals of *P. pyramidalis* in the studied areas (n = 788 Control Area and n = 814 Experimental Area). Sap flow measurement was adapted by Granier method (Granier, 1985) of thermal dissipation probe (Scholz, Bucci, Goldstein, Meinzer, & Franco, 2002). Thermocouple sensors were installed in two regions of branch: one at the base and the other one-meter above (Figure 1C). The flow results to each branch was the difference of base sensors values with above sensors values. Sensors were connected by duplex insulated copper-constantan extension cable to a datalogger (CR10X, Campbell Scientific, Logan, USA). All equipment and Protected branch were protected with barbed wire (Figure 1C).

The diameters (cm) were registered daily by an automated recording dendrometer (DBL60 Stand-Alone Logging Dendrometer, Armidale, Australia). The dendrometers were installed at the height of trunk base (20 cm, see Figure 1C). Data were recorded by a data logger (DendroLog, Ancara, Turkey). The aboveground individual volume (trunk and branches, m^3) was estimated by an industrial 3D-scanner (3D scanner – KDLS – DK – FK – four Lens, Guangdon, China). The basic wood density (g cm^{-3}) was measured in samples collected at 0, 25, 50, 75 and 100% of total plant height, with an increment borer (Haglöf, Sweden). Data of this variable were collected by high-frequency densitometry method on LignoStationTM (Rinntech, Heidelberg, Germany), and on LignoScan to surface scanner (Shchupakivskyy, Clauder, Linke, & Pfriem, 2014). The leaf area index (LAI) was estimated by plant canopy analyzer (LAI-2000, LiCOR, Lincoln, USA), with the data collected in thirty random points below the canopy to 20 cm from soil surface, once a month (Santana, Cuniat, & Imaña-Encinas, 2010).

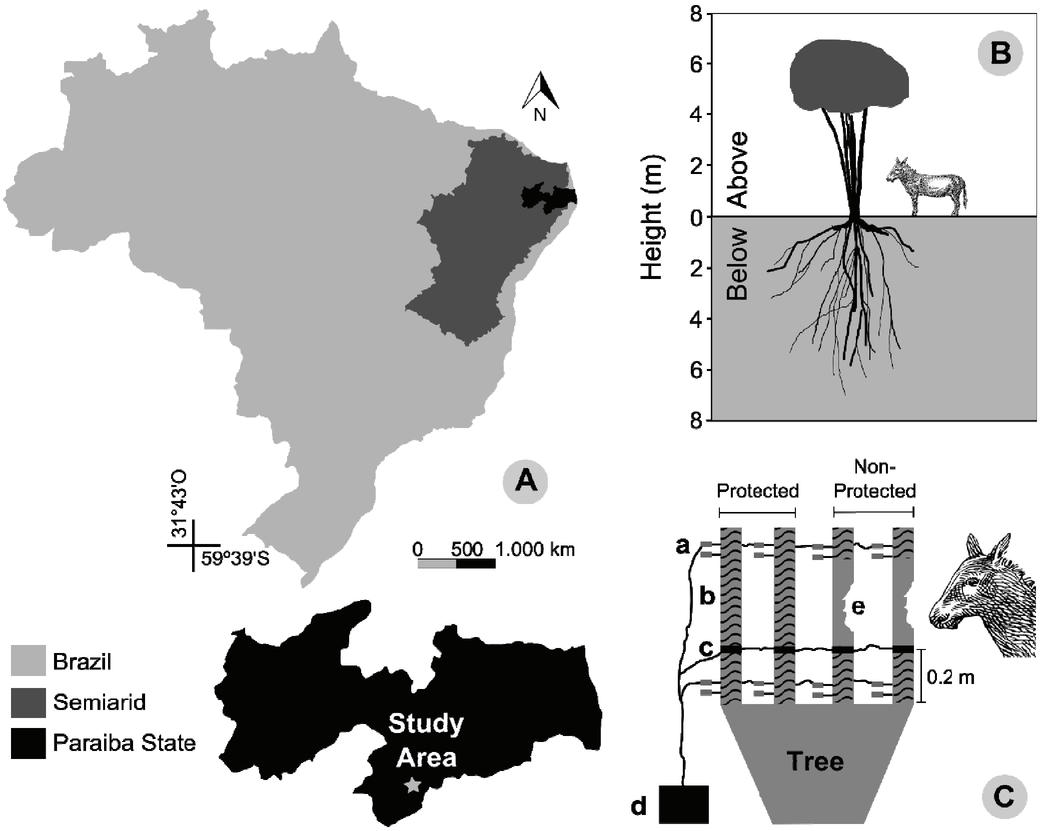

Figure 1. A) Site of study area; B) Visual height of *Poincianella pyramidalis* (Tul.) L.P. Queiroz and *Equus africanus asinus* Linnaeus; C) Scheme of the experimental model for data record: a) Granier sap flow-sensors, b) barbed wire, c) automatic dendrometers, d) dattalogers, and e) damage caused by *E. africanus asinus*. Source: Prepared by the authors.

In five years (2002, 2005, 2008, 2011 and 2014), total dry biomass of whole *P. pyramidalis* were dried at 70°C in an oven (Kunlun Drying Stove; Guangdong, China) until stabilization of weight and measured by weighing-machine (Micheletti MIC4CEL, São Paulo, Brazil), in 10% of individuals of each area (2% per year). Roots were excavated. ANOVA followed by Dunnett test was conducted to calculate p-value (effect of *Eqqus* sp. presence). Paired t-test was applied to compare two years, in general the first and the last, with biomass and leaf area data, or between protected and non-protected sample groups. Shapiro-Wilk normality test preceded all statistical analysis and the analysis were conducted at a 95% confidence level (Zar, 1999).

Results

All data in each sample group of the studied variables had normal distribution ($p < 0.001$). The results of the dendrophysiological variables showed significant effects ($p < 0.001$) of the presence of *E. africanus asinus* on *P. pyramidalis* population (Figure 2). In the beginning (from 2001 to 2005), the values of variables showed no significant differences ($p > 0.05$) between the three studied sample groups. In *E. africanus asinus* presence (from 2006 to 2010), values of the dendrophysiological variables reduced in non-protected branch and increased in protected branch in the same tree individual, differently from branch in the control area (Figure 1). From 2011 to 2015, in non-protected branches (without the presence of *E. africanus asinus*), values of the studied variables increased, indicating the resilience of the species. In protected branches, values of sap flow, density and leaf area index (LAI) were stable over time (from 2011 to 2015), and diameter and volume values increased. All values of variables in protected branches of the experimental area were higher than in control areas ($p < 0.001$, from 2006 to 2015).

The reduction in sap flow values was observed ($p < 0.001$) immediately after damage caused by *E. africanus asinus* (Figure 3). With the presence of *E. africanus asinus*, in non-protected branches, there was sap flow but with lower value than that observed in control area. In this same time, the protected branches increased the sap flow values (Figure 3).

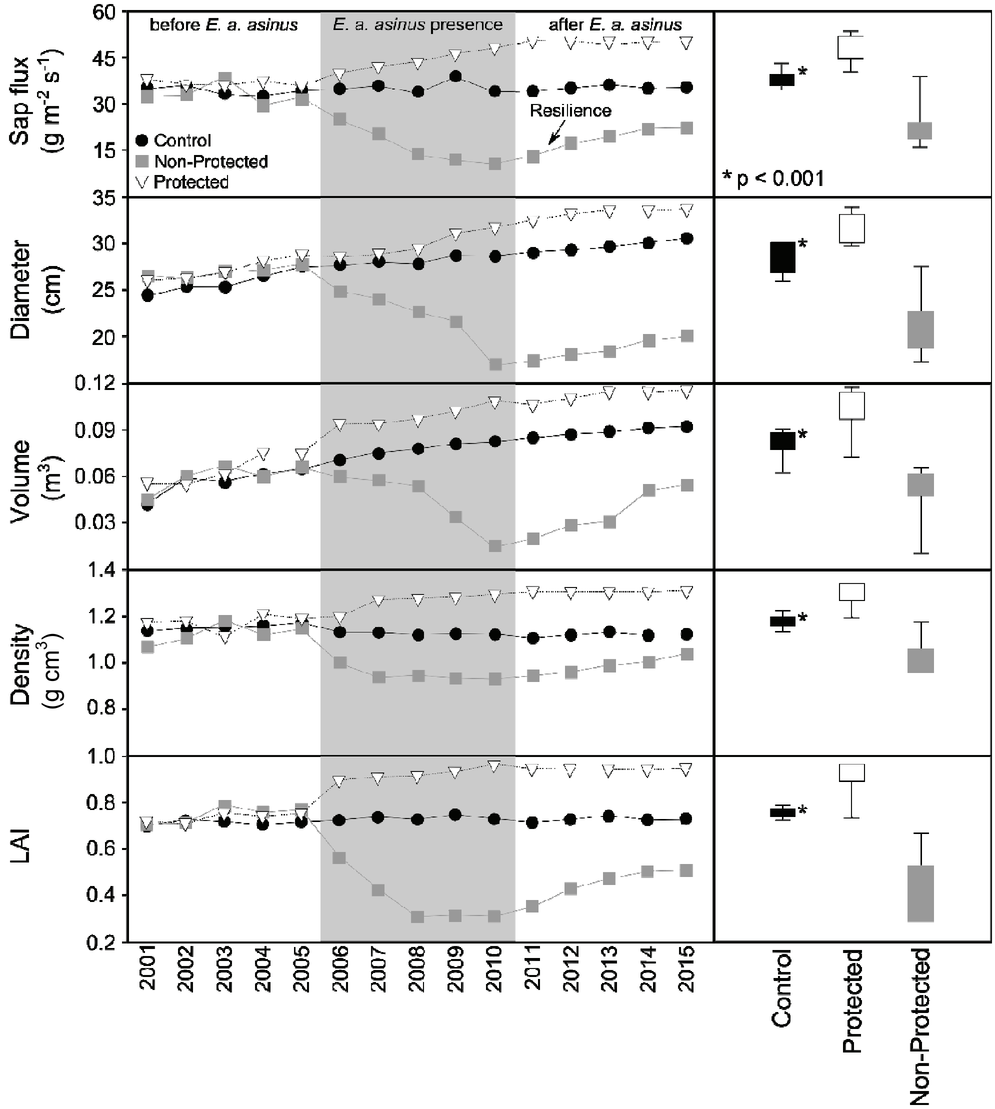

Figure 2. Dendrophysiological variables of *Poincianella pyramidalis* (Tul.) L.P. Queiroz in control area, protected and non-protected branches, over time. *All had significant differences ($p < 0.001$) by ANOVA followed by Dunnett test in the presence of *Equus africanus asinus* Linnaeus. Source: Prepared by the authors.

Dry biomass of *P. pyramidalis* increased aboveground (43%) over time ($p < 0.001$, from 2002 to 2014) and the values of belowground were stable, without significant increase or reduction ($p > 0.05$, from 2002 to 2014) in control area (Figura 4A and B). In experimental area, the dry biomass aboveground had a reduction (-24%, $p < 0.001$, from 2002 to 2014), mainly in 2008, with the presence of *E. africanus asinus*. From this year on, dry biomass values began to increase significantly (57%, $p < 0.001$, from 2008 to 2014). Damage caused by *E. africanus asinus* did not exceed 35% of basal area of the branch (Figure 4C). When the damage reached 35%, *E. africanus asinus* individuals searched for another tree individual for herbivory. Other observation was the reduction (-20%, $p < 0.001$, from 2002 to 2014) in leaf area index, in branches of the experimental area, and in the leaf area (-40%, $p < 0.001$, from 2002 to 2014) (Figure 4D).

Discussion

The range of data in each studied variable occurred according to literature (Table 1). When *E. africanus asinus* bites the *P. pyramidalis* individual, the first response is the reduction in sap flow. Sap flow is important to keep water and nutrients distribution in the plant, from roots to leaf and from leaf to roots. When sap reduces flow rate, the plant reduces photosynthesis, because of water and nutrients shortage. Moreover, the reduction in the photosynthesis process reduces the synthesis and accumulation of carbohydrates (carbon) (Scholz et al., 2002; Cunningham et al., 2009). Thus, non-protected branches showed reduction of dendrometric variables: density, diameter and volume. The leaf area index and leaf area reductions were observed in response to the need of reducing photosynthesis (Santana & Encinas, 2011).

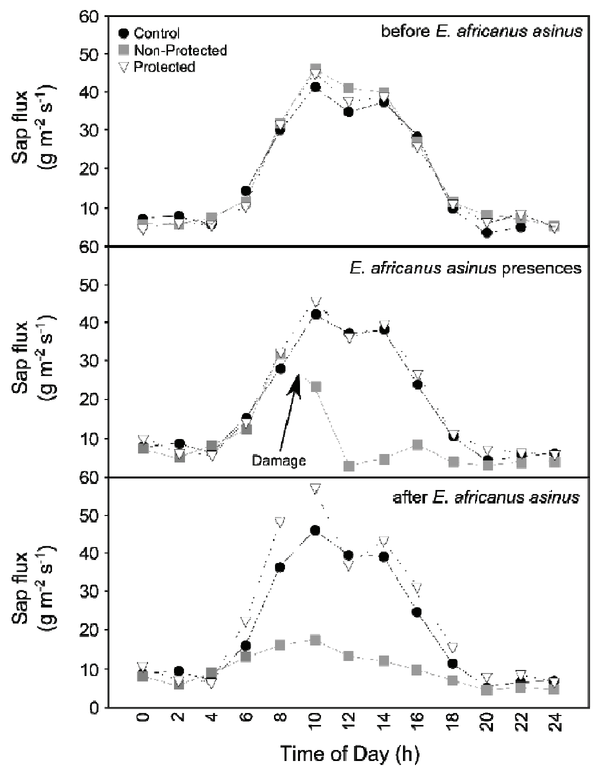

Figure 3. Sap flow of *Poincianella pyramidalis* (Tul.) L.P. Queiroz branches by time of day, before (March 15, 2006) and after (March 17, 2006) the presence of *Equus africanus asinus* Linnaeus, and at the moment of branch damage (March 16, 2006). Source: Prepared by the authors.

Researchers conducted in dystrophic environments (water and nutrients shortage) showed the plant sensitivity to minimal changes in climate or abiotic data and herbivory attack (Santos et al., 2014; Santana et al., 2010; Santana & Encinas, 2011, 2013; Santana, Encinas, Inácio, Amorim, & Vilaverde, 2013; Santana, Santos, Silva, Morais, & Encinas, 2015), and this was observed in this work. The plant individual takes out efficiently the available resource and this is an attribute of Semiarid and Arid species (Santos et al., 2014). Other characteristic is the resilience presented by *P. pyramidalis* after environmental impact, also described in other studies in this same environment (Figuerôa et al., 2006; Albuquerque & Oliveira, 2007).

Poincianella pyramidalis compensates for tissue losses and dendrophysiological strategies by increasing the values of sap flow rate and biomass stock (density, diameter and volume) in protected branches. In individuals undergoing damage, it was observed a temporal regulation of photosynthesis rate (and sap flow) and increase in root biomass, all this as a strategy for preservation (Cunningham et al., 2009; Ribeiro et al., 2001). *E. africanus asinus* did not scarify full branch, it scarified until 35% of basal area. This behavior was also described in the literature, showing an ecological relationship between predation and commensalism (Freeland & Choquenot, 1990; Carrion et al., 2007; Martin, Benhamou, Yoganand, & Owen-Smith, 2015).

With these ecological interactions and ecophysiological strategies (survival strategies), *P. pyramidalis* individuals are frequent and dominant (amplified importance value > 50%) in semiarid northeastern, as also found in a survey in permanent plots in the Caatinga (Silva, Lopes, Lopez, Melo, & Trovão, 2014; Santos, Santos, Silva, Araújo, & Araújo, 2016) and in this work. Thus, the species is considered as a bioindicator for ecosystem management and conservation (Souza, Menezes, & Artigas, 2015). In this study, the ecophysiological strategies (reduced sap flow and leaf area index) are short-term strategies to endure animal attack; however, the increase in root biomass indicated a strategy for survival (long-term) of the individuals and the species. It is clear that when tree individuals did not need to invest in increasing root biomass (control area); the tree individuals did not invest.

This strategy for survival is directly related to the maintenance of nutrients and water in the system. By allocating biomass to the roots, the tree individuals maintain nutrients and carbon in the system, not losing these nutrients to non-endemic and occasional animals in area (Freeland & Choquenot, 1990). In 'water' issue, the reduction in gas exchange and LAI reduce soil water loss to the atmosphere by hydraulic lift (Scholz et al., 2002). In 'fauna' issue, the depredation of the aerial part of plant would cause, in the short-term, a reduction in number of habitat and food quantity for endemic fauna, but in the long term, with the eradication of exotic species (*E. africanus asinus*), the native fauna could return to the region (Weber & Jeltsch, 2000). The increase of associated fauna in the roots (e.g. insects) and the increase of mycorrhiza (symbiotic association between plant tissues with fungi) would be the compensation for reducing endemic fauna (Pagano, Zandavalli, & Araújo, 2013). Other important factor, in areas that tree individuals have low aerial biomass and high underground biomass, the albedo is still low, in other words, there is a high light absorption in the system, because the soil with high organic matter absorbs more light than soil with low organic matter (Robinove, Chavez Jr., Gehring, & Holmgren, 1981).

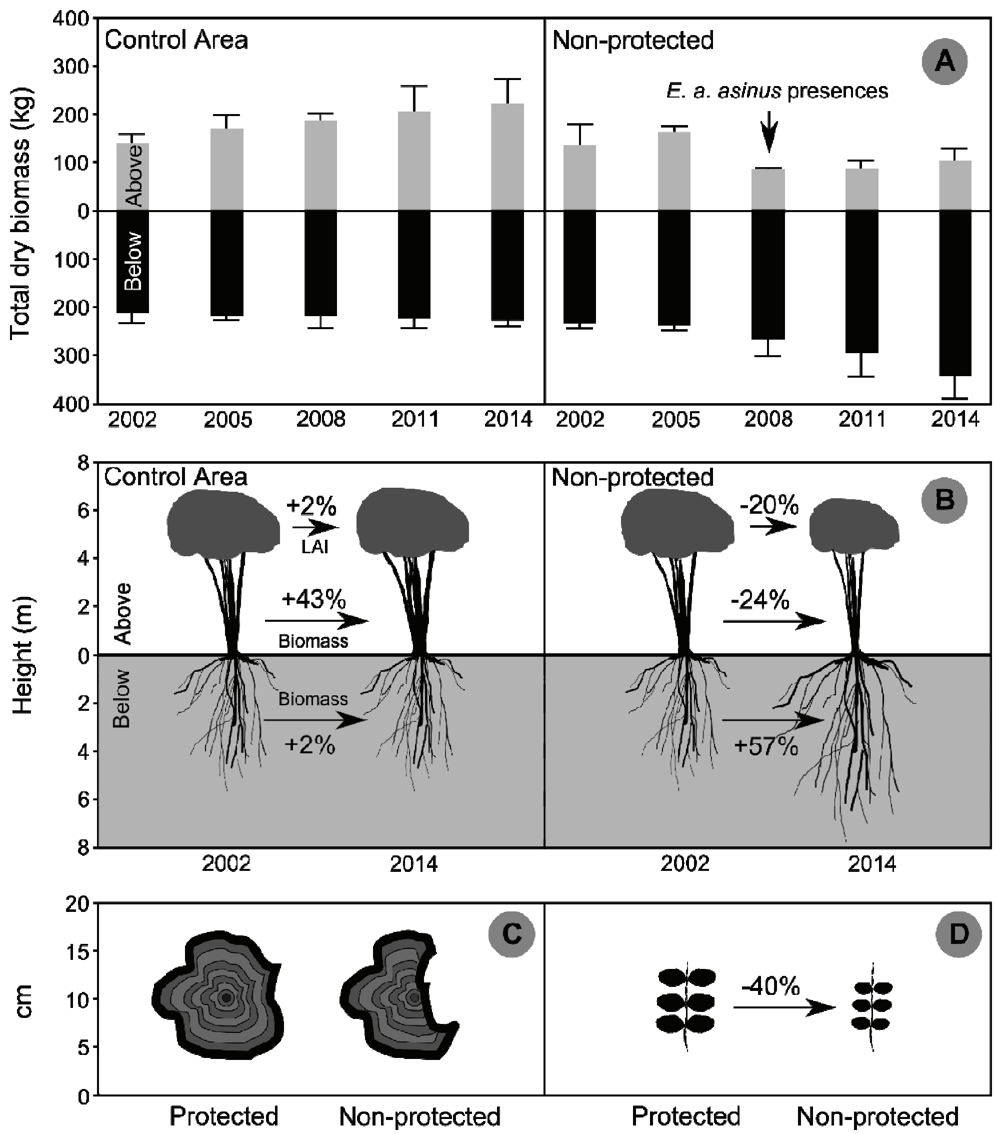

Figure 4. A) Total dry biomass above- and below ground of *Poincianella pyramidalis* (Tul.) L.P. Queiroz on five years sampled, in control and non-protected areas; B) Scheme of the biomass and leaf area index differences from 2002 to 2014, of *Poincianella pyramidalis* (Tul.) L.P. Queiroz in control and non-protected areas; C) Scheme of basal area differences of *Poincianella pyramidalis* (Tul.) L.P. Queiroz in protected and non-protected branches; and D) Scheme of leaf area differences of *Poincianella pyramidalis* (Tul.) L.P. Queiroz in protected and non-protected branches. Source: Prepared by the authors.

Table 1. Range of data in this work and others found in literature.

Variables	Present study	Range in the literature	References
Sap flow	23 - 34	19 – 45	Reyes-García, Andrade, Simá, Us-Santamaría, & Jackson (2012)
Diameter (cm)	11 - 35	0 – 50	Sampaio & Silva (2005); Silva, Santos, Gasson, & Cutler (2009)
Aboveground individual volume (m^3)	0.05 - 0.23	0.03 – 0.31	Sampaio & Silva (2005)
Basic density ($g\ cm^{-3}$)	0.8 - 1.2	0.6 – 1.3	Sampaio & Silva (2005), Silva et al. (2009)
Total dry biomass (kg)	214 - 461	141 – 630	Figuerôa et al. (2006); Sampaio et al. (2010); Costa et al. (2014)
Leaf Area Index	0.3 - 0.9	0.2 – 2.1	Hardesty, Box, & Malechek (1988)

Source: Prepared by the authors.

Conclusion

The increase of abandoned populations of *Equus africanus asinus* Linnaeus in semiarid areas resulted in impact and responses from *Poincianella pyramidalis* (Tul.) L.P. Queiroz. This plant species compensates for dendrometric losses and physiological activities reduction using two strategies: i) increasing the belowground biomass stock (increased root biomass), and ii) increasing the sap flow in non-disturbed branches, and consequently, increasing basic density, diameter, volume and leaf area index values.

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