The Use of Highly Diverse Clades As A Surrogate For Habitat Integrity Analysis: A Practical Tool For Rapid Assessments

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Abstract

Human activities have impacted many different habitat types on Earth, and there is a requirement for tools with which to accurately assess the level of damage incurred by ecosystems. For environmental analyses and monitoring, rapid stream assessment techniques emphasize geomorphological characteristics, biological potential, and habitat integrity characteristics. Using the principles and concepts of aquatic biology and ecology, we determined whether the visual-based habitat evaluation score is related to Odonata species diversity at different taxonomic levels. We hypothesized that habitat assessment is correlated positively with the local diversity of one Odonata taxonomic group. We found that the abundance, species richness, and diversity of *Argia*, one of the most locally diverse genera in southeastern Mexico, are positively correlated with habitat integrity scores. High richness (of up to eight species per site) corresponds to high integrity scores. Simultaneously, habitat integrity scores increase 23.51 times when *Argia* diversity (surface area) increases. We discuss the possible advantages of using a diverse Odonata clade (*Argia*) as a surrogate for local habitat assessments. Long-term biomonitoring programs could be applied using this novel approach in this specific Neotropical area. This study is framed within the focus of biodiversity and ecosystem functioning (BEF), however, it must be tested with other indices and a reliable and consistent relationship must be verified between diverse clades and environmental assessment scores.

Introduction

Ecosystems, both aquatic and terrestrial, face an unprecedented environmental crisis. The high number of extreme meteorological events (Luque et al., 2013), increased presence of chemicals with toxic effects on human health (Shen and Zuo, 2020) and loss of species (Dirzo et al. 2014) are three of the most critical challenges we currently face. Freshwater habitats in particular represent one of the world's most threatened ecosystems (Dudgeon et al., 2006; Voß & Schäfer; 2017). For example, rivers ecosystems are increasingly affected by various factors as a result of the development of human activity (Valero et al., 2015). Maintenance of safe freshwater resources is therefore an urgent requirement worldwide, and there is a general trend towards examining threats over a broad range of scales, local to global, from both social and biological perspectives (Vörösmarty et al., 2010; Clausnitzer et al., 2012, Pinto et al., 2014).

River macrobenthic invertebrates have been widely reported and described as ecological indicators in the literature since the 1980s (Cairns & van der Schalie, 1980; Chovanec & Waringer, 2001; Ogbeibu & Oribhabor, 2002; Clews et al., 2014). Ecological indicators have evolved from the use of simple metrics describing indicator taxa or measures of biological diversity to quality targeted and weighted indices of taxon sensitivity to specific stressors (Clews et al., 2014; Siddig et al., 2016), such as changes in physical and chemical water quality parameters, urbanization, deforestation, and pollution. Moreover, investigations of dragonfly and damselfly assemblages have become a reliable tool for ecological characterization and assessment of aquatic systems and evaluation of water management activities (Oertli, 2008; Bried and Samways, 2015).

Odonates are vital in the water bodies of aquatic ecosystems (Gómez-Tolosa et al., 2021). They are also ecologically important as dominant predators, while also constituting a significant prey for a considerable range of organisms and contributing a large proportion of total invertebrate biomass and species richness (Sahlén and Ekestubbe, 2001; Sang and Teder, 2011; Simaika and Samways, 2011). Many studies of ecological characterization (according to Chelli and Moulaï, 2019) are based on adult odonates because they are relatively easy to identify, collect and observe *in situ* (Silva et al., 2010; Simaika and Samways, 2011; Kutcher and Bried, 2014).

On the other hand, habitat assessment has been defined as evaluating the surrounding physical habitat structure that influences the quality of the water resource and the resident aquatic community (Barbour et al. 1996). An integral approach to assessing habitat structure includes evaluating substrate variety and quality, channel morphology, bank structure and riparian vegetation (Barbour et al., 1999). Rapid habitat assessments are often based on an observer rating the habitat integrity of the site by matching specific habitat features (Hannaford et al., 1997). Habitat assessments are, therefore, an efficient method for the characterization of stream habitat (Habberfield et al., 2014).

Therefore, there is a requirement for methods to identify pre-existing conditions and efficiently prioritize projects within stream corridors, especially in streams where data is sparse or non-existent (Habberfield et al., 2014). According to Habberfield et al. (2014), the most common and cost-effective methods used to identify and prioritize stream restoration sites include Visual-Based Rapid Assessment techniques that evaluate the quality of the physical conditions of the stream. Despite their common usage, few studies have related rapid assessment techniques with the macroinvertebrate communities, specifically with Odonata assemblages (e.g. Smith et al., 2007). Smith et al. (2007) hypothesized that a range of environmental conditions will place extreme demands on species composition at various sites (local scale). In contrast, other river systems would provide variation on a broader landscape scale. Rapid stream assessment techniques emphasize geomorphological characteristics as well as biological potential and parameters of habitat integrity (Barbour et al., 1999; Habberfield et al., 2014), whereas Odonata species are related to habitat conditions (Mendes et al., 2017; Carvalho et al., 2018) and probably reflect the proportion of specialists and generalists (Dolný et al., 2012; Šigutová et al., 2019). Indices featuring these species have been developed, including the Odonata Habitat Index (Chovanec and Waringer, 2001, Chovanec et al., 2015), Dragonfly Biotic Index (Simaika and Samways, 2009), Habitat Physical Integrity Score (HPIS) for adult odonates (Silva et al., 2010) and Coefficient of Conservatism (Kutcher and Bried, 2014).

Among other species, members of the *Argia* are related to high-quality habitat conditions (Azrina et al., 2006, Silva et al., 2010, Kutcher and Bried, 2014, Rodrigues et al., 2016, Valente-Neto et al., 2016, and Miguel et al., 2017). For example, *Argia tinctipennis* (Pinto et al., 2012), *A. modesta* (Silva et al., 2010) and *A. reclusa* (Juen et al., 2014) are related to high habitat integrity. In contrast, *Argia collate* (Calvão et al., 2016) and *A. pulla* (Gómez-Anaya et al., 2011; Gómez-Tolosa et al., 2015) have been reported as being tolerant to habitat disturbance. According to Cardinale et al. (2012), biodiversity can be used to predict some ecosystem functions (the BEF framework). In this context, we explore whether Odonata biodiversity can predict the habitat integrity. The objective in this study was to analyze the relationship between the Visual-Based Habitat Assessment Score (VBHAS; Barbour et al., 1999) and the parameters of abundance, species richness and diversity, at different taxonomic levels in streams of Neotropical basins. Specifically, we tested whether one taxonomic group can sufficiently explain habitat integrity to be of utility as a surrogate for rapid habitat assessment. We hypothesized that habitat assessment will correlate positively with a diverse clade, particularly the genus *Argia* because most of these species are typically specialists and thus sensitive to environmental quality (Šigutová et al., 2019), and could therefore be used as an indicator of habitat integrity in this specific area. We then compared the relationship using the information derived from General Linear Models (GLM). This comparison allows the discussion of techniques that attempt to correlate odonates diversity—specifically *Argia* diversity—and habitat quality for local environmental assessments. Below, we discuss the possible use of *Argia* diversity for local long-term biomonitoring programs in tropical regions. However, we open the debate regarding the value of focusing on studying diverse clades as practical proxies of habitat integrity and verify whether there is a reliable and consistent relationship with other taxa and environmental indices, in the Neotropical region.

Methods

Study site

We carried out this study in three permanent basins, Cintalapa, Vado Ancho and Huixtla (Figure 1) in the region of Costa-Soconusco de Chiapas, southeastern Mexico (the geographic coordinates for the extremes of the study area are 15°30'59.25 N, 92°49'40.83 W, and 14°55'50.41 N 92°12'42.40 W). According to Köppen's climatic classification (modified by García, 2004, for Mexican conditions), the upstream region is classified as semi-warm humid, midstream as humid, and downstream as warm-sub humid with hot summers and dry winters. On average, the temperature in the hottest month is higher than 35.8 °C, whereas that of the coldest month is around 22.8 °C. According to the Mexican Meteorological Service of the National Water Commission, the rainy season occurs from May to October, with annual rainfall ranging between 1200 and 3000 mm (30 years of periodic observations).

Sampling method

We delimited each sampling unit (**SU**) as an area of 15 - 20 m in length of the river with a 1 - 3 m wide strip of vegetation on either bank (depending on the topography and accessibility of each site). A total of 11 **SUs** were selected: three (numbers one, two and three) were along the Cintalapa basin (C), four (four, five, six and seven) were within the Vado Ancho basin (VA) and four (eight, nine, 10 and 11) were in the Huixtla basin (H). We selected these **SUs** according to the goals of the project: "Inventory and comprehensive management program for the conservation of the Soconusco wetlands through their delimitation, ecological, hydrological, social characterization, and degree of risk" (Alonso Eguía-Lis et al., 2013), also considering other criteria such as the accessibility and other logistical factors, attempting to cover the streams along the basins. Each **SU** was characterized according to the combination of environmental conditions, river and locality name (for a detailed description, see Supplementary Material Appendix 1). To avoid the effect of spatial autocorrelation between **SUs**, we ran a Moran's autocorrelation Index (Supplementary Material Appendix 2). Each **SU** was visited three times throughout one complete hydrological cycle of the year. Sampling of adult dragonflies and damselflies took place in March 2012, September 2012, and January 2013 to cover both seasons: dry (March 2012 and January 2013) and rainy (September 2012). We captured mature adults in tandem (males and females), or mature male adults that exhibited territorial behavior, in order to facilitate taxonomic identification and ensure that the specimens sampled were breeding adults (Foote and Hornung, 2005; Bried et al., 2015;

Chovanec et al., 2015; Patten et al., 2019). We collected insects using an entomological hand net between the hours of 09:30 and 15:30 hs., when the streams were illuminated by sunlight. Once species identification was completed, the individuals were released at their corresponding sampling sites. Where taxonomic identification in the field was not possible, each individual was preserved by placing in a cooler at 4 ºC for at least 10 min to decrease the metabolism, then injected with 99% acetone and immersed for 24 hours in 99% acetone in order to preserve the original color. We carried out identification in the field and laboratory using taxonomic keys (Westfall & May, 1996; Förster 2001; Garrison et al., 2010a; 2010b). Each identified specimen was subsequently compared with the species described for the state of Chiapas, according to González-Soriano and Paulson (2011).

Visual-Based Habitat Assessment Score (VBHAS)

We carried out the analyses of habitat quality for each **SU** according to a **VBHAS** proposed by Barbour et al. (1999) and adjusted for the area by Alonso Eguía-Lis et al. (2013) and Gómez-Tolosa et al. (2015). We included the riparian forest, riverbanks and channel structure related to human impact (Silva et al., 2010). Analyses of habitat quality for each **SU** were carried out according to a proposed **VBHAS** (Supplementary Material Appendix 3). Each unique feature was determined, and the scores were calculated as the sum of each value. A high score therefore reflects a better habitat condition. All parameters were evaluated and rated on a numerical scale of 0 to 20 (highest) for each **SU**. The ratings were then totaled and compared to a reference condition (according to Barbour et al., 1999; Supplementary Material Appendix 3) to provide a final habitat ranking. Kolem-Jaa—a site located on the state limits between Chiapas and Tabasco—was used as a reference site with which to compare the **SU** because of its null anthropogenic impact status and location within the same ecoregion. Scores rise with increasing habitat quality, and descriptions of the physical parameters and relative criteria were included in the rating form (Alonso Eguía-Lis et al., 2013) in order to ensure consistency in the evaluation procedure. The judgment criteria for each of the habitat parameters were calibrated for the stream classes under study, with some modifications applied on a regional basis. Each person was trained in the visual-based habitat assessment technique for the applicable region in order to give a particular score, after which the highest and lowest scores were eliminated, and the remaining estimations used to provide an average score for each **SU**. Habitat assessment was done in the driest month of the year (March 2012), during the odonate survey. At each visit to the **SU**, water samples were taken and temperature, pH, dissolved oxygen and conductivity were measured with a Hanna model HI-9829 Multiparameter. The average values that characterize each site are presented in the Supplementary Material Appendix 4.

Statistical analyses

Sampling representativeness was determined using the nonlinear Chao 2 estimator in the software EstimateS, Version 9.1. (Colwell, 2013). We ran the estimations for each taxonomic level, from order to genus. To analyze the relationship between **VBHAS** and the Odonata group, we calculated several diversity indices. The BioFTF package (Di Battista et al., 2016) was executed in R version 4.0.0 (R Core Team, 2020) using the interphase RStudio version 1.1.463 (RStudio Team, 2020) to calculate i) species richness (S), ii) Simpson's domination (D), iii) Shannon-Wiener diversity (H') and iv) the area under the Beta diversity curve (hereafter referred to as **surface area**), which is a scalable measure that reflects the information provided by the biodiversity profile and allows ordering of communities with different richness values (as suggested by Di Battista et al., 2016. For more details, see Supplementary Material Appendix 5) at different taxonomic levels (from Odonata order to *Argia* genera). We used the package BioFTF to order ecological assemblages based on their biodiversity, considering both richness and evenness, avoiding the effect of differences between sample sizes and the number of species recorded (Supplementary Material Appendix 6).

As a dependent variable for the VBHAS data, we set the binomial distributions to Gaussian (normal), Poisson or Negative, using an R script for the dataset in the Supplementary Materials Appendix 7. To fit data distributions and find parameter estimates for those distributions, we used the package fitdistrplus (Delignette-Muller and Dutang, 2015). We performed all statistical analyses in RStudio version 1.1.463 (RStudio Team, 2020) for R, version 4.0.0 (R Core Team, 2020). To quantify the relationship between abundance, richness and diversity with the VBHAS, we ran a Beta and Dirichlet Regression Model according to Douma & Weedon (2019), using the packages DirichletReg (Maier, 2020), ggplot2 (Wickham, 2016), betareg (Cribari-Neto & Zeileis, 2010).

Results

During the sampling period, we recorded a total of 40 Odonata species from the following families: Libellulidae (16 spp.), Coenagrionidae (18 spp.), Protoneuridae (2 spp.) and Calopterygidae (4 spp.). A summary of all adult Odonata sampled by species is shown in Supplementary Material Appendix 9. *Argia pulla* was the only species recorded at all sites, while *Argia pipila, Anatya guttata*, *Erythemis peruviana*, *Erythemis plebeja*, *Macrothemis extensa*, *Macrothemis inequiunguis*, *Paltothemis lineatipes* and *Tramea calverti* were each recorded at only one **SU**. Within the Coenagrionidae, *Argia* had more species (13), which is consistent with results found at other localities in Mexico, where this genus has been reported to present the highest species richness.

The results of Moran's Index test showed that the **SU**s are spatially independent, in terms of **VBHAS** (Moran's Index = 0.0083, z-score = 0.488 and p = 0.625). For the Odonata taxonomic level, with 512 individuals captured, 81.32% of the total expected species was reached; the Zygoptera suborder, with 469 individuals, presented 89.79% of the expected number of species; the Coenagrionidae family, with 363 individuals, reached 88.80%; and *Argia*, with 351 individuals, reached 98.26% (Figure 2).

Regarding the **VBHAS** for each **SU**, El Triunfo had the highest score with 199 points, whereas El Arenal presented the lowest score with 46 points (Supplementary Material Appendix 8). In general, the three sites at the lower part of the basin (El Arenal, Puente Teziutlán and El Palmar) presented the lowest scores, while the **SU** at the central part of the basin (El Triunfo, Zapote Mocho, and Huixtla) had the highest scores.

Independencia (**SU** 2) and Unión Hermosillo (**SU** 4) presented the highest species richness (13 species in each **SU**), whereas Puente Chorro presented the lowest richness, with only four species (Table 1). According to **surface area** (Table 1), the **SU** can be ordered from more diverse to less diverse as follows: Unión Hermosillo (**SU** 4), Zapote Mocho (**SU** 6), El Triunfo (**SU** 1), Independencia (**SU** 2), El Recuerdo (**SU** 5), Tolimán (**SU** 8), Huixtla (**SU** 10), Puente Chorro (**SU** 9), El Palmar (**SU** 7), El Arenal (**SU** 11) and Puente Teziutlán (**SU** 3).

Table 1. Results of diversity analyses in the 11 localities (**SU**s) along the rivers, from order to genera, and habitat integrity scores. Bold numbers indicate the highest value found for each variable.

	Sample Units (Localities)										
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Odonata abundance	51	62	66	64	39	**75**	44	14	14	30	53
Odonata richness	11	12	11	**13**	12	11	12	5	4	9	11
Odonata surface area	5.98	6.35	5.17	**6.93**	6.81	6.03	6.01	3.57	2.94	5.42	4.92
Zygoptera abundance	50	57	61	62	33	**73**	34	13	12	25	49
Zygoptera richness	10	8	7	**11**	9	10	6	4	2	4	7
Zygoptera surface area	5.63	4.97	3.73	**6.29**	5.62	5.66	3.49	3.02	1.73	3.33	3.45
Coenagrionidae abundance	45	45	43	55	23	**64**	28	5	3	12	40
Coenagrionidae richness	8	6	2	**9**	7	8	4	3	1	2	4
Coenagrionidae surface area	4.78	4.04	0.87	5.41	4.60	4.76	2.22	3.00	1.33	1.90	1.78
***Argia* abundance**	44	45	42	53	21	**64**	25	5	3	12	37
***Argia* richness**	7	6	1	**8**	5	**8**	2	3	1	2	1
***Argia* surface area**	4.42	4.04	0.44	**5.01**	3.70	4.76	1.08	3.00	1.33	1.90	0.46
VBHAS	**199.00**	143.00	92.00	135.00	174.00	195.00	51.0	150.00	168.00	189.00	46.0

In this preliminary rapid assessment study with Odonata, we found the following relationships: The GLM analysis showed a positive correlation between **VBHAS** and *Argia* species richness (**S**), with an estimated slope of 12.06±5.09 (AIC = 119.30, p = 0.04; Table 2, Figure 3a). For Coenagrionidae diversity (**surface area),** we found an estimated slope of + 20.03±9.36 (AIC = 120.11, p = 0.06; Table 2, Figure 3b) and, for *Argia* diversity (**surface area**), the estimated slope was 23.51±7.16 (AIC = 115.97, p > 0.01; Table 2, Figure 3c). For Odonata and Zygoptera, we did not find any relationship with **VBHAS** for abundance, species richness, or diversity.

Table 2. General Linear Model summary for abundance, richness, and diversity, where p is the probability of rejecting the null hypothesis and AIC corresponds to the Akaike Index Criteria. For all cases, n = 11. Bold numbers represent statistical significance for p

< 0.05.

	Taxonomic level	Coefficient	Standard error	*p*	AIC
ABUNDANCE	Odonata	-0.27	0.9	0.77	124.52
	Zygoptera	-0.05	0.9	0.95	124.62
	Coenagrionidae	8.90E-03	0.09	0.99	124.63
	Argia	0.12	0.92	0.9	124.61
RICHNESS	Odonata	-3.43	6.2	0.59	124.26
	Zygoptera	3.87	6.32	0.55	124.18
	Coenagrionidae	7.66	6.1	0.24	122.85
	Argia	**12.06**	**5.09**	**0.04**	**119.3**
SURFACE AREA	Odonata	4.84	14.57	0.75	124.49
	Zygoptera	15.42	11.88	0.23	122.74
	Coenagrionidae	*20.03*	*9.36*	*0.06*	*120.1*
	Argia	**23.51**	**7.16**	**9.49E-03**	**115.97**

Discussion

As expected, our results indicate that a highly diverse clade approach can be used to predict the environmental integrity of the streams in this study site. There is a growing need to identify rapid and effective biological indicators for measuring environmental health and quality (Kutcher and Bried, 2014; Voß and Schäfer, 2017). However, the use of indicator species has been criticized for several reasons, most notably the lack of justification given for selecting a particular indicator (Siddig et al., 2016). However, Mendoza-Penagos et al. (2021) recently demonstrated that a focus on odonate families for environmental monitoring could be advantageous in terms of cost- and time effectiveness and the quality of the information obtained. Moreover, these authors concluded that rapid assessments can be conducted effectively by selecting an adequate taxonomic level.

In this sense, adult damselflies and dragonflies (Odonata) have several attributes that make them appropriate for environmental evaluations (Dolný et al., 2012; Kutcher and Bried, 2014; Berquier et al., 2016; Miguel et al., 2017; Šigutová et al., 2019). Odonata species are increasingly used as indicators of water quality (Chovanec and Waringer, 2001; Simaika and Samways, 2009, 2011, 2012; Harabiš and Dolný, 2010; Silva et al., 2010; Kutcher and Bried, 2014; De Oliviera-Jr. et al., 2015; Berquier et al., 2016; Golfieri et al., 2016; Valente-Neto et al., 2016), multiple modalities of climatic change (Hassall, 2015), habitat integrity (Mendes et al., 2017), forest fragmentation (Renner et al., 2016), logging activities (Calvão et al., 2016), land use intensification (Rocha-Ortega et al., 2019) and the effects of urbanization (Bried and Samways, 2015). Pinto et al. (2012) demonstrated a higher wing fluctuating asymmetry in adults of *Argia tinctipennis* when riparian vegetation was removed, while Rocha-Ortega et al. (2019) showed that adult Odonata body size seems to be a more suitable variable for measuring the integrity of original vegetation than the more commonly used species richness indices.

In tropical regions, nine Odonata species were classified as useful indicators of ecosystem health (De Oliviera-Jr. et al., 2015). Four of these have been associated with more degraded streams (three species from Anisoptera and one from Zygoptera), while five Zygoptera species were indicative of optimal environmental conditions (De Oliviera-Jr. et al., 2015). These findings suggest the use of sets of species that are sensitive to environmental conditions.

The **SU**s downstream were lower in habitat integrity (measured with the **VBHAS**) since they presented a low score for velocity (depth regimes), with categories of poor quality in El Palmar (**SU**7) and El Arenal (**SU**11). This is in contrast to the midstream and upstream **SU**s, which present optimum and suboptimum habitat integrity, respectively. Some species, such as *Argia pipila* and *A. pocomana*, are associated with riffles, while other species are associated with pools (*Erythemis plebeja*, *Neoerythromma cultellatum*, *Tramea calverti*). Accordingly, further studies of rapid assessments have found that *Argia modesta* (Silva et al., 2010) and *A. indocilis* (Dalzochio et al., 2011) are abundant in sites with higher habitat integrity scores. In contrast, Montero-Junior et al. (2015) found that the population size of *Argia* species decreased when areas of urbanization and deforestation increased. Consequently, the mixture of specialist and generalist species acted to conceal the relationship with VBHAS, which was evaluated at a higher taxonomic level (order).

Classical species diversity measures use species richness, heterogeneity or evenness; however, as Magurran (2004) stated, no index is universally applicable across all ecological assemblages. Consequently, there is no single index that can summarize species diversity concepts (Whittaker, 1972; Purvis and Hector, 2000; Morris et al., 2014). Traditional diversity indices represent various phenomena because some indices prioritize species richness over uniformity (or vice versa). As a result, communities could be ranked differently depending on the index applied (Hurlbert, 1971). According to Stirling and Wilsey (2001), species diversity should be measured using a compound statistical metric. Since traditional diversity indices cannot summarize species diversity, a composite statistical measure is required (Guisande et al., 2017). In this context, Di Battista et al. (2016) provide a scalar measure that leads to a community classification, using the area under the curvature function (Supplementary Material Appendix 5) and avoiding bias towards either dominant or rare species.

Moreover, previous studies have analyzed the relationship between biotic (Simaka and Samways, 2011) and habitat integrity indices (Alves-Martins et al. 2018, De Oliveira-Junior and Juen, 2019), using estimates of diversity. Our study includes an analysis of the total diversity, abundance and species richness of odonates at different taxonomic levels (order, sub-order, family, and genera) with a habitat integrity index (VBHAS). We found that *Argia* species richness and diversity both increase with increasing habitat integrity indices. This relationship means that analysis at the genus level could be more accurate than at higher taxonomic levels for this particular region.

Unfortunately, little is known regarding the life cycles, geographic distribution and tolerance to environmental change of many odonate species in this region. It is therefore difficult to relate the environmental factors that affect each life cycle stage to presence or absence in a particular site. For this reason, we found insufficient information for this specific Neotropical region to compare our results with other indices; for example, the Odonata Habitat Index (Chovanec and Waringer, 2001) or the Dragonfly Biotic Index (Simaika and Samways, 2009).

Moreover, Raebel et al. (2010), Patten et al. (2015), Bried et al. (2016), Khelifa (2019) and Šigutová et al. (2019) discussed the advantages and disadvantages of using the adult stage and concluded that adult-based bioassessment methods are reliable and easily applied to various types of tropical forest habitats worldwide. For this study, we monitored a complete hydrological cycle using only resident adults and insects that showed any reproductive activity, such as tandem or oviposition behavior.

With regard to our hypothesis, we suggested that habitat assessment will correlate positively with a diverse clade, particularly the speciose *Argia* genus, and therefore expected a positive relationship since most of these species are typically running water specialists and sensitive to environmental integrity. Moreover, since these species belong to the same clade, they must share a common evolutionary and colonization history in this specific area. We found a robust positive relationship between VBHAS with *Argia* richness and diversity, regardless of geographic position (latitude, longitude, and elevation). Habitat integrity scores increase 12.06 times when *Argia* species richness increases. At the same time, habitat integrity scores increase 23.51 times when *Argia* diversity (surface area) increases, which is consistent with the theoretical fundamentals of rapid assessment evaluation (Azrina et al., 2006; Harabiš and Dolný, 2010; Harabiš and Dolný, 2012).

El Triunfo, the **SU** with the highest **VBHAS**, has eight of the 13 *Argia* species; and Zapote Mocho, the **SU** with the second highest **VBHAS**, has nine of the 13 *Argia* species, two of which are exclusive to this site, supporting the notion that *Argia* species are better indicators of habitat integrity. These results coincide with those of other studies that have related habitat quality to species of the Suborder Zygoptera (Dutra and De Marco, 2015; Monteiro-Júnior et al., 2015; Rodrigues et al., 2016) and the genus *Argia* (Novelo-Gutiérrez and Gómez-Anaya, 2009; Silva et al., 2010; Calvão et al., 2016).

In terms of establishing monitoring protocols for each of the three Soconusco basins in this region, environmental quality assessment is more efficient when using only the genus *Argia* (13 spp.) rather than all of the odonate species (40 spp.). Previous studies have shown a relationship between species assemblage and habitat integrity. For example, Miguel et al. (2017) and Schöder et al. (2020) found that *Argia* species were abundant under better habitat conditions (i.e., using an index of habitat integrity proposed by Nessimian et al., 2008).

The study of Mendoza-Penagos et al. (2021) found that abundance had the highest concordance with habitat integrity variations at the Coenagrionidae level, while that of Valente-Neto et al. (2016) focused on the genus composition. However, to our knowledge, no specific studies have used a diverse species clade belonging to *Argia* with habitat integrity indices. *Argia* occurs throughout the New

World, with its highest diversity found in our study area (Caesar & Wenzel, 2009). Our approach also differs in that we tested different taxonomic levels (from order to genera) as predictors of habitat integrity. Nevertheless, this approach must be tested with other quality indices and other highly diverse clades in order to determine its accuracy.

Conclusions

Odonata species are of value to the assessment of lotic habitat integrity, especially in Neotropical ecosystems. However, when we compare the results obtained from the analyses between the different diversity indices and the VBHA scores, the parameters of richness and diversity were significant for *Argia* species.

This study demonstrates that it is possible to monitor *Argia* species associated with environmental integrity, preserved environments, and degraded streams, and the results show that species richness and diversity are both positively related to the visual habitat integrity index (**VBHAS**) scores in this Neotropical zone. *Argia* diversity has the lowest AIC value of all analyzed models.

This monitoring method can be applied by local people with no specialized biological training. However, further fieldwork is necessary before establishing monitoring protocols. More data are required through the collection of female specimens to develop a field guide that helps the identification of specimens by local non-specialist monitors.

We recommend the use of diverse clades for evaluating environmental integrity in order to test our hypothesis. We strongly suggest using odonates and other taxa for rapid environmental evaluations in the Neotropical region.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated and analyzed during this study are included in this published article as supplementary information files.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: MGT, EGS, SL; Methodology: MGT, SL; Formal analysis and investigation: MGT, EGS, LFMC, SL; Writing - original draft preparation: MGT, SL; Writing - review and editing: EGS, LFMC, RMPM, TMRP, HOS, GRV, FEPG; Funding acquisition: EEEM; Resources and supervision: EGS, LFMC, SL; Software and visualization: MGT, SL.

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Figures

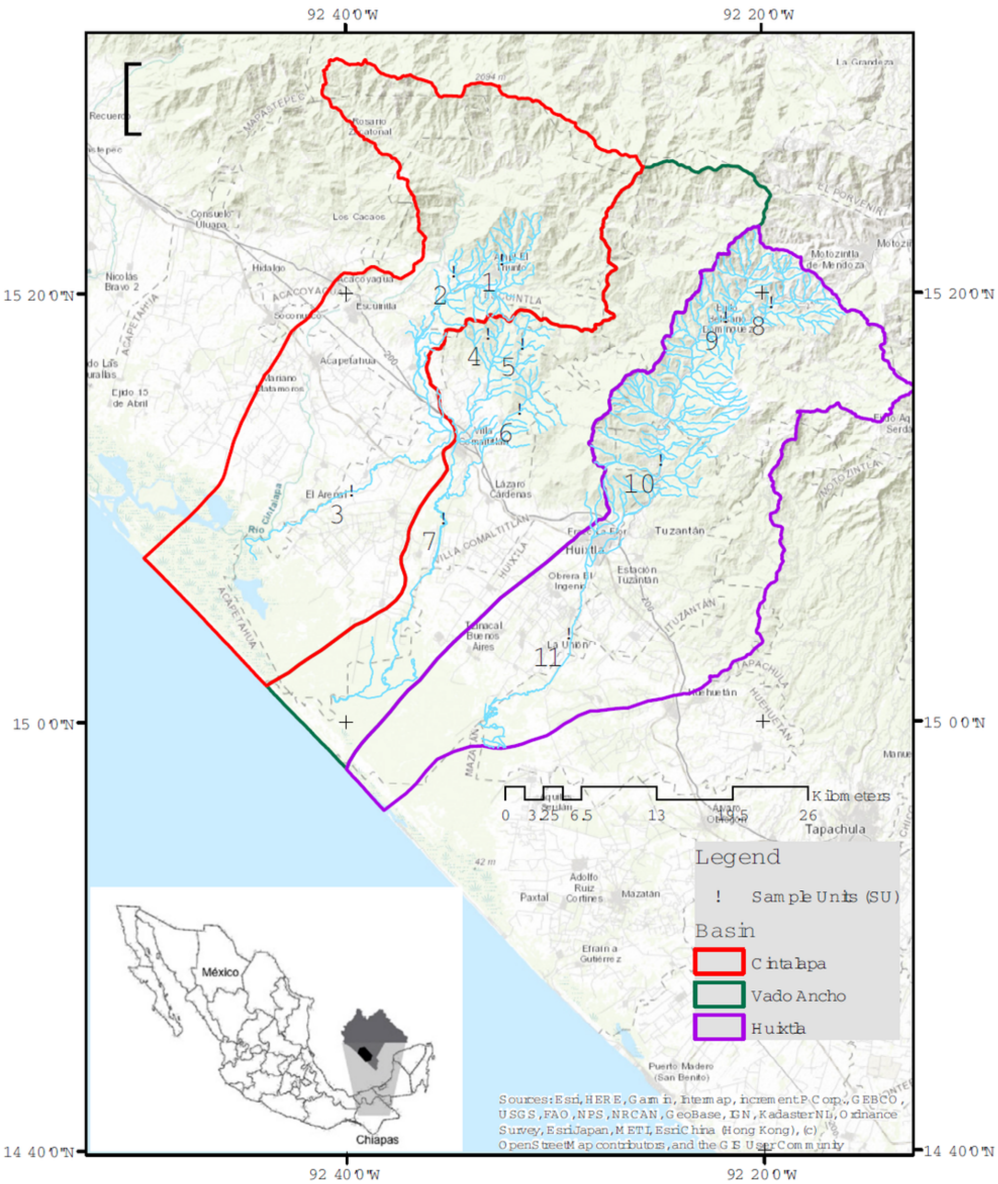

Figure 1

Location and distribution of sampling units (SU) along the Cintalapa, Vado Ancho and Huixtla Rivers. Black dots correspond to each SU: El Triunfo = 1; Independencia = 2; Puente Teziutlán = 3; Unión Hermosillo = 4; El Recuerdo = 5; Zapote Mocho = 6; El Palmar = 7; Tolimán = 8; Puente Chorro = 9; Huixtla = 10; El Arenal = 11

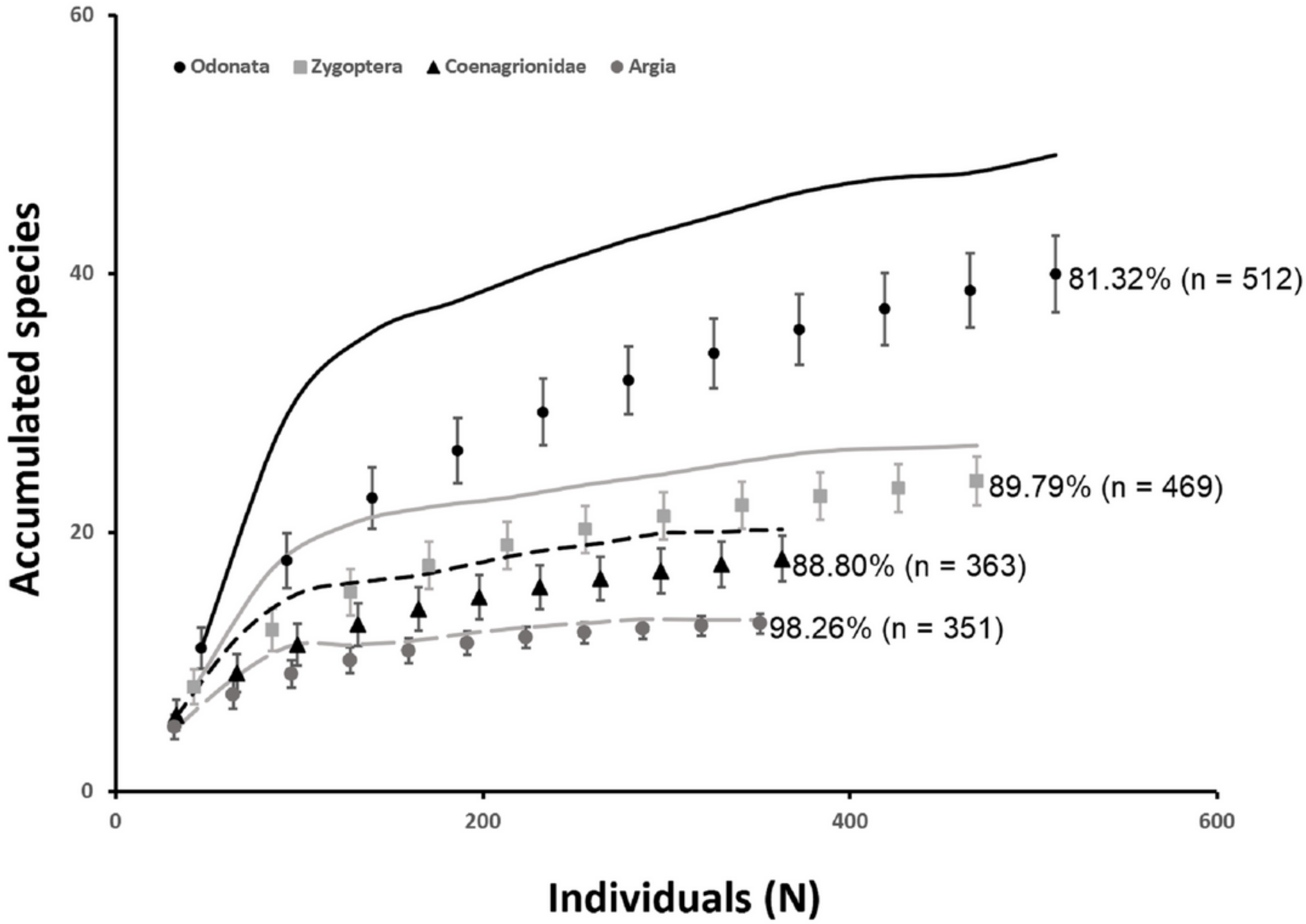

Figure 2

Rarefaction curves for different taxonomic arrangements (Odonata = black dots, Zygoptera = grey squares, Coenagrionidae = black triangles and Argia = grey dots) in each SU. Species richness observed (± standard error) versus captured individuals. Lines represents species accumulation based on Chao model two (Odonata = black line, Zygoptera = grey line, Coenagrionidae = black dashed line and Argia = grey dashed line)

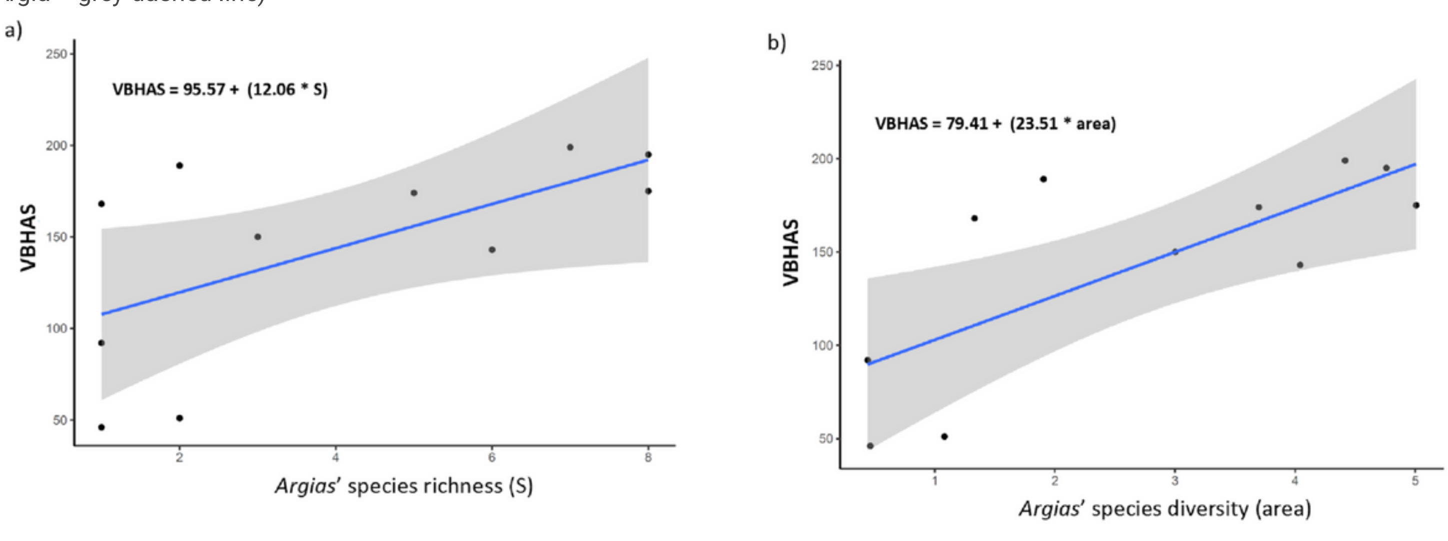

Figure 3

Generalized linear model analyses of elevation (in meters above sea level, masl), for different taxonomic arrangements in each SU. a) Odonata, b) Zygoptera, c) Coenagrionidae and d) Argia total abundance; e) Odonata species richness (S) and f) diversity (D). The blue line denotes the expected linear regression, black dots correspond to observed values, and grey zones represent the confidence interval at 95%

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