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Diversity and abundance of dragonflies and damselflies in Tampa Bay, Florida

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Abstract

Little is known about the community of dragonflies and damselflies in Tampa Bay, Florida, USA. To address this gap, we conducted 2 longitudinal surveys of adult odonates in a natural floodplain of the Hillsborough River in 2013 and 2017. Along with abundance and species diversity, we also measured intraspecific variation in body size, sexual dimorphism, wing-cell asymmetry, and water mite ectoparasitism. Our first weekly survey from Oct 2013 to Oct 2014 sampled 327 adults (230 female, 97 male) from 8 dragonfly species, with the eastern pondhawk (*Erythemis simplicicollis* Say; Odonata: Libellulidae) representing 79% of captures, followed by the second most abundant (14%), the Florida non-native and neotropical hyacinth glider (*Miathyria marcella* Selys; Odonata: Libellulidae). Our second weekly survey from Sept to Dec 2017, which focused on both damselflies and dragonflies and captured 205 adults from 8 species, with the fragile forktail (*Ischnura posita* Hagen; Odonata: Coenagrionidae) being the most abundant with 70% of captures. Female-biased sexual size dimorphism was found in both *E. simplicicollis* and *I. posita*; however, both sexes were equally variable in size and symmetric in a meristic trait. Female and male *M. marcella* were equally variable, monomorphic, and symmetric. Combing symmetry data from each sex, only *I. posita* damselflies were asymmetric overall. Finally, we did not observe any parasitism by larval water mites in either survey. We aim to continue surveys to track seasonal and climate-driven changes in dragonfly diversity and phenology in this region.

Key Words: wing-cell asymmetry; fluctuating asymmetry; phenology; flight season; sexual size dimorphism; Odonata

Resumen

Poco se sabe sobre la comunidad de libélulas (Odonata: Libellulidae) y caballitos del diablo (Odonata: Coenagrionidae) en Tampa Bay, Florida, EE. UU. Para abordar esta falta, realizamos 2 encuestas longitudinales de odonatos adultos en una llanura de inundación natural del Río Hillsborough en el 2013 y el 2017. Junto con la abundancia y la diversidad de especies, también medimos la variación intraespecífica en el tamaño del cuerpo, el dimorfismo sexual, la asimetría de las células del ala, y el ectoparasitismo de los ácaros acuáticos. Nuestro primer sondeo semanal de octubre del 2013 a octubre del 2014, muestreó 327 adultos (230 hembras, 97 machos) de 8 especies de libélulas, con *Erythemis simplicicollis* Say (Odonata: Libellulidae) presente en el 79% de las capturas, seguido por el segundo más abundante (14%), *Miathyria marcella* Selys (Odonata: Libellulidae), una especie no nativa de la Florida. Nuestro segundo sondeo semanal desde septiembre hasta diciembre del 2017, se enfocó sobre los caballitos del diablo y las libélulas y capturó 205 adultos de 8 especies, con *Ischnura posita* Hagen (Odonata: Coenagrionidae) la especie más abundante en el 70% de las capturas. Se encontró dimorfismo sexual de tamaño sesgado hacia las hembras tanto en *E. simplicicollis* como en *I. posita*; sin embargo, ambos sexos fueron igualmente variables en tamaño y simétricos en su rasgo merístico. Las hembras y los machos de *M. marcella* fueron igualmente variables, monomórficos y simétricos. Combinando datos de simetría de cada sexo, solo *I. daita* caballitos del diablo fueron asimétricos en general. Finalmente, no observamos ningún parasitismo por los ácaros acuáticos sobre las larvas en ninguna de los sondeos. Nuestro objetivo es continuar los sondeos para rastrear los cambios estacionales y climáticos en la diversidad y fenología de las libélulas en esta región.

Palabras Claves: asimetría de células de ala; asimetría fluctuante; fenología temporada de vuelo; dimorfismo de tamaño sexual; Odonata

The phenology of many dragonflies have been shifting forward in time due to a warming climate (e.g., Hassall et al. 2007; Dingemanse & Kalkman 2008), and several geographic range expansions also have been reported (e.g., Beckemeyer 2009; McMurray & Simon 2011). Natural history surveys are key to informing the extent and rates of these trends; however, ongoing gaps in geographic information impede global assessments and predictions (Reece & McIntyre 2009). Florida is a key gap region due to its wide vertical gradient in climate that includes both the southernmost range of many north-temperate dragonflies and damselflies (Dunkle 1992), and the northernmost range of the largest group of endemic odonates found in any state or province (Dunkle & Westfall 1982). Further, despite a historically rich tradition in reporting and documenting Florida Odonata (e.g., Davis 1921; Byers 1930; Westfall 1941; Wright 1944; Needham 1946; Westfall 1953; Paulson 1966, 2001; Daigle 1978; Dunkle 1992), regional surveys and county checklists are now uncommon. This is concerning given that since the second half of the 20th century Florida has experienced rampant urbanization, eutrophication, freshwater modification and loss (Nagy et al. 2012), taxa introductions (Frank & McCoy 1992), and is poised for considerable climate change effects (Paulson 2001).

Here we report the first longitudinal surveys of adult dragonflies and damselflies in the Tampa Bay region (Hillsborough County, Florida, USA) since 1965 (Paulson 1999). The aims of our surveys are to: (1) determine

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the community composition in this county with a long-term goal to track shifts in phenology and range expansion among dragonflies (following Paulson 2001), and (2) report intraspecific measures of body size, fluctuating asymmetry, and parasitism. This intraspecific information is useful to provide insight on environmental stress (Daufresne et al. 2009; Gardner et al. 2011; McCauley et al. 2014), and how these stressors interact with a warming world to impact the phenology and ranges of dragonflies and damselflies (Hassall et al. 2007; Richter et al. 2008).

Materials and Methods

We conducted 2 surveys of adult dragonflies (Odonata: Anisoptera) and damselflies (Odonata: Zygoptera) at the University of South Florida Riverfront Park, Tampa, Florida, USA, located along a natural floodplain of the Hillsborough River (Hillsborough County, Florida, USA; 28.0705°N, 82.3786°W). This area is mostly fresh water wetland with hardwood hammocks, pine flatwoods, cypress domes, and open mowed recreational space for picnics, and a disc golf course. Lettuce Lake Conservation Park (97 ha) is located on the neighboring side of the river. The nearest previous survey of odonates was completed in Manatee County, Florida, USA, which is about 80 km south (i.e., Manatee River; Paulson 1966).

In our first survey, 1 individual sampled only dragonflies weekly for 1 yr (6 Oct 2013 to 5 Oct 2014) around midday (about 11:00 A.M. to 2:00 P.M.) for 1 h with a canvas sweep net. There are 2 sampling gaps in this survey: the park was closed on 20 Oct 2013, and again from 14 Dec 2013 to 6 Jan 2014. Our second survey occurred weekly from 22 Sep 2017 to 1 Dec 2017 in the late afternoon (about 3:00 P.M. to 5:00 P.M.). Here, 4 to 5 individuals sampled both dragonflies and damselflies for 25 min using canvas sweep nets, butterfly nets, and scoop nets. There are 4 sampling gaps in this second survey: 29 Sep 2017, 3 Nov 2017, 10 Nov 2017, and 24 Nov 2017. Finally, all captured odonates were placed into coin envelopes or jars marked with date and time, then then transported back to the University of South Florida for −10 °C freezer preservation.

Species and sex of each preserved specimen were identified following Garrison et al. (2006), Beckemeyer (2009), and Paulson (2011). As a surrogate of body size (Serrano-Menanes et al. 2008), the distance from nodus to pterostigma of left forewings was measured with digital calipers (± 0.02 mm; Pittsburgh item #93293, Carmarillo, California, USA). We estimated sexual size dimorphism in mean body size (mm) of each sex using linear regression models Z-tests ($\alpha = 0.05$), and when possible, we used linear mixed models to control for sampling effects between our 2 surveys (by treating survey identity as a random effect). Finally we compared the variance in body sizes with F-tests (assuming the ratio of the variances of males and females as one). Linear regression models analyses were performed in base R (R Core Team 2013) and linear mixed models with the lmer() function of the lme4 R package (Bates et al. 2015).

Following Lajeunesse (2007), wing-cell asymmetry was measured as the difference in wing-cell counts between the right and left forewings, where wing-cells were counted from nodus to pterostigma using a 10× loupe. To calculate and compare asymmetry frequency among individuals, a mixed-effect logistic regression model (with logit function) was implemented with the glmer() function of the lme4 package. This model included survey identify as a random-factor to control for sampling differences among the 2 surveys. A Z-test from a logistic model including a parity offset was used to test whether the ratio of asymmetric and symmetric individuals deviate from an equal frequency of observation between asymmetric and symmetric odonates (i.e., parity = 0.5). Finally, the ratio of asymmetric individuals and 95% confidence intervals were first estimated with the predicted values from the logistic model using the glht() function from the multcomp R package (Hothorn et al. 2014), and then using the inv.logit() function (generalized inverse logit function) from gtools R package (Warnes et al. 2013) to back-transform the 95% confidence intervals into a non-logged ratio scale.

Results

SPECIES RICHNESS, ABUNDANCE, AND FLIGHT SEASON

In total, 532 dragonflies and damselflies from 12 species (9 dragonflies, 3 damselflies) were sampled (Table 1). Four of the 9 dragonfly species sampled in our first survey ($N = 327$) were not recaptured in our second, but our second survey ($N = 205$) included a previously unsampled species (little blue dragonlet, *Erythrodiplax minuscula* Rambur; Odonata: Libellulidae). Finally, all damselflies captured in our second survey were forktails (Odonata: Coenagrionidae).

The most abundant dragonfly species at our site was the eastern ponkhawk (*Erythemis simplicicollis* Say; Odonata: Libellulidae), making up 49.8% of all captures ($N = 265$) and 81% from our first survey, which focused primarily on dragonflies (Table 1). Based on samples from both surveys, its estimated flight season is from 13 Apr to 13 Oct (Fig. 1), which matches very closely the typical rainy season in the Tampa Bay area (May to Nov). The second most abundant dragonfly, the non-Florida native hyacinth glider (*Miathyria marcella* Selys; Odonata: Libellulidae), represented 12% of all captures ($N = 64$). Its flight season appears bivoltine (Fig. 1), with a short season occurring at the beginning of the rainy season (30 Mar–18 May) and a second near the end (21 Aug–20 Sep). The third most abundant was the red saddlebags (*Tramea onusta* Hagen; Odonata: Libellulidae; $N = 11$) with a short flight season near the end of the rainy season (21 Sep–1 Dec). Finally in rank order of abundance, the following species represented only 3% of all captures: *Pachydiplax longipennis* Burmeister (Odonata: Libellulidae; $N = 7$; flight season: 7 Jul–22 Aug), *Phanogomphus minutus* Rambur (formerly *Gomphus minutus*; Odonata: Gomphidae; $N = 3$), *Celithemis eponina* Drury (Odonata: Libellulidae; $N = 2$), *E. minuscula* (Odonata: Libellulidae; $N = 2$), *Aphylla williamsoni* Gloyd (Odonata: Gomphidae; $N = 1$), and *Pantala flavescens* Fabricius (Odonata: Libellulidae; $N = 1$).

Among the damselflies surveyed, the most abundant was the fragile forktail (*I. posita*; Odonata: Coenagrionidae; $N = 144$), which were sampled the entire span of our second survey (22 Aug 22–1 Dec; Fig. 1). Finally, we captured few citrine forktails (*Ischnura hastata* Say; Odonata: Coenagrionidae; $N = 4$) and Rambur's forktails (*Ischnura ramburii* Selys; Odonata: Coenagrionidae; $N = 1$).

BODY SIZE VARIABILITY

Because of the low number of captures for most species, we were only able to assess sexual size dimorphism in 3 species (Table 1). Combining data from both surveys, there was female-biased sexual size dimorphism in both *E. simplicicollis* (linear regression models by sex: $t = -7.04$; $P < 0.001$; $N = 264$; female mean wing-length: 15.18; SD = 0.73; $N = 184$; male mean wing-length: 14.53; SD = 0.55; $N = 80$), and *I. posita* (linear regression models by sex: $t = -7.29$; $P < 0.001$; $N = 133$; female mean wing-length: 8.39; SD = 1.067; $N = 79$; male mean wing-length: 7.12; SD = 0.85; $N = 54$). Comparing body size variability between sexes, there were no differences in wing-length variances for *E. simplicicol-*

Table 1. Summary of two odonate surveys in Tampa Bay (Florida, USA). In rank order of capture abundance (TOTAL SAMPLED), odonates are grouped by infraclass (INF) as Zygoptera (Z) or Anisoptera (A), and sex. Wing-size and wing-cell fluctuating asymmetry is reported here as the proportion of asymmetric individuals and their lower (L) and upper (U) 95% confidence intervals (CI) were estimated using the Clopper & Pearson (1934) method. Sample sizes (*N*) of measurements differ from capture numbers due to wing damage during transport and preservation.

				Wing-length (mm)			Fluctuating asymmetry	
Species	Inf	Sex	Total sampled	Mean	SD	*N*	Prop. [95% CI]	*N*
				Survey 6 Oct 2013 to 5 Oct 2014				
Erythemis simplicicollis (Say, 1839)	A	♀	180	15.12	0.6	178	0.51 [0.44, 0.59]	178
		♂	80	14.54	0.55	80	0.49 [0.37, 0.60]	80
Miathyria marcella (Selys in Sagra, 1857)	A	♀	32	14.06	0.5	31	0.41 [0.24, 0.59]	31
		♂	14	14.31	0.6	14	0 [0, 0.23]	14
Tramea onusta Hagen, 1861	A	♀	8	19.02	0.38	8	0.5 [0.16, 0.84]	8
		♂	2	18.90	0.99	2	1 [0.16, 1]	2
Pachydiplax longipennis (Burmeister, 1839)	A	♀	4	12.55	1.33	4	0.25 [0.01, 0.81]	4
Phanogomphus minutus (Rambur, 1842)	A	♀	3	11.20	0.26	3	1 [0.29, 1]	3
Celithemis eponina (Drury, 1773)	A	♀	2	13.45	1.2	2	0.5 [0.01, 0.99]	2
Aphylla williamsoni (Gloyd, 1936)	A	♂	1	17.20	NA	1	1 [0.03, 1]	1
Pantala flavescens (Fabricius, 1798)	A	♀	1	16.20	NA	1	0 [0, 0.97]	1
				Survey 22 Sep 2017 to 1 Dec 2017				
Ischnura posita (Hagen, 1861)	Z	♀	85	8.39	1.07	73	0.43 [0.33, 0.55]	73
		♂	59	7.12	0.85	47	0.61 [0.47, 0.73]	47
Ischnura hastata (Say, 1839)	Z	♀	3	9.05	1.48	3	0.33 [0.01, 0.91]	3
		♂	1	6.91	NA	1	1 [0.03, 1]	1
Ischnura ramburii (Selys, 1850)	Z	♀	1	10.43	NA	1	0.47 [0.23, 0.72]	1
Miathyria marcella (Selys in Sagra, 1857)	A	♀	17	12.94	1.95	16	0 [0, 0.97]	16
		♂	1	16.91	NA	1	0.4 [0.05, 0.85]	1
Erythemis simplicicollis (Say, 1839)	A	♀	5	17.26	1.71	5	0.33 [0.01, 0.91]	5
Pachydiplax longipennis (Burmeister, 1839)	A	♀	3	15.09	1.9	2	0.5 [0.01, 0.99]	2
Erythrodiplax minuscula (Rambur, 1842)	A	♂	2	12.34	2.45	1	1 [0.03, 1]	1
Tramea onusta Hagen, 1861	A	♀	1	21.9	NA	1	0.43 [0.33, 0.55]	1

lis (variance *F*-test = 1.178; df = [178, 79]; *P* = 0.411; variance ratio = 1.178; 95% confidence intervals = [0.797, 1.694]), or *I. posita* (variance *F*-test = 1.58; df = [78, 53]; *P* = 0.08; variance ratio = 1.575; 95% confidence intervals = [0.946, 2.561]).

In contrast, *M. marcella* dragonflies had male-biased sexual size dimorphism (linear regression models by sex: *t* = −2.24; *P* = 0.029; *N* = 47; female mean wing-length: 13.68; SD = 1.297; *N* = 32; male mean wing-length: 14.48; SD = 0.887; *N* = 15). However, we caution that this overall male-biased sexual size dimorphism is inconsistent among our 2 surveys (Table 1; linear regression models by Sex: *F* = 6.21; df = 1; *P* = 0.0156; Survey: *F* = 6.51; df = 1; *P* = 0.0133; Sex by Survey: *F* = 10.03; df = 1; *P* = 0.002), and when accounting for this variability using a mixed-model, *M. marcella* dragonflies were sexually monomorphic (linear mixed models by Sex with Survey as random factor: *t* = 1.74; *P* = 0.088). Finally, there were no differences among the wing-length variances between females and males (variance *F*-test = 2.14; df = [46, 14]; *P* = 0.122; variance ratio = 2.14; 95% confidence intervals = [0.807, 4.634]).

FLUCTUATING ASYMMETRY

Again, only 3 species had enough samples to adequately compare and contrast fluctuating asymmetry of a meristic trait (i.e., wing-cell counts; Table 1). In aggregate, and treating survey identify as a random-effect in mixed-model analyses, male and female *E. simplicicollis* were equally symmetric (GLMM contrast by sex: *Z* = −0.31; *P* = 0.757; females fluctuating asymmetry = 0.508; confidence intervals = [0.426, 0.590]; *N* = 183; males: fluctuating asymmetry = 0.487; confidence intervals = [0.366, 0.611]; *N* = 80), and also when assessing symmetry overall by combining sexes (GLMM for *E. simplicicollis*: *Z* = 0.06; *P* = 0.951; fluctuating asymmetry = 0.502; confidence intervals = [0.442, 0.562]; *N* = 263). Male *M. marcella* were more symmetric than females (GLMM contrast by sex: *Z* = −2.09; *P* = 0.037; females fluctuating asymmetry = 0.404; confidence intervals = [0.259, 0.569]; *N* = 47; males: fluctuating asymmetry = 0.067; confidence intervals = [0.007, 0.42]; *N* = 15), and this pattern remained overall when combining sexes (GLMM for *M. marcella*: *Z* = −2.73; *P* = 0.006; fluctuating asymmetry = 0.323; confidence intervals = [0.219, 0.448]; *N* = 62). Finally, there is inadequate evidence to conclude differences in symmetry among *I. posita* sexes (GLMM contrast by sex: *Z* = 1.82; *P* = 0.069; females fluctuating asymmetry = 0.342; confidence intervals = [0.231, 0.475]; *N* = 73; males: fluctuating asymmetry = 0.511; confidence intervals = [0.352, 0.667]; *N* = 47); however, overall when combining sexes the species was asymmetric (GLMM for *I. posita*: *Z* = −1.99; *P* = 0.046; fluctuating asymmetry = 0.408; confidence intervals = [0.324, 0.498]; *N* = 120).

WATER MITE PARASITISM

Ectoparasitic water mites were not found on any dragonfly or damselfly in either survey.

Discussion

Similar to Paulson's (1966) observations, many of our estimated flight times indicate clear seasonality in Odonata activity in the Tampa Bay area, with either low abundance or absence during the coldest periods during the dry season (i.e., Nov–Mar). Tampa Bay is located

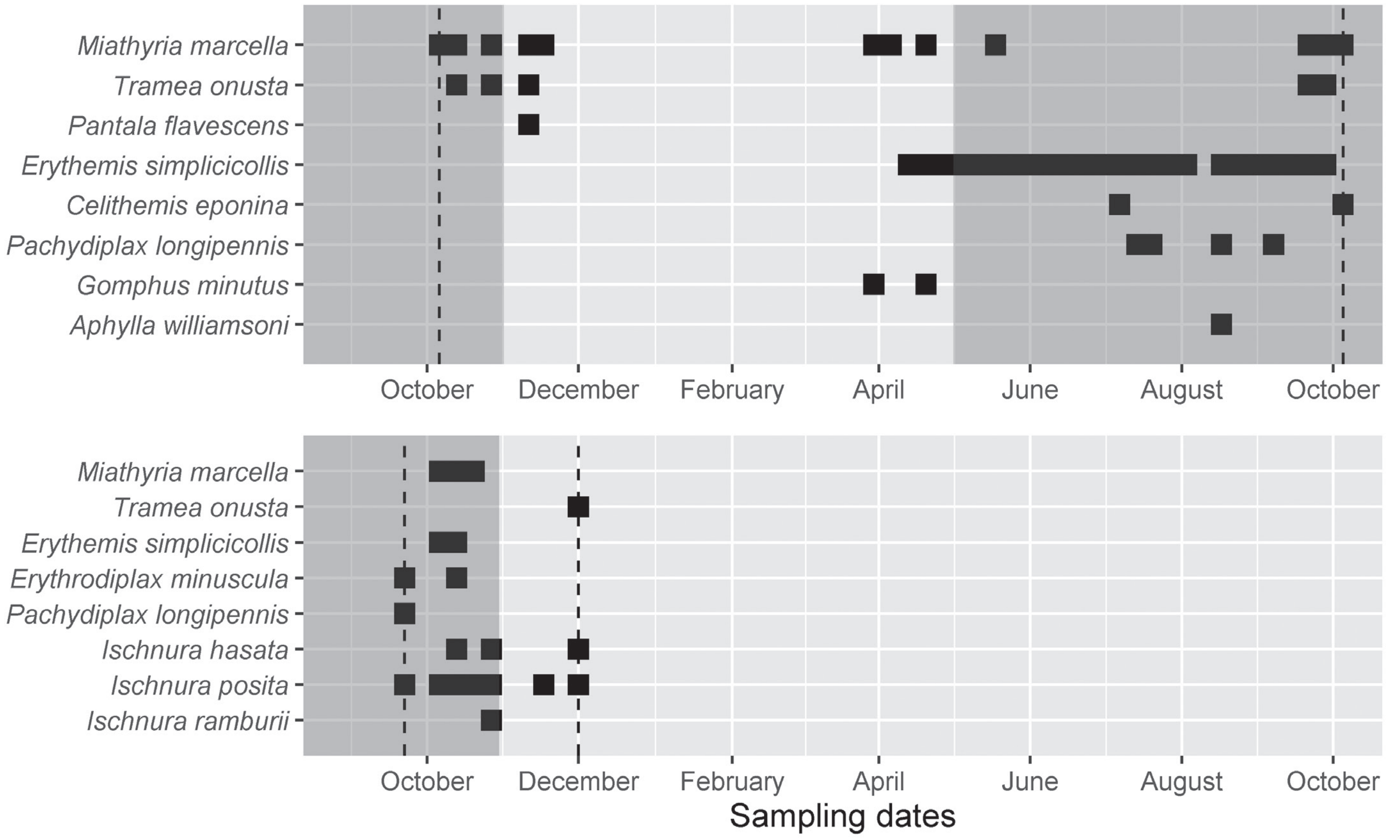

Fig. 1. Capture dates of 12 odonate species captured between Oct 2013 to Oct 2014 (top panel), and again from Sep 2017 to Dec 2017 (bottom panel) in the University of South Florida's Riverfront Park in Tampa, Florida, USA. Dashed lines indicate the start and end of surveys, and shaded areas indicates the typical wet season. Blocks indicate the wk when individuals were captured; spaces without blocks indicate periods when no individuals were captured.

at the southernmost frost point of the state (about 27.9506°N). Below this frost line, Odonata may have flight seasons yr round (Paulson 1999); however in Tampa Bay, there is still a high risk of at least 1 frost (0 °C) per dry season. In fact, our first survey experienced 0 °C on 7 Jan. This frost may explain the bivoltine flight time of the Neoptropical *M. marcella* (Fig. 1), because frost would have killed both adults and the invasive plant that nymphs use as habitat (the common water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Commelinales: Pontederiaceae) (Beckemeyer 2009). The common water hyacinth is present at our site, but abundance has not been tracked for seasonal changes. Beginning in Mar and the start of the rainy season, the first dragonfly species to emerge were *M. marcella* and *E. simplicicollis* (Fig. 1), then later in the summer (about Jul), *C. eponina*, *P. longipennis*, and *A. williamsoni* emerged. The only species captured throughout the entire wet season until Oct was *E. simplicicollis*. Finally, the skimmer *T. onusta* emerged briefly in late fall (as also described by Paulson 1966), along with the second emergence of *M. marcella* (Fig. 1). Our second survey was too brief to estimate flight times of damselflies.

Odonates may indicate aquatic and terrestrial environmental health because of their semi-aquatic life cycles (Bustos-Baez & Frid 2003; Bybee et al. 2016), and because their body size and fluctuating asymmetry may be used as surrogates of environmental stress (Jentzsch et al. 2003). This includes sexual size dimorphism because environmental stress or change can differentially impact nymph growth between females and males (Baker 1986). There was some variability in these traits among the odonates we surveyed. We found that female *E. simplicicollis* were larger, but not more variable than males in forewing-length, which confirms other reports of female-biased sexual size dimorphism based on body-length (McVey & Smittle 1984) and wing-loading (mg per cm^2; Locklin & Vodopich 2010). Female-biased sexual size dimorphism also was found among *I. posita* damselflies; however, size data for this species is limited, but Serrano-Meneses et al. (2008) reported this species as slightly male-biased. Likewise we could not find reports of sexual size dimorphism for *M. marcella* dragonflies; however, we found them to be monomorphic. We did not find differences in symmetry in either sex for *E. simplicicollis*, *I. posita*, or *M. marcella*; however, when combining data from each sex, *I. posita* damselflies were asymmetric. However, it is difficult to assess whether this asymmetry has functional importance at this site without clear stressors to link this asymmetry.

Following Lajeunesse (2007), the primary environmental stressor we aimed to measure was larval water mite parasitism; however, we did not capture any parasitized odonates at our site. Many of these species do have reports of water mite parasitism; for example, see Mitchell (1961) for *E. simplicicollis*; Botman et al. (2002) and Mlynarek et al. (2013) for *I. posita*; and Rodrigues et al. (2013) for *M. marcella* water mite parasitism within its native range (Brazil). Water mites are found in almost every type of freshwater habitat, but uncommonly in marine or brackish water (Wolcott 1905), and there are several permanent and temporary fresh water sources near our site. Our sampling site is located on the banks of the Hillsborough River which empties into Tampa Bay, and its salinity can fluctuate with the tides. However, this fluctuation is unlikely to affect water mite activity in our river section, which is over 32.2 km (20 miles) upriver from the mouth, and separated by the Hillsborough River Reservoir dam. Our sampling site also has several ephemeral ponds and swamp land that can dry up during the dry season (about 1 km); however, we sampled only near the river's edge since 23 Apr 2015, when 1 parasitized *I. posita* damselfly was captured (MJ Lajeunesse, personal observation). This female had 23 water mite larvae (7 thorax and 16 abdomen), which were dark orange with dark brownish-black spots, and 1 larvae was lodged between the ovipositor and the last abdominal (10th) segment. Given the lack of parasitized damselflies in our second survey, this parasitized individual may have migrated from a neighboring site and future surveys will target these ephemeral ponds to improve water mite sampling.

There are several ways we can improve the quality and scope of our surveys. Raebel et al. (2010) recommend collecting dragonfly exuviae for diversity surveys because it decreases capture biases (Lajeunesse et al. 2004), and in a similar vein, emergence traps also may provide better quality flight season data. These approaches avoid challenges with differentiating between site-residents and immigrants, which we could not separate in our surveys. Finally, Florida has a strong baseline of dragonfly and damselfly surveys in the early- to mid-20th century (Paulson 1966), but more recent surveys are lacking. We hope our surveys encourage more regional assessments throughout Florida. These would significantly improve long-term forecasts of changes in phenology and geographic ranges of odonates, especially if surveys span the broad latitudinal gradient of the Florida peninsula.

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