Acta Botanica Brasilica 28(2): 293-297. 2014.

Survival dynamics of *Melocactus conoideus* Buining & Brederoo (Cactaceae), a threatened species endemic to northeastern Brazil

Hévila Prates Luz-Freire[1], Diego Pires Ferraz da Trindade[2], Raymundo José de Sá-Neto[2] and Michele Martins Corrêa[2]

Received: 17 July, 2013. Accepted: 19 December, 2013

ABSTRACT

Studies on the survival of species are essential to understanding their biology and to developing effective conservation and management plans. This study aimed to determine the best model to explain the survival of the species *Melocactus conoideus* on the basis of time, density, age structure and habitat location, as well as to describe the interactions among those factors. The study was conducted in three *M. conoideus* habitat patches in the municipality of Vitória da Conquista, in the state of Bahia, Brazil, only one of which was within a "conservation unit" (protected area). In each patch, we selected 120 specimens of *M. conoideus*, which were marked with identification plates and classified by developmental stage and density. The survival of those individuals was monitored for a period of one year. The overall survival of *M. conoideus* was 87.5% and was found to correlate with the month, as well as with the interaction between the factors Patch and Density. Our results show that the survival of *M. conoideus* individuals is related to the intrinsic characteristics of each habitat patch and suggest that more areas should be set aside for the conservation of this species.

Key words: Cactus, Mortality, Population ecology, Spatial aggregation

Introduction

Melocactus conoideus Buining & Brederoo (Cactaceae) is a species whose distribution is restricted to patches of quartz gravel in the municipality of Vitória da Conquista, located in the southwestern portion of the state of Bahia, Brazil (Taylor & Zappi 2004; Cerqueira-Silva & Santos 2008). *M. conoideus* is currently considered critically endangered (Martinelli & Moraes 2013), because of overexploitation of individuals for the European trade and uncontrolled urban growth threatening its habitat (Cerqueira-Silva & Santos 2008). The development of management and conservation plans for *M. conoideus* is hindered by the scarcity of studies related to its basic biology (Taylor & Zappi 2004; Cerqueira-Silva & Santos 2007; Brito-Kateivas & Corrêa 2012), including survival analysis, despite the fact that such studies are essential for evaluating the long-term viability of the species in the environment (Cerqueira-Silva & Santos 2008).

Plant survival can be affected by various ecological factors, including temperature and rainfall, as well as the age structure and population density (Martinez *et al*. 1994; Godínez-Álvarez *et al.* 2003; Mandujano *et al.* 2007; Hughes *et al*. 2011). During periods of low rainfall, plants often show lower growth rates and increased mortality due to the decline in soil moisture (Godínez-Álvarez *et al.* 2003; Hughes *et al*. 2011). Differences among age states could affect survival among cacti because younger individuals have a lower chance of survival (Godínez-Álvarez & Valiente-Banuet 2004; Mandujano *et al.* 2007; Hughes *et al*. 2011). In general, higher rates of individual aggregation result in greater competition among those individuals. Therefore, the scarcity of essential resources, such as water, light, nutrients and space (Lehn & Resende 2007; Agostinetto *et al*. 2008), causes a decrease in plant development in denser patches (Harper 1967; Godínez-Alvarez *et al*. 2003) ultimately threatening the persistence of species in their natural habitats (Rizzardi *et al*. 2001).

All the factors discussed above should be considered for the establishment of conservation areas with the purpose of preserving endangered plant species (Giulietti *et al.* 2005; Nogueira *et al.* 2009; Noon *et al.* 2012). Within the Cactaceae family, there are many threatened species (Godínez-Alvarez *et al*. 2003; Martinelli & Moraes 2013), mainly due to their low individual growth rates and high vulnerability in the early developmental stages, as well other inherent characteristics, such as their unique biogeographical patterns and slow demographic response after disturbance (Hernández-Oria *et al*. 2007). In this context, this study aimed to determine the best model to explain the survival

[1] Universidade Estadual do Sudoeste da Bahia, Programa de Pós Graduação em Ciências Ambientais, Itapetinga, Brazil
[2] Universidade Estadual do Sudoeste da Bahia, Departamento de Ciências Naturais, Laboratório de Biodiversidade do Semi-árido, Vitória da Conquista, Brazil
[3] Author for correspondence: freire_hpl@yahoo.com.br

of the species *Melocactus conoideus* on the basis of time factors, density-dependence effects, age structure and habitat location, as well as the interaction among these factors. Our hypotheses were that survival rates would be higher among aggregated individuals than among isolated individuals; that mature individuals would survive more often than would young individuals; and that survival would be higher in a protected habitat than in unprotected areas.

Material and methods

Study area

The study was carried out in three habitat patches, at an average of 11.5 km from each other. The patches consist of quartzite gravel outcrops, 900-1050 m above sea level, within the Bate-Pé-Tremedal formation, situated in the municipality of Vitória da Conquista (14°50'53"S; 40°50'19"W). Patch 1 (14°49'49"S; 40°50'0.3"W) is located within Serra do Periperi Municipal Park, a "conservation unit" (protected area) whose purpose is the conservation of *Melocactus conoideus* and of the headwaters of the Verruga River. Patch 2 (14°52'31"S; 40°43'52"W) and Patch 3 (14°52'20"S; 40°45'15"W) are both located on private property, outside the boundaries of the park and away from the urban perimeter. The patches are, respectively, 3.05, 5.46 and 4.01 ha in size. The municipality of Vitória da Conquista has a semi-humid to semi-arid tropical climate, with an average annual temperature of 19.6°C and average annual rainfall of 700-1200 mm, with a rainy season extending from November to January and a dry season extending from May to September (Jesus 2010; Cardoso *et al*. 2005). The vegetation of the region represents an ecotone between seasonal forest and the steppic savanna (BRASIL, 1981). Survival was assessed on a monthly basis, from July 2011 to July 2012.

Melocactus conoideus Buining & Brederoo

Melocactus conoideus was first described in 1973 and has been listed as critically endangered in Appendix I of the International Union for Conservation of Nature since June 1992 (Taylor & Zappi 2004). More recently, the species was added to the Red List of Brazilian Flora, on which it is also listed as critically endangered (Martinelli & Moraes 2013). In *M. conoideus*, phenological events (flowering and fruiting) occur almost monthly (Cerqueira-Silva & Santos 2007). Flowers of the species are pinkish magenta and ca. 22 × 10 mm (Taylor & Zappi 2004). The fruits are lilac-magenta, with a length of 17.1 to 21.5 mm and lowest and highest widths between 3.1 to 4.0 mm and 6.3 to 7.5 mm (Zappi & Taylor 2004; Brito-Kateivas & Corrêa 2012). Seeds are small and black (Taylor 1991). The seeds are dispersed, opportunistically, over short distances by ants (Brito-Kateivas & Corrêa 2012) and over long distances probably by lizards, as reported for other *Melocactus* species (Figueira *et al.* 1994; Romão *et al.* 2007). Seed germination is zero in the absence of light and is highest when there is a 12/12-h light/dark cycle (Rebouças & Santos 2007). However, there are no available data on other aspects of *M. conoideus* population ecology, such as the survival of individuals over time.

Sampling

Melocactus conoideus survival was investigated through factorial analysis of variance (3 × 2 × 4), totaling 24 treatments, which corresponded to three habitat patches (Patch 1, Patch 2 and Patch 3), two types of spatial density (aggregated and isolated) and four developmental stages (G1, G2, G3 and G4).

We randomly selected 30 individuals of *Melocactus conoideus* at each developmental stage and in each type of spatial density, totaling 120 individuals per patch. All individuals were tagged with numbered identification plates and grouped by developmental stage, as defined by cladode diameter (1.0 cm < G1 ≤ 4.0 cm; 4.1 < G2 < 8.0 cm; and G3 ≥ 8.0 cm) or maturity (G4, reproductive individuals with a cephalium, a specialized terminal dense inflorescence; Britton & Rose 1919).

Spatial density was defined by the minimum distance among individuals: > 30 cm = isolated; and ≤ 30 cm = aggregated. This cut-off distance was suitable for the present study because it is above the median of the minimum distances among individuals recorded in previous studies of the spatial distribution of this species (unpublished data).

Data Analyses

The survival data were transformed into one binary variable, survivors and nonsurvivors being assigned values of zero (0) and one (1), respectively (Colosimo & Giolo 2006; Giolo *et al*. 2009). To observe which factors, including interactions, best explained the survival of *Melocactus conoideus*, we conducted a likelihood ratio test for a logistic model with a 5% significance level. The complete model was Survival ≈ Time + Patch × Density × Age Group, from which each parameter was removed and a new simpler model was compared with the complete model. If the simpler models had significant difference of the complete model, then that parameter was designated as having made a significant contribution to explaining the survival of *M. conoideus*. We conducted survival analyses using the program R, version 2.15.1 (R Development Core Team 2011) and its survival package (Lumley 2011).

Temperature and rainfall data were obtained from the National Institute of Meteorology and the Ministry of Agriculture and Food Supply. We used a cross-correlation function to observe relationships between climate variables, from no time lag to three-month delay, and the overall monthly mortality rate for *Melocactus conoideus* populations. All variables were transformed by the natural logarithm to comply with linearity assumptions of correlation. The observed results were the compared to 10,000 Monte Carlo simulations to obtain a significance probability.

Results

The survival rate for individuals of *M. conoideus* over the one-year study period was 87.5%, 45 of the 360 individuals having died during the study: 13 in Patch 1 (four G1, two G2, three G3 and four G4); 15 in Patch 2 (five G1, five G2, three G3 and two G4); and 17 in Patch 3 (two G1, eight G2, two G3 and five G4). The best fit statistical model in the likelihood test was Survival ≈ Time + Patch × Density, showing that individual survival is dependent on the time interval, as well as on the interaction between the factors Patch and Density (Tab. 1).

The influence that the interaction between patch and density had on survival is attributed to the fact that survival was better among aggregated individuals than among isolated individuals in patches 1 and 3, despite being better among isolated individuals in patch 2 (Fig. 1A-C). In the survival analysis, time is important, because survival did not decrease at a constant rate but rather varied over the months of observation (Fig. 2). Finally, the factor developmental stage group did not contribute significantly to explaining the survival of *Melocactus conoideus* (Tab. 1).

The cross-correlation for mortality did not show *Melocactus conoideus* mortality to correlate significantly with the maximum or minimum temperature at any time delay (Tab. 2) but did show a positive correlation for thermal amplitude and a negative correlation for rainfall, in both cases during the month of mortality (Tab. 2).

Discussion

We found that the survival of individuals of the species *Melocactus conoideus* depended on the interaction between habitat and density, as well as on the time interval. These results refute our first hypothesis, because there was no density-dependent survival pattern. This indicates that *M. conoideus* survival depends on the intrinsic conditions of habitat patches, which, despite having the same geological origin (Jesus 2010), probably present one or more differences related to edaphic conditions, such as nutrient availability, texture, permeability and soil pH (Peixoto *et al.* 2011); to pressure from predators or parasites, including natural agents of population growth control, such as the cactus moth *Cactoblastis cactorum* (Berg.) (Lepidoptera: Pyralidae), released to control the invasive species *Opuntia cacti* (Cactaceae) (Legaspi & Legaspi Jr. 2007); and to habitat loss caused by sand and gravel extraction for local civil construction use (Taylor 1991; Taylor & Zappi 2004; Cerqueira-Silva & Santos 2008) or by the disposal of urban trash into quartz gravel patches (M.M.C. pers. obs.), two common activities in the municipality.

Our results also refute our hypothesis of increased survival in the protected area, because we found that survival depended on the interaction between the area of occurrence and the pattern of density. Currently, only one population of *Melocactus conoideus* is effectively protected within an urban conservation unit in Serra do Periperi Municipal Park. According to conservation studies (Nogueira *et al.* 2009; Nascimento *et al.* 2012), a single protected area can successfully conserve a species if the species is organized in a metapopulation and if the protected area provides the best habitat for it survival. We could not demonstrate a metapopulation organization of the species, because was not the aim of our study. However, our results show that survival in the protected area was similar among the patches of *M. conoideus*. Therefore, an increase in the number of protected populations of the species could be a better way to conserve *M. conoideus* populations.

For *Melocactus conoideus* populations, the chances of survival were found to be similar for all age classes

Table 1. Likelihood ratio test for a logistic model of *Melocactus conoideus* (Cactaceae) survival in quartz gravel patches in the municipality of Vitória da Conquista, in the state of Bahia, Brazil.

Source of variation	*df**	LRT**	*p*
Time	12	24.464	0.017
Developmental stage	3	1.881	0.597
Density	1	0.678	0.410
Patch	2	0.656	0.720
Density:developmental stage	3	1.0824	0.781
Patch:developmental stage	6	4.403	0.622
Patch:density	2	9.140	0.010

*df: degree freedom
**LRT: likelihood ratio test.

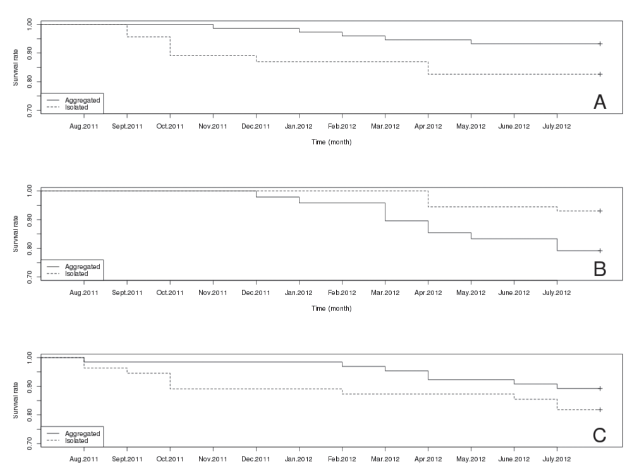

Figure 1. Estimated survival of *Melocactus conoideus* Buining & Brederoo (Cactaceae) among aggregated and isolated individuals in three habitats: (A) Patch 1, in Serra do Periperi Municipal Park; (B) Patch 2; and (C) Patch 3.]

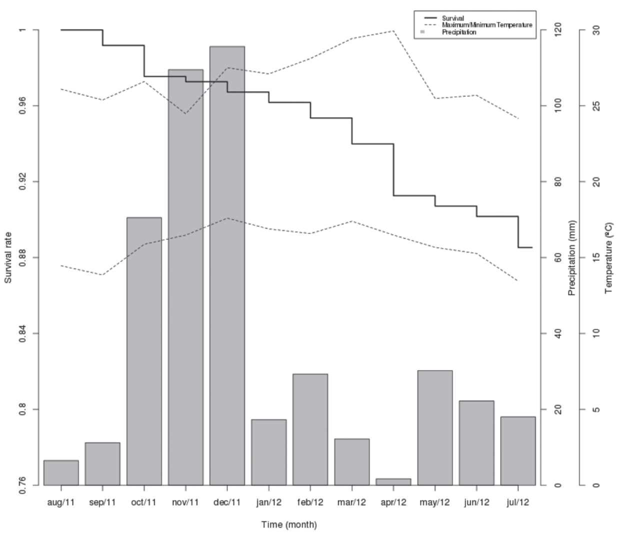

Figure 2. Estimated overall survival of *Melocactus conoideus* Buining & Brederoo (Cactaceae) in relation to temperature and precipitation in the municipality of Vitória da Conquista, in the state of Bahia, Brazil, during the study period (August 2011 to July 2012).

(developmental stages). The rate of decline in the survival of individuals remained constant regardless of developmental stage. The pattern of survival of *M. conoideus* individuals by developmental stage differed from that found for other species of Cactaceae, in which the probability of survival typically increases with plant growth (Godínez-Álvarez & Valient-Banuet 2004; Mandujano *et al.* 2007; Hughes *et al.* 2011; Ferrer-Cervantes *et al.* 2012). In addition, if we consider only the adult (G4 stage) individuals of *M. conoideus*, the rate of survival was high, which is in agreement with the patterns reported for other species in the family (Godínez-Álvarez *et al.* 2003; Godínez-Álvarez & Valiente-Banuet 2004; Hughes *et al*. 2011; Ferrer-Cervantes *et al*. 2012).

The decline of survival of *Melocactus conoideus* along of the months revealed a seasonal influence. This was also observed by Hughes *et al.* (2011) in *Melocactus ernestii*, which showed a high rate of mortality (90%) in seedlings, caused by seasonal droughts. This pattern is often observed in species living in environments with an unpredictable climate, such as the semi-arid region of Brazil (Figueroa & Castro 2000; Rojas *et al.* 2005; Lima 2011). Limited rainfall during the dry season typically alters the metabolic processes and causes water stress, ultimately affecting plant development and survival (Martinez *et al*. 1994; Figueroa & Castro 2000; Coronado *et al*. 2002; Cavalcanti & Resende 2006; Hughes *et al*. 2011).

To our knowledge, this was the first study to assess the survival of *Melocactus conoideus* in its natural habitat. Our data add to the body of information regarding the biology of this species. Here, we have shown that the survival of this species is influenced by density-dependent components, seasonality and location. Due to the complexity of factors that account for the survival of the species, further studies on *M. conoideus* ecology are needed. Such studies should address all aspects of its population dynamics, including floral biology, pollination, long-distance seed dispersal, parasitology and growth of individuals. Those data are needed in order to establish the best conservation model design for this species, which is rare, endangered and so little known by science (Taylor & Zappi 2004; Cerqueira-Silva & Santos 2007; Rebouças & Santos 2007; Cerqueira-Silva & Santos 2008; Rebouças *et al*. 2009; Godinho *et al*. 2010; Brito-Kateivas & Corrêa 2012).

Acknowledgments

We are grateful to the Environmental Authority of the municipality of Vitoria da Conquista, for allowing the fieldwork to be conducted in Serra do Periperi Municipal Park; to the owners of the farms on which patches 2 and 3 are located, for allowing us access to the study area; to the *Universidade Estadual do Sudoeste da Bahia* (UESB, Southwest Bahia State University), for the logistical support provided; and to Esdras Santos Freire and Jéssica Figueredo Campos de Jesus, for their help in the data collection. This study received financial support from the *Fundação de Amparo à Pesquisa do Estado da Bahia* (FAPESB, Foundation for the Support of Research in the State of Bahia; scholarship grants to HPL-F and DPFT) and to PRONEX PNX0016/2009".

Table 2. Cross-correlations among climate metrics and monthly *Melocactus conoideus* (Cactaceae) mortality rates over a one-year period (August 2011 to July 2012) in the municipality of Vitória da Conquista, in the state of Bahia, Brazil.

Delay	Temperature				Thermal amplitude		Rainfall	
	Maximum		Minimum					
	$r(\tau)$	p	$r(\tau)$	p	$r(\tau)$	p	$r(\tau)$	p
−3 months	0.229	0.394	0.425	0.070	−0.128	0.689	−0.013	0.967
−2 months	0.078	0.772	0.164	0.524	−0.034	0.915	0.044	0.900
−1 month	0.180	0.532	−0.082	0.756	0.332	0.296	−0.330	0.292
None*	0.468	0.128	−0.181	0.572	0.813	0.002*	−0.612	0.033*

*Month of occurrence.

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