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Taxonomy & Inventories

Diversity of an Odonata assemblage from a tropical dry forest in San Buenaventura, Jalisco, Mexico (Insecta, Odonata)

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Abstract

Background

The patterns of richness, diversity, and abundance of an odonate assemblage from San Buenaventura, Jalisco are presented here. A total of 1087 specimens from seven families, 35 genera and 66 species were obtained through monthly samplings of five days each during a period of one year. Libellulidae was the most diverse family (28 species), followed by Coenagrionidae (21), Gomphidae (7), Aeshnidae (6), Calopterygidae (2), Lestidae (1) and Platystictidae (1). *Argia* was the most speciose genus. The highest species richness and Shannon diversity were found during August and September, whereas the highest abundance was observed in June and the highest Simpson diversity was recorded in September — all of which were associated with the rainy season. The highest values of phylogenetic diversity were found from June to October. The different diversity facets of this assemblage were positively correlated with precipitation and minimum temperature, whereas maximum temperature showed no influence. In addition, we found that this

odonate diversity was higher than most Mexican localities with tropical dry forest (TDF) studied.

New information

We continue our efforts to describe the patterns of richness, diversity and abundance of some insect groups associated with the tropical dry forest ecosystem in Mexico, following a latitudinal gradient of the distribution of this ecosystem in the country. Our emphasis here was to evaluate the spatial and temporal patterns of richness and diversity of an Odonata assemblage from Jalisco, Mexico.

Keywords

richness, temporal diversity, phylogenetic diversity, abundance, Odonata assemblage, tropical dry forest

Introduction

This study continues our efforts to describe the patterns of richness, diversity and abundance of some insect groups associated to the tropical dry forest in Mexico (e.g. Noguera et al. 2002, Zaragoza–Caballero et al. 2003, Noguera et al. 2007, González-Soriano et al. 2008, González-Soriano et al. 2009, González-Soriano et al. 2021). Tropical dry forests (abbreviated hereinafter as TDFs) are defined as forests with pronounced seasonality in rainfall distribution, resulting in several months of drought (Mooney et al. 1995). TDFs are highly diverse ecosystems that harbour a large number of endemic species not found in any other ecosystem in the world. These forests also face an intense pressure due to deforestation and the conversion of original lands into lands for agriculture and cattle raising, specially in Latin America (Sánchez-Azofeifa et al. 2005, DRYFLOR et al. 2016). In Mexico, the extension of TDFs has been dramatically diminishing over several years ago at an amazing rate (Miles et al. 2006). To protect and conserve these rich ecosystems is an urgent issue, by means of the study of their biodiversity before it disappears. For this and other reasons, we — a group of entomologists from the Institute of Biology at the National Autonomous University of Mexico — started a project since 1997, with the aim of identifying the spatial and temporal patterns of richness and diversity of selected groups of insects through a latitudinal gradient of the distribution of this ecosystem in Mexico. Previous studies have been performed at several sites along the Pacific Mexican Coast and at some sites at south Central Mexico (e.g. Noguera et al. 2002 , Zaragoza–Caballero et al. 2003, Noguera et al. 2007, González-Soriano et al. 2008, González-Soriano et al. 2009, Noguera et al. 2009, Noguera Martínez et al. 2012, Noguera et al. 2017). Here, we present the results of a faunistic study made during 1996-1997 at one of these sites: San Buenaventura, Jalisco, in central-western Mexico.

Materials and methods

Study site

San Buenaventura (from here on SBV) is located on the eastern slope of the Sierra de Cacoma-Sierra de Manantlan, Jalisco, Mexico (latitude 19°45'19", 19°48'50" N and longitude -104°01'25", -104°08'25" W; Fig. 1). The climate is warm sub-humid type according to the Köeppen climate classification modified by García (1988). The average annual precipitation from the nearest weather station Presa Basilio Vadillo (Comisión Nacional del Agua and Servicio Metereológico Nacional 2023) was 747 mm, while the average air temperature was 23.8°C, with average maximum and minimum temperatures of 31.9°C and 15.8°C respectively. The highest temperature during the study period was recorded in May and the lowest in January (Fig. 2). The dominant vegetation in the area is TDF. The dominant tree species are *Lysiloma acapulcense* (Kunth) Benth (Fabaceae), *L. divaricatum* (Jacq.) J.F.Macbr, *Jacaratia mexicana* A. DC. (Caricaceae), *Amphipterygium adstringens* (Schltdl.) Standl. (Anacardiaceae), *Entada polystachya* (L.) DC. (Fabaceae), *Ceiba aesculifolia* (Kunth) Britten & Baker f. (Malvaceae), *Senegalia macilenta* (Rose) Britton & Rose (Fabaceae), *Vitex mollis* Kunth (Lamiaceae), *Ipomoea bracteata* Cav. (Convolvulaceae), *Bursera* spp. (Burseraceae) and *Cochlospermum vitifolium* (Willd.) Spreng. (Bixaceae) (Jardel 1992). A gallery forest, characterised by trees taller than those of the TDF, extends along streams and narrow canyons. Flat areas in the zone have been open to agriculture and hillsides are used as grazing areas for cows and goats, which has resulted in the near disappearance of the native understorey.

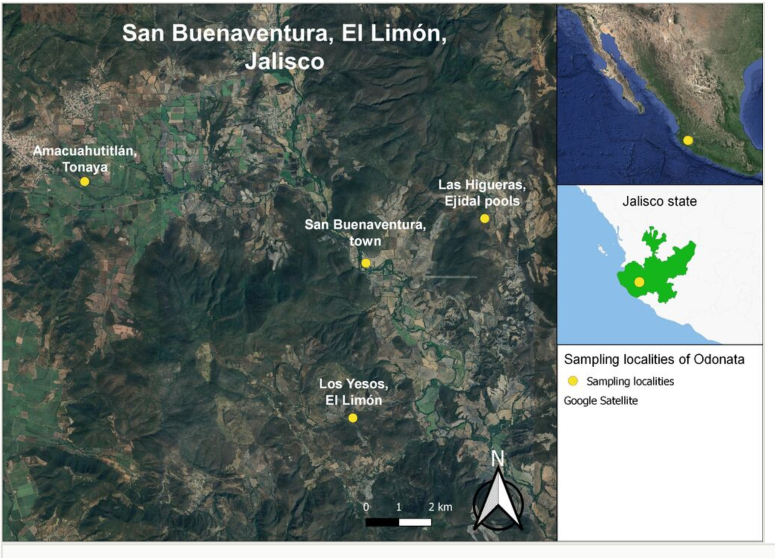

Figure 1. doi

Sampling localities of Odonata species in San Buenaventura, Jalisco, Mexico. Entomological samplings were performed from 1996-1997. Imagery 2015, INEGI Maxar Technologies CNES/ Airbus. Downloaded August 2023.

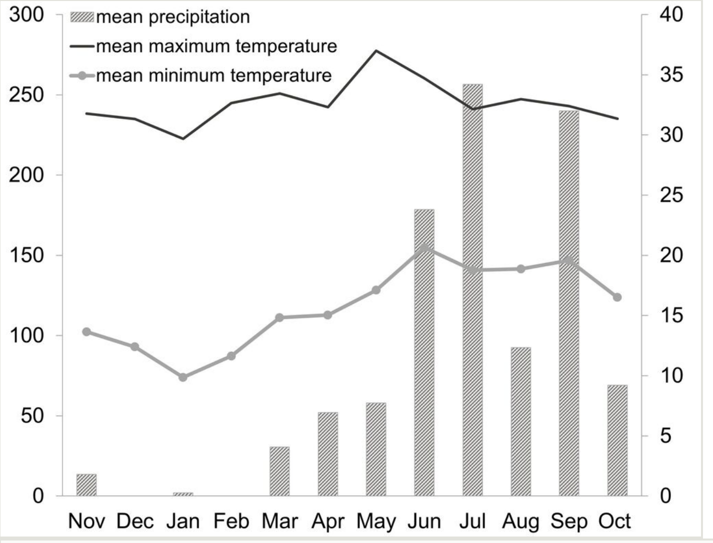

Figure 2. doi

Monthly variation of rainfall and temperature in San Buenaventura, Jalisco during 1996-1997.

Sampling methods and regimes

The study area is located within the Ayuquila-Armeria River Basin and, more specifically within the Tuxcacuesco River and Ayuquila sub-basins (Guevara Gutiérrez et al. 2019, Rodríguez-Contreras et al. 2019). Sampling collections were done around three main localities: SBV town, Los Yesos and Amacuahutitlán, and only occasionally at Las Higueras (see Table 1, Fig. 1).

Table 1.

San Buenaventura, Jalisco localities where odonate sampling collection was performed (1996-1997).

Sampling locality	Municipality	Coordinates
San Buenaventura, town	El Limón	19.79357°N, -104.0554°W
Los Yesos, El Limón	El Limón	19.7511°N, -104.0592°W
Las Higueras, Ejidal pools	El Limón	19.80578°N, -104.02077°W
Amacuahutitlán	Tonaya	19.81593°N, -104.1374°W

The SBV samplings were made along the margins of the Ferreria River, a permanent river that crosses the town. Samplings in Amacuahutitlán and Los Yesos were done at small open streams and finally, at the site of Las Higueras consisting of a small, mostly shaded, spring-fed shallow stream with abundant aquatic plants on its surface (Fig. 3). Most collecting sites belong to the Municipality of El Limón, except for Amacuahutitlán, which is located within the Municipality of Tonaya (see Table 1).

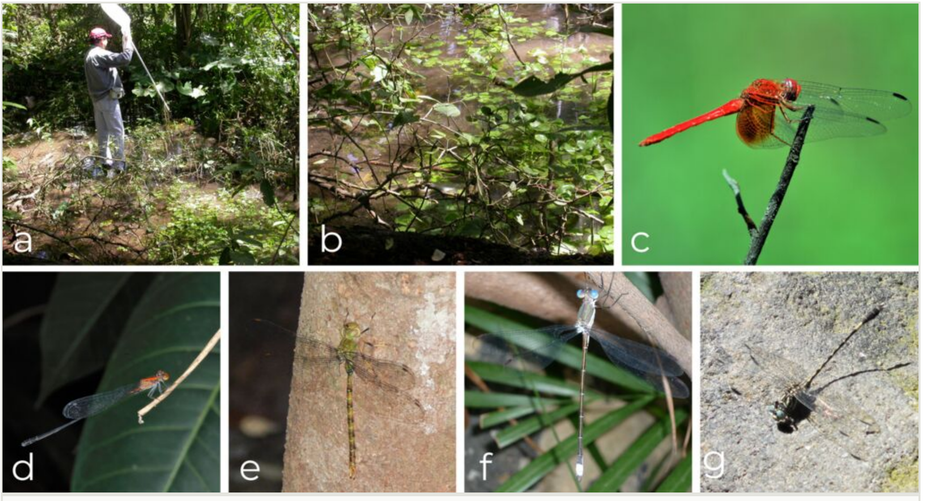

Figure 3. doi

Habitats and Odonata species from four localities in San Buenaventura, Jalisco, Mexico; **a, b** microhabitat of *Anisagrion allopterum*; **c** *Dythemis maya*; **d** *Neoneura amelia*; **e** *Gynacantha helenga*; **f** *Archilestes grandis*; **g** *Progomphus clendoni*. Photos: a, b, César Durán; c, f, g Enrique González Soriano; d, Enrique Ramírez; e, Eric Hough (Naturalista).

Fieldwork in SBV was always conducted by two people between November 1996 and October 1997. Collections were carried out for a period of five days every month. Specimens were obtained through direct collecting, between 09:00 h and 15:00 h (10:00 h-16:00 h in the daylight-saving time).

All the Odonata records collected in SBV, Jalisco, Mexico for this work were included in the GBIF dataset Digitization and Systematization of the National Biological Collections of the Institute of Biology, UNAM from the National Autonomous University of Mexico (Sánchez Cordero Dávila 2023). Data on the phenology and the number of specimens collected (between parentheses) were added in the Odonata species list (Results section); additional information can be consulted in the Supplementary materials and photographs of some species in Fig. 3.

Diversity analysis

The diversity of the SBV odonate assemblage was analysed through different metrics of species and phylogenetic diversities. We first quantified:

(a) abundance, measured as the number of specimens collected through a species rank abundance curve;

(b) species richness, as the number of species observed (diversity order 0, ^{0}D);

(c) Shannon diversity, which corresponds to the exponential of the Shannon Index (diversity order 1, ^{1}D); and

(d) Simpson diversity, which corresponds to the inverse of the Simpson Index (diversity order 2, ^{2}D) (Jost 2006, Chao et al. 2014).

The measurement unit for ^{1}D and ^{2}D is the number of effective species, also referred to as Hill numbers, in such a way that ^{1}D indicates the effective number of equally abundant species within an assemblage and ^{2}D showed the effective number of the most abundant or most dominant equally abundant species.

We then calculated the maximum expected richness value of diversity for ^{0}D, ^{1}D and ^{2}D to compare those values with our observed sample. We used the Spade R package (Chao et al. 2015) to compute the non-parametric abundance-based Chao 1-bias corrected estimator and the estimators proposed by Magurran for ^{0}D, ^{1}D and ^{2}D, respectively (Magurran 1988, Chao 2005, Chao et al. 2013). We also calculated a cumulative species curve for the whole Odonata assemblage from SBV, through the interpolation-extrapolation method proposed by Chao et al. (2014) for ^{0}D, ^{1}D and ^{2}D and using the iNEXT R package (Hsieh et al. 2016).

In addition, we evaluated monthly abundance, ^{0}D, ^{1}D, and ^{2}D to analyse temporal diversity patterns in the Odonata assemblage. In addition, we analysed temporal phylogenetic diversity through the taxonomic diversity (Δ) and taxonomic distinctness (Δ^*) indices, which are based on the abundance and the average taxonomic distinctness ($\Delta+$) index, based on species incidence (Warwick and Clarke 1995, Clarke and Warwick 2001). Taxonomic diversity and taxonomic distinctness analyse phylogenetic divergence amongst species within communities or assemblages according to their topological organisation, i.e. the phylogenetic relationships amongst taxa and their taxonomic hierarchy; these measures calculate how closely related the specimens (Δ) or the species within the assemblage are (Δ^*) or how evenly distributed their evolutionary paths are through the taxonomic hierarchy ($\Delta+$) (Clarke and Warwick 1998, Clarke and Warwick 2001). Since the most recent odonate phylogenies do not include all taxa within the order (e.g. Bybee et al. (2021)), we used the hierarchical classification above species-level as a proxy to calculate taxonomic distances amongst taxa using diferent phylogenetic diversity metrics (Clarke and Warwick 2001; Tucker et al. 2016). In particular, the phylogenetic hypothesis of Bybee et al. (2021) for suprafamily levels and Dijkstra et al. (2014) and Carle et al. (2015) for suprageneric levels of Anisoptera and Zygoptera suborders, respectively were used for this purpose. We included seven taxonomic levels to evaluate monthly phylogenetic divergence within the SBV odonate assemblage: order, suborder, superfamily, subfamily, tribe, genus and species. Phylogenetic divergence was calculated through the *taxondive* and *taxa2dist* functions of the Vegan R package (Oksanen et al. 2015).

Relationship between odonate diversity and abiotic factors

To analyse whether species and phylogenetic diversity of the SBV odonate assemblage are related to abiotic factors, we performed Pearson's correlation analyses between monthly species diversity (abundance, ^{0}D, ^{1}D and ^{2}D), monthly phylogenetic diversity (Δ, Δ^*, $\Delta+$) and monthly mean rainfall and temperature documented in SBV, Jalisco during the sampling time. Values of precipitation and temperature were obtained from the closest weather station (Presa Basilio Vadillo) through the National Meteorological System (Comisión Nacional del Agua and Servicio Metereológico Nacional 2023). We found a positive correlation between temperature and precipitation. Pearson's correlation analyses were done in Past software (Hammer et al. 2001). In addition, we generated a heatmap using the *pheatmap* R package (Warnes et al. 2012) to display the presence and abundance that each odonate species showed monthly. Monthly diversity and phylogenetic divergence analyses allowed us to evaluate how the species diversity and the taxonomic assemblage structure were related to monthly changes of temperature and humidity. In other words, those analyses allowed us to evaluate how the abiotic factors can be associated with the temporal structure of the Odonata community of the TDF.

List of Odonata species registered from San Buenaventura, Jalisco, Mexico

Archilestes grandis (Rambur, 1842)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Aug (2), Sep (3), Oct (4).

Palaemnema domina Calvert, 1903

Distribution: Las Higueras, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Sep (2).

Hetaerina americana (Fabricius, 1798)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Nov (2), Dec (18), Jan (7), Feb (13), Mar (22), Apr (4), May (2), Jun (61), Jul (1), Aug (5), Sept (6), Oct (8).

Hetaerina capitalis Sélys 1873

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jul (1)

Anisagrion allopterum Sélys, 1876

Distribution: Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Aug (3), Sept (1)

Apanisagrion lais (Brauer in Sélys, 1876)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Jan (3), Mar (1), Apr (2), Jul (1), Sept (1), Oct (1)

Argia anceps Garrison, 1996

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Dec (3), Jan (1), Feb (1), Apr (1), May (3), Jun (8), Jul (4), Aug (6), Sept (10), Oct (1).

Argia carlcooki Daigle, 1995

Distribution: Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Mar (3), Apr (1), Jun (1), Aug (4), Sept (1), Oct (1)

Argia extranea (Hagen, 1861)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Feb (13), Mar (2), Apr (10), May (1), Jun (11), Aug (7), Sept (6), Oct (9)

Argia harknessi Calvert, 1899

Distribution: San Buenaventura, Las Higueras, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (3), Jan (6), Feb (10), Mar (7), Apr (2), Jun (7), Jul (1), Aug (1), Sep (5), Oct (1)

Argia mayi González-Soriano, 2012

Distribution: Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Aug (5)

Argia oculata Hagen in Sélys, 1865

Distribution: San Buenaventura, Amacuahutitlan, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Feb (1), Mar (1), Apr (2), Jun (1), Aug (1), Sept (3)

Argia oenea Hagen in Sélys, 1865

Distribution: San Buenaventura, Amacuahutitlan, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Dec (2), Jan (1), Aug (1)

Argia pallens Calvert, 1902

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Mar (2), Apr (1), Jun (3), Sep (3)

Argia pulla Hagen in Sélys, 1865

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Dec (3), Jan (3), Feb (11), Mar (12), Apr (8), May (1), Jun (12), Aug (6), Sep (3), Oct (9)

Argia tezpi Calvert, 1902

Distribution: San Buenaventura, Las Higueras, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Dec (3), Jan (3), Feb (5), Mar (5), May (1), Jun (5), Jul (2), Aug (1), Sep (3), Oct (1)

Enallagma civile (Hagen, 1861)

Distribution: San Buenaventura, Los Yesos, Jalisco, MX

Notes: Phenology in SBV: Dec (2), Apr (2)

Enallagma novaehispaniae Calvert, 1907

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Nov (2), Dec (6), Jan (5), Feb (8), Mar (4), Apr (5), Jun (13), Aug (1), Sep (4), Oct (1)

Enallagma semicirculare Sélys, 1876

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Dec (2), Feb (3), Apr (6)

Ischnura hastata (Say, 1840)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Dec (2), Feb (2), Mar (4), Apr (6), May (3), Jun (4).

Ischnura ramburii (Sélys, 1850)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Mar (1), Apr (4)

Neoneura amelia Calvert, 1903

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Dec (1), Jun (1), Jul (2), Sep (2), Oct (6)

Protoneura cara Calvert, 1903

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (2), Feb (7), Mar (3), May (1), June (2), Jul (2), Sep (4), Oct (6)

Telebasis levis Garrison, 2009

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (7)

Telebasis salva (Hagen, 1861)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (5), Jan (3), Feb (7), Mar (5), Apr (2), May (2), Jun (7), Jul (2), Aug (2), Sep (1), Oct (2)

Anax junius (Drury, 1773)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Aug (1)

Gynacantha helenga Williamson & Williamson, 1930

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Apr (1)

Remartinia luteipennis (Burmeister, 1839)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (1), Sep (2)

Remartinia secreta (Calvert, 1952)

Distribution: San Buenaventura, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Jul (1), Aug (1), Sept (1)

Rhionaeschna multicolor (Hagen, 1861)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: May (1), Jun (1)

Rhionaeschna psilus (Calvert, 1947)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Feb (2), Sep (1)

Aphylla protracta (Hagen in Sélys, 1859)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Aug (3)

Erpetogomphus elaps Sélys, 1858

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Jul (1), Aug (1), Sep (9), Oct (2)

Phyllocycla elongata (Sélys, 1858)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Aug (5), Sep (1), Oct (1)

Phyllogomphoides luisi González y Novelo, 1990

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Aug (1), Sep (5), Oct (1)

Phyllogomphoides pacificus (Sélys, 1873)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Jun (1), Jul (3), Aug (26), Sep (10), Oct (11)

Progomphus belyshevi Belle, 1991

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Aug (1)

Progomphus clendoni Calvert, 1905

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (1), Aug (1), Sep (3)

Brechmorhoga praecox (Hagen, 1861)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Feb (1), Aug (2)

Cannaphila insularis Kirby,1889

Distribution: Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Aug (4), Sep (4)

Dythemis maya Calvert, 1906

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Aug (2), Sep (6), Oct (2)

Dythemis nigrescens Calvert, 1899

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Dec (2), Jan (2), May (3), Jun (1), Jul (2), Aug (4), Sep (2), Oct (6)

Dythemis sterilis Hagen, 1861

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Dec (6), Jan (2), Feb (1), Mar (1), Apr (2), Jun (2), Jul (2), Aug (2), Sep (2), Oct (1)

Erythemis haematogastra (Burmeister, 1839)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Dec (1)

Erythrodiplax basifusca (Calvert, 1895)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Feb (3), Mar (10), Apr (6), May (2), Jun (8), Sep (1)

Erythrodiplax funerea (Hagen, 1861)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (2), Jul (1), Aug (3), Sep (1)

Libellula croceipennis Sélys, 1868

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Jun (7), Aug (4), Sep (5), Oct (3)

Macrothemis hemichlora (Burmeister, 1839)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Feb (1)

Macrothemis inacuta Calvert, 1898

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (1), Feb (1), Jun (3), Jul (1), Aug (5), Sept (1)

Macrothemis inequiunguis Calvert, 1895

Distribution: Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Jun (1)

Macrothemis pseudimitans Calvert, 1898

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (2), Mar (1), May (1), Jun (5), Jul (2), Aug (3), Sep (2)

Miathyria marcella (Sélys in Sagra, 1857)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Dec (4), Aug (1)

Micrathyria aequalis (Hagen, 1861)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Dec (5), Aug (1), Sep (1), Oct (1)

Micrathyria didyma (Sélys in Sagra, 1857)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (2), Jul (1), Aug (3), Sep (2)

Micrathyria paulsoni González-Soriano, 2020

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (8), Jul (4), Aug (1), Sep (2)

Orthemis discolor (Burmeister, 1839)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Nov (1), Dec (4), Feb (3), Apr (2), Jun (3), Aug (2), Sep (1), Oct (8)

Orthemis ferruginea (Fabricius, 1775)

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Nov (4), Dec (3), Jan (1), Feb 1), Jun (5), Jul (1), Sep (1)

Orthemis levis Calvert, 1906

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (14), Sept (1)

Pantala flavescens (Fabricius, 1798)

Distribution: San Buenaventura, Amacuahutitlan, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Aug (5)

Pantala hymenaea (Say, 1840)

Distribution: San Buenaventura, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Aug (6)

Perithemis domitia (Drury, 1773)

Distribution: San Buenaventura, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Jun (2), Aug (1)

Perithemis intensa Kirby, 1889

Distribution: San Buenaventura, Amacuahutitlan, Jalisco, MX

Notes: Phenology in SBV: Dec (5), Feb (3), Mar (2), Apr (3), May (2), Jun (3), Aug (1), Oct (5)

Perithemis tenera (Say, 1840)

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Feb (2)

Pseudoleon superbus (Hagen, 1861)

Distribution: San Buenaventura, Las Higueras, Jalisco, MX

Notes: Phenology in SBV: Nov (3), Dec (2), Mar (1), Aug (1)

Tauriphila azteca Calvert, 1906

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Jun (2), Aug (3)

Tramea onusta Hagen, 1861

Distribution: San Buenaventura, Jalisco, MX

Notes: Phenology in SBV: Aug (3), Sept (2)

Analysis

Species richness and diversity

We documented a total of 1087 specimens belonging to seven families, 35 genera and 66 species of odonates in the assemblage (Figs 4, 5). Those values represent 87.5% of the families, 80% of the genera and 51% of the total species previously reported for the State of Jalisco (González-Soriano and Novelo-Gutiérrez 2014; Suppl. material 1). Libellulidae and Coenagrionidae were the families with the highest number of species, with 28 (42.4%) and 21 (31.8%), respectively, followed by Gomphidae (7), Aeshnidae (6), Calopterygidae (2), Lestidae (1) and Platystictidae (1). At the generic level, Libellulidae had the highest numbers of genera (15), followed by Coenagrionidae (8), Gomphidae (5), Aeshnidae (4), Lestidae (1), Calopterygidae (1) and Platystictidae (1). *Argia* was the most speciose genus with 10 species, followed by *Macrothemis* with four and the remaining genera with 1-3 species. *Phyllogomphoides luisi* was recorded for the first time in the State of Jalisco and *Anisagrion allopterum* represented the first northernmost documented record of this species in America (Fig. 3). The total species richness (66 species) represented 88.9% from the total expected richness (^0D, 74.16 effective species), 96.3% (35.4) of the expected Shannon diversity (^1D) and 97.97% (22.2) of the expected Simpson diversity (^2D) (Table 2, Fig. 5). The estimated species richness suggests that there could be another eight species in the site, whereas observed evenness (^1D) and dominance (^2D) showed values close to the estimated values of those diversity metrics.

Species abundance during all the sampling was very heterogeneous. Only a few species were very abundant and most were represented by one or few specimens (Figs 4, 6). *Hetaerina americana* was by far the most abundant species with 149 specimens, followed by the coenagrionids *Argia pulla* (68), *A. extranea* (59), *Phyllogomphoides pacificus* (51), *Enallagma novaehispaniae* (49) and *A. harknessi* (44). Those six species represented 41%

of the total abundance of the assemblage (420 specimens). Surprisingly, one anisopteran, *P. pacificus*, appeared within the group of abundant species with more than 50 specimens. This contrasts with our other previous studies in TDF where the most abundant species belong to the suborder Zygoptera. On the contrary, 16 species were represented by only 1-3 specimens and contributed only 3% of the total abundance (31 specimens).

Table 2.

Monthly values of temperature (°C) and precipitation (mm), odonate species diversity and phylogenetic diversity from SBV during 1996-1997. Tmax, mean maximum temperature; Tmin, mean minimum temperature; PPM, mean precipitation; N, abundance (specimen count); ${}^0D$, species richness; ${}^1D$, Shannon diversity; ${}^2D$, Simpson diversity; Δ, taxonomic diversity; Δ*, taxonomic distinctness; Δ+, average taxonomic distinctness. Additionally, expected values of different measures of diversity correspond to the whole assemblage (${}^0D$, ${}^1D$, ${}^2D$) or by month (Δ, Δ*, Δ+).

Month	**Tmax**	**Tmin**	**PPM**	**N**	**${}^0D$**	**${}^1D$**	**${}^2D$**	**Δ**	**Δ***	**Δ+**
Nov	31.76	13.64	13.5	17	11	9.44	8.1	73.44	79.13	79.42
Dec	31.32	12.39	0	83	24	18.40	13.21	75.71	80.97	76.08
Jan	29.68	9.85	2	31	11	9.03	7.81	63.71	70.92	70.39
Feb	32.64	11.63	0	94	22	15.6	12.61	63.68	68.48	76.26
Mar	33.45	14.82	30.5	82	19	11.99	8.46	65.70	73.66	69.67
Apr	32.3	15.03	52	68	20	15.83	13.24	63.32	67.51	69.71
May	37	17.1	58	21	13	11.76	10.79	75.51	79.60	78.24
Jun	34.7	20.64	178.5	202	36	18.33	9.52	73.50	81.75	77.36
Jul	32.13	18.76	256.5	35	21	18.58	16.49	78.03	80.82	81.62
Aug	32.97	18.86	92.5	137	44	29.24	17.91	76.16	80.10	78.37
Sep	32.4	19.57	240	119	40	30.35	24.32	78.14	80.82	80.21
Oct	31.35	16.5	69	89	24	17.03	14.01	77.67	82.72	80.06
Expected values					74.16	36.72	22.23	81.58	76.42	80.37

Variation in temporal species and phylogenetic diversity

We observed a high variation in the different facets of diversity species of the odonate assemblage throughout the year. The highest species richness was recorded in August (44 species) and September (40), while the lowest was observed in November (11) and January (11). In addition, the highest value of abundance was observed in June (202 specimens), during the rainy season and the lowest in November (17) and May (21), during the dry season (Table 2, Fig. 6). The highest Shannon diversity was also documented in August and September, while the highest value of Simpson diversity was recorded in September (Table 2).

Phylogenetic divergence also showed a high variation throughout the year (Table 2): the taxonomic diversity showed its highest values from July to October; the taxonomic distinctness (Δ*) was higher in June and October. In general, it was high throughout the rainy period, whereas we observed lower values than the expected (76.42 species) from January to April except December. In general, the monthly taxonomic diversity (Δ) and the average taxonomic distinctness (Δ+) were lower than the expected.

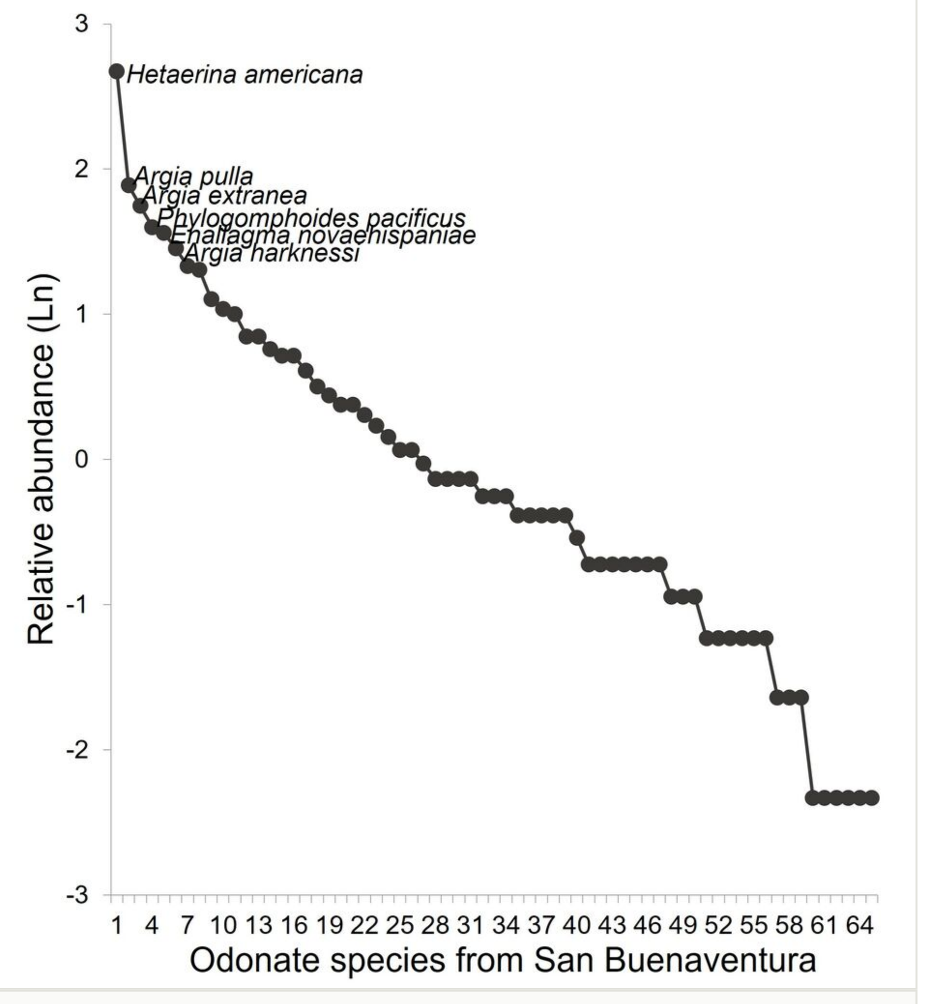

Figure 4. doi

Species rank-abundance curve for the odonate species collected in San Buenaventura, Jalisco during 1996-1997.

Relationship between odonate diversity and abiotic factors

Variation in precipitation showed a positive, moderate correlation with Shannon and Simpson diversities of the SBV odonate assemblage, as well as with phylogenetic divergence (Δ* and Δ+) (Table 3); whereas variation in minimum temperature also showed a positive, moderate correlation with monthly variation in species richness, Shannon diversity and all metrics of phylogenetic diversity (Table 3). Maximum temperature did not show any influence on the different metrics performed.

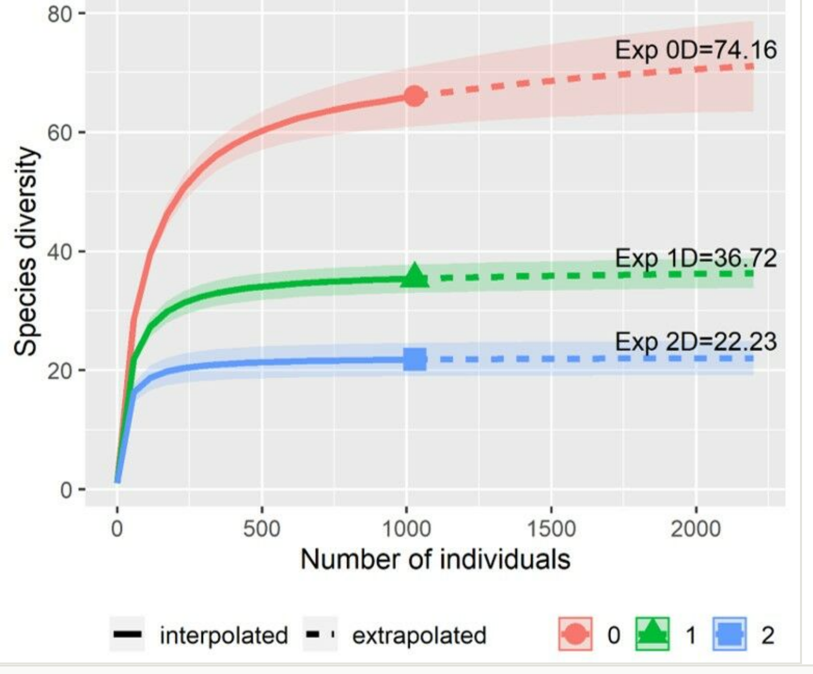

Figure 5. doi

Interpolation-extrapolation cumulative curve, based on the number of odonate specimens collected in San Buenaventura, Jalisco (1996-1997) for three diversity orders: ^{0}D, species richness; ^{1}D, Shannon diversity; ^{2}D, Simpson diversity. Exp, expected values of diversity of order 0, 1 and 2.

Monthly precipitation was strongly correlated with monthly minimum temperature (r = 0.833, P < 0.001); abundance showed a high, positive correlation with species richness and Shannon diversity (Table 3), which, in turn, were strongly correlated with Simpson diversity; also, taxonomic diversity and taxonomic distinctness showed a high, positive correlation between them. In addition, average taxonomic distinctness was highly and positively correlated with the diversity metrics of most species.

Comparison with other TDF regions

In contrast with other TDF Mexican localities studied where coenagrionids were dominant (e.g. Dominguillo, Oaxaca; Huautla, Morelos; San Javier, Sonora), the odonate assemblage from SBV was dominated by one abundant calopterygid species: *Hetaerina americana* (Fig. 2). In addition, odonate species richness in SBV (66 species) was higher than the richness reported from Sierra de Huautla, Morelos (57) (González-Soriano et al. 2008); San Javier, Sonora (52) (González-Soriano et al. 2009); Río Pinolapa, Michoacán

(51) (Novelo-Gutiérrez and Gómez-Anaya 2009); Dominguillo, Oaxaca (50) (González-Soriano et al. 2021); and Aguililla, Michoacán (40) (Novelo-Gutiérrez and Gómez-Anaya 2009). However, it was lower than that reported for Chamela, Jalisco (González-Soriano et al. 2004), which is the TDF site with the largest number of species recorded so far (78). SBV shares 71.2% species with Huautla; 63.6% with Chamela; 56.6% with Río Pinolapa; 53% with San Javier; 48.5% with Aguililla; and 42.4% with Dominguillo.

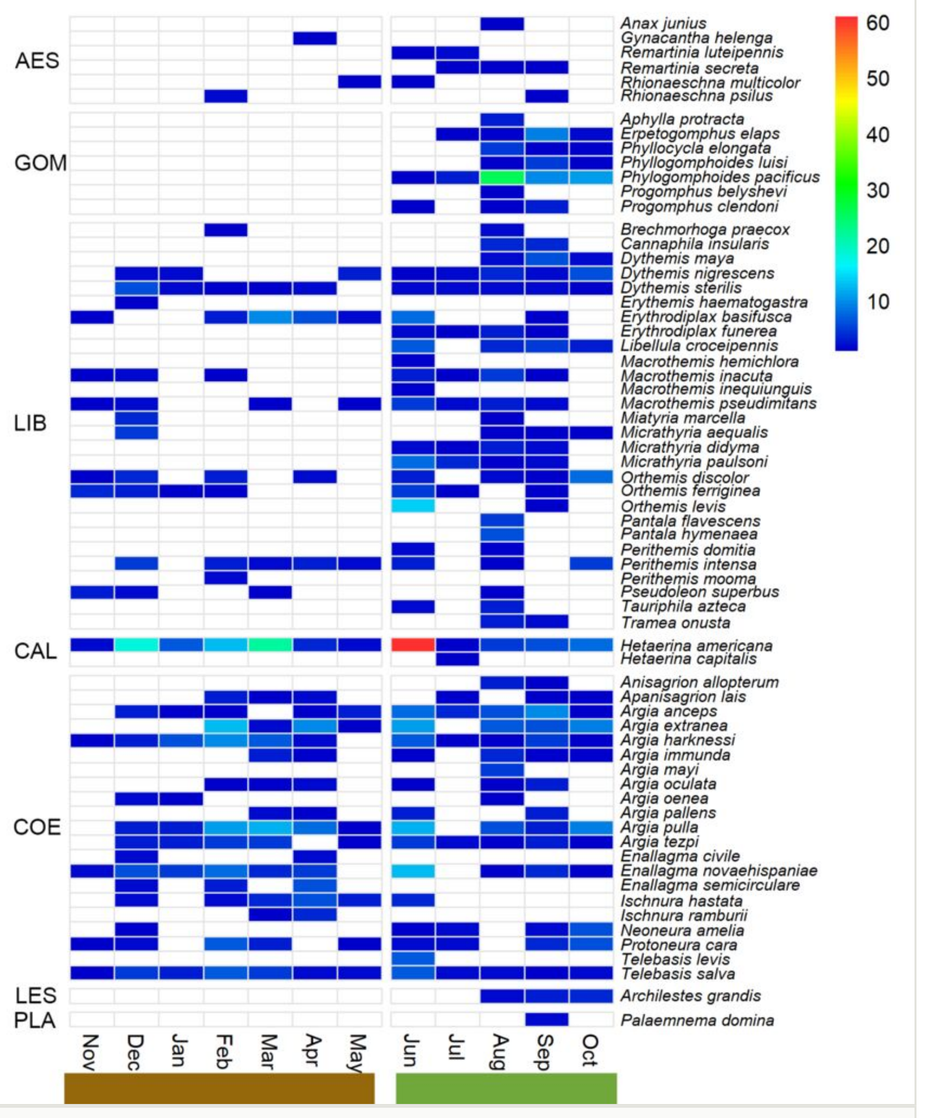

Figure 6. doi

Heatmap showing monthly abundance (number of specimens) of odonate species collected in SBV, Jalisco. Species in rows are ordered according to their suborder and family. AES, Aeshnidae; GOM, Gomphidae; LIB, Libellulidae; CAL, Calopterygidae; COE, Coenagrionidae; LES, Lestidae; PLA, Platystictidae.

Table 3.

Pearson correlation coefficients between temperature, precipitation and odonate species diversity and phylogenetic diversity from SBV and amongst diversity metrics performed. Tmax, mean maximum temperature; Tmin, mean minimum temperature; PPM, mean precipitation; N, abundance; ^{0}D, species richness; ^{1}D, Shannon diversity; ^{2}D, Simpson diversity; Δ, taxonomic diversity; Δ*, taxonomic distinctness; Δ+, average taxonomic distinctness. Additionally, expected values of different measures of diversity correspond to the whole assemblage (^{0}D, ^{1}D, ^{2}D) or by month (Δ, Δ*, Δ+). *P < 0.05, **P < 0.01.

	Abiotic factors			**Species diversity**				**Phylogenetic diversity**	
	Tmax	**Tmin**	**PPM**	**N**	**^{0}D**	**^{1}D**	**^{2}D**	**Δ**	**Δ***
N	0.198	0.531	0.348						
^{0}D	0.127	0.677*	0.551	0.847**					
^{1}D	0.032	0.636*	0.609*	0.612*	0.931**				
^{2}D	-0.055	0.529	0.644*	0.289	0.701**	0.903**			
Δ	0.196	0.659*	0.580*	0.148	0.431	0.526	0.529		
Δ *	0.209	0.629*	0.501	0.243	0.34	0.401	0.321**	0.954**	
Δ +	0.126	0.699*	0.587*	0.821**	0.996**	0.942**	0.729**	0.493	0.454

Discussion

The high species richness found in SBV compared to other Mexican TDF assemblages (Chamela, Jalisco, which is the only locality with a higher species richness reported for Mexican TDF) seems to be explained by several factors. For instance, samplings were done along a greater diversity of aquatic habitats, including: (a) permanent ponds at the sides of the Ferreria river; (b) a permanent large river in SBV; (c) a shallow pond located along a narrow shady spring fed stream at Las Higueras, the habitat in which we found *Anisagrion allopterum*, their northernmost published record in Mexico (Fig. 3); and (d) a temporal stream in Los Yesos. Additionally, the presence of permanent semi-shaded ponds with abundant floating and rooted vegetation seems to influence the presence of more species of endophytic odonates, especially of the Aeshnidae family, with six species reported in SBV. Only in two of the previous studied localities (except for Chamela with 10 species and Huautla with 7 species), this family was as well represented as in SBV.

Temporal variation of abundance and species richness shows a pattern similar to other odonate and insect assemblages from the Mexican TDF, wherein higher values of richness and abundance were recorded during the rainy season (e.g. Odonata, González-Soriano et al. (2021)). However, those variables are not correlated with the variation in precipitation in SBV and only species richness is being influenced by minimum temperature. A different scenario can be seen in other diversity orders where the structure of the entire assemblage is analysed: evenness and dominance (^{1}D and ^{2}D in Table 3) do fluctuate with variation in precipitation and evenness also fluctuates with variation in monthly minimum temperature; i.e. higher levels of monthly precipitation lead to an increase in the monthly diversity and a more evenly distributed abundance of odonate species. In contrast, other odonate assemblages from the Mexican TDF forests show different phenological patterns than those from SBV, either showing an inverse pattern in which the highest values of species richness and diversity have been recorded at the end of the rainy season (e.g. Huautla, González-Soriano et al. (2008)) or showing a shorter period with high levels of richness, abundance and diversity (e.g. Dominguillo, González-Soriano et al. (2021)).

In addition, variation in precipitation and minimum temperatures also influence the variation in the taxonomic structure of the SBV odonate assemblage: the higher the precipitation, the greater the taxonomic distance amongst odonate specimens and the more evenly distributed the abundances are amongst odonate species in the taxonomic hierarchy of the whole assemblage. Additionally, higher values of minimum temperature lead to greater taxonomic distances amongst odonate species within the assemblage structure. A similar pattern has been previously recorded for Santiago Dominguillo, Oaxaca and it is likely associated to a higher availability of niches and resources during the rainy season than that of the dry season (González-Soriano et al. 2021).

On the other hand, we found that minimum temperature was more informative than the maximum temperature values recorded in the sampling year, which suggest that it might be more convenient for odonate and other insect assemblages to explore other climatic variables associated with their diversity patterns (e.g. average monthly temperature) as those variables could be more biologically meaningful. In addition, some diversity metrics were redundant amongst them: it seems that the most informative and non-redundant metrics for the SBV odonate assemblage were Shannon diversity and taxonomic diversity metrics. Choosing the metrics that are the most complementary and informative will help us achieve a better understanding of the structure of ecological communities and the factors influencing them.

In SBV, some odonate families (such as Gomphidae, Lestidae and Platystictidae) exhibited a more seasonal pattern than the others and were recorded only during the rainy season. Gomphidae and Platystictidae have also been mainly recorded during that season in other TDF assemblages, such as San Javier (Sonora), Chamela (Jalisco) and Dominguillo (Oaxaca) (González-Soriano et al. 2004, González-Soriano et al. 2009, González-Soriano et al. 2021). Conversely, many Coenagrionidae species can be found throughout most of the year.

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Supplementary material

Suppl. material 1: Species richness by family from the State of Jalisco and San Buenaventura locality doi

Authors: González-Soriano, E
Data type: Table
Brief description: In parentheses, the proportion of SBV species in relation to Jalisco diversity, based on González-Soriano & Novelo-Gutierrez (2013) and González-Soriano, unpublished data.
Download file (14.89 kb)