ROHDE, CLÁUDIA; SILVA, DIVA MARIA IZABEL O.; OLIVEIRA, GEÓRGIA F.; MONTEIRO, LIV S.; MONTES, MARTÍN A.; GARCIA, ANA CRISTINA L.

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Anais da Academia Brasileira de Ciências, vol. 86, núm. 4, diciembre, 2014, pp. 1711-1718
Academia Brasileira de Ciências
Rio de Janeiro, Brasil

Anais da Academia Brasileira de Ciências,
ISSN (Printed Version): 0001-3765
aabc@abc.org.br
Academia Brasileira de Ciências
Brasil

Anais da Academia Brasileira de Ciências (2014) 86(4): 1711-1718
(Annals of the Brazilian Academy of Sciences)
Printed version ISSN 0001-3765 / Online version ISSN 1678-2690
http://dx.doi.org/10.1590/0001-3765201420130314
www.scielo.br/aabc

Richness and abundance of the *cardini* group of *Drosophila* (Diptera, Drosophilidae) in the *Caatinga* and Atlantic Forest biomes in northeastern Brazil

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Manuscript received on July 31, 2013; accepted for publication on March 11, 2014

ABSTRACT

Brazil has a high diversity of flies of the genus *Drosophila*, and part of this richness is represented by the *cardini* group. We analyzed the fluctuations in the richness and abundance of this group, in environments that had never previously been studied in the northeastern region of Brazil. Among the 28,204 drosophilids sampled, 1,294 belonged to the *cardini* group and were represented by *D. polymorpha, D. cardini*, *D. neocardini* and *D. cardinoides*. Occurrences of *D. neocardini* and *D. cardinoides* were registered for the first time in the *Caatinga*. In this biome, *D. cardini* stood out as having the highest abundance, and *D. polymorpha* was not observed. In the coastal Atlantic Forest, *D. cardini* was not registered, but *D. polymorpha* was found in all the localities investigated. Mangrove swamps were the environment with the lowest abundance and richness of the *cardini* group. The High-altitude Forest presented the highest richness of this group. We suggest that the high abundance of *D. polymorpha* in the High-altitude Forest and in the coastal Atlantic Forest may be a reflection of the historical relationship between these two environments.

Key words: ecology, mangrove, Neotropical region, Pernambuco.

INTRODUCTION

In Brazil, the small flies that make up the genus *Drosophila* Fallén are classified into 28 taxonomic groups (Bächli 2014), and among these is the *cardini* group. The species in the group present abdominal pigmentation that is highly polymorphic in its coloring pattern and intensity (Brisson et al. 2006).

The *cardini* group includes 16 species that inhabit different areas of the Neotropical region and are distributed between the *dunni* and *cardini* subgroups, defined on the basis of their patterns of external morphology and male genitalia (Heed 1962). The *dunni* subgroup is restricted to the Antilles and is composed of seven species: *D. antillea* Heed, *D. arawakana* Heed, *D. belladunni* Heed and Krishnamurthy, *D. caribiana* Heed, *D. dunni* Townsend and Wheeler, *D. nigrodunni* Heed and Wheeler and *D. similis* Williston. The *cardini* subgroup is widely distributed across the Americas and is composed of nine species: *D. acutilabella*

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Stalker, *D. bedicheki* Heed and Russell, *D. cardini* Sturtevant, *D. cardinoides* Dobzhansky and Pavan, *D. neocardini* Streisinger, *D. neomorpha* Heed and Wheeler, *D. parthenogenetica* Stalker, *D. polymorpha* Dobzhansky and Pavan and *D. procardinoides* Frydenberg (Heed and Krishnamurthy 1959, Heed 1962, Heed and Russell 1971).

Among the species of the *cardini* subgroup, the following have been recorded in Brazil: *D. polymorpha*, *D. cardini, D. cardinoides, D. neocardini, D. neomorpha* and *D. parthenogenetica*. The first four of these have widespread geographical distribution in the country (Pavan 1959, Martins 1989, Vilela et al. 2002, Tidon 2006, De Toni et al. 2007). *Drosophila neomorpha* and *D. parthenogenetica* are more restricted and have only been observed in certain localities in the northern, central-western and southern regions of Brazil (De Toni et al. 2005).

More than 30 years ago, a wide-ranging study on the geographical distribution of species of the genus *Drosophila* in different morphoclimatic domains of Brazil was started. It included sampling from the Atlantic Forest, sand spits, the Pantanal, the Pampas, coastal regions, the Chaco, the savanna (*Cerrado*) and the *Caatinga* (Sene et al. 1980). In this study, most of the individuals identified as *D. cardinoides* were in reality *D. cardini*, which resulted in another paper in which these drosophilids were again analyzed. In this investigation, emphasis was placed on the richness and abundance of the *cardini* group in the different environments studied (Vilela et al. 2002).

Here, we continued along the lines of the study by Vilela et al. (2002), with analysis of the occurrences of the *cardini* group in environments that had never previously been studied in relation to the fauna of drosophilids, including ecosystems associated with the Atlantic Forest, such as the High-altitude Forest and Mangrove swamps located in the northeastern region of Brazil. New localities within the Atlantic Forest and the *Caatinga* were also studied. The present study included analyses on the variation in richness and abundance of the species of the *cardini* group in periods of contrasting rainfall. The trapping methods and bait were standardized in the different samples.

MATERIALS AND METHODS

Adult drosophilids were collected between June 2008 and December 2010, from the *sertão*, *agreste*, coastal Atlantic Forest, Mangrove swamp and High-altitude Forest environments at 14 localities in the state of Pernambuco, in the northeastern region of Brazil (Table I and Figure 1). Sampling was done during both the dry and the rainy season.

The *agreste* and *sertão* are part of the *Caatinga* biome. In the *agreste*, the vegetation is generally denser than in the *sertão*, the soil is generally deeper and rainfall is higher and more regular (Andrade-Lima 2007). The *agreste* is characterized as an intermediate region between the areas of humid and dry climates, with a rainy period occurring between March and June, and with a mean annual rainfall of 756.87 mm (Silva et al. 1985, Silva et al. 2010). In the *sertão*, the highest rainfalls occur during the months of January to April (60 to 70% of the annual total), and March is often the wettest month. For this region, the mean annual rainfall is 611.63 mm (Silva et al. 1985).

The High-altitude Forest, the coastal Atlantic Forest and the Mangrove swamps belong to the Atlantic Forest biome. The first occurs at heights of more than 500 meters and consists of islands of forest surrounded by semi-arid vegetation (*Caatinga*). The High-altitude Forest receives rainfall of over 1200 mm/year, which ensures moist conditions and milder temperatures than in the neighboring areas (Tabarelli and Santos 2004, Andrade-Lima 2007).

The vegetation in the coastal Atlantic Forest is formed predominantly by large-sized trees and several lower strata composed by small trees and bushes and a vast wealth of epiphytes (Klein

TABLE I
Environments and codes for the localities and municipalities investigated in relation to the abundance and richness of the *cardini* group of the genus *Drosophila*, in the state of Pernambuco, northeastern region of Brazil.

Biome	Environment	Locality code	Municipality	Coordinates
Caatinga	*Sertão*	SET-1	Serra Talhada	07°57'S/38°18'W
		SET-2	Serra Talhada	07°56'S/38°17'W
		SET-3	Serra Talhada	07°57'S/38°17'W
	Agreste	CAT-1	Buíque	08°24'S/37°09'W
		CAT-2	Buíque	08°36'S/37°14'W
		BUI	Buíque	08°37'S/37°09'W
Atlantic Forest	Coastal Atlantic Forest	POM	Pombos	08°08'S/35°23'W
		SAL	Tamandaré	08°45'S/35°06'W
		ZOO	Recife	08°03'S/34°52'W
	Mangrove swamp	PIN	Recife	08°03'S/34°52'W
		TAM	Tamandaré	08°45'S/35°06'W
	High-altitude Forest	TRI	Triunfo	07°50'S/35°06'W
		TAQ	Taquaritinga do Norte	07°54'S/36°02'W
		BEZ	Bezerros	08°53'S/36°29'W

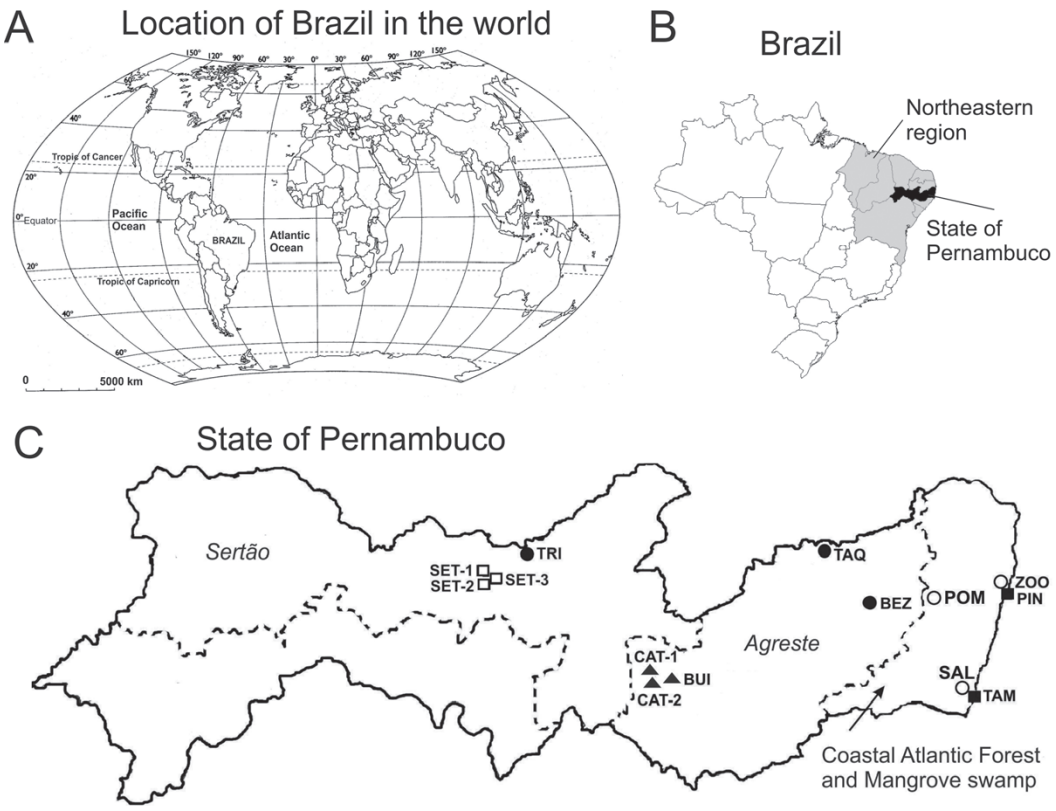

Figure 1 - A) World map with the geographical location of Brazil. **B)** Map of Brazil, with the northeastern region highlighted in grey and the state of Pernambuco in black. **C)** State of Pernambuco, highlighting the drosophilid sampling localities. White squares indicate localities in the *sertão*; black circles indicate areas of High-altitude Forest; black triangles indicate localities in the *agreste*, white circles indicate localities in coastal Atlantic Forest areas; and black squares indicate Mangrove swamp areas. The codes for the sampling localities are explained in Table I.

1978). Mangrove swamps are characterized by areas of contact between marine saltwater and freshwater from rivers (Andrade-Lima 2007). Periodic flooding, soil with high salinity and low oxygenation, and the mechanical action of the water are reflected in flora and fauna with specific adaptations for survival in this very particular environment (Lacerda 1984). The rainy period is from March to August in the coastal Atlantic Forest and Mangrove swamps (Silva et al. 2010).

The sampling method consisted of capturing adult flies with retention traps baited with banana (Tidon and Sene 1988). For each sampling period, ten traps were used, and these remained in the sampling localities for three consecutive days to attract drosophilids. The specimens of the *cardini* group were identified by means of analysis on the external morphology and the male genitalia (Vilela et al. 2002), as described by Wheeler and Kambysellis (1966).

RESULTS

In the four environments investigated, 28,204 drosophilids were collected, of which 4.6% belonged to the *cardini* group of *Drosophila*. This group included four species as follows, in decreasing order of abundance: *D. polymorpha*, *D. cardini*, *D. neocardini* and *D. cardinoides* (Table II).

The *cardini* group was more abundant in collections made during the rainy season, when 879 individuals were sampled, as opposed to the 415 collected during dry season. The most abundant species during the rainy season was *D. polymorpha*, with 524 individuals, and during the dry season, it was *D. cardini*, represented by 286 specimens (Table II).

The *cardini* group presented heterogeneity of species richness and abundance of individuals in the different environments studied. In the *Caatinga*, this group represented 4.88% of the drosophilids collected, and three species were observed: *D. cardini*, *D. cardinoides* and *D. neocardini*. Of these, *D. cardini* was the species of greatest abundance, representing more than 96% of the total number of individuals sampled in this group. This species was also the only one that was sampled in all the localities investigated in the *Caatinga*. In contrast, *D. polymorpha* was not captured in this biome. The abundance of individuals in relation to the season of the year presented two patterns: in the *agreste* localities, the *cardini* group predominated in the rainy season, while in the *sertão* localities, it predominated in the dry season (Table II).

In the coastal Atlantic Forest, the *cardini* group represented 3.29% of the individuals collected. No presence of *D. cardini* was registered in this environment, whereas *D. polymorpha* occurred in all the localities investigated. This latter species and *D. neocardini* were the most abundant species of the *cardini* group. *Drosophila cardinoides* was only collected in a single locality, in low abundance. In all the localities investigated in the coastal Atlantic Forest, greater abundance of the *cardini* group was always observed in samplings done during the rainy season (Table II).

Mangrove swamps were the environment with the lowest abundance and richness in relation to the *cardini* group, with only one species presented, *D. cardini*, which accounted for approximately 0.28% of the total number of drosophilids collected. In all sampling periods, this species was more abundant in the rainy season (Table II).

The greatest abundance of the *cardini* group was found in the High-altitude Forest, which accounted for 7.94% of the total number of drosophilids sampled. This was also the environment with the greatest richness of this group, and all four species observed in the present study were registered there. Approximately 60% of the *cardini* group was represented by *D. polymorpha*. The two species of lowest abundance, *D. cardini* and *D. neocardini*, were the only ones registered in all three High-altitude Forest localities investigated. Also in these

TABLE II

Absolute abundance of the *cardini* group of *Drosophila* in different areas of the *sertão, agreste*, coastal Atlantic Forest, Mangrove swamps and High-altitude Forest, in the state of Pernambuco, northeastern region of Brazil. CAR = *D. cardini*; NEO = *D. neocardini*; DES = *D. cardinoides*; POL = *D. polymorpha*. * Codes for localities are as explained in Table I.

Environment (Biome)	Locality code*	Season	Date (month/year)	*cardini subgroup of Drosophila*					Other species	Total
				POL	CAR	NEO	DES	Total		
Sertão (*Caatinga*)	SET- 1	Rainy	02/2009	0	0	0	0	0	109	109
		Dry	09/2008	0	133	0	0	133	953	1,086
	SET-2	Rainy	02/2009	0	0	0	0	0	109	109
		Dry	09/2009	0	6	0	2	8	21	29
	SET-3	Rainy	02/2009	0	0	0	0	0	784	784
		Dry	09/2009	0	130	0	5	135	206	341
Agreste (*Caatinga*)	CAT-1	Rainy	06/2008	0	10	3	0	13	964	977
		Dry	02/2009	0	0	0	0	0	273	273
	CAT-2	Rainy	06/2009	0	16	0	0	16	546	562
		Dry	02/2009	0	0	0	0	0	350	350
	BUI	Rainy	06/2009	0	19	0	3	22	1.715	1.737
		Dry	02/2009	0	0	0	0	0	348	348
	Total			0	314	3	10	327	6.378	6.705
Coastal Atlantic Forest (Atlantic Forest)	POM	Rainy	07/2008	173	0	89	0	262	2.237	2.499
		Dry	01/2009	6	0	4	0	10	431	441
	SAL	Rainy	08/2008	4	0	85	0	89	796	885
		Dry	01/2009	1	0	0	0	1	1.954	1.955
	ZOO	Rainy	08/2008	5	0	0	4	9	3.746	3.755
		Dry	02/2009	0	0	0	0	0	1,719	1,719
	Total			189	0	178	4	371	10.883	11.254
Mangrove swamps (Atlantic Forest)	PIN	Rainy	08/2009	0	3	0	0	3	139	142
		Dry	02/2010	0	1	0	0	1	388	389
	TAM	Rainy	04/2009	0	4	0	0	4	1.949	1.953
		Dry	12/2009	0	0	0	0	0	361	361
	Total			0	8	0	0	8	2.837	2,845
High-altitude Forest (Atlantic Forest)	TRI	Rainy	06/2009	0	12	3	0	15	1,658	1.673
		Dry	01/2009	0	6	0	0	6	301	307
	TAQ	Rainy	09/2010	206	2	4	4	216	523	739
		Dry	12/2010	0	0	0	0	0	23	23
	BEZ	Rainy	07/2008	136	2	45	47	230	3.962	4.192
		Dry	09/2009	7	10	13	91	121	345	466
	Total			349	32	65	142	588	6.812	7.400
General total				538	354	246	156	1,294	26.910	28.204

localities, there was greater abundance of the *cardini* group in samplings done during the rainy season (Table II).

Regarding abundance, *D. polymorpha* was the dominant species in the coast Atlantic Forest and High-altitude Forest, while *D. cardini* was dominant in the *sertão*, the *agreste* and the Mangrove swamps.

DISCUSSION

This study was the first to make an assessment of the richness and abundance of the *cardini* group in different environments located in the northeastern region of Brazil during periods of contrasting rainfall. The sampling was standardized with the same number and type of trap and bait, which made it possible to compare the observed results more efficiently.

Until now, the *cardini* group had been collected in the northeastern region of Brazil in the states of Bahia (Malogolowkin 1951, Pavan 1959, Sene et al. 1980, Tidon-Sklorz and Sene 1995), Maranhão (Dobzhansky and Pavan 1950, Tidon-Sklorz and Sene 1995), Paraíba (Sene et al. 1980) and Rio Grande do Norte (Sene et al. 1980). This study therefore provides the first records of this group in the state of Pernambuco.

In the six areas of the *Caatinga* investigated, *D. cardini* was the most abundant species of the *cardini* group, whereas *D. polymorpha* was not observed. Similar results in this biome were mentioned by Vilela et al. (2002). In the present study, we recorded occurrences of *D. neocardini* and *D. cardinoides* in the *Caatinga* for the first time.

In relation to sampling done in the *Caatinga*, two patterns were observed regarding the abundance of the *cardini* group. In the collections made during the dry season in the *sertão* (SET-1, SET-2 and SET-3), there was greater abundance of the *cardini* group, while this same pattern was observed in the *agreste* (CAT-1, CAT-2 and BUI) in the rainy season. This relationship may have occurred because the rainfall pattern of the *agreste* is more similar to that of the coastal Atlantic Forest (Silva et al. 2010), where the greater abundance of the *cardini* group was also observed in the rainy season.

In the coastal Atlantic Forest, the most abundant species in the *cardini* group was *D. polymorpha*. This was also the most abundant species of this group in several studies conducted in the same biome in the southern and southeastern regions of Brazil (Sene et al. 1980, Tidon-Sklorz and Sene 1992, Medeiros and Klaczko 2004, De Toni et al. 2007, Döge et al. 2008). Although *D. cardini* was not registered in the localities of the coastal Atlantic Forest in the northeastern region of Brazil investigated here, this species was previously mentioned in other samplings done in the coastal Atlantic Forest in the southern region of this country (Döge et al. 2008).

Drosophila cardini was found to be the only representative of this group in the two areas of Mangrove swamps studied. This species represented less than 1% of the drosophilids of this environment. In a study conducted by Schmitz et al. (2007) in Mangrove swamps in southern Brazil, the *cardini* group also accounted for just over 1% of the drosophilids collected, and the following were observed, in decreasing order of abundance: *D. polymorpha*, *D. neocardini*, *D. cardini* and *D. cardinoides*. These results lead us to conclude that there are differences in the composition of this group of species in Mangrove swamps in Brazil.

Since only eight individuals of the *cardini* group were collected in all the sampling done in Mangrove swamps in northeastern Brazil, the analysis on this group in this environment needs to be done cautiously. However, it is worth highlighting that only one individual of the *cardini* group was sampled in the dry season, which may indicate that this group is less represented during this season. Although Schmitz et al. (2007) collected different species of drosophilids in Mangrove swamps, these authors did not provide information regarding the representation of the *cardini* group during different seasons of the year.

The fauna of the *cardini* group in the High-altitude Forest was registered and evaluated for the first time. This area had the greatest abundance and richness of species of this group. Similar to what was observed in the present study, several other authors have highlighted the importance of the High-altitude Forest with regard to having high species diversity (Pôrto et al. 2004, Santiago et al. 2004, Rodal et al. 2005, Pereira et al. 2010).

In the same way as observed for the sampling done in the coastal Atlantic Forest, the most abundant species of the *cardini* group in the environment of the High-altitude Forest was *D. polymorpha*. This species has also been reported to be relatively abundant in the different morphoclimatic domains of Brazil, except in the

Caatinga (Sene et al. 1980). The high abundance of *D. polymorpha* in the High-altitude Forest areas, as also seen in the coastal Atlantic Forest, may be a reflection of the historical formation of the High-altitude Forest areas. These areas were formed as a consequence of climatic variations that occurred during the Pleistocene, which allowed the coastal Atlantic Forest to penetrate into the domain of the *Caatinga*. After the interglacial period, when the coastal forest returned to its original distribution, islands of Atlantic Forest remained in localities with a favorable microclimate, thus making the High-altitude Forest veritable refuges for species of the Atlantic Forest of northeastern Brazil, within the *Caatinga* (Andrade-Lima 1982).

In all the environments of the coastal Atlantic Forest, similar to what was observed in the High-altitude Forest areas studied, greater abundance of individuals of the *cardini* group was always observed during the rainy season. In a study on areas of coastal Atlantic Forest in southern Brazil, De Toni et al. (2007) also observed greater representation of drosophilids of this group during wetter periods.

The present study has contributed towards a greater knowledge of the richness and abundance of species of the *cardini* group in different biomes and environments of the state of Pernambuco in northeastern Brazil. The *cardini* group forms an interesting set of species for studying the functional and evolutive mechanisms that are responsible for abdominal pigmentation changes in *Drosophila* (Brisson et al. 2006). Thus, comprehension of the ecological versatility of its species is very important information for understanding the population dynamics of these drosophilids in nature.

ACKNOWLEDGMENTS

The authors are grateful to the funding agencies Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE), Pro-Rectory for Research and Postgraduate Affairs (PROPESQ) of the Federal University of Pernambuco (UFPE) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); and also to their colleagues in the Genetics Laboratory of CAV-UFPE for assistance during field excursions.

RESUMO

O Brasil apresenta alta diversidade de moscas do gênero *Drosophila* sendo parte desta riqueza representada pelo grupo *cardini*. Nós analisamos as flutuações na riqueza e na abundância deste grupo em ambientes que nunca haviam sido estudados na região Nordeste do Brasil. Entre os 28.204 drosofilídeos amostrados, 1.294 pertenceram ao grupo *cardini* e foram representados por: *D. polymorpha*, *D. cardini*, *D. neocardini* e *D. cardinoides*. As ocorrências de *D. neocardini* e *D. cardinoides* foram registradas pela primeira vez para a Caatinga. Neste bioma, *D. cardini* destacou-se como a espécie mais abundante e *D. polymorpha* não foi observada. Na Floresta Atlântica costeira *D. cardini* não foi registrada, mas *D. polymorpha* foi observada em todas as localidades investigadas. Os manguezais foram os ambientes com a menor abundância e riqueza do grupo *cardini*. Os Brejos de Altitude apresentaram a maior riqueza deste grupo. Nós sugerimos que a alta abundância de *D. polymorpha* nos Brejos de Altitude e na Floresta Atlântica Costeira pode refletir a relação histórica entre estes dois ambientes.

Palavras-chave: ecologia, manguezal, região Neotropical, Pernambuco.

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