

## Odonata of Curaçao, southern Caribbean, with an update to the fauna of the ABC islands

Dennis R. Paulson<sup>a\*</sup>, Carel de Haseth<sup>b</sup> and Adolphe O. Debrot<sup>c</sup>

<sup>a</sup>*Slater Museum of Natural History, University of Puget Sound, Tacoma, WA 98416, USA;* <sup>b</sup>*Kaya Oy Sprock 40, Curaçao;* <sup>c</sup>*IMARES, Wageningen University Research Center, Bevesierweg 4, PO Box 57, 1780, AB Den Helder, the Netherlands*

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A three-year field study (January 2011–December 2013) of the Odonata of Curaçao, supported by photos and exuvial collections, recorded a total of 21 species from the island, almost doubling its previously known fauna. The lists of Odonata known from Aruba and Bonaire were also updated by specimen and photo records, and 24 species are now known from these three islands. During the period of the study, odonates decreased in abundance and diversity in Curaçao, apparently because heavy rains just before the study began led to colonization of the island by several nonresident species that subsequently declined and disappeared as wetlands diminished during a period with normal rainfall.

**Keywords:** Odonata; dragonfly; Curaçao; biogeography; dispersal; seasonality

### Introduction

The Odonata fauna of the “ABC islands” (Aruba, Bonaire, Curaçao) of the southern Caribbean has remained virtually undocumented until recent years. The early publications referring to this fauna are those of Geijskes (1934), Ris (1911, 1916), and Werner (1925), who reported a total of six species from the three islands (two from Aruba, three from Bonaire, and five from Curaçao). Subsequently, Daigle (2011) mentioned 12 species found on a brief visit to Aruba. Recent surveys make it clear that updating this list is warranted.

Geijskes (1934) actually thought that his list of six species represented the fauna of these islands and remarked that it was interesting that species occurred on one or more islands but not all of them. However, the fauna has turned out to be much richer than he suspected (Table 1). All of these species except *Miathyria marcella* have been documented by specimens or photos from their respective islands.

Two additional recorded species, *Erythrodiplax fusca* (Rambur) (Geijskes, 1934; Ris, 1911) and *Orthemis ferruginea* (Fabricius) (Werner, 1925; Geijskes, 1934), are presumably in error. *Erythrodiplax fusca* is a common and widespread mainland species, known from south Texas to Argentina, and also the Lesser Antilles from Martinique to Grenada (Meurgey & Poiron, 2012; Paulson, 2003). It is a species that seems likely to occur on near-shore islands in the Caribbean, but with considerable sampling to date, it has not been found on the ABC islands. The male in the Selys collection (now in IRSNB, Royal Belgian Institute of Natural Sciences,

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\*Corresponding author. Email: [dennispaulson@comcast.net](mailto:dennispaulson@comcast.net)

Table 1. Odonata species recorded from Aruba, Bonaire, and Curaçao (ABC islands).

	Aruba	Bonaire	Curaçao
<i>Lestes forficula</i> Rambur			X
<i>Acanthagrion fluviatile</i> (De Marmels)			X
<i>Enallagma civile</i> (Hagen)			X
<i>Ischnura ramburii</i> (Selys)	X,4	X	X
<i>Anax amazili</i> (Burmeister)			X
<i>A. ephippiger</i> (Burmeister)	X		X
<i>A. junius</i> (Drury)	X,4 <sup>a</sup>		
<i>Brachymesia furcata</i> (Hagen)	X,2 <sup>b</sup> ,4	X	X
<i>B. herbida</i> (Gundlach)	X,4		X
<i>Erythemis plebeja</i> (Burmeister)			X
<i>E. vesiculosa</i> (Fabricius)	X,4	X	X
<i>Erythrodiplax berenice</i> (Drury)	X,4	X	X,1,2,3
<i>E. umbrata</i> (Linnaeus) <sup>c</sup>	X	X	X
<i>Miathyria marcella</i> (Selys)	X,4		
<i>Micrathyria aequalis</i> (Hagen)			X
<i>Orthemis aequilibris</i> Calvert <sup>d</sup>			X
<i>Orthemis</i> sp. <sup>d</sup>	X	X	X
<i>Pantala flavescens</i> (Fabricius)	X,4	X,2 <sup>b</sup>	X,2
<i>P. hymenaea</i> Say	X		X
<i>Tauriphila australis</i> (Hagen)	X		
<i>Tholymis citrina</i> Hagen			X
<i>Tramea abdominalis</i> (Rambur)	X,4	X,3 <sup>d</sup>	X,1
<i>T. calverti</i> Muttkowski	X,4		X
<i>T. onusta</i> Hagen	X,4	X	X
Total	16	9	21

Notes: X indicates a record from the present study; numerals refer to published records, as follows: 1, Ris (1909–1919); 2, Geijskes (1934); 3, Borror (1942); 4, Daigle (2011).

<sup>a</sup>Later thought perhaps to be *A. amazili*.

<sup>b</sup>Larval record only.

<sup>c</sup>*Erythrodiplax fusca* was reported by Ris (1911) and Geijskes (1934) based on a probably mislabeled specimen in the Selys collection; see text.

<sup>d</sup>*Orthemis ferruginea* was reported by Geijskes (1934) from all three islands and by Werner (1925) from Bonaire; Daigle (2011) reported *Orthemis* as either *O. ferruginea* or *O. sulphurata* from Aruba. As noted in the text, neither species is now thought to occur in any of the islands.

Brussels, Belgium) cited by authors was presumably correctly identified, but we suspect it was mislabeled. The identity of the *Orthemis* Hagen of these islands is yet to be determined, but they are not *O. ferruginea*, which is known from southern USA to Costa Rica and sparingly in Cuba.

Many more records are now available from these islands, both specimens and photos. Adolphe O. Debrot (AOD) acquired 113 specimens of 11 species from Curaçao (10 June–1 July 2005) and 27 specimens of nine species from Bonaire (30 June 2005). Allen E. Barlow (April 2005) and Steven G. Mlodinow (March 2003, March 2005, October 2007, February 2014) visited Aruba and attempted to photograph all odonate species they saw. DRP has examined all of these specimens and many of the photos, and they are now in his collection (specimens to be donated to the Florida State Collection of Arthropods in Gainesville, Florida).

Theo and Mars Muusse photographed odonates on Aruba in July–August 2007 and Curaçao in March 2009 and have a website devoted to those efforts (Muusse & Muusse, 2013). They added greatly to the knowledge of odonates of the region during these visits, recording 10 species on Aruba and 12 in Curaçao. However, these records are not available in the scientific literature.

## Material and methods

Carel de Haseth (CdH) photographed Odonata in Curaçao in January–February 2005 and then began a serious photographic study of the group in January 2011. He contacted the first author

(DRP) and began to send him photos to be identified. This partnership has continued to the time of this writing (August 2014), and DRP has archived over 3400 photos of Odonata and habitats in Curaçao taken by CdH. CdH also collected a total of over 500 exuviae from numerous localities on the island. Adults of all species recorded in Curaçao are readily identified from photographs, and all exuviae are readily identified to genus with existing literature. Furthermore, DRP has extensive field experience with and specimens of all species but *Acanthagrion fluviatile*. The local name for odonates in Curaçao is *yeye*, also used for some other insects.

The species presently known from the three islands are listed in Table 1. Some of them were recorded widely on one or more islands, but localities are not given, as the islands are small and uniform enough that it is assumed a species occurs in most appropriate habitats on an island from which it has been recorded.

### The ecology and climate of Curaçao

Curaçao is a low (highest elevation 375 m) island, with gentle hills covering much of it; most wetlands are in the lowest areas. Xeric scrub vegetation predominates, but large parts of the island are well vegetated, providing much undisturbed upland habitat for odonates.

Even though Curaçao and its sister islands are quite arid, they do have seasonal fresh and brackish wetlands that possess a significant diversity of euryhaline fish species and crustaceans (Debrot, 2003a, 2003b; Hulsman, Vonk, Aliabadian, Debrot, & Nijman, 2008). Since European colonization, the hydrology of Curaçao has been severely altered and fully “natural” fresh water hardly exists. Whereas the island may have had two small semi-permanent streams in the pre-colonial era, today there are only seasonal streams (Debrot, 2009). Pre-colonial man made use of at least four types of primitive freshwater sources, namely springs, natural karst wells (named “buraku di awa”), shallow hand-dug walk-in groundwater wells (“pos di pia”) in areas where it is possible to dig using stone-aged implements, and hand-dug water catchments for surface run-off (“tanki”) (Debrot, 2009). Many of these can still be found and are actively used by Odonata.

There are also upwards of 1000 agricultural colonial-era water catchment dams, most of which still exist. Some of the largest dams were built in the 1950s by Shell Oil and by the Agricultural Service (Henriquez, 1962). Two of these, namely Malpais and Muizenberg, have been internationally recognized as Important Bird Areas (Wells & Debrot, 2008) and have also been accorded international RAMSAR protected wetland status. In these and other large dams, water may be present for six months or more during the rainy season, and in exceptional instances they carry through from one rainy season to the next. Debrot (2003a) and Hulsman et al. (2008) have described water parameters for many semi-natural fresh and brackish waters. The island further has many colonial-era wide-rimmed hand-dug wells (“pos”), and agricultural water basins (“baki”), all of which are variously used by Odonata. Two more recent types of freshwater sources that are also available to Odonata year-round are waste-water treatment plants and large artificial ponds associated with golf courses.

Curaçao and its sister islands of Bonaire and Aruba lie in a “Caribbean dry region” (Sarmiento, 1976) of semi-arid and arid climates in a region off the north coast of Venezuela and Colombia. Average temperature is 27.6°C. September is the hottest month with an average maximum of 32.2°C, while January is the coolest month with an average minimum of 24.1°C (Beers, de Freitas & Ketner, 1997). Average annual rainfall is 554 mm, of which about half falls from October to December. The peak rainfall months are October–December, with on average 8–10 cm falling in each month. The driest months are March to June, with 1–2 cm falling in each. However, rainfall is quite variable year to year. Figure 1 shows a wetland at the Malpais dam during wet and dry periods.



Figure 1. Dam at Malpais, Curaçao, in wet (16 January 2011) and dry (18 December 2013) periods.

The hilly western half of the island has slightly higher rainfall than the flatter eastern side. Average annual rainfall shows a roughly 6–7-year cycle (Henriquez, 1962; Debrot, Miller, Miller, & Leysner, 1999) as linked to the El Niño-La Niña oscillation (Martis, van Oldenborgh & Burgers, 2002). Average wind direction and speed is NE at  $6.9 \text{ m s}^{-1}$  (10 m height).

## Results

The Odonata of Curaçao have now been extensively surveyed. Nevertheless, a species new to the island was discovered as recently as September 2012, and one species is as yet known only from exuviae collected. Only adult specimens are listed below; exuvial collections are mentioned under species names. Authors of species are given in Table 1.

### *Species recorded in Curaçao*

#### *Lestes forficula*

Specimens examined: West Punt, 29 April 2005, 3♂.

A common and widespread species on the island, although it has not been found at as many localities as the ubiquitous *Ischnura ramburii*. It was not detected during July–August of both 2011 and 2012 and during June–October of 2013, so either the adults are present but very hard to find or the species spends the dry season in the egg stage. The latter strategy is rare in the tropics (Corbet, 1999) and not so far reported for any *Lestes*. Egg dormancy may be less likely in the tropics because of high temperatures, and further surveys should aim to determine whether *L. forficula* eggs collected at the beginning of the dry season could maintain viability for several months.

*Acanthagrion fluviatile*

Specimen examined: near Santa Rosa, 17 September 2012, 1♀.

Known from a single mature female collected on the side of CdH's house. No others have been found subsequently, and it is possible that it emerged from a larva brought to the island through human activities.

*Enallagma civile*

Specimen examined: Ri Malein, 12 March 2011, 1♂.

This species was surprisingly rare, having been found only at extensive wetlands at Ri Malein and Muizenberg. It may need permanent water, unlike *L. forcicula* and *I. ramburii*. Perhaps because of its scarcity, it was documented only in March and August 2011, February 2012 and February 2013. This is the first record of *E. civile* from the southern Caribbean.

*Ischnura ramburii*

Specimens examined: Girouette Dam, 27 March 2005, 2♂; De Savaan, 30 March 2005, 4♂ 3♀; Daaibooi, 31 March 2005, 1♂ 3♀; Piscadera Bèrde, 2 April 2005, 2♀; Malpais, 14 April 2005, 2♂; West Punt, 29 April 2005, 1♂ 1♀; Tanki Martha Koosje CNR, 1 July 2005; 1♀; Pos Monton, Christoffel Park, 1 July 2005; 1♂.

One of the most abundant and widespread odonates in Curaçao, occurring at just about every wetland and often in large numbers. It becomes much less abundant, however, when many of the wetlands dry up seasonally, and we presume it disperses readily from sources of permanent water when the rains come. On males and androchromatic females, the amount of blue on the dorsal surface of S9 varies from none to almost complete, with no obvious mode. A small number of heteromorph females (< 5% of > 100 photos of this stage) have S8 partially to almost entirely pale above, a condition not seen by DRP in other populations of the species.

*Anax amazili*

Only a single adult was documented, a mature female photographed at Malpais on 8 June 2011. However, exuviae were found at five sites in February, March, June, July and December 2011 and January and August 2012.

*Anax ephippiger*

Seen only a few times, males photographed over the water at LVV and Muizenberg in October 2011. Surprisingly, no aeshnids were seen perched or flushed from a perch despite extensive searches. Furthermore, no adults have been seen since 2011. As with *A. amazili*, exuviae were indicative of a much greater abundance; they were found at five sites in February and October 2011.

This Old World species has been reported in and around the Caribbean with increased frequency in recent years after the first records in French Guiana in 2003 (Machet & Duquef, 2004) and Guadeloupe in 2006 (Meurgey, 2006), and it is clearly well established in this region. One was photographed in Aruba by Gert Veurink on 17 January 2013 (<http://observado.org/soort/photos/618?from=2013-01-17&to=2013-01-17>).

Although some authors place this species in *Hemianax* (von Ellenrieder, 2002), we use *Anax*, as did Dijkstra and Lewington (2006), as relationships among the species in this genus are unclear at present (K-D. B. Dijkstra, personal communication).

### *Brachymesia furcata*

Specimens examined: Tanki Martha Coosje, 1 July 2005; 1♂.

Abundant in Curaçao and found at most bodies of open water; females were common in the nearby bush. The species persists in some numbers through the dry season at most wetlands that retain water. *Brachymesia* exuviae were commonly collected early in the study, but unfortunately distinguishing the two species was not feasible.

### *Brachymesia herbida*

Common in Curaçao in 2011 and the beginning of 2012, it was absent after June 2012, nor was it recorded during fieldwork in 2005. This is an easily identified species that perches in the open, and its status was dramatically different between the beginning and the end of the photo survey.

### *Erythemis plebeja*

Uncommon and local, this species was photographed only at Julianadorp, LVV and Muizenberg between March and December 2011. Breeding was confirmed by an exuvia in a collection from the island without further data.

### *Erythemis vesiculosa*

Specimens examined: Girouette, 26 March 2005, 3♂; Girouette Dam, 27 March 2005, 1♂; Pos Shimaron, Savonet, 28 March 2005, 1♂; Daaibooi, 31 March 2005, 2♂ 1♀; Piscadera Bèrde, 2 April 2005, 6♂ 2♀; Malpais, 14 April 2005, 1♀.

One of the more common dragonflies in Curaçao. Never present in large numbers, it was nevertheless found at most water bodies.

### *Erythrodiplax berenice*

Specimens examined: Rif Water, 29 March 2005, 3♂ 6♀.

Common on and near the coast at several brackish locations. Borror (1942) described the color changes that both sexes undergo as they mature, but he did not point out that some females in mainland North American populations may be entirely shiny black with the dorsum of S3–7 mostly orange (photos and specimens in DRP collection). Interestingly, none of the many photos from Curaçao show that coloration. Perhaps it is absent in Curaçao and other Caribbean populations, which comprise the distinctive subspecies *E. b. naeva* (Hagen), listed as a species by Borror (1942). Mature females in the West Indies and the Florida Keys become almost entirely pruinose gray, with vaguely indicated color pattern, and DRP has not seen this condition in mainland populations. Borror (1942) did not describe any differences in body color pattern in the two taxa.



*Erythrodiplax umbrata*

Specimens examined: Piscadera Bèrde, 2 April 2005, 1♂.

This species prefers marshy situations rather than open water, and it was found primarily in places where there was abundant emergent vegetation. Thus it was more limited in distribution than other common species, but it was seen at least sporadically throughout the period of the study and was still present in 2014 (CdH).

*Micrathyria aequalis*

One of the least common species during the Curaçao survey. It was photographed at only one wetland, at Julianadorp, and only from 1–27 February 2012. Exuviae of the same species were collected there on 17 March.

*Orthemis aequilibris*

Specimens examined: Fuik Plantation, 4 May 2005, 1♂.

This species was much less common than the “ABC” species, usually a few individuals at most of the same places where the latter was common. It was seen from the beginning to the end of the study but was recorded in fewer than half of the months. At a distance it could have been mistaken for the next species. It was most often found at the small dams at LVV, near the home of CdH.

*Orthemis* sp. “ABC”

Specimens examined: Girouette, 26 March 2005, 6♂ 5♀; Girouette Dam, 27 March 2005, 2♂; Pos Shimaron, Savonet, 28 March 2005, 1♂; Girouette, 31 March 2005, 1♀; Piscadera Berde, 2 April 2005, 1♂; Fuik Plantation, 4 May 2005, 1♂ 1♀; Tanki Martha Koojsje CNR, 10 June 2005, 2♂; Pos Monton, Christoffel Park, 1 July 2005, 2♂.

One of the most common and ubiquitous odonates in Curaçao, found at essentially all freshwater bodies in abundance. Like others, it is much scarcer during the dry season, but nevertheless a few persist wherever there is water, much like the situation with *Brachymesia furcata*. These two are the most likely odonates to be seen wherever water is present. The taxonomy of the *Orthemis ferruginea* group of species needs revision (Donnelly, 1995; von Ellenrieder, 2012), and there is no name to be applied unambiguously to this one, which could be called the “ABC” *Orthemis*. It may or may not be the same as a widespread red Antillean species that is also still unnamed (Donnelly, 1995) but is distinct from the recently resurrected *O. macrostigma* (Rambur) of the Lesser Antilles (Meurgey & Daigle, 2007).

*Pantala flavescens*

Specimens examined: Daaibooi, 31 March 2005, 2♂ 2♀; Malpais, 4 April 2005, 1♀; West Punt, 12 May 2005, 1♂.

This species breeds at many of the wetlands on the island and, more than any other, is also seen widely away from water. It was seen throughout the period of the study. Especially large numbers of this and the following species were seen in August–September 2012 during repeated rains but when most wetland basins on the island were still dry. Both species of *Pantala* are known to be migratory (Corbet, 1999), and perhaps such dispersal movements bring many of them to the ABC islands.

### *Pantala hymenaea*

*P. hymenaea* is much less common than *P. flavescens* in Curaçao, and rarely were more than a few seen at any time and place except on a few occasions as discussed under *P. flavescens*. Nevertheless, it was well represented in large collections of exuviae, although fewer individuals than *P. flavescens*.

### *Tholymis citrina*

Exuviae of this species were fairly common at ponds at Malpais and Kabayé in February and March 2011, but no adult has been seen. This crepuscular flier, cryptic when hanging up during the day, is easily overlooked, but CdH has spent a great deal of time in wooded habitats that were likely places for daytime roosting with no sightings of any dragonfly that looked as if it might have been this species. It presumably disappeared from the island, as other species did during the study.

### *Tramea abdominalis*

Specimens examined: Piscadera, 24 March 2005, 1♂; Girouette, 26 March 2005, 1♂ 1♀; Girouette Dam, 27 March 2005, 2♂ 1♀; Pos Shimaron, Savonet, 28 March 2005, 1♂; Rif Water, 29 March 2005, 4♀; Daaibooi, 31 March 2005, 1♂ 2♀; Piscadera Berde, 2 April 2005, 1♀; Malpais, 14 April 2005, 1♂; Fuik Plantation, 4 May 2005, 1♀; Tanki Martha Koojsje CNR, 1 July 2005, 3♂; Tanki Daniel, 1 July 2005, 2♂; Pos Monton, Christoffel Park, 3♂.

This is one of the most common and widespread odonates in Curaçao, present throughout the period of the photo study in small to substantial numbers. CdH collected 294 *Tramea* exuviae, the most of any genus, but so far we have not been able to distinguish among the three species. Similarly, quite a few sight records could not distinguish between this and the next species.

### *Tramea calverti*

Specimens examined: Daaibooi, 31 March 2005, 1♀.

This species is much less common than *T. abdominalis* in Curaçao but lives in the same places and has similar habits. This is generally true of *Tramea* species wherever they are sympatric. Like *T. abdominalis*, it was found throughout the study period.

### *Tramea onusta*

Specimens examined: Rif Water, 29 March 2005, 1♂; Daaibooi, 31 March 2005, 3♂ 1♀. Malpais, 14 April 2005, 1♂.

Like *T. calverti*, this species was less common than *T. abdominalis* but also coexisted often with both of the other species. However, none was seen after May 2012 except for a single individual in December of that year.

While most libellulids perch with all six legs contacting the substrate, individuals of *Tramea* and some other genera typically perch with two pairs of legs, the prothoracic legs tucked up behind the head. CdH's photos allow us to assess the frequency of perching with six versus four legs in this genus.

The frequency of four-legged perching appears to be similar in all three species (Table 2). Wildermuth (2014) noted this variation in *Lindenia tetraphylla* (Vander Linden) (Gomphidae), but otherwise it has not been the subject of study.



Table 2. Proportion of individuals using front legs in perching by *Tramea* species. Photos were treated as independent except when there was an obvious series of one individual. In most photos it was obvious whether four or six legs contacted the perch, but in a few, one of the two front legs did so for a total of five legs in contact with the perch.

Species	Four legs	Five legs	Six legs	N
<i>T. abdominalis</i>	0.89	0.01	0.10	188
<i>T. calverti</i>	0.93	0.01	0.06	67
<i>T. onusta</i>	0.93	0.02	0.05	59

### ***Additional species of the ABC islands***

The species known from this island group but not yet recorded from Curaçao are *Anax junius*, *Miathyria marcella*, and *Tauriphila australis*, all from Aruba. A recently emerged *A. junius* was photographed at Noord Aruba on 17 January 2013 by Gert Veurink (<http://observado.org/soort/photos/20629>). *Tauriphila australis* was collected by Allen Barlow at Bubali, and *M. marcella* was observed by Daigle (2011). The *Anax junius* reported in that paper was in fact *A. amazili* (J. Daigle, in litt.) a species also not previously known from Aruba.

*Miathyria* and *Tauriphila* species are usually associated with floating macrophytes such as water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) (Paulson, 2011), and the *Tauriphila* specimen from Aruba was at a pond covered with water lettuce. These plants have not covered any wetlands extensively in Curaçao, although small numbers occur there.

## **Discussion**

### ***Biogeographic speculation***

It seems likely that Curaçao received its odonate fauna from Venezuela, the nearby mainland country. This is in spite of prevailing winds being from the northeast, as all it takes is a single event to bring colonizers to the island. Indeed, only one species (*Anax ephippiger*) is known from Curaçao that is not also known from Venezuela. It is a new visitor to the Caribbean from Africa and may well occur in Venezuela by this time.

A surprising number of Curaçao species (*Acanthagrion fluviatile*, *Enallagma civile*, *Anax amazili*, *A. ephippiger*, *Erythrodiplax berenice*, *Orthemis aequilibris*, *Pantala hymenaea*, *Tholymis citrina*, and *Tramea abdominalis*) have not been recorded from Falcón (Jürg De Marmels, personal communication), the nearest coastal state of Venezuela. However, this may be due only to inadequacy of sampling in that state. Of these species, *A. fluviatile* and *O. aequilibris* are not known from the West Indies and must have come from the South American mainland. Most of the other Curaçao species occur widely in the West Indies, but neither *Enallagma civile* nor *Erythemis plebeja* have been found in the Lesser Antilles (Meurgey and Poiron 2012).

*Enallagma civile* is known widely from northern Venezuela (Mérida, Tachira, Trujillo, and Caracas states) and probably reached Curaçao from the mainland rather than through the West Indies, where it is known from only the Greater Antillean islands. It does seem likely that the entire odonate fauna of Curaçao reached the island from the adjacent mainland, only about 65 km away.

### ***Habitat use***

Many of the species are known for their ability to breed in seasonal wetlands, and this may be the case with all of them. These wetlands usually lack fish, important predators on odonates

(Corbet, 1999), and thus may present optimal habitat for many odonate larvae. CdH on numerous occasions found that when a basin contained water after a rain, odonates appeared soon afterwards.

The only species that seemed to be restricted in habitat was *Erythrodiplax berenice*, found only in brackish waters at the coast. It was very common at “Saliña” and seen there throughout the year, and it was also found at other coastal localities. The species is well known to breed in salt water (Borror, 1942).

Unlike the mainland tropics, there was no indication that any Curaçao species was restricted to swamps (wetlands within woody vegetation) or even was likely to occur in them, perhaps because these habitats are very limited on Curaçao. With no permanent streams, there are also no stream species in these islands.

Few dragonflies were seen by CdH in upland parts of the island well away from wetlands, although he spent much time hiking through such areas. Only occasional individuals of *Pantala* or *Tramea* species were seen, with larger numbers occurring at times after rains. Most odonates were confined to permanent or seasonal wetlands and adjacent low areas.

### Seasonality

The number of species recorded, both by photo and sighting, in each month is given in Figure 2. In each of the three years diversity was lowest toward the end of the dry season as wetlands were presumably reduced. However, all adults should have been present during those periods, unless they were represented by larvae in one or more permanent wetlands.

Still unknown, as in many other tropical areas, is the fate of the odonate fauna during the dry season. Despite the intensity of effort on Curaçao, we still are no closer to answering that question. As brief as this survey has been, it is obvious that the mix of species has not been consistent at a given locality over the three-year period. Nevertheless, it seems apparent that the basic set of about a dozen species (out of 21 recorded) is present through the year, probably in much reduced numbers in the dry season. From scattered observations in tropical mainland areas (Corbet, 1999), individuals of some species spend the dry season in wooded areas that are presumably more productive of insect prey, yet CdH saw very few adults within woodland at any season; most were associated with water or out in open areas.

CdH made exuvial collections from December to March when exuviae were a very prominent component of the wetlands. A few of the adult photos are clearly tenerals, and the 11 tenerals photographed ranged from December to July, also indicating emergence in that period late in the rainy season. The question remains whether adult individuals, at least among the long-term

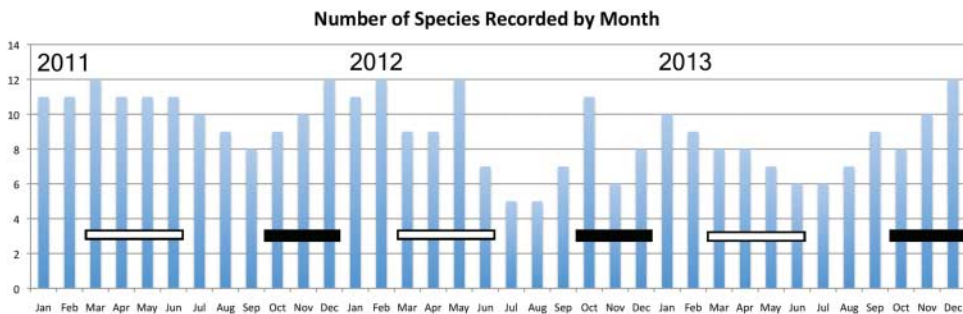


Figure 2. Number of Odonata species recorded in Curaçao in each month from January 2011 to December 2013. The months usually having highest rainfall are indicated by dark bars, and those usually having the lowest rainfall by open bars. There is much annual variation.

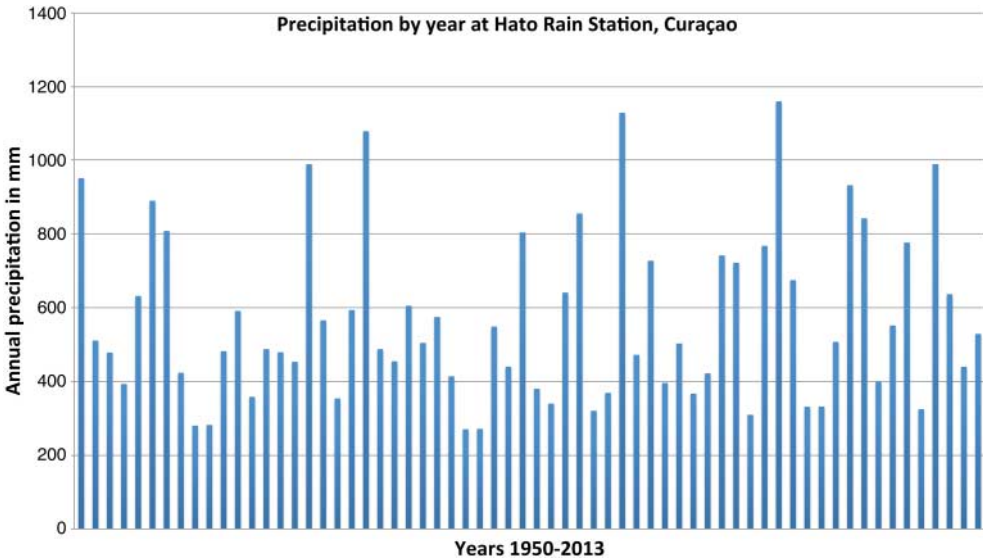


Figure 3. Annual precipitation at Rain Station Hato, Curaçao, from 1950 to 2013.

Table 3. Apparent temporal status of adult Odonata on Curaçao.

Temporal status	Species
Recorded throughout study and throughout year	<ul style="list-style-type: none"> <li>• <i>Ischnura ramburii</i></li> <li>• <i>Brachymesia furcata</i></li> <li>• <i>Erythrodiplax berenice</i></li> <li>• <i>Orthemis</i> sp.</li> </ul>
Recorded throughout study but not detected for significant periods	<ul style="list-style-type: none"> <li>• <i>Lestes forficula</i></li> <li>• <i>Erythemis vesiculosa</i></li> <li>• <i>Erythrodiplax umbrata</i></li> <li>• <i>Orthemis aequalibris</i></li> <li>• <i>Pantala flavescens</i></li> <li>• <i>P. hymenaea</i></li> <li>• <i>Tramea abdominalis</i></li> <li>• <i>T. calverti</i></li> </ul>
Recorded early in study, apparently absent from island by end of study	<ul style="list-style-type: none"> <li>• <i>Anax amazili</i></li> <li>• <i>A. ephippiger</i></li> <li>• <i>Brachymesia herbida</i></li> <li>• <i>Erythemis plebeja</i></li> <li>• <i>Micrathyria aequalis</i></li> <li>• <i>Tholymis citrina</i></li> <li>• <i>Tramea onusta</i></li> </ul>
Too few records to be confident of status	<ul style="list-style-type: none"> <li>• <i>Acanthagrion fluviatile</i></li> <li>• <i>Enallagma civile</i></li> </ul>

residents, persist between rainy seasons to recolonize temporary wetlands, or whether the few permanent wetlands are the source of continuing populations.

***The hurricane invasion***

We consider the most significant finding of this research on Curaçao has been the apparent decrease of species over time on the island (Table 3, Figure 2).

We speculate that this decrease was because odonates increased greatly over the normal island complement after tropical storm Tomas. That storm dropped as much as 26.5 cm of rain in a single day at the beginning of November 2010, almost equal to half the annual precipitation, and turned the island into a dragonfly paradise. We suspect that numerous species rode storm winds from the mainland to augment the basic assemblage normally present on Curaçao. It is also possible that mainland populations were stimulated to disperse as a consequence of heavy rains, in anticipation of increased breeding habitat. Either or both of these factors could have brought more individuals to the island. As coincidence would have it, CdH started his photo survey soon after that.

Rainfall in both 2010 and 2011, the beginning of this study, was higher than normal and very likely played a part in the abundance and diversity of odonates in the first year of the study. Precipitation at Rain Station Hato (Figure 3), which we chose to be representative of the island, was greater in 2010 than in any previous year back to 1999. Total precipitation at Hato was 162.6 cm in 2010 plus 2011, but only 96.9 cm in 2012 plus 2013. Interestingly, the 52.9 cm that fell in 2013 was not much below the 64-year average of 56.8 cm at Hato, but the island remains very dry up to October 2014.

The situation has perhaps gone back to normal with the absence of any tropical storms since then, or it is possible that the decreased rains of 2012 and thereafter produced conditions worse than usual for odonates. Whatever the reason, the fauna, as of December 2013, was considerably reduced from that of the peak period after Tomas and remains low into October 2014 (CdH continues to monitor the fauna). It remains to be seen whether diversity and abundance would rise again with another such rainfall event.

There are very few observations of the short-term colonization of islands by dragonflies, but Sibley (1999) reported the same phenomenon on much smaller Guana Island, an island without permanent water, in the British Virgin Islands. He found 10 species on that and nearby Anegada Island in October 1997, when a major storm passed through, but only three on the same island in October 1998, the same three that were present on Guana before the storm. Interestingly, two of those three are among those that persist on Curaçao – *Ischnura ramburii* and *Erythrodiplax umbrata*, as well as the ABC *Orthemis*, closely related to the Greater Antillean red *Orthemis* sp. that persisted on Guana. However, most of the temporary species found by Sibley – *Erythemis vesiculosa*, *Pantala flavescens*, *P. hymenaea*, *Tramea abdominalis* and *T. calverti* – also persist on Curaçao, where there is permanent water.

Unlike the situation on Guana, the colonizing species on Curaçao all had the opportunity to breed during 2011, but then as wetland after wetland dried up over the subsequent two years, some of them apparently were unable to persist on the island. Two species, *Brachymesia herbida* and *Tramea onusta*, were even common to abundant after the hurricane but subsequently disappeared. Odonates have great dispersal powers and are good island colonizers, but they are always limited by the absence or scarcity of permanent wetlands.

Rainfall on Curaçao has varied greatly over the period of record keeping (Figure 3), with three times as much precipitation in the wettest years as in the driest ones, and it may be that its odonate fauna has varied similarly, with colonization from the mainland during especially wet years and disappearance of many species during the drier years that follow. This phenomenon is not difficult to understand for a group well known for its dispersal abilities.

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