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Fish-based Index of Biotic Integrity for wadeable streams from Atlantic Forest of south São Paulo State, Brazil

Índice de Integridade Biótica utilizando a comunidade de peixes para riachos de cabeceira que cruzam a Mata Atlântica do sul do estado de São Paulo, Brasil

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Abstract: Understanding the relationship between environmental quality of streams and biological integrity of fish assemblages is critical to successful ecosystem management. **Aim:** We adapted the Index of Biotic Integrity (IBI) using ecological data of the fish assemblages that occur in headwater streams from the Atlantic Forest in southern São Paulo State. **Methods:** We sampled the ichthyofauna and collected environmental data in 27 streams stretches during the dry season of 2010. The fish species were categorized into trophic group, position in the water column and preference for rapid meso-habitats. Candidate metrics were screened for range, responsiveness and redundancy. **Results:** Of the 17 metrics tested, four metrics were included in the IBI. They belonged to attributes species diversity: percentage of individuals as Loricariidae family; habitat use: percentage of individuals as benthic riffles; and trophic function: percentage of individuals as omnivores and percentage of individuals as herbivores/detritivores. Eight streams (30%) were classified as excellent or good and fourteen (50%) as poor or very poor. **Conclusions:** On a regional scale, many aspects of biological integrity were altered but there are streams that can be used as biological reference.

Keywords: ichthyofauna; biomonitoring; multimetric index; neotropical.

Resumo: Compreender a relação entre qualidade ambiental de riachos e a integridade biótica de comunidades de peixes é crucial para um bom gerenciamento ecossistêmico. **Objetivo:** Nós adaptamos um Índice de Integridade Biótico (IIB) utilizando dados das comunidades de peixes que ocorrem em riachos de cabeceira da Mata Atlântica no sul do Estado de São Paulo. **Métodos:** Nós amostramos a ictiofauna e coletamos dados ambientais de 27 trechos de riachos durante a estação seca de 2010. Os peixes foram organizados em grupos tróficos, posição na coluna d'água e preferência por meso-habitat corredeira. As métricas candidatas foram examinadas quanto à amplitude, capacidade de resposta e redundância. **Resultados:** Das 17 métricas testadas, quatro foram selecionadas para compor o IIB. Elas pertencem aos atributos diversidade de espécies: porcentagem de indivíduos da família Loricariidae; uso de hábitat: porcentagem de indivíduos bentônicos de corredeiras; e função trófica: porcentagem de indivíduos onívoros e herbívoros/detritívoros. Oito riachos (30%) foram classificados como excelente ou bom e 14 (50%) foram classificados como pobres ou muito pobres. **Conclusões:** Em escala regional, muitos aspectos da integridade biótica foram alterados mas ainda existem riachos que podem ser utilizados como referência biológica.

Palavras-chave: ictiofauna; biomonitoramento; índice multimétrico; neotropical.

1. Introduction

In urban areas, studies point to dramatic changes in the quality of streams, primarily due to sewage emission (Pinto et al., 2006). In rural areas, these changes are generally related to a decline in riparian vegetation to provide area for cultivation and forestry and to the presence of plumbing and drain-laying work for construction of secondary roads (Ferreira & Casatti, 2006; Roth et al., 1996).

Several studies demonstrated a relationship between environmental quality of streams and biological integrity of fish assemblages. Since the Index of Biotic Integrity – IBI was proposed (Karr, 1981), environmental assessment systems based on biological community attributes have supplemented those based only on water quality. The IBI focus at the biological responses to physical or chemical characteristics of water bodies of the different organisms that make up the assemblages (Karr, 1981), by grouping multiple indicators of abundance, composition and functional organization patterns of these assemblages into a single index (Karr & Dudley, 1981). Thus, it can be used as an indicator for assessing and monitoring the quality of water bodies.

The integrity of the assemblages provides a direct measure of the ecological conditions of water resources (Angermeier & Davideanu, 2004) and, when compared to an intact reference system, these environments can be positioned along a continuum of environmental degradation. In São Paulo state several studies generated streams IBIs based in fish community (Marciano et al., 2004; Ferreira & Casatti, 2006; Casatti et al., 2009, 2012; Esteves & Alexandre, 2011). Streams at headwater regions are generally less degraded than downstream stretches of the river basins, also presenting smaller natural variations in physical, chemical and biological conditions. Due to these characteristics, these regions can be used as references sites in environmental assessment (Drake, 2004).

Although the natural variability in these systems can be considered low, when the results of anthropogenic modifications are considered, headwaters can be quite heterogeneous spatially, and characterized by diverse interacting patches ranging from human-dominated environments to conservation units. In the present study we developed an IBI based on stream fish communities that can provide potential implications for the management in headwater streams that flow through the Atlantic Forest in the south of the São Paulo state.

2. Material and Methods

2.1. Study area

The Maciço de Piedade has a highly heterogeneous relief, contributing to the formation of numerous small-sized watercourses. In this region, the drainage basin is topographically separated by the Serra de Paranapiacaba, which represents a geographical barrier of the adjacent basins of the Sorocaba, Paranapanema and Ribeira de Iguape rivers (Figure 1). The hydrographic basin of the Sorocaba river is characterised by a well-developed industry and a population density of about

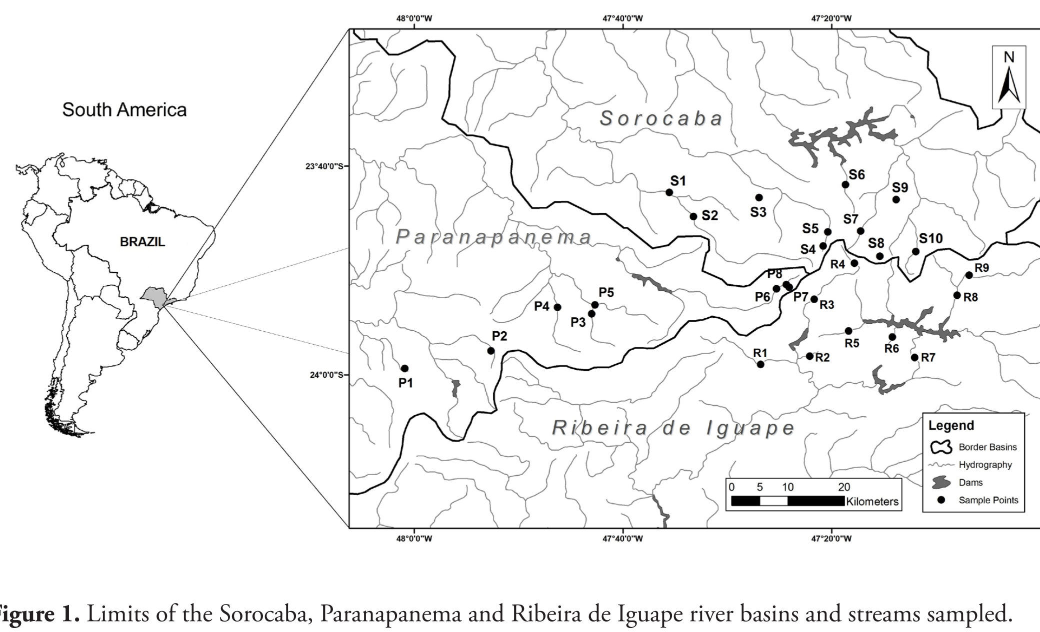

Figure 1. Limits of the Sorocaba, Paranapanema and Ribeira de Iguape river basins and streams sampled.

140 inhabitants.km^{-2}. The Alto Paranapanema river basin presents agricultural characteristics, a population density of about 30 inhabitants.km^{-2} with about 15% of native vegetation and headwaters covered by reforestation areas, mainly *Eucaliptus* and natural forests. In the hydrographic basins of the Ribeira de Iguape river about 60% of its territory has native vegetation and it has a population density of about 15 inhabitants.km^{-2}.

2.2. Streams classification

During the dry period in 2010 (July – November), we sampled the ichthyofauna and structural environmental data to represent the full range of habitat types and stream quality within each sub-drainage system. Twenty-seven sample sites distributed in the Sorocaba river basin (n=10), Alto Paranapanema river basin (n=8) and in the Ribeira de Iguape river basin (n=9) were sampled (Figure 1). The streams in this study measured 3.9 m ± 2.14 m in width and 28.7 cm ± 11.02 cm in depth (mean +/- sd) (Cetra et al., 2012). To characterize the reaches we used a physical habitat index (PHI) adapted from Barbour et al. (1999). We evaluated the stretches with four habitat parameters: epifaunal substrate/available cover, sediment deposition, frequency of riffles and bank stability (Table 1). The PHI range classification was: 0 to 20 (Poor), 21 to 40 (Marginal), 41 to 60 (Suboptimal) and 61 to 80 (Optimal).

2.3. Fish collections

Considering that seasonal fluctuation of the water level is one of the most important factors to influence the structure of fish assemblages (Rodríguez & Lewis, 1997), the sampling period for the ichthyofauna was the dry season. During this period, connections between the structure of the fish assemblage and the habitat structure are more robust, and the effect of temporal variation can be controlled (Willis et al., 2005). Sampling is also more efficient due to the smaller volume of water and consequent increase in the density of fish (Pease et al., 2012).

Sampling was performed with an electrofishing apparatus, between 8:00hs and 17:00hs without contention nets, at the upper and lower limits. The ichthyofauna was collected in 70-meter stretches, a distance that is sufficient for representing the range of available mesohabitats, i.e., a repeating sequence of riffle, pool and run. The apparatus consists of a transformer supplied by a generator (Toyama 2000W) connected to two dip nets, that in the water release a continuous current (2A). Two individuals handled the nets in a single downstream-upstream movement to capture the fish.

2.4. Data analysis

Based on the literature (Oyakawa et al., 2006; Casatti et al., 2012) species were categorized into trophic group, position in the water column and preference for rapid meso-habitats (Table 2). Seventeen metrics were considered to define the list of candidate metrics of the IBI (Table 3). Candidate metrics were screened for range, responsiveness, and redundancy. First, a principal component analysis (PCA) was used to detect the metrics with a low variance. We used a broken-stick model to decided which axes are important and representative. Metrics with a factor loading > 0.7 were rejected. Second, a Spearman's rank correlation coefficient (rs) significance ($\alpha < 0.05$) was used to examine the responsiveness of the remaining candidate metrics discriminating the minimally and the most disturbed sites based in the PHI index. Third, Pearson's correlation coefficient was used to test redundancy. Pairs of the metrics with strong positive correlations ($r > 0.75$) were considered redundant. The redundant metrics were then selected basing on their responsiveness and the applicability to the study area (Casatti et al. 2009; Jia et al., 2013).

The metrics were trissected in the 75th and 25th percentiles. Values above the 75th were given score 5 and those below the 25th were given score 1; and intermediate values were given score 3. For the metrics negatively related to the PHI 5 and 1 were reversed. The IBI was composed from the sum of scores for each metric by stretch stream.

3. Results

Frequency of riffles and epifaunal substrate parameters varied from poor to optimal. About 50% of the streams has a sediment deposition classified as optimal. The streams bank stability was classified as poor, marginal and suboptimal. The PHI streams ranged from 12 (poor) to 66 (optimal). About 67% of the streams was classified as suboptimal and marginal (Table 4).

A total of 2,892 fish was caught. Of the 17 metrics tested, 7 metrics were first removed because of the low factor loading on PC1, PC2 and PC3. These axes were selected to analysis the range of metrics, because they

Table 1. Habitat parameters, condition categories and scores of the sampled streams from Atlantic Forest of south São Paulo State (adapted from Barbour et al., 1999).

Habitat parameter	Condition category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Epifaunal Substrate/ Available Cover	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Bank Stability	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
Score	Left bank 10 9 Right bank 10 9	8 7 6 8 7 6	5 4 3 5 4 3	2 1 0 2 1 0

accounted for 70.16% of the total variation (35.18, 22.85, 12.14%, respectively), were higher than broken-stick model and most metrics had the highest values on them. From the remaining 10 metrics, 4 failed the responsiveness test due to P value > 0.05 (Table 5). We exclude two redundant metrics: (i) number of herbivores/detritivores species (Sherb) was considered redundant with proportion of herbivores/detritivores individuals (%Nherb) and; (ii) proportion of benthic riffles individuals (%Nrif) was considered redundant with number of benthic riffles species (Srif). Four metrics were finally included in the IBI. They belonged to attributes species diversity (%Nlor), habitat use (%Nrif) and trophic function (%Noniv and %Nherb) (Table 6). Eight streams (30%) was classified as excellent or good and fourteen (50%) as poor or very poor (Table 7), indicating that, on a regional scale, many aspects of biological integrity are altered but there are streams that can be used as biological reference.

Table 2. Classification of sampled species according to attributes related to position in the water column.

Order/family/species	Position	Trophic	Riffles	Basin
Characiformes				
Characidae				
Astyanax altiparanae Garutti & Britski, 2000	nec	oni		P/S
Astyanax bockmanni Vari & Castro, 2007	nec	oni		P
Astyanax fasciatus (Cuvier, 1819)	nec	oni		P/S
Astyanax paranae Eigenmann, 1914	nec	oni		P/S
Astyanax ribeirae Eigenmann, 1911	nec	inv		RI
Astyanax sp.	nec	oni		RI
Astyanax sp2	nec	oni		RI
Bryconamericus iheringi (Boulenger, 1887)	nec	oni		S
Bryconamericus microcephalus (Ribeiro, 1908)	nec	inv	R	S
Bryconamericus stramineus Eigenmann, 1907	nec	inv		P
Deuterodon iguape Eigenmann, 1907	nec	oni	R	RI
Hyphessobrycon anisitsi (Eigenmann, 1907)	nec	inv		P/RI/S
Piabina argentea Reinhardt, 1867	nec	oni		P/S
Crenuchidae				
Characidium gomesi Travassos, 1955	bent	inv	R	P/S
Characidium lanei Travassos, 1967	bent	inv	R	RI
Characidium oiticicai Travassos, 1967	bent	inv	R	P/S
Characidium pterostictum Gomes, 1947	bent	inv	R	RI
Characidium schubarti Travassos, 1955	bent	inv	R	P
Characidium zebra Eigenmann, 1909	bent	inv	R	P/S
Erythrinidae				
Hoplias malabaricus (Bloch, 1794)	nec	car		P/RI/S
Parodontidae				
Apareiodon ibitiensis Campos, 1944	bent	oni	R	S
Parodon nasus Kner, 1859	bent	herb-det	R	S
Cyprinodontiformes				
Poeciliidae				
Phalloceros reisi Lucinda, 2008	nec	oni		P/RI/S
Gymnotiformes				
Gymnotidae				
Gymnotus pantherinus (Steindachner, 1908)	nec	inv		RI
Gymnotus silvius Albert & Fernandes-Matioli, 1999	nec	inv		P/RI/S
Perciformes				
Cichlidae				
Australoheros facetus (Jenyns, 1842)	nec	oni		P/RI/S
Geophagus brasiliensis (Quoy & Gaimard, 1824)	nec	oni		P/S
Geophagus iporangensis Haseman, 1911	nec	oni		RI
Siluriformes				
Callichthyidae				
Callichthys callichthys (Linnaeus, 1758)	bent	oni		S
Corydoras aeneus (Gill, 1858)	bent	oni		S
Heptapteridae				
Cetopsorhamdia iheringi Schubart & Gomes, 1959	bent	inv	R	P/S
Imparfinis mirini Haseman, 1911	bent	inv	R	P
Imparfinis borodini Mees & Cala, 1989	bent	inv	R	P/S
Phenacorhamdia tenebrosa (Schubart, 1964)	bent	inv	R	P
Pimelodella avanhandavae Eigenmann, 1919	bent	inv		P/S
Pimelodella transitoria (Ribeiro, 1907)	bent	inv		RI
Rhamdia quelen (Quoy & Gaimard, 1824)	bent	car		P/RI/S

nec – nektonic; bent – benthonic, trophic group (oni – omnivorous; inv – invertivorous; car – carnivorous; herb-det – herbivorous/detritivorous); riffles (R) and river basin (P – Paranapanema; S – Sorocaba; RI – Ribeira de Iguape.

Table 2. Continued...

Order/family/species	Position	Trophic	Riffles	Basin
Loricariidae				
Harttia kronei Miranda-Ribeiro, 1908	bent	herb-det	R	RI
Hisonotus sp1	bent	herb-det	R	P
Hypostomus ancistroides (Ihering, 1911)	bent	herb-det	R	P/RI/S
Hypostomus variipictus (Ihering, 1911)	bent	herb-det	R	S
Isbrueckerichthys duseni (Miranda-Ribeiro, 1907)	bent	herb-det	R	RI
Isbrueckerichthys epakmos Pereira & Oyakawa, 2003	bent	herb-det	R	RI
Neoplecostomus ribeirensis Langeani, 1990	bent	herb-det	R	P/RI
Neoplecostomus cf. *yapo* Zawadzki, Pavanelli & Langeani, 2008	bent	herb-det	R	RI
Neoplecostomus sp.	bent	herb-det	R	S
Rineloricaria pentamaculata Langeani & Araújo, 1994	bent	herb-det	R	P
Trichomycteridae				
Ituglanis proops (Miranda-Ribeiro, 1908)	bent	inv		RI
Trichomycterus iheringi (Eigenmann, 1917)	bent	inv	R	S
Trichomycterus cf. *zonatus* (Eigenmann, 1918)	bent	inv	R	RI
Trichomycterus sp.	bent	inv	R	P
Synbranchiformes				
Synbranchidae				
Synbranchus marmoratus Bloch, 1795	nec	car		P/S

nec – nektonic; bent – benthonic, trophic group (oni – omnivorous; inv – invertivorous; car – carnivorous; herb-det – herbivorous/detritivorous); riffles (R) and river basin (P – Paranapanema; S – Sorocaba; RI – Ribeira de Iguape.

Table 3. Candidate metrics for the Index of Biotic Integrity and the expected response to an increase in environmental degradation.

Metric	Response
Species diversity	
Species richness (S)	Reduces
Simpson's equitability index (ED)	Reduces
ABC curve statistics (W)	Reduces
Number of fish species, family Loricariidae (Slor)	Reduces
Proportion of individuals, family Loricariidae (%Nlor)	Reduces
Habitat use	
Number of benthic riffles species (Srif)	Reduces
Proportion of benthic riffles individuals (%Nrif)	Reduces
Trophic function	
Number of trophic categories (Troph)	Reduces
Simpson's equitability index for the number of trophic categories (TrophED)	Reduces
Number of carnivores species (Scar)	Reduces
Proportion of carnivores individuals (%Ncar)	Reduces
Number of invertivores species (Sinver)	Reduces
Proportion of invertivores individuals (%Ninver)	Reduces
Number of omnivores species (Soniv)	Increases
Proportion of omnivores individuals (%Noniv)	Increases
Number of herbivores/detritivores species (Sherb)	Reduces
Proportion of herbivores/detritivores individuals (%Nherb)	Reduces

Table 4. Number of streams by PHI parameter classification.

Parameter	Classification			
	Optimal	Suboptimal	Marginal	Poor
Epifaunal substrate	2	9	7	9
Sediment deposition	14	8	4	1
Frequency of riffles	6	7	7	7
Bank stability	-	4	11	12
PHI (total)	4	10	8	5

Table 5. Minimum (Min), Maximum (Max), Mean and coefficient of variation (CV) of the candidate metrics (see Table 3 legend) for the IBI. Range and responsiveness significance: PCA metric loadings (PC1, PC2, PC3) and Spearman's rank correlation coefficient with PHI (PHI_{rs}).

	Min	Max	Mean	CV	PC1	PC2	PC3	PHI_{rs}
S	4	15	8.89	34.37	-	0.74	-	-
ED	0.21	0.82	0.44	31.55	-	-	0.88	-
W	–0.27	0.41	0.01	1679.75	-	-	-	-
Slor	0	3	1.48	60.29	-	-	-	-
%Nlor	0	0.81	0.17	134.39	-	-0.78	-	0.52
Srif	0	10	3.85	78.12	0.89	-	-	0.41
%Nrif	0	0.95	0.41	79.83	0.81	-	-	0.63
Troph	2	4	3.37	16.76	-	-	-	-
TrophED	0.32	0.79	0.55	29.62	-	-	-	-
Scar	0	3	1.04	77.89	-	-	-	-
%Ncar	0	0.15	0.03	116.36	-	-	-	-
Sinver	0	8	2.37	104.75	0.77	-	-	-
%Ninver	0	0.90	0.30	98.24	0.72	-	-	-
Soniv	2	6	3.81	30.01	-	-	-	-
%Noniv	0.05	0.98	0.49	66.36	–0.89	-	-	–0.48
Sherb	0	4	1.70	62.66	0.84	-	-	0.42
%Nherb	0	0.81	0.18	127.64	-	–0.77	-	0.59

Table 6. IBI metrics and scoring criteria for Atlantic Forest of south São Paulo State streams.

Metric	Scoring criteria		
	1	3	5
Species diversity			
1. Percentage of individuals as Loricariidae family	≤ 2	2-21	≥ 21
Habitat use			
2. Percentage of individuals as benthic riffles	≤ 5	5-60	≥ 60
Trophic function			
3. Percentage of individuals as omnivores	≥ 87	17-87	≤ 17
4. Percentage of individuals as herbivores/detritivores	≤ 2	2-21	≥ 21

Table 7. Detailed descriptions of stream biotic integrity, IBI values and number of streams by category (n).

Categories	Values	Description	n
Excellent	19-20	Comparable to the best situation without human disturbance; the relative contribution of individuals as benthic riffles is high without omnivores.	3
Good	16-18	Fish community represented by individuals as Loricariidae family, benthic riffles and herbivores/detritivores and trophic structure shows some signs of stress.	5
Fair	13-15	Signs of additional deterioration include loss of individuals as benthic riffles and moderate skewed trophic structure with increasing frequency of omnivores.	5
Poor	9-12	Fish community dominated by omnivores with less abundance of individuals as benthic riffles.	4
Very poor	4-8	Dominated by omnivores.	10

4. Discussion

The current Index of Biotic Integrity (IBI) used the stream fish community and consisted of four metrics that reflected, in a satisfactory manner, the environmental gradient found in wadeable headwater streams, which generally show little environmental change.

The four selected metrics for the IBI reflected the structure of the assemblages mainly in terms of proportional species abundance of the attributes species diversity, habitat use and trophic function. In the present study, surprisingly, we did not have the expected response of species richness that has been extensively used to infer the quality of ecological systems (Roth et al., 2000). Perhaps the species richness variation is best explained by stream position in the longitudinal gradient than in the present disturbance gradient.

The predominance of individuals as Loricariidae family and herbivores/detritivores in preserved streams is expected in streams with shading because the presence of riparian vegetation increasing primary productivity, especially Periphyton that can be used as a food resource by these organisms. In degraded conditions, the intense sediment supply increase the unstable substrate, preventing the accumulation or attachment of periphyton and thus the individuals with such food habits become rare in the impacted environment (Ferreira & Casatti, 2006). Our explanation would be linked to the bank stability rather than shading, because the streams with poor classification have low scores on the parameter bank stability.

The relative contribution of individuals as benthic riffles is high in streams with low sediment deposition with little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition. With this metric we were able to discriminate excellent from poor or very poor biotic integrity in the streams. Benthic rifles species lived on or near the bottom and usually did not feed on the surface (Noble et al., 2007), and were sensitive to the stream siltation (Oberdoff & Hughes, 1992)

Alterations in habitat quality, including bank stability, commonly result in changing availabilities of food resources (Karr, 1981). The omnivores dominated streams with biotic integrity very poor. In tropical and sub-tropical rivers and streams, the omnivore food category is predominant (Esteves & Aranha, 1999; Castro et al., 2003; Pinto et al., 2006), although the same behavior is expected where the increase in the degree of omnivory reflects the destructuring of aquatic habitats.

5. Conclusion

The current adaptation of the IBI is a first step in the establishment of an assessment protocol and the monitoring of Atlantic Forest streams in the headstreams of the Alto Paranapanema, Ribeira de Iguape and Sorocaba river basins. The survey of the four metrics that integrate the IBI and their scores should be sufficient to accompany the environmental changes in these systems. Thus, given the great utility of these results in the biomonitoring of headwater streams in the region, we have confidence in transmitting this information to the decision makers so that sophisticated statistical techniques will no longer be necessary for the adequate accompaniment of anthropogenic changes to these systems.

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