Ecologia e Meio Ambiente

The influence of shoreline availability on the density and richness of Chironomid larvae in Neotropical floodplain lakes

Influência da disponibilidade de margem sobre a densidade e a riqueza de larvas de Chironomidae *em lagoas de inundação neotropical*

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ABSTRACT

The shoreline development index was created for temperate lakes. However, Neotropical lakes have different geological formations. For example, the difference between the littoral and limnetic zones in Neotropical lakes is not as sharp as those in temperate one, due to their low depths. Here, we proposed a modification of the shoreline development index for tropical lakes. We applied the modified index in 27 floodplain lakes of the Upper *Paraná* River. We found significant and positive relationships between the modified index and the density and richness of chironomids. These results suggest that the higher the availability of margins the higher the density and richness of larvae. The littoral zone of some lakes is complex, with submersed or emergent macrophytes, as well as branches and leaves that provide a wealth of habitats in this region. Therefore, the larger littoral zone seems to be the main factor structuring the chironomid community. Therefore, the modified index is an important statistical tool to indicate lakes in which chironomid richness is high due to the higher availability of littoral zone.

Key words: Biodiversity. Invertebrates. Littoral zone. Margin region. Upper Paraná River. Zoobenthic community.

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RESUMO

Os índices de disponibilidade de margem em lagoas foram criados para a região temperada. No entanto, lagoas de ambientes temperados e neotropicais possuem diferentes formações geológicas. Por exemplo, a diferença entre a zona litorânea e a limnética não é tão acentuada em lagoas da região neotropical, devido às suas baixas profundidades. Neste estudo são propostas adaptações do índice de Hutchinson para lagoas tropicais. Aplicou-se este novo índice em 27 lagoas da planície aluvial do Alto Rio Paraná. O novo índice de disponibilidade de margens foi positivamente relacionado com a densidade e riqueza de Chironomidae. *Estes resultados sugerem que quanto maior a disponibilidade de margens, maiores serão a densidade e a riqueza de larvas. A zona litorânea de algumas lagoas é complexa, com macrófitas submersas ou emergentes, além do substrato formado por galhos e folhiços que favorece a formação de diversos habitats nessa região. Portanto, a maior disponibilidade da zona litorânea parece ser o principal fator estruturador da comunidade de* Chironomidae. *Logo, o índice modificado demonstrou ser uma importante ferramenta estatística para indicar lagoas onde provavelmente encontram-se maiores valores de riqueza de* Chironomidae, *devido a maior disponibilidade em regiões litorâneas.*

Palavras-chave: *Biodiversidade. Invertebrados. Região litoral. Região marginal. Alto Rio Paraná. Zoobentos.*

INTRODUCTION

Tropical river-floodplain systems have both high habitat heterogeneity and biodiversity (Lowe-McConnell, 1999). However, studies that tried to understand the origin of this diversity only began in the 1980s with the development of landscape ecology and spatial methods (Turner, 2005). The aim of landscape ecology is to understand how ecological processes affects spatial patterns. This discipline develops models and theories of spatial relationships, and foster investigations on spatial scales rarely addressed in ecology (Pickett & Cadenasso, 1995).

The importance of littoral zones of lakes as habitat for invertebrates and vertebrates has been widely explored (Weatherhead & James, 2001; Winfield, 2004; Porej & Hetherington, 2005). This zone provides heterogeneous areas with varying degrees of structural complexity, forming a mosaic of different microhabitats (Chick & McIvor, 1994). The high diversity found in floodplains and their lakes make these environments appropriated to test predictions about ecological processes (Bini *et al*., 2003).

Lakeshores have always been used for human settlement and activities (Liddle & Scorgie, 1980; Ostendorp *et al*., 2004). These environments are increasingly being developed and altered by humans throughout the world (Radomski & Goeman, 2001; Beeton, 2002; Gulati & van Donk, 2002). These areas are important, since they represent the primary habitat for many species and play a key role in whole-lake functioning (Wetzel, 1990; Blumenshine *et al*., 1997; Schindler & Scheuerell, 2002; Vadeboncoeur *et al*., 2002). However, little is known about the contribution of the littoral zone to the diversity in lake ecosystems.

Studies on shoreline development in impacted lakes have grown since the 1980s. These studies investigated the zoobenthic fauna in those areas to make decisions on conservation and management (Brauns *et al*., 2007). However, most of these studies were developed in temperate lakes and marine environments, and equivalent counterparts in the Neotropics are still scarce. The Upper *Paraná* River floodplain is the last preserved area of this river and has a large variety of aquatic habitats with high diversity (Thomaz *et al*., 2007). This region is an important area for studies about the relationships between shoreline development and the density and richness of organisms.

Chironomidae larvae are a key component of aquatic communities inhabiting the littoral zone of lakes (Pinha *et al.*, 2013), both in density and diversity (Epler, 2001; Walther *et al.*, 2006; Mokany *et al.*, 2008). Moreover, this group is useful to test species-environment relationships in ecological communities (Epler, 2001; Pinha *et al.*, 2013) along lake microhabitats (Maasri *et al.*, 2008).

Here, we proposed a new shoreline development index, and test its usefulness in floodplain lakes using chironomids as a case study. Based on the premise that lakes with more margins favor the establishment of chironomids. Therefore, we hypothesize that floodplain lakes with higher values of shoreline development index will have higher values of chironomid density and richness.

MATERIAL AND METHODS

Study area

This study was carried out in the Upper *Paraná* River floodplain, between the reservoirs of *Porto Primavera* and *Itaipu*, covering approximately 230 km (Souza-Filho & Stevaux, 1997). Floodplains like the Upper *Paraná* River have high environmental heterogeneity (Thomaz *et al.*, 2007; Lansac-Tôha *et al.*, 2009), with a mosaic of aquatic habitats at the transition between the terrestrial and aquatic realms (Thomaz *et al.*, 2007). The Upper *Paraná* floodplain has several lakes (Souza Filho & Stevaux, 2004) that may be isolated from the main channel or not.

We sampled chironomids in 27 floodplain lakes in June, September, and December 2010, a period of low water. Half of them were connected to the main channel (*Peroba, Boca do Ipoitã, Patos, Finado Raimundo, Sumida, Pombas, Manezinho, Guaraná, Bilé, Leopoldo, Pau Véio, Porcos, Maria Luíza,* and *Gavião*); while the other half were isolated (*Ventura, Zé do Paco, Capivara, Jacaré, Cervo, Osmar, Traíra, Genipapo, Clara, Fechada, Pousada das Garças, Aurélio,* and *Onça*) (Figure 1).

Sampling and identification

We established a transect that crossed each lake from one margin to another with three sampling points. We collected four samples at each point using a modified Petersen grab (0.0345m^2), three to estimate density and richness of chironomids and one for granulometric analysis. The samples were placed in plastic containers and sieved using a set of sieves (mesh size 2.0, 1.0, and 0.2mm). The organisms retained on the 2.0 and 1.0mm sieves were removed and all sediment retained in the 0.2mm mesh was fixed in 80% ethanol. Samples were further sorted under stereoscopic microscope.

Chironomid larvae were dissected and mounted in slides with Hoyer medium following Trivinho-Strixino (2011). Larvae were identified to the lowest possible taxonomic level following Trivinho--Strixino (2011) and Epler (2001). Slides are stored at the Zoobentos laboratory *Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura/Universidade Estadual de Maringá* (Nupelia/UEM), *Maringá, Paraná,* Brazil.

We measured depth three times in each point. We used satellite images of the lakes to calculate area, using the software Image-Pro Plus 4.5 (Media Cybernetics, 2001).

Index of littoral zones development

The shoreline development index (Hutchinson, 1957) relates actual lake shoreline length to one of a perfectly circular lake of equal area (Aronow, 1982).

The maximum value is 1.0, the ratio for a perfectly circular lake. The index value is influenced by the lake basin origin. Lakes in volcanic craters or caldera, limestone sinkholes, meteor craters, or in some glacial kettles usually have smaller index than those large ones from oxbows of alluvial plains or in glacial troughs.

The original formula proposed by Hutchinson (1957) for the shoreline development index is as follows:

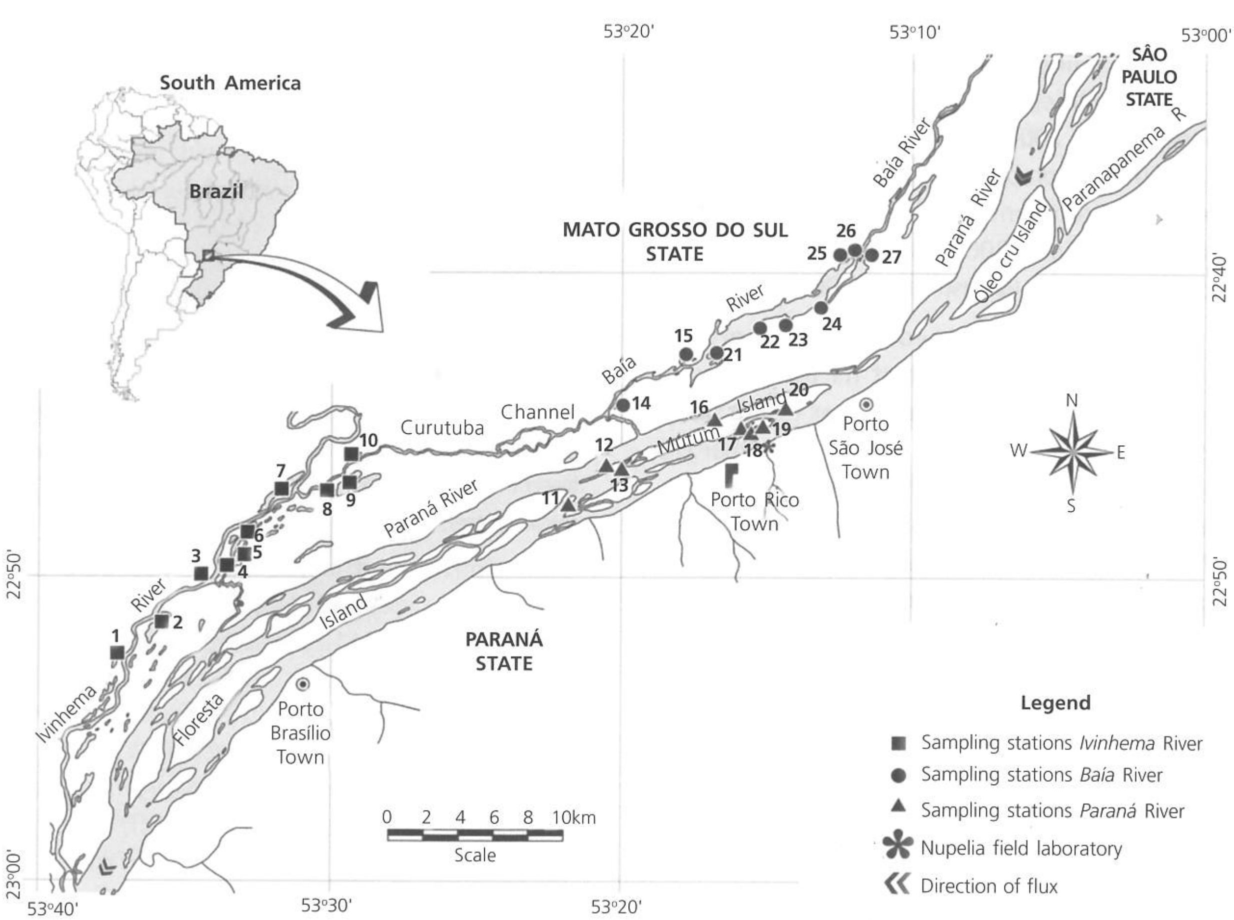

Figure 1. Location of the floodplain lakes sampled.
Note: 1. *Peroba*, 2. *Ventura*, 3. *Zé do Paco*, 4. *Boca do Ipoitã*, 5. *Patos*, 6. *Capivara*, 7. *Finado Raimundo*, 8. *Jacaré*, 9. *Sumida*, 10. *Cervo*, 11. *Pombas*, 12. *Manezinho*, 13. *Osmar*, 14. *Traíra*, 15. *Guaraná*, 16. *Bilé*, 17. *Leopoldo*, 18. *Genipapo*, 19. *Clara*, 20. *Pau Véio*, 21. *Fechada*, 22. *Pousada das Garças*, 23. *Porcos*, 24. *Aurélio*, 25. *Maria Luiza*, 26. *Gavião*, 27. *Onça*.

$$DL = \frac{\text{Perimeter}}{\left(\sqrt{\pi * Area}\right) * 2}$$

The shoreline development index was created based on temperate marine and lacustrine environments. However, previous studies have pointed out some limitations of this index when applied to tropical lakes. The main limitation is that those lakes are shallower than their temperate counterparts, due to their distinct geological formations. Then, to circumvent this drawback we added the difference in depth between the limnetic and littoral zones to the original index.

Thus, the formula of the modified index is as follows:

$$DL = \left(\frac{\text{Perimeter}}{\left(\sqrt{\pi * \text{Area}}\right) * 2}\right) \Big/ \left(\text{Depth.center} - \text{Depth.littoral}\right)$$

Linear regression

We used linear regressions to test for the influence of shoreline development index on the density and richness of chironomids. Linearity, homoscedasticity, and normality were evaluated. The model formulae were:

$$\text{richness} = \alpha + \beta_{DL} * DL \quad \text{and} \quad \text{density} = \alpha + \beta_{DL} * DL$$

where a is the intersept, DL is the Shoreline Development Index, and β_{DL} is the regression slope.

RESULTS

We recorded 6,991 Chironomidae larvae from 104 morphotypes belonging to three subfamilies: 75 Chironominae, 4 Orthocladiinae, and 25 Tanypodinae. The richness was higher in lakes with high shoreline development index, such as the *Bilé* and *Clara* lakes (Chart 1).

There was a strong positive relation ship between the shoreline development index and chironomid density (R^2=0.37; p<0.001; Chart 1; Figure 2). The regression model to predict chironomid density is as follows:

$$\text{Density of Chironomidae} = 3.084 + 0.506 * DL$$

We also found positive relationship between the shoreline development index and chironomid richness (R^2=0.45; p<0.001; Figure 3). The regression model to predict chironomid richness is as follows:

$$\text{Richness of Chironomidae} = 9.472 + 9.619 * DL$$

DISCUSSION

We found that the shoreline development index modified for floodplain Neotropical lakes influenced the density and richness of chironomids. This supports our hypotheses, which predicted a linear relationship between the shoreline development index and chironomid density and richness.

Contrarily to previous studies, our results demonstrated not only a difference within a lake (Stoffels *et al.*, 2005; Stander & Johnson, 2008, Schreiber & Brauns, 2010), but also between lakes. Accordingly, the shoreline development index seems to be a useful variable to predict the diversity of zoobenthic organisms, such as chironomid larvae.

The littoral zone of lakes is an important refuge for many organisms, such as juvenile fish whose diet is based on aquatic invertebrates like insect larvae (Paterson & Whitfield, 2000; Stunz & Minello, 2001; Harter & Heck, 2006). Therefore, the predation by fish may have decreased the density of chironomids. Thus, we claim that predation should be accounted for when developing new indexes.

Richness showed a linear relationship with shoreline development index (R^2=0.45), which demonstrates the effectiveness of the modified index to predict chironomid richness.

Many studies pointed out that the high richness of floodplain lakes (Hamilton *et al.*, 2002; Zalocar De Domitrovic, 2003; Mitsch & Gosselink, 2007; Ragonha *et al.*, 2013) is mainly determined by lake morphometry. This relationship is still little understood due to the difficulty in sampling a large number of floodplain lakes, especially in the Neotropics (Fantin-Cruz *et al.*, 2008).

The differences in density and richness between the *Bilé*, *Clara,* and *Genipapo* lakes, with higher values and the *Ventura*, *Boca do Ipoitã* and *Gavião* with the lower values concur with our predictions that the inclusion of depth differences between the littoral and limnetic zones is important (Figure 4) to understand the community structure of chironomids. This correction in the index turned it suitable for Neotropical lakes.

The distribution of benthic organisms in lentic ecosystems is related to several factors, such as: food quality and availability, and substrate type (e.g., sandy, stone, wood, and aquatic macrophytes) (Palmer *et al.*, 1994; Quinn & Hickey, 1994; Townsend *et al.*, 1997). Our modified index showed to be appropriated to predict chironomid richness and density. However, it should be used along with other tools, such as those of landscape ecology, including edge effect and species area relationship, which could indicate environments that deserve to be further explored.

Chart 1. Incidence of chironomid morphospecies in the 27 floodplain lakes sampled. Continued

Chironominae (family)	Occurrence Lakes
Aedokritus sp.1	Bil and Ven
Asheum sp.1	Bil, Gen, Leo, Osm, Pve, Man, Pat, Pgr, Fec, Mlu, Sum, Cer, Gua, Por and Per
Beardius phytophilus - Trivinho-Strixino & Strixino, 2000	Gen, Leo, Osm, Pve, Man, Pgr, Onc, Fec, Mlu, Cer, Gua and Por
B. xylophilus - Trivinho-Strixino & Strixino, 2000	Man
Caladomyia type A	Gen
Caladomyia type C	Gen and Mlu
Caladomyia type D	Pve
C. ortoni - Sawedall, 1981	Bil, Cla, Gen, Leo, Osm, Pve, Pat, Pgr, Fec, Cer, Gua, Ven and Bip
C. riotarumensis - Reiss, 2000	Pve
Chironomus type D	Bil, Cla, Gen, Pom, Osm, Pve, Man, Pat, Aur, Pgr, Fec, Mlu, Sum, Por, Cap and Gav
Chironomus type E	Leo
Chironomus type F	Cla, Gen
Chironomus gr. salinarius	Bil, Cla, Gen, Pom, Leo, Osm, Pve, Man, Cer and Ven
Chironomus sp.1	Mlu
C. antonioi - Correia & Trivinho-Strixino, 2007	Cla
C. fittkaui - Correia & Trivinho-Strixino, 2007	Bil, Cla, Gen, Pom, Leo, Osm, Pve, Man, Pat, Aur, Pgr, Onc, Sum, Cer, Tra, Fra, Por, Cap and Ven
C. gigas - Reiss, 1974	Onc, Sum, Cer and Jac
C. paragigas - Reiss, 1974	Leo
C. reissi - Correia & Trivinho-Strixino, 2007	Cla and Gen
C. sancticaroli - Strixino & Strixino, 1982	Cla, Gen, Leo, Osm and Aur
C. strenzkei Fittkau, 1986	Bil, Cla, Gen, Osm and Aur
Cladopelma sp. 1	Leo and Gua
Cladopelma sp. 2	Gen
Cladopelma sp. 3	Sum
C. forcipis - Rampel, 1939	Bil, Gen, Pom, Osm, Aur, Tra and Cap
Cryptochironomus reshchikov - Silvia *et al.*, 2010	Cla, Gen, Pve, Pat, Pgr, Onc, Fec, Mlu, Gua, Fra, Por and Ven
Dicrotendipes sp. 1	Gen, Pve, Fec, Mlu and Tra
Dicrotendipes sp. 2	Bil and Pve
Dicrotendipes sp. 3	Bil, Gen, Leo, Pve, Pat, Pgr, Fec aand Mlu
Endotribelos sp. 2	Bil, Cla, Gen, Pom, Leo and Pve
Endotribelos sp. 3	Cla, Gen, Leo and Pve
E. calophylli - Roque & Trivinho-Strixino, 2008	Bil, Pve and Man
E. euterpe - Roque & Trivinho-Strixino, 2008	Leo
Fissimentum sp. 2	Cla, Gen and Leo
Fissimentum sp. 3	Pve
Fissimentum sp. 5	Vem
Goeldichironomus type A	Cla, Gen, Leo and Jac
Goeldichironomus type B	Cla, Gen and Osm
G. holoprasinus Goeldi, 1905	Fec
G. luridus - Trivinho-Strixino & Strixino, 2005	Bil, Pom, Pgr and Tra
G. neopictus - Trivinho-Strixino & Strixino, 1998	Bil, Cla, Gen, Pat, Pgr, Onc, Fec, Mlu, Sum, Cer, Gua, Tra, Fra, Jac, Por, Per, Vem, Bip and Gav
G. petiolicola - Trivinho-Strixino & Strixino, 2005	Gen and Osm
Lauterborniella sp. 1 - Thienemann & Bause, 1913	Bil and Bip
Nilothauma sp. 1	Gen, Pom, Pve and Ven
Nilothauma sp. 2	Vem
Oukuriella jatai - Trivinho-Strixino & Messias, 2005	Cla, Gen, Pve and Man
Parachironomus cayapo - Fittkau & Reiss, 1994	Bil, Cla, Gen, Leo, Osm, Aur, Mlu, Cer, Gua, Tra and Ven
P. longistilus - Paggi, 1997	Sum and Cap
P. tirio - Spies, Fittkau & Reiss, 1994	Per
Paralauterborniella sp. 1	Cla, Gen and Leo
Pelomuns psamophilus - Trivinho-Strixino & Strixino, 2008	Bil, Cla, Gen, Leo, Pve, Pat, Onc, Fec, Mlu, Sum, Cer, Gua, Fra, Por, Cap and Ven

Chart 1. Incidence of chironomid morphospecies in the 27 floodplain lakes sampled. Continued

Chironominae (family)	**Occurrence Lakes**
Polypedilum sp. 1	Onc
Polypedilum sp. 2	Onc, Mlu, Cap and Gav
Polypedilum sp. 3	Cla, Gen, Leo and Ven
Polypedilum sp. 4	Cla, Leo, Fec, Cer and Zpc
Polypedilum (Tripodura) sp. 3	Cla, Gen, Pom, Leo, Pve, Pat, Aur, Pgr, Onc, Fec, Mlu, Sum, Cer, Zpc, Tra, Fra, Jac, Por, Per, Ven and Bip
Polypedilum (Tripodura) sp. 4	Bil, Cla, Gen, Pom, Leo, Osm, Pve, Man, Pat, Pgr, Onc, Mlu, Sum, Cer, Gua, Fra, Jac, Por, Per, Cap, Ven, Bip and Gav
Rheotanytarsus sp. 1	Bip
Saetheria sp. 1	Bil, Pom, Leo, Pat, Onc, Mlu, Sum, Por and Vem
Stempellina sp. 1	Gen, Leo and Pve
Stenochironomus sp. 1	Bil, Cla, Gen, Leo and Pve
Tanytarsus type A	Bil, Pom, Pve, Mlu and Gua
Tanytarsus type B	Bil
Tanytarsus type C	Bil, Pom, Pve, Man, Pat, Sum, Gua and Por
Tanytarsus type D	Bil, Cla, Gen, Leo, Osm, Pve, Man, Aur, Pgr, Fec, Mlu, Cer, Tra, Fra and Ven
Tanytarsus type E	Cla, Gen, Leo, Pgr, Fec, Zpc and Ven
T. fittkaui - Sanseverino & Trivinho-Strixino, 2010	Cla, Gen, Fec, Cer and Ven
T. giovannii - Sanseverino & Trivinho-Strixino, 2010	Leo and Gua
T. magnus - Trivinho-Strixino & Strixino, 2004	Bil and Pve
T. obiriciae - Trivinho-Strixino & Sonada, 2006	Leo
Xestochironomus - Borkent, 1984	Cla and Gen
Zavreliella sp. 1	Cla, Gen, Fec, Cer and Tra
Zavreliella sp. 2	Bil, Gen, Leo, Osm, Pve, Pgr, Fec, Mlu and Fra
Orthocladiinae (family)	
Corynoneura sp. 3	Gen
Cricotopus sp. 1 - Wulp, 1874	Pve and Onc
Paracladius sp. 1	Gua
Tanypodinae (family)	
Ablabesmya (Karelia) sp. 1	Bil, Cla, Gen, Pom, Leo, Osm, Pve, Man, Pat, Pve, Onc, Mlu, Sum, Cer, Gua, Por, Ven and Gav
Ablabesmya (Karelia) sp. 2	Mlu
A. annulata sp. 1	Leo, Pat, Aur, Pgr, Onc, Fec, Mlu, Sum, Cer, Zpc, Gua, Tra, Por, Cap, Ven and Gav
Clinotanypus sp. 1	Onc and Por
Coelotanypus sp. 1 - Kieffer, 1913	Cla, Gen, Osm, Pat, Pgr, Onc, Mlu, Cer, Gua, Tra, Fra, Por, Ven and Gav
Coelotanypus sp. 2 - Kieffer, 1913	Bil, Cla, Gen, Pom, Leo, Osm, Pve, Man, Pat, Aur, Pgr, Onc, Fec, Mlu, Sum, Cer, Gua, Fra, Por, Per, Cap and Ven
Coelotanypus sp. 3	Gen and Onc
Djalmabatista sp. 2	Leo and Pat
D. pulchra Johannsen, 1908	Fec
Fittkauimyia sp. 1	Leo
Labrundinia sp. 2	Leo
Labrundinia sp. 5	Gen and Cer
Labrundinia sp. 10	Fec and Fra
Labrundinia sp. 12	Bil, Leo, Osm, Pgr, Fec, Mlu, Sum, Gua, Tra, Cap and Ven
Labrundinia sp. 13	Pat
Labrundinia sp. 14	Leo
Labrundinia sp. 15	Cer
Labrundinia sp. 16	Cap
Labrundinia sp. 17	Gen and Leo

Chart 1. Incidence of chironomid morphospecies in the 27 floodplain lakes sampled. Conclusion

Tanypodinae (family)	
Procladius type B	Bil, Pve, Man, Pat, Aur, Pgr, Onc, Fec, Mlu, Sum, Cer, Gua, Fra, Jac, Por, Per, Ven, Bip and Gav
prox. Procladiini	Gua
Tanypus sp. 2	Osm, Pat, Onc, Mlu, Sum, Jac, Ven and Bip
Tanypus sp. 3	Gen, Osm, Aur, Sum, Cer, Tra and Jac
T. stellatus - Coquillett, 1902	Bil and Pve
T. punctipennis - Coquillett, 1902	Leo, Onc, Mlu, Jac, Por, Cap and Ven
Thienemannimyia sp. 1	Gen

Note: Legend: Bil: *Bilé*; Cla: *Clara*; Gen: *Genipapo*; Pom: *Pombas*; Leo: *Leopoldo*; Osm: *Osmar*; Pve: *Pau Véio*; Man: *Manezinho*; Pat: *Patos*; Aur: *Aurélio*; Pgr: *Pousada das Garças*; Onc: *Onça*; Fec: *Fechada*; Mlu: *Maria Luiza*; Sum: *Sumida*; Cer: *Cervo*; Zpc: *Zé do Paco*; Gua: *Guaraná*; Tra: *Traíra*; Fra: *Finado Raimundo*; Jac: *Jacaré*; Por: *Porcos*; Per: Peroba; Cap: Capivara; Ven: *Ventura*; Bip: *Boca do Ipoitã*; Gav: *Gavião*.

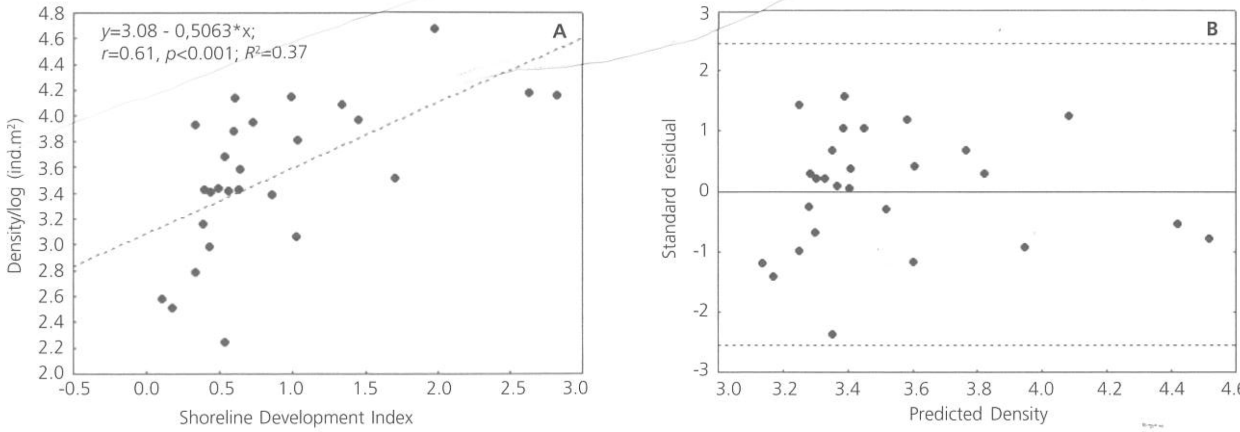

Figure 2. Regression results (A) and Standard Residual plot (B) between the modified shoreline development index and the density of chironomids.

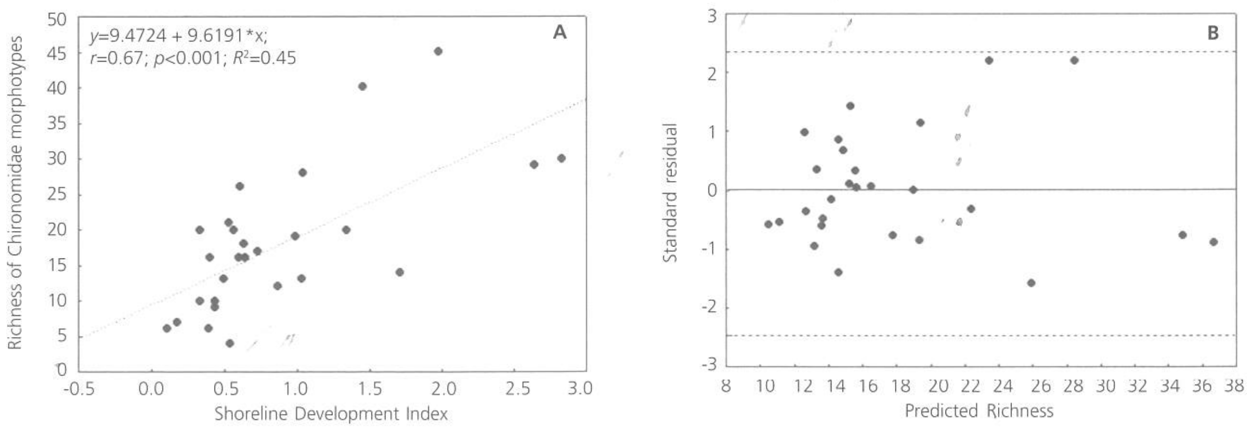

Figure 3. Regression results (A) and Standard Residual plot (B) between the modified shoreline development index and the richness of chironomids.

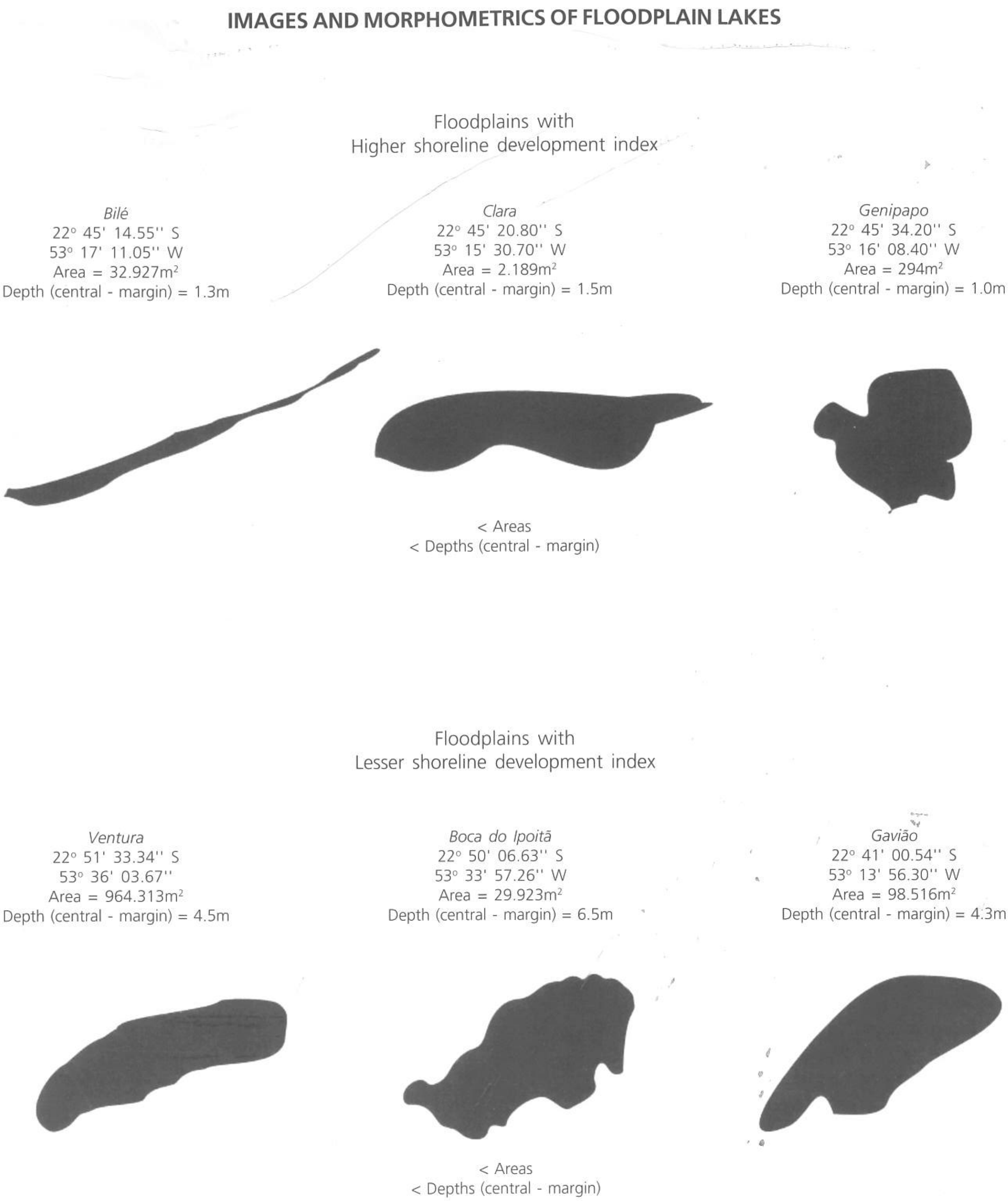

Figure 4. Satellite image of floodplain lakes with the three highest and three lowest shoreline development index, along with their area and depth (central - margin).

The modification of the shoreline development index for tropical regions predicted satisfactorily chironomid richness and density. Therefore, this index can be used in future studies on other aquatic organisms, contributing to the conservation and management of Neotropical floodplain lakes. Moreover, the easiness in obtaining the data required makes it an important tool for identifying areas with high aquatic biodiversity.

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