**SUPPLEMENTARY MATERIAL**

**Alternatives for the biomonitoring of fish and phytoplankton in tropical streams**

**TABLES**

**Table S1** List of studies using optimization strategies involving fish biomonitoring. The strategies used in the research (NR= Numerical resolution, SG= Surrogate group, TR= Taxonomic resolution), the studied environment and association or not with phytoplankton (Phyto) are shown.

| **Author/Year** | **Strategy** | **Search environment** | **Phyto** |
| --- | --- | --- | --- |
| (Kilgour and Barton 1999)  | SG | Stream | No |
| (Paszkowski and Tonn 2000) | SG | Lakes | No |
| (Paavola et al. 2003)  | SG | Stream and River | No |
| (Bowman et al. 2008) | SG | Lakes | Yes |
| (Grenouillet et al. 2008)  | SG | Stream | Yes |
| (Larsen et al. 2012) | SG | Stream | No |
| (Padial et al. 2012)  | SG | Floodplain and main river channel | Yes |
| (Mueller et al. 2013) | TR, NR | Floodplain and rivers | No |
| (Bae et al. 2014) | SG | Stream | No |
| (Backus-Freer and Pyron 2015)  | SG | Stream | No |
| (Ribas and Padial 2015) | SG, TR, NR | Floodplain and main river channel | Yes |
| (Kimmel and Argent 2016)  | SG | Stream | No |

**Table S2** Environmental characterization of streams sampled in the upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. Data obtained from Barbosa et al. 2019.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Local and landscape environmental variables** | **Average** | **Coefficient of variation (%)** | **Minimum** | **Maximum** |
| Chlorophyll-a (mg/L) | 1.37 | 45.27 | 0.30 | 2.95 |
| Total nitrogen (mg/L) | 0.41 | 31.82 | 0.12 | 0.71 |
| Total phosphorus (mg/L) | 5.38 | 81.68 | 0.71 | 15.28 |
| Conductivity (μS/cm) | 147.58 | 50.25 | 45.50 | 343 |
| Dissolved oxygen (mg/L) | 5.81 | 16.52 | 4.06 | 7.35 |
| pH | 6.87 | 10.17 | 5.05 | 8.01 |
| Turbidity (NTU) | 28.97 | 74.35 | 10.90 | 88.70 |
| Water temperature (°C) | 25.98 | 8.56 | 22 | 29.20 |
| Flow (rot./s) | 445.62 | 60.43 | 71.56 | 1039.11 |
| Shading (%) | 37.55 | 60.83 | 4.52 | 77.42 |
| Depth | 15.98 | 38.18 | 7.41 | 31.87 |
| Average width | 3.11 | 37.68 | 1.44 | 6.08 |
| Consolidated substrate (%) | 40.46 | 58.21 | 0 | 72.78 |
| Leaf litter substrate (%) | 11.49 | 83.85 | 0 | 42.78 |
| Leaf litter banks (%) | 4.12 | 139.21 | 0 | 26.67 |
| Forest width (m) | 16.02 | 58.11 | 0 | 30 |
| Remaining vegetation in buffer 500 m (%) | 71.55 | 30.77 | 10.52 | 100 |
| Pasture in watershed (%) | 18.08 | 76.04 | 0.40 | 57.77 |
| Pasture in buffer 100 m (%) | 22.17 | 116.02 | 0 | 100 |
| Bare soil in watershed (%) | 0.20 | 140.92 | 0 | 1.32 |
| Bare soil in buffer 500 m (%) | 0.39 | 212.36 | 0 | 3.23 |
| Bare soil in buffer 100 m (%) | 0.17 | 529.15 | 0 | 4.90 |
| Watershed area (km2) | 15.78 | 78 | 0.14 | 49.56 |
| Mean (watershed) slope (%) | 21.18 | 23.95 | 11.37 | 32.17 |
| Altitude (m) | 475.45 | 8.98 | 392 | 562 |

**Table S3** List of fish species captured in the North region of Goiás, Upper Tocantins system, sub-basin of the Santa Teresa river, Cerrado biome, Brazil. Abundance, Occurrence, ecological classification of habitat use in relation the position in water column and trophic category are also presented. See list of abbreviations for their descriptions.

| **Taxon** | **Abundance** | **Occur** | **Ecological classification** |
| --- | --- | --- | --- |
| **Habitat use** | **Trophic category** |
| **Total** | **Max** | **Bent** | **Nect** | **Nectben** | **Marg** | **Detrit** | **T-Invert** | **A-Invert** | **Piscivore** | **Algivore** | **Herbivore** |
| **CHARACIFORMES** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Anostomidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Leporinus friderici* (Bloch, 1794) | 2 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 22.21 | 0 | 44.43 | 0 | 33.36 |
| *Leporinus* sp. | 3 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 0.12 | 62.44 | 0 | 4.49 | 32.94 |
| **Characidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Astyanax elachylepis* Bertaco and Lucinda, 2005 | 156 | 31 | 12 | 0 | 1 | 0 | 0 | 0 | 89.12 | 0 | 1.21 | 2.42 | 7.25 |
| *Astyanax novae* Eigenmann, 1911 | 441 | 55 | 27 | 0 | 1 | 0 | 0 | 0 | 35.53 | 0.65 | 0.73 | 0 | 63.09 |
| *Bryconops melanurus* (Bloch, 1794) | 35 | 8 | 10 | 0 | 1 | 0 | 0 | 0 | 95.3 | 2.88 | 0 | 0 | 1.82 |
| *Creagrutus britskii* Vari and Harold, 2001 | 368 | 68 | 21 | 0 | 0 | 1 | 0 | 0 | 3.29 | 93.75 | 0 | 0 | 2.97 |
| *Hemigrammus ataktos* Marinho, Dagosta and Birindelli, 2014 | 362 | 93 | 19 | 0 | 1 | 0 | 0 | 49.02 | 41.18 | 3.14 | 0 | 4.9 | 1.76 |
| *Jupiaba apenina* Zanata, 1997 | 16 | 7 | 5 | 0 | 1 | 0 | 0 | 0 | 82.77 | 9.27 | 0 | 0.87 | 7.09 |
| *Knodus* cf. *chapadae* (Fowler, 1906) | 3448 | 230 | 29 | 0 | 1 | 0 | 0 | 0 | 92.14 | 5.56 | 0 | 0.46 | 1.83 |
| *Moenkhausia oligolepis* (Günther, 1864) | 125 | 14 | 22 | 0 | 1 | 0 | 0 | 2.15 | 74.52 | 1.14 | 0 | 0.03 | 22.17 |
| *Moenkhausia pankilopteryx* Bertaco and Lucinda, 2006 | 11 | 11 | 1 | 0 | 1 | 0 | 0 | 0.58 | 59.02 | 1.47 | 0.15 | 0.07 | 38.72 |
| *Phenacogaster* sp. | 2 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| *Serrapinnus tocantincinsis* Malabarba and Jerep, 2014 | 48 | 48 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Crenuchidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Characidium* aff. *zebra* Eigenmann, 1909 | 1353 | 161 | 28 | 0 | 0 | 1 | 0 | 0 | 0 | 99.77 | 0 | 0 | 0.23 |
| **Curimatidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Steindachnerina amazônica* (Steindachner, 1911) | 38 | 20 | 8 | 0 | 0 | 1 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| **Erytrhinidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Hoplias malabaricus* (Bloch, 1794) | 67 | 8 | 20 | 0 | 0 | 0 | 1 | 3.53 | 16.31 | 80.15 | 0 | 0 | 0 |
| **Parodontidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Apareiodon machrisi* Travassos, 1957 | 50 | 8 | 18 | 0 | 0 | 1 | 0 | 85.84 | 0 | 0 | 0 | 14.16 | 0 |
| **GYMNOTIFORMES** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Apteronotidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Apteronotus camposdapazi* de Santana and Lehmann, A 2006 | 16 | 3 | 9 | 0 | 0 | 0 | 1 | 0 | 0 | 100 | 0 | 0 | 0 |
| **Gymnotidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Gymnotus* aff. *carapo* Linnaeus, 1758 | 50 | 7 | 17 | 0 | 0 | 0 | 1 | 9.01 | 0 | 90.99 | 0 | 0 | 0 |
| **Sternopygidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Eigenmannia* aff. *trilineata* López and Castello, 1966 | 3 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 2.6 | 0 | 0 | 97.4 |
| *Sternopygus macrurus* (Bloch and Schneider, 1801) | 19 | 5 | 9 | 0 | 0 | 0 | 1 | 0 | 1.16 | 98.84 | 0 | 0 | 0 |
| **PERCIFORMES** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Cichlidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Cichlasoma araguaiense* Kullander, 1983 | 40 | 12 | 9 | 0 | 0 | 1 | 0 | 5.06 | 0.1 | 94.84 | 0 | 0 | 0 |
| *Crenicichla labrina* (Spix and Agassiz, 1831) | 36 | 9 | 12 | 0 | 0 | 1 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| *Retroculus lapidifer* (Castelnau, 1855) | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| **SILURIFORMES** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Callichthyidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Aspidoras albater* Nijssen and Isbrücker, 1976 | 179 | 33 | 16 | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| **Cetopsidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Cetopsis arcana* Vari, Ferraris and de Pinna, 2005 | 4 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 95.47 | 4.36 | 0 | 0.17 | 0 |
| **Heptapteridae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Cetopsorhamdia molinae* Miles, 1943 | 11 | 5 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| *Cetopsorhamdia* sp. | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| *Imparfinis* cf. *borodini* Mees and Cala, 1989 | 5 | 3 | 2 | 1 | 0 | 0 | 0 | 5.2 | 0 | 73.88 | 0 | 0 | 20.91 |
| *Imparfinis* cf. *schubarti* (Gomes, 1956) | 31 | 12 | 9 | 1 | 0 | 0 | 0 | 0 | 0.54 | 99.46 | 0 | 0 | 0 |
| *Phenacorhamdia* sp. | 143 | 18 | 27 | 1 | 0 | 0 | 0 | 0 | 1.36 | 98.46 | 0 | 0 | 0.17 |
| *Pimelodella* sp. | 42 | 23 | 4 | 0 | 0 | 1 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| *Rhamdia* aff. *quelen* (Quoy and Gaimard, 1824) | 24 | 5 | 11 | 0 | 0 | 1 | 0 | 0 | 35.29 | 17.65 | 47.06 | 0 | 0 |
| *Rhamdia* cf. *itacaiunas* Silfvergrip, 1996 | 4 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 99.29 | 0 | 0 | 0 | 0.71 |
| **Loricariidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Ancistrus* cf. *aguaboensis* Fisch-Muller, Mazzoni and Weber, 2001 | 149 | 42 | 7 | 1 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| *Ancistrus* cf. *minutus* Fisch-Muller, Mazzoni and Weber, 2001 | 309 | 32 | 27 | 1 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| *Farlowella* cf. *oxyrryncha* (Kner, 1853) | 5 | 5 | 1 | 0 | 0 | 0 | 1 | 100 | 0 | 0 | 0 | 0 | 0 |
| *Harttia punctata* Rapp Py-Daniel and Oliveira, 2001 | 276 | 44 | 18 | 1 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| *Hemiancistrus cerrado* de Souza, Melo, Chamon and Armbruster, 2008 | 7 | 7 | 1 | 1 | 0 | 0 | 0 | 99.87 | 0 | 0.04 | 0 | 0.09 | 0 |
| *Hypostomus* sp.1 | 285 | 48 | 21 | 1 | 0 | 0 | 0 | 99.06 | 0 | 0 | 0 | 0.94 | 0 |
| *Hypostomus* cf. *ericae* Hollanda Carvalho and Weber, 2005 | 116 | 22 | 23 | 1 | 0 | 0 | 0 | 99.67 | 0 | 0 | 0 | 0.33 | 0 |
| *Loricaria* sp. | 15 | 9 | 4 | 1 | 0 | 0 | 0 | 50.78 | 0 | 49.22 | 0 | 0 | 0 |
| *Nannoplecostomus eleonorae* Ribeiro, Lima and Pereira, 2012 | 80 | 59 | 2 | 1 | 0 | 0 | 0 | 84.51 | 0 | 0 | 0 | 15.49 | 0 |
| *Rineloricaria lanceolata* (Günther, 1868) | 23 | 5 | 11 | 1 | 0 | 0 | 0 | 91.59 | 0 | 8.41 | 0 | 0 | 0 |
| *Spatuloricaria* cf. *evansii* (Boulenger, 1892) | 49 | 11 | 9 | 1 | 0 | 0 | 0 | 49.15 | 11.3 | 39.55 | 0 | 0 | 0 |
| **Trichomycteridae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Ituglanis goya* Datovo, Aquino and Langeani, 2016 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 13.59 | 81.52 | 0 | 0 | 4.89 |
| **SYNBRANCHIFORMES** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Synbranchidae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Synbranchus* cf. *marmoratus* Bloch, 1795 | 11 | 11 | 1 | 0 | 0 | 0 | 1 | 76.42 | 0 | 23.58 | 0 | 0 | 0 |

**FIGURES**

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**Fig. S1** Percentage of land use anthropic and land natural cover in 29 streams watershed of the sub-basin of the Santa Teresa river, Cerrado biome, Brazil. Data obtained from Barbosa et al. 2019.

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**Fig. S2** Schematic representation of taxonomic and numerical resolution (see blue arrows for fish and green for phytoplankton), ecological substitute group (see red arrows for fish and yellow for phytoplankton), and surrogate group (see purple arrows). See list of abbreviations for their descriptions.



**Fig. S3** Abundance of fish (number of individuals) found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil, distributed in five orders.

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**Fig. S4** Density of phytoplankton (individuals.mL-1) by taxonomic class found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil.



**Fig. S5** Density of phytoplankton (individuals.mL-1) by Morphology-Based Functional Groups found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil.



**Fig. S6** Density of phytoplankton (individuals.mL-1) by Reynolds Functional Groups found in 29 streams of Upper Tocantins river basin, sub-basin of the Santa Teresa river, Cerrado biome, Brazil.

**List of abbreviations**

| **Abbreviation** | **Description** |
| --- | --- |
| **Table S3**  |  |
| A-Invert | aquatic invertivore |
| bent | benthic |
| Detrit | detritivore |
| marg | marginal |
| nect | nektonic |
| nectben | nektobenthic |
| Occur | occurrence |
| T-Invert | terrestrial invertivore |
| **Figure S2** |  |
| EC | ecological classifications |
| Fa |  family |
| Fab | axes of PCoA with abundance data of family |
| Fden | axes of PCoA with density data of family |
| FG | functional group |
| Fpa | axes of PCoA with family presence/absence data |
| Gab | axes of PCoA related to data on abundance of genus |
| Gden | axes of PCoA related to data of density of genus |
| Ge | genus |
| Gpa | axes of PCoA related to genus presence/absence data |
| HUGab | the axes of PCoA with abundance data of habitat use guilds |
| HUGab+TGab | axes of PCoA with abundance data of habitat use guilds in conjunction with trophic guilds |
| MBFG | axes of PCoA with density data of phytoplankton Morphology-Based functional groups |
| n | number of sites sampled |
| Oab | axes of PCoA with abundance data of orders |
| Oden | axes of PCoA with order density data |
| Opa | axes of PCoA with order presence/absence data |
| Or | order |
| R | streams sampled |
| RFG | axes of PCoA with density data of phytoplankton Reynolds Functional Groups |
| Sab | axes of PCoA with abundance data of species |
| Sden | axes of PCoA with species density data |
| Sp | species |
| Spa | axes of PCoA with species presence/absence data |
| TGab | axes of PCoA with abundance data of trophic guilds |

**References**

Backus-Freer J, Pyron M (2015) Concordance among fish and macroinvertebrate assemblages in streams of Indiana, USA. Hydrobiologia 758 (1): 141-150. http://dx.doi.org/10.1007/s10750-015-2281-6

Bae M-J, Li F, Kwon Y-S, Chung N, Choi H, Hwang S-J, Park Y-S (2014) Concordance of diatom, macroinvertebrate and fish assemblages in streams at nested spatial scales: implications for ecological integrity. Ecological Indicators 47: 89-101. http://dx.doi.org/10.1016/j.ecolind.2014.07.030

Barbosa HO, Borges PP, Dala-Corte RB, Martins PTA, Teresa FB (2019) Relative importance of local and landscape variables on fish assemblages in streams of Brazilian savanna*.* Fisheries Management and Ecology 26 (2): 1–12. https://doi.org/10.1111/fme.12331

Bowman MF, Ingram R, Reid RA, Somers KM, Yan ND, Paterson AM, Morgan GE, Gunn JM (2008) Temporal and spatial concordance in community composition of phytoplankton, zooplankton, macroinvertebrate, crayfish, and fish on the Precambrian Shield. Canadian Journal of Fisheries and Aquatic Sciences 65(5): 919-932. http://dx.doi.org/10.1139/f08-034

Grenouillet G, Brosse S, Tudesque L, Lek S, Baraillé Y, Loot G (2008) Concordance among stream assemblages and spatial autocorrelation along a fragmented gradient. Diversity and Distributions 14(4): 592-603. https://www.jstor.org/stable/20172013

Kilgour BW, Barton DR (1999) Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. Freshwater biology 41 (3): 553-566. http://dx.doi.org/10.1046/j.1365-2427.1999.00402.x

Kimmel WG, Argent DG (2016) Community concordance between fishes and benthic macroinvertebrates among adventitious and ordinate tributaries of a major river system. Ecological Indicators 70: 15-22. https://doi.org/10.1016/j.ecolind.2016.05.037

Larsen S, Mancini L, Pace G, Scalici M, Tancioni L (2012) Weak concordance between fish and macroinvertebrates in Mediterranean streams. PLoS One 7(12): e51115. https://doi.org/10.1371/journal.pone.0051115

Mueller M, Pander J, Geist J (2013) Taxonomic sufficiency in freshwater ecosystems: effects of taxonomic resolution, functional traits, and data transformation. Freshwater Science 32 (3): 762-778. https://doi.org/10.1899/12-212.1

Paavola R, Muotka T, Virtanen R, Heino J, Kreivi P (2003) Are biological classifications of headwater streams concordant across multiple taxonomic groups? Freshwater biology 48 (10): 1912–1923. https://doi.org/10.1046/j.1365-2427.2003.01131.x

Padial AA, Declerck SAJ, Meester L, Bonecker CC, Lansac-Tôha FA, Rodrigues LC, Takeda A, Train S, Velho LFM, Bini LM (2012) Evidence against the use of surrogates for biomonitoring of neotropical floodplains. Freshwater biology 57 (11): 2411-2423. https://doi.org/10.1111/fwb.12008

Paszkowski, CA, Tonn WM (2000) Community concordance between the fish and aquatic birds of lakes in northern Alberta, Canada: the relative importance of environmental and biotic factors. Freshwater biology 43 (3): 421-437. https://doi.org/10.1046/j.1365-2427.2000.00512.x

Ribas LGS, Padial, AA (2016) Erratum to: The use of coarser data is an effective strategy for biological assessments. Hydrobiologia 779 (1): 259-259. https://doi:10.1007/s10750-016-2876-6