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Campsurus truncatus Ulmer, 1920 (Polymitarcyidae): an Ephemeroptera in eutrophic waters

Campsurus truncatus Ulmer, 1920 (Polymitarcyidae): um Ephemeroptera em águas eutrofizadas

Mônica Luisa Kuhlmann[1]*, Hélio Rubens Victorino Imbimbo[1] and Helena Mitiko Watanabe[1]

[1]Setor de Comunidades Aquáticas – ELHC, Companhia Ambiental do Estado de São Paulo – CETESB, Av. Prof. Frederico Hermann Jr., 345, CEP 05459-900, São Paulo, SP, Brasil
*e-mail: mkuhlmann@sp.gov.br

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Abstract: Aim: The order Ephemeroptera, together with Trichoptera and Plecoptera, has been considered as sensitive in environmental quality assessment. However, the species *Campsurus truncatus* Ulmer 1920 (Polymitarcyidae) has been sampled in anthropically altered sites. In this paper, data on the occurrence of that species in the water quality monitoring network of the Environmental Agency of São Paulo State (CETESB) were gathered to review its position in the environmental gradient and in the quality assessment of rivers and reservoirs. **Methods:** For this, a compilation of the occurrences and densities of *Campsurus* obtained in rivers and reservoirs of São Paulo state between 2001 and 2018, with grab samplers, was carried. Environmental factors, the Trophic State Index (TSI) and the Benthic Community Index (BCI) were related to the species densities to define its environmental requirements. **Results:** The sublittoral zone of reservoirs was the most common habitat to *C. truncatus*, occurring more frequently at mesotrophic sites with fair ecological quality. Higher mean densities were recorded at eutrophic sites with good ecological quality conditions. The statistical analysis did not show linear correlation between *C. truncatus* densities and any of the analyzed environmental variable such as grain size, organic matter content, DO and light penetration, although there was a tendency for higher species densities occur in muddy, dark sediments and with intermediate levels of organic matter. As described in literature the presence of aquatic plants can actually benefit that population once the highest densities were observed in sites with many macrophytes, as Salto Grande reservoir, but it may be confusing the relationship between population density and environmental factors. **Conclusions:** The high occurrence and densities of *C. truncatus* obtained in eutrophic environments suggest that the species should not be considered as a sensitive taxon in qualitative indexes, such as the BCI for rivers and the sublittoral region of reservoirs. Moreover, its exclusion from the richness of sensitive groups had low impact on the diagnoses already performed at the CETESB monitoring network.

Keywords: biomonitoring; macroinvertebrates; biological indicator; water quality.

Resumo: Objetivo: A ordem Ephemeroptera, juntamente com Trichoptera e Plecoptera, tem sido empregada na diagnose de qualidade ambiental como sensível. No entanto, a espécie *Campsurus truncatus* Ulmer 1920 (Polymitarcyidae) tem sido observada em ambientes antropicamente alterados. Neste trabalho foram reunidos os dados obtidos na rede de monitoramento da qualidade das águas da CETESB, para reavaliar a posição do grupo no gradiente ambiental e no diagnóstico de qualidade de rios e reservatórios. **Métodos:** Para tanto, foram utilizadas os dados de ocorrência e densidade de

Campsurus em amostras obtidas em rios e reservatórios do estado de São Paulo no período de 2001 a 2018, com pegadores. Fatores ambientais e os índices de estado trófico (IET) e da comunidade bentônica (ICB) foram comparados com a ocorrência e densidade desta espécie na tentativa de definir suas preferências ambientais. **Resultados:** A região sublitoral de reservatórios foi o habitat preferencial da espécie, sendo que *C. truncatus* ocorreu com maior frequência em ambientes mesotróficos e de qualidade ecológica regular, mas apresentou maiores densidades médias em ambientes eutróficos e de qualidade ecológica boa. As análises estatísticas não evidenciaram relação linear de suas densidades com nenhum dos fatores abióticos analisados, como a granulometria, conteúdo de matéria orgânica, OD e penetração de luz, embora tenha havido uma tendência para a ocorrência das maiores densidades em sedimentos lodosos, com menos de 1% de penetração de luz e com teores intermediários de matéria orgânica. Como descrito na literatura, a presença de plantas aquáticas pode de fato beneficiar a população de *Campsurus truncatus*, uma vez que os as densidades mais elevadas foram observadas em ambientes com muitas macrófitas, como o res. Salto Grande, mas é um fator que pode estar confundindo a relação populacional com as variáveis ambientais. **Conclusões:** A frequência de ocorrência e as elevadas densidades obtidas em ambientes eutrofizados sugerem que a espécie não deve ser considerada forma sensível em índices qualitativos, como a riqueza de espécies sensíveis utilizada no cálculo do ICB para rios e região sublitoral de reservatórios. Além disso, sua exclusão na riqueza de grupos sensíveis surtiu baixo impacto sobre os diagnósticos já realizados pela rede de monitoramento da CETESB.

Palavras-chave: biomonitoramento; macroinvertebrados; indicador biológico; qualidade de água.

1. Introduction

The Polymitarcyidae family of aquatic insects of the Ephemeroptera order is widespread, occurring at Holartic, Ethiopian-Oriental and Neotropical regions (Domínguez et al., 2006). In South America, the family is represented by three genera: *Campsurus*, *Asthenopus* and *Tortopus*. Of these, *Campsurus* is the genus with the highest number of species, 28 (Molineri et al., 2015). Their nymphs burrow U-shapped tunnels in bottom sediments of lentic habitats (Domínguez et al., 2006). The species C*ampsurus truncatus* Ulmer 1920 occurs in Brazil, Bolivia, Colombia and Peru (Molineri et al., 2015). At Águas Claras reservoir (State of MG/Brazil), specimens of *C. truncatus* reached 2.4 cm in length and its population, with high secundary production (3.2 $g.m^{-2}.year^{-1}$), was classified as multivoltine, with the aquatic phase lasting between 16 and 24 weeks (Lima & Pamplin, 2017). The potential high secondary production of the species is an important issue for the energy flow and nutrient cycling for the aquatic system, as they are preferential food item for some fish species (Meschiatti, 1995). In addition, it has been reported that populations of the genus play a significant role in the sediment bioturbation (Leal et al., 2003; Figueiredo-Barros et al., 2007), with potential to alter the carbon cycle (Leal et al., 2007) that, in impacted environments, can lead to the resuspension of contaminants and nutrients accumulated in the sediments to the water column. The burial behavior also modifies the substrate by altering its composition and increasing its oxygenation, which would favor colonization at greater depths by other species of benthic fauna and microbial fauna (Leal et al., 2003, 2005).

As a biological indicator of pollution, the species is recognized as relatively sensitive (Henriques-de-Oliveira et al., 2007). The order, Ephemeroptera, and also Plecoptera and Trichoptera, are considered sensitive to the environmental changes promoted by anthropic activities and, together (EPT), have produced a series of metrics based on both their densities and their occurrences, especially applicable to the diagnosis of small lotic environments, such as streams. Even so, the Richness of sensitive group (S_{sens}) metric, which includes the EPT families, was incorporated in the diagnosis of larger rivers and the sublittoral reservoir region in the Benthic Community Index (BCI) adopted by the Environmental Agency of São Paulo State (CETESB, 2018), in spite of its naturally lower richness and density in these types of environments.

The water quality monitoring network of CETESB evaluates the ecological quality of water bodies in the São Paulo State, through the incorporation of biomonitoring with aquatic macroinvertebrates since 2002. Until 2018, 280 assessments were performed, comprising 49 rivers and 38 reservoirs, with diagnoses for the sublittoral and profundal regions, from the 22 Water Resource Management Units (WRMU) of the state. In these surveys, the species *Campsurus truncatus* was often observed colonizing degraded environments, making questionable its classification as sensitive, as well as its incorporation in the S_{sens} metric in the BCI multimetric index. This work evaluates the concordance between species occurrence and its sensibility and its application in the diagnosis of the ecological quality of rivers and reservoirs.

2. Material and Methods

Triplicate samples were obtained in the winter/dry period in each habitat type, using Ponar or van Veen grab, in depositional banks of rivers and sublittoral zone of reservoirs, and Ekman-Birge grab, in profundal zone of reservoirs. Taxonomic identification to family-level and counting of the organisms were made in the laboratory under stereoscopic microscope. The identification of the species was performed by Dr C. Molineri (Molineri et al., 2015). Water transparency, chlorophyll-a and total phosphorus of surface water, dissolved oxygen in the bottom water, as well as grain size and organic matter content in the sediments were obtained on the same dates. Table 1 resumes the methods used for each variable.

The trophic state of the sites was evaluated by a modified Trophic Sate Index (TSI) (Lamparelli, 2004) that consider chlorophyll-a and total phosphorus data. To evaluate the benthic community integrity was applied the Benthic Community Index (BCI), a multimetric index that incorporates diversity, richness, sensitivity and tolerance measurements. The methods of calculations of both indices are described in CETESB (2018). Table 2 presents the potential diagnoses for the two indices and their representatives white and grey patterns. The depth to 1% light penetration, sufficient for the primary production, was obtained by multiplying the transparency result by factor 2.709 (Esteves, 2011). *Campsurus* densities were log $^{(x+1)}$ transformed and related by Pearson correlation test with abiotic variables and TSI and BCI gradients. All statistical calculations were performed by the Past software (Hammer et al., 2001).

3. Results

The Polymitarcyidae *Campsurus truncatus* was observed in only 19 of the 84 environments investigated between 2002 and 2018, located in nine of 22 Water Resource Management Units (WRMU) of the state that comprise the basins of the Tiete (WRMU 6, 5, 10, 13 and 16), Mogi-Guaçu (WRMU 9), Paranapanema (WRMU 14), Paraíba do Sul (WRMU 2) and Juqueriquerê (WRMU 3) rivers (Figure 1).

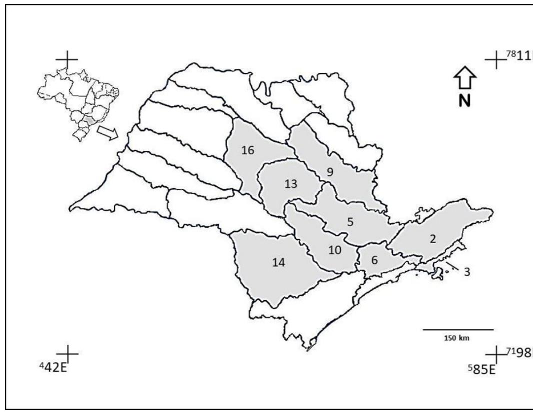

Figure 1. Water Resource Management Units (WRMU) of São Paulo State where *Campsurus truncatus* occured between 2002 and 2018. WRMU names: 2 = Paraiba do Sul; 3 = North Littoral; 5 = Piracicaba, Capivari, Jundiaí; 6 = High Tietê; 9 = Mogi-Guaçu; 10 = Sorocaba and Medium Tietê; 13 = Tietê – Jacaré; 14 = High Paranapanema; and 16 = Tietê – Batalha.

Table 1. Analytical methods and their references.

Variable	Method	Reference
Transparency	Secchi disc	APHA (2012)
Chlorophyll-a	spectrophotometric	APHA (2012)
Total phosphorus	spectrometric	USEPA (2012)
Dissolves oxygen	eletrometric	APHA (2012)
Grain size	sieving and sedimentation	CETESB (1995)
Organic matter	gravimetric	APHA (2012)

Table 2. Potential diagnoses and their representative white and grey patterns by the Trophic State Index (TSI) and the Benthic Community Index (BCI).

TSI	BCI
ULTRAOLIGOTROPHIC	EXCELLENT
OLIGOTROPHIC	GOOD
MESOTROPHIC	FAIR
EUTROPHIC	BAD
SUPEREUTROPHIC	VERY BAD
HYPEREUTROPHIC	

Although it occurred in the three habitat types sampled in the monitoring network, it was more frequent in reservoir sublittoral regions (Table 3), where it also reached the highest mean densities (Figure 2).

While the species occurs along almost the entire trophic gradient, except in the hypereutrophic condition, its frequency of occurrence (Figure 3) shows a bell shaped distribution being more common in sites with some degree of organic enrichment (meso and eutrophic state), reaching higher mean values of density at eutrophic sites (Figure 4). As the relationship was not linear, no significant correlation was found between the *Campsurus* density and the TSI values (r = -0.05; p = 0.7695) or classes (r = -0.15; p = 0.4029).

In the ecological quality gradient stated by the benthic community index (BCI), the species only occurred in the quality range between excellent and fair. Although more commonly found in fair quality

Table 3. Densities (ind.m^{-2}) of *Campsurus truncatus* in CETESB's monitoring network and the site diagnosis considering their trophic status (TSI) and ecological quality (BCI). White and grey patterns as in table 2.

WRMU	aquatic system	habitat	year	density (ind.m^{-2})	TSI	BCI
2	Paraibuna res.	SL	2015	28	**51**	**3**
	Jaguari res.	SL	2012	337	**55**	**1**
		SL	2013	295	**56**	**1**
3	Claro river	DB	2013	14	**38**	**2**
	Pirassununga river	DB	2012	56	**52**	**2**
5	Salto Grande res.	SL	2007	25	**62**	**3**
		SL	2008	1819	**61**	**2**
		SL	2009	5271	**62**	**2**
6	Jundiaí res.	SL	2006	24	**60**	**3**
	Taiaçupeba res.	SL	2003	252	**56**	**3**
		SL'	2003	33	**56**	**3**
		SL	2004	12	**54**	**2**
	Rio Grande res.	SL	2011	56	**58**	**3**
	Billings res.	SL	2006	61	**65**	**3**
		SL	2008	256	**61**	**3**
		SL	2009	689	**62**	**3**
		SL	2010	14	**66**	**3**
	Guarapiranga res.	SL	2006	12	**60**	**3**
		P	2006	17	**60**	**3**
		SL	2007	25	**59**	**3**
	Claro river	DB	2014	282	**30**	**2**
9	Cachoeira de Cima res.	SL	2011	239	**53**	**3**
		P	2011	28	**53**	**2**
		SL	2012	197	**48**	**3**
		SL'	2012	828	**48**	**2**
10	Barra Bonita res.	SL	2006	12	**65**	**2**
13	Bariri res.	SL	2006	992	**53**	**2**
	Broa res.	P	2018	68	**53**	**2**
	Ibitinga res.	SL	2008	51	**63**	**2**
		P	2008	623	**63**	**1**
14	Guareí river	DB	2007	13	**55**	**3**
16	Promissão res.	SL	2007	442	**56**	**2**
		P	2007	99	**56**	**1**
	Três Irmãos res.	SL	2006	196	**53**	**2**

WRMU = Water Resources Management Unit; SL = sublittoral zone; SL' = sublittoral zone, at the deepest region; P = profundal zone; DB = depositional bank; TSI = Trophic State Index; BCI = Benthic Community Index.

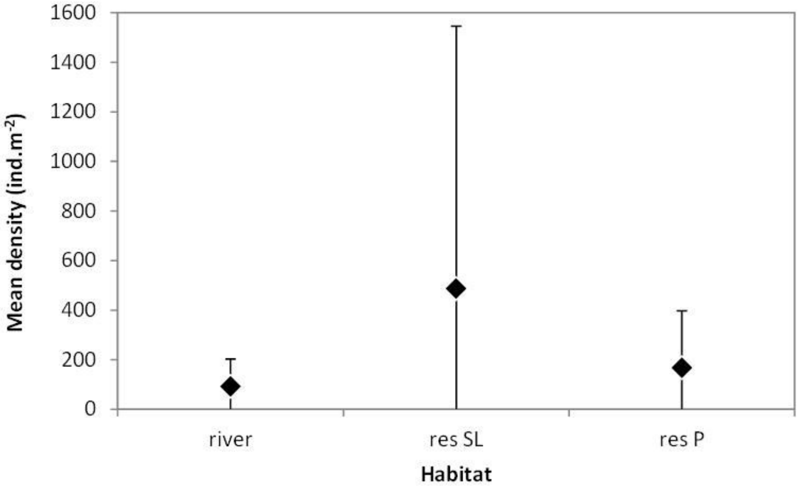

Figure 2. Mean density (ind.m^{-2}) and standard deviation for *Campsurus truncatus* at three evaluated habitats in CETESB's monitoring network. res SL = reservoir sublittoral; res P = reservoir profundal.

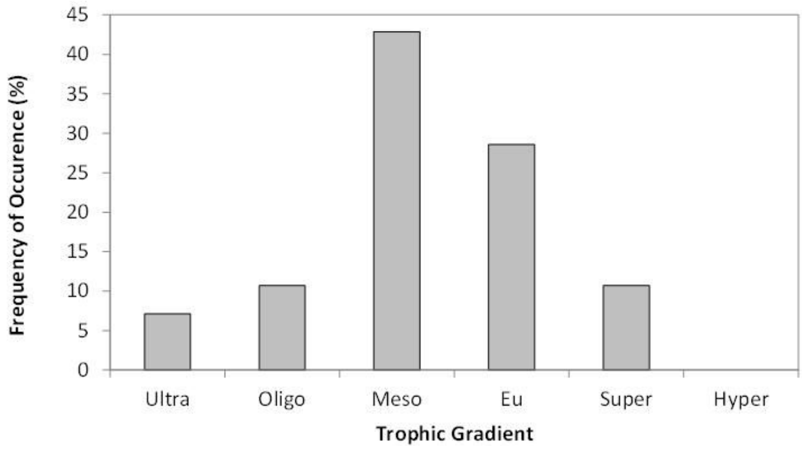

Figure 3. Frequency of occurence (%) for *Campsurus truncatus* along a trophic gradient. Ultra = Ultraoligotrophic, Oligo = Oligotrophic, Meso = Mesotrophic, Eu = Eutrophic, Super = Supereutrophic, Hyper = Hypereutrophic.

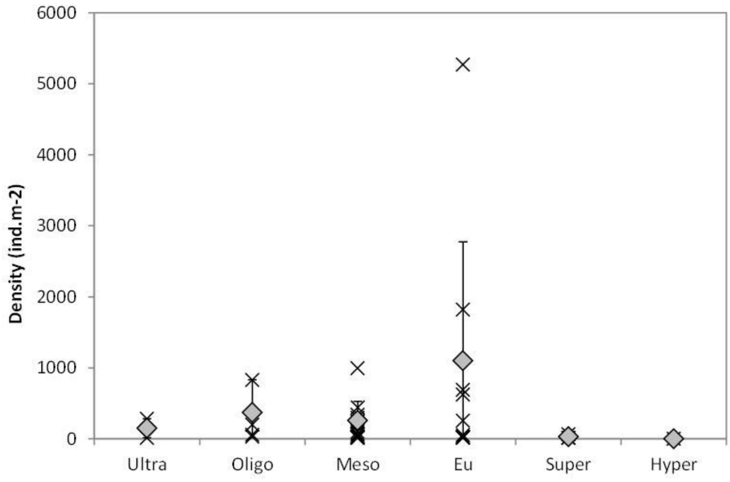

Figure 4. Densities distribution (X), mean densities (◇) (ind.m^{-2}) and standard deviations for *Campsurus truncatus* along a trophic gradient. Ultra = Ultraoligotrophic; Oligo = Oligotrophic; Meso = Mesotrophic; Eu = Eutrophic; Super = Supereutrophic; Hyper = Hypereutrophic.

environments (Figure 5), the mean density was higher in good quality (Figure 6). Since the species was absent in the bad and very bad categories, the relationship between *Campsurus* densities and the BCI result was falsely linear, because it included only part of the quality gradient, and the correlation was significantly negative (r = -0.37 ; p = 0.03).

No significant linear correlation was found between the densities of *Campsurus truncatus* and the abiotic data (Table 4) of sand% (r = -0.16, p = 0.3682), silt% (r = -0.03, p = 0.8446), clay% (r = 0.21, p = 0.2454), silt% + clay% (r = 0.16, p = 0.3654), light (r = 0.09, p = 0.999) and dissolved oxygen in deep water (r = 0.02, p = 0.9109). Even so, the XY graphs (Figure 7) show that there is a tendency for higher species densities in muddy, dark sediments with intermediate levels of organic matter.

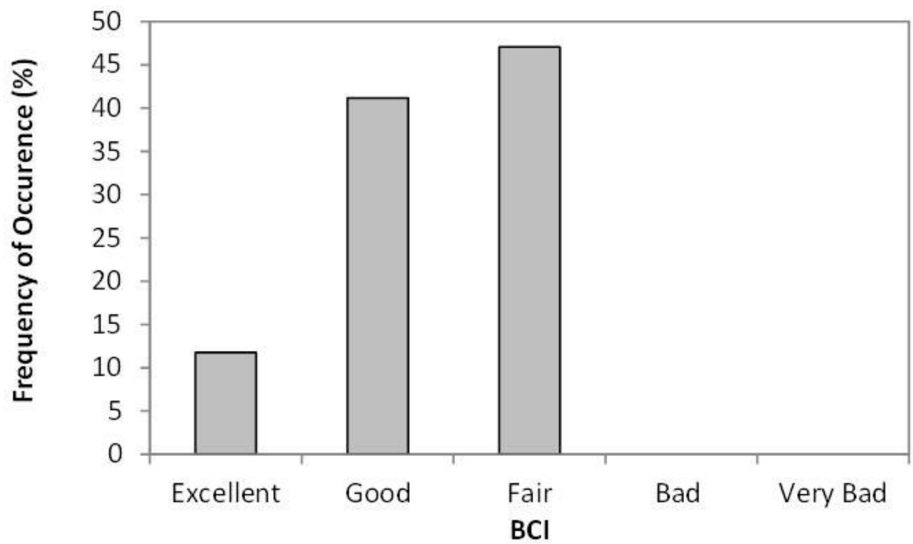

Figure 5. Frequency of occurence (%) for *Campsurus truncatus* along an ecological quality gradient. BCI = Benthic Community Index.

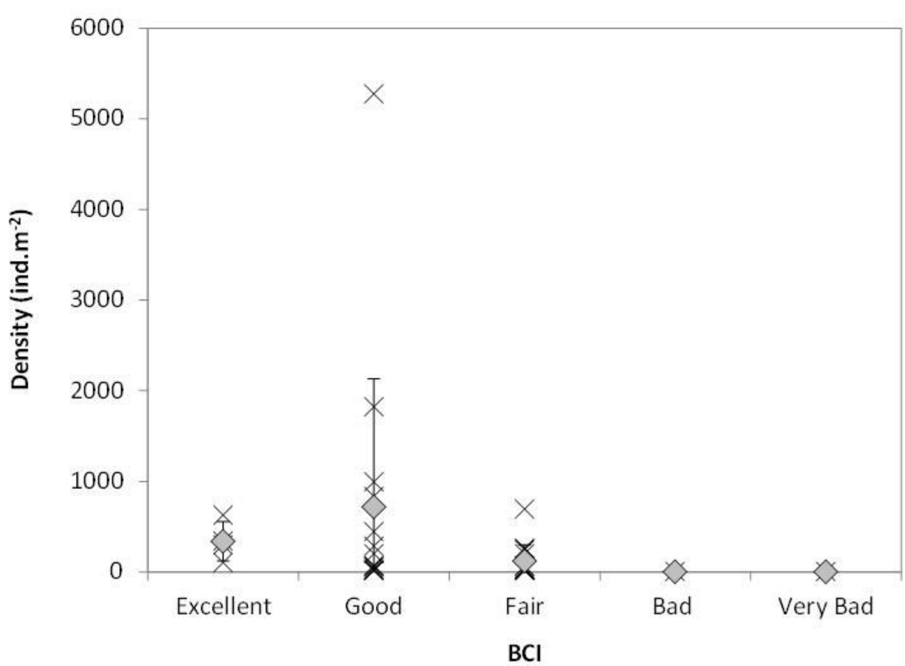

Figure 6. Densities distribution (X), mean densities (◇) (ind.m^{-2}) and standard deviation for *Campsurus truncatus* along an ecological quality gradient. BCI = Benthic Community Index.

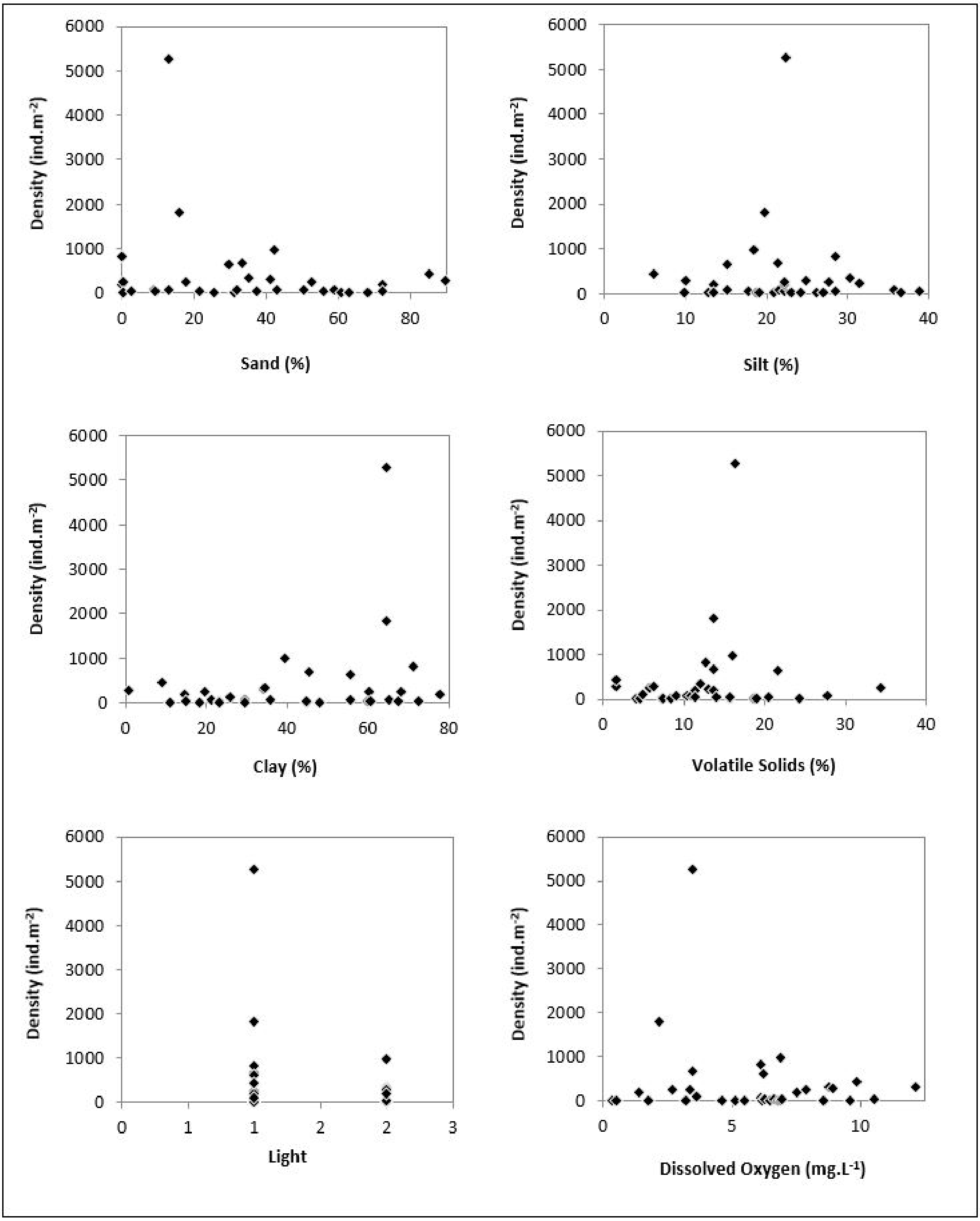

Figure 7. XY plots relating *Campsurus trucatus* densities to abiotic data. For light, 1 = less than 1% of light penetration; 2 = more than 1% of light penetration.

4. Discussion

Most sampled in the sublittoral region of reservoirs, in this study *Campsurus truncatus* did not occur only under conditions of hypertrophy in the trophic gradient. Although most frequently observed in mesotrophic environments, it was in an eutrophic and macrophyte-rich environment that it reached its highest densities. No significant linear relationship was observed between densities and abiotic factors that could describe possible environmental requirements for the species, but a trend was observed for the occurrence of higher densities in muddy environments, with less than 1% light penetration and with intermediate content of organic matter.

Because of its burial habit, it was expected that the population of *Campsurus truncatus* would be

Table 4. Environmental data related to *Campsurus truncatus* occurrences.

WRMU	aquatic system	habitat	year	sand (%)	silt (%)	clay (%)	VS (%)	light	DO ($mg.L^{-1}$)
2	Paraibuna res.	SL	2015	9.1	23.1	67.7	15.7	no	6.89
	Jaguari res.	SL	2012	35.3	30.3	34.4	12.0	yes	12.10
		SL	2013	40.9	24.9	34.2	6.3	yes	8.80
3	Claro river	DB	2013	68.0	20.9	11.2	8.3	no	8.53
	Pirassununga river	DB	2012	50.3	28.5	21.2	10.3	yes	6.60
5	Salto Grande res.	SL	2007	21.3	19.0	59.7	19.0	no	0.35
		SL	2008	15.7	19.6	64.7	13.7	no	2.14
		SL	2009	13.1	22.4	64.5	16.3	no	3.47
6	Jundiaí res.	SL	2006	55.8	20.8	23.3	24.3	yes	5.12
	Taiaçupeba res.	SL	2003	17.8	22.2	60.0	34.4	yes	7.90
		SL’	2003	37.6	17.8	44.6	20.5	yes	6.80
		SL	2004	60.5	9.8	29.7	7.2	yes	9.59
	Rio Grande res.	SL	2011	31.8	38.9	29.3	9.0	no	6.30
	Billings res.	SL	2006	42.9	21.6	35.5	11.0	no	6.96
		SL	2008	52.7	27.8	19.6	5.7	yes	3.37
		SL	2009	33.2	21.2	45.5	13.7	no	3.50
		SL	2010	25.4	26.2	47.8	15.7	no	3.20
	Guarapiranga res.	SL	2006	63.0	18.7	18.3	-	no	6.50
		P	2006	0.5	27.0	72.5	18.67	no	4.60
		SL	2007	72.2	12.8	15.0	4.7	no	5.51
	Claro river	DB	2014	89.5	10.0	0.5	1.7	yes	8.94
9	Cachoeira de Cima res.	SL	2011	0.2	31.5	68.3	13.0	no	2.70
		P	2011	2.7	36.5	60.7	14.0	no	0.50
		SL	2012	0.1	22.2	77.8	13.7	no	1.40
		SL’	2012	0.2	28.5	71.3	12.7	no	6.10
10	Barra Bonita res.	SL	2006	63.1	13.5	23.4	4.0	no	6.15
13	Bariri res.	SL	2006	42.1	18.5	39.5	16.0	yes	6.91
	Broa res.	P	2018	8.6	35.8	55.6	27.7	no	6.09
	Ibitinga res.	SL	2008	12.6	22.1	65.3	11.3	yes	10.53
		P	2008	29.4	15.1	55.5	21.7	no	6.25
14	Guareí river	DB	2007	31.3	24.2	44.6	7.3	no	1.74
16	Promissão res.	SL	2007	85.0	6.1	9.0	1.7	no	9.87
		P	2007	59.1	15.1	25.8	5.0	no	3.63
	Três Irmãos res.	SL	2006	72.1	13.3	14.6	11.3	yes	7.50

WRMU = Water Resources Management Unit; SL = sublittoral zone; SL’ = sublittoral zone, at the deepest region; P = profundal zone; DB = depositional bank; VS = volatile solids content; DO = dissolved oxygen.

favored by fine sediments, similar to that observed by Leal & Esteves (2000) in Lake Batata, where the substrate alteration promoted by clay was favorable to the population of *C. notatus*. On the other hand, in a Uruguayan lagoon system, Clemente et al. (2018) obtained a negative correlation between the density of *C. violaceus* and the percentage of fine fractions (clay and silt) in one of the study years. The absence of a positive linear correlation between the density of the species and the fine grain size in our study may indicate that multiple factors act together to control its population.

The organic matter in the sediments, as well as the possibility of the presence of trophic chain components associated with the primary production, would be factors enriching the potential food source for the species, but no correlation was observed between the densities of *Campsurus* and these two factors, although the higher density values occurred in organic substrate (VS> 10%). In these cases, there was not enough light for photosynthesis to occur to sustain a grazing food chain. Although Clemente et al. (2018) obtained a positive correlation between the densities of *C. violaceus* and organic matter, our data showed a tendency for the highest densities of *C. truncatus* occur under intermediate values, corroborating the response of that parameter to the trophic gradient measured by the TSI.

Being a taxon belonging to the EPT group, it would be expected that *Campsurus truncatus* would be sensitive regarding the availability of dissolved oxygen. However, not only the dissolved oxygen concentrations did not have a significant linear and positive effect on the population, but the highest densities occurred under low concentrations (3.5 and 2.1 mg.L^{-1}) of this variable, already considered restrictive for insect components of the benthic fauna (Heliövaara & Väisänem, 1993). Takeda et al. (2003) observed that the oxygen contained in the plant tissues of aquatic plants can supply individuals of the genus *Campsurus* in a situation of hypoxia, when the authors observed the migration of nymphs of the genus towards the lower portion of macrophytes. That adaptive behavior can explain its independence from the dissolved oxygen concentrations of the environment.

Many of the sites where *C. truncatus* occurred presented aquatic plants, even as a result of the process of their enrichment. In addition to supplying oxygen for some taxa, macrophyte clumps represent habitat and food for the macroinvertebrates and their presence in the environment may have interfered in the expected relationship between the density of *C. truncatus* and the environmental factors tested. The presence of macrophytes diversifies habitats and can positively influence the richness of the community. Perhaps for this reason the highest mean densities of *Campsurus* were observed in environments considered good for the development of biota, but already eutrophic.

Populations of the genus *Campsurus* have been reported in domestic sewage receiving environments (Henriques-de-Oliveira et al., 2007), already eutrophic (Clemente et al., 2018) and impacted by mining residues (Leal & Esteves, 2000). Although not occurring in extreme situations of poor ecological quality, as other authors have also observed (Henriques-de-Oliveira et al., 2007), we suggest that the species *Campsurus truncatus* be disregarded as a sensitive taxon, especially in qualitative metrics, as they occur more frequently in environments with intermediate degrees of degradation. In a score system for rivers and reservoirs, as in the biotic qualitative or quantitative indexes commonly used in streams, the species would receive an intermediate score. The impact of the removal of the species from the calculation of richness of sensitive groups (S_{sens}) on the diagnoses of BCI expanded its occurrence to environments classified as poor concerning ecological quality. However it changed the diagnosis one quality class worst in only four cases (1.4% of total diagnoses): in the sublittoral zones of Taiaçupeba (2003), Billings (2008) and Guarapiranga (2006) reservoirs, which were poor, and in Claro river - UGRHI 3 (2013), which was regular. This low impact is due to the fact that the BCI is a multimetric index and the richness of sensitive groups is only one of its four components for reservoir's sublittoral and rivers assessment.

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