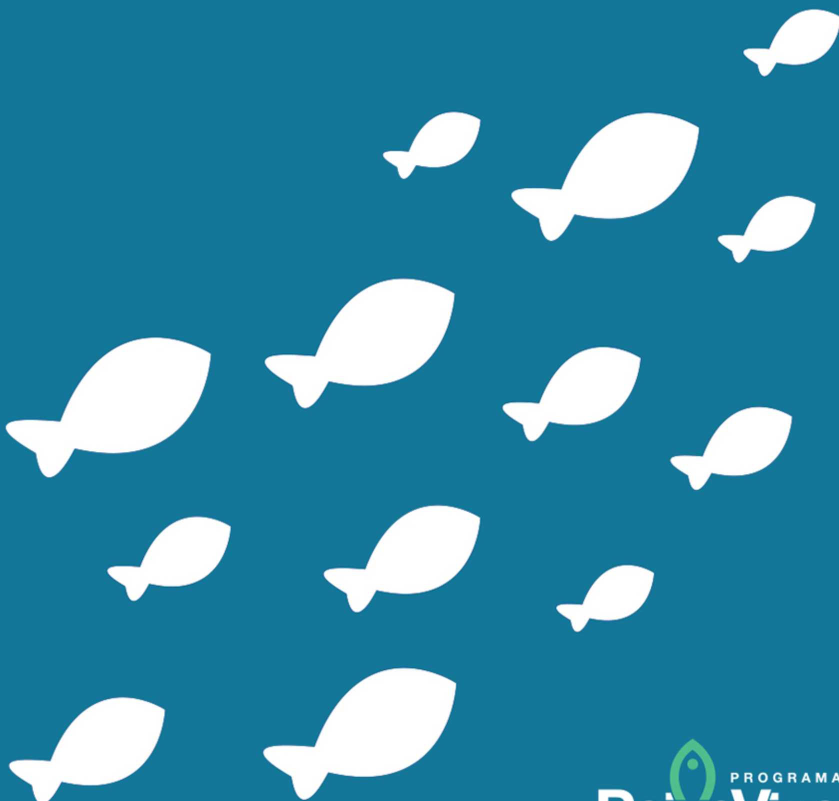
SÉRIE PEIXE VIVO

ECOLOGICAL CONDITIONS IN HYDROPOWER BASINS



PROGRAMA PeixeVivo
CEMIG
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COMPANHIA ENERGÉTICA DE MINAS GERAIS – CEMIG

ECOLOGICAL CONDITIONS IN HYDROPOWER BASINS

BELO HORIZONTE

CEMIG

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This book is dedicated to the memory of our friend Volney Vono. We miss him, his funny stories, and his ecological knowledges.

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PREFACE

Brazil's energy matrix consists almost entirely of hydroelectric power plants, because the country has one of the planet's largest stocks of water in large river basins with high potential for hydroelectricity generation. Companhia Energética de Minas Gerais (Cemig), which is Brazil's third largest electricity generator, has 66 plants in operation. Of these, 60 are hydroelectric power plants, three are thermal plants and three are wind farms. Total installed capacity totals 7,038 MW. In recent years Cemig has experienced remarkable growth. It has acquired new assets to become one of the soundest and most important companies in Brazil's electric energy industry. Through its wholly owned subsidiaries and associated and affiliated companies, Cemig's operations are coordinated by a holding company, Cemig, and three subsidiaries: Cemig Generation and Transmission S.A. (Cemig GT) and Cemig Distribution S.A. (Cemig D), and it also holds stakes in 120 companies, 16 consortia and an equity fund, with assets in 23 Brazilian states and in Chile.

Damming rivers to generate electricity causes a host of modifications to the aquatic ecosystem, including alteration of the hydrological regime and the vertebrate and invertebrate fauna inhabiting rivers. Brazil's electric energy industry has sought to understand the dynamics of the reservoirs formed when its hydroelectric power plants are built, plus how managing the territory in which the projects are located can alter water quality and physical habitat structure. Much of the knowledge about our fish and the water quality of our rivers and reservoirs has been funded by the industry and we notice a growing concern with environmental issues to ease impacts caused by impoundment.

The Peixe Vivo Program was launched in 2007 after Cemig's management realized that more effective measures were needed to conserve the fish populations in the rivers where the Company's projects are located. Its primary actions are summed up in the program's mission, which is "To minimize impact on fish populations by looking for management solutions and technologies that enable Cemig to generate electricity while conserving the native fish species and involving the community". Since its creation, the program has worked on two fronts with one attempting to preserve the fish populations in the state of Minas Gerais and the other focusing on defining protection strategies to reduce fish mortality at Cemig's hydroelectric power plants. Both fronts are attacked in three ways: development of research projects in association with research centers; conservation actions within the company itself; and involvement with the community by creating opportunities for citizens to express their expectations and suggestions.

After the Peixe Vivo Program was established, we discussed research proposals with academicians and citizens. On analyzing the research proposal "Development of biotic integrity indices (IBI) as a tool to assess environmental quality and support restoration of habitats in fingerling release areas by Cemig", we saw an important tool that could be applied in Cemig's drainage basins and reservoirs. The IBI project was based on applications in North America, Europe, and Australia, where those indices were developed as tools to monitor the ecological condition of surface waters at continental scales. In Brazil, work dealing with IBIs was rare. In general, IBIs incorporate biological data from sites with differing physical and chemical conditions, consider the effects of multiple stressors, and synthesize multiple biological measurements into a single value that can be used to assess the site's general condition.

Therefore, in 2009, Cemig's Peixe Vivo Program funded a research partnership that involved scientists from four Minas Gerais institutions: Universidade Federal de Minas Gerais (UFMG), Universidade Federal de Lavras (UFLA), Pontifícia Universidade Católica de Minas Gerais (PUC-Minas) and the Centro Federal de Educação Tecnológica de Minas Gerais (CEFET-MG). In addition, scientists at two U.S. institutions: Oregon State University (OSU) and the U.S. Environmental Protection Agency (USEPA) participated in the project. Four study areas were chosen for developing this tool: the reservoir basins at Nova Ponte on the Araguari River, at Três Marias on the São Francisco River, at Volta Redonda on the Grande River, and at São Simão on the Paranaiba River.

To date over 50 scientific products have been produced, including theses, dissertations, monographs, journal articles and presentations at scientific meetings. In addition, the project fostered collaborations among over 40 team members, including data sharing and joint publications, and stimulated further studies funded by the Agência Nacional de Energia Elétrica (ANEEL)/Cemig during a second phase from 2013 to 2015.

This book is another product resulting from the partnership between the Peixe Vivo Program and Research Centers and the project's multidisciplinary team. The information presented here is in line with the Program's guiding principles: objectives and adopted environmental conservation strategies must be scientifically defensible, and everyone involved must be committed to transparency regarding disclosure of the information produced for society. The book chapters describe initial research towards developing indices of biological integrity for use in environmental assessment of hydropower watersheds in neotropical regions, and they offer major contributions to the level of knowledge regarding the conservation of important river basins in Minas Gerais. We believe this book will stimulate the interest of environmental students, researchers, analysts and managers in what will become important tools for improving the environmental quality of reservoirs and watersheds throughout Brazil—including the importance of working as multi-disciplinary research teams.

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FOREWORD

In his book, *Collapse*, Jared Diamond discussed the reasons for the collapse of some civilizations. According to the author, a common denominator to many such collapsed civilizations was the unsustainable use of resources. The unsustainability results largely from our ignorance about our world, which requires reconciling the desired population and economic welfare with the preservation of that world for future generations. Given that human actions cause changes in our environment, it is essential to document, understand, and quantify their implications for biodiversity, ecological processes that maintain the systems, and ecosystem services to humans.

Understanding the relationship between the environment and human activities has been led primarily by academia. However, some industries have themselves taken in their hands the responsibility to learn about the environment where they carry out their activities and the ecological effects of their own activities. To fulfill these objectives they frequently monitor changes in ecosystems. What for some might seem nonsense (what is not known, does not exist), for others it is a necessity to learn about the ecological system in order to apply scientifically sound management decisions so as to avoid, minimize and/or mitigate ecological changes. Cemig is one such industry.

The program for monitoring and evaluating environmental quality in streams and hydroelectric projects supported by Cemig is a venture that requires a multidisciplinary approach carried out by a large number of researchers from various universities of Minas Gerais and other Brazilian states. This partnership involves ichthyologists, invertebrate specialists, geographers, hydrologists, statisticians, and many others. The teams have established partnerships with international experts from leading institutions, such as Oregon State University and the Environmental Protection Agency, both in the United States. In addition to these major partnerships others were established with scientists from Spain and Portugal.

The sampling network is unique in terms of number of sites, and biological and environmental parameters. It generated data allowing the establishment of relationships between the environment and the assemblage structure of fish and macroinvertebrates. Those studies have generated a large number of scientific publications, many in international journals. The studies were also the subjects of undergraduate mongraphs, masters theses, doctoral dissertations, post-doctoral articles and magazine articles for the general public.

In addition, the research generated an impressive amount of data that, when properly placed in databases, may provide information on the distribution of species and their vulnerability. The data will be important in the identification of bioindicators of prevailing environmental conditions and life-histories of species. These databases also can be used to learn how communities respond to situations of global changes in climate, land use, biodiversity loss, and increased nutrient loading on inland waters. Knowledge about the effects of global change can be analyzed following the strategy of the "reference condition approach" used in reverse, i.e, taking the current conditions as a reference so that future deviations can be expressed quantitatively and in probabilistic terms. Those deviations could result from further deterioration of current environmental conditions or improved conditions resulting from better management practices (e.g., widespread use of wastewater treatment plants, changes in the size of riparian buffer zones, dam removal). However, to make such quantitative comparisons, biotic and abiotic sampling should always be standardized. This was precisely the first step carried out by the working groups, which led to protocols that were tested under a wide range of natural and anthropogenic conditions.

This book tells a story. Where did the idea of assessing environmental quality in watersheds of hydropower projects come from? How did the researchers plan their research? Which were the main challenges and outcomes and what are their plans for the future? Cemig and the researchers who worked on this project provide a great service to science and the environment. This is their story.

Manuel A.S. Graça
Coimbra, 22 December 2013

SÉRIE
PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 1
EXECUTIVE SUMMARY

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1 – INTRODUCTION

In this Chapter we summarize the book's major findings to aid employees of Cemig and other enterprises in their decision-making processes. The information includes 1) key metrics for assessing sediment transport; 2) anthropogenic disturbance assessments; 3) biodiversity inventories; 4) environmental metrics that best explain macroinvertebrate and fish taxa richness; and 5) sampling recommendations.

2 – RESULTS

2.1 Sediment Transport

Relative bed stability, percent fine sediments, and sediment critical and geometrical diameters indicated differing potentials for stream sediment transport among the four drainages (Santos et al., THIS VOLUME). Likewise, differing levels of land use, riparian vegetation condition, and riparian human disturbance were associated with those differing sediment transport levels. The relative bed stability (LRBS) in the Volta Grande drainage was close to zero, meaning that the stream beds there were less like to erode than those in the other drainages, where higher levels of percent fines also indicated that they were transporting sediments.

2.2 Anthropogenic Disturbance Levels of the Study Sites

Varying levels of local- and catchment-scale anthropogenic disturbances affect stream habitats and their biological assemblages (Callisto et al., 2001). Efficient conservation, management practices, and decision-making depend on knowledge of stream ecological conditions and indentification of the most vulnerable areas and the major landscape and hydrological pressures (Callisto et al., 2012). By employing an Integrated Disturbance Index (IDI) (Ligeiro et al., 2013; THIS VOLUME), we estimated how many and which sites were in poor and good condition—independently from their biology (Figure 1). In general, Nova Ponte sites had greater disturbance levels than Tres Marias sites; however more Nova Ponte sites were in good ecological condition. Least-disturbed sites were generally found inside conservation units (e.g., the Cemig Galheiros Environmental Station) or in less populated regions little used for agriculture or pasture (Figure 2). On the other hand, highly disturbed sites were found near cities or large mechanized agricultural ventures. In the latter situations, the stream channels and surroundings were significantly disturbed, with silted beds, a lack of riparian vegetation, and pollution discharges (e.g., the stream that runs through Araxá; Figure 3). Such environmental diagnoses can aid decision-makers in wisely allocating resources for reclaiming degraded areas and protecting key areas for maintaining aquatic biodiversity.

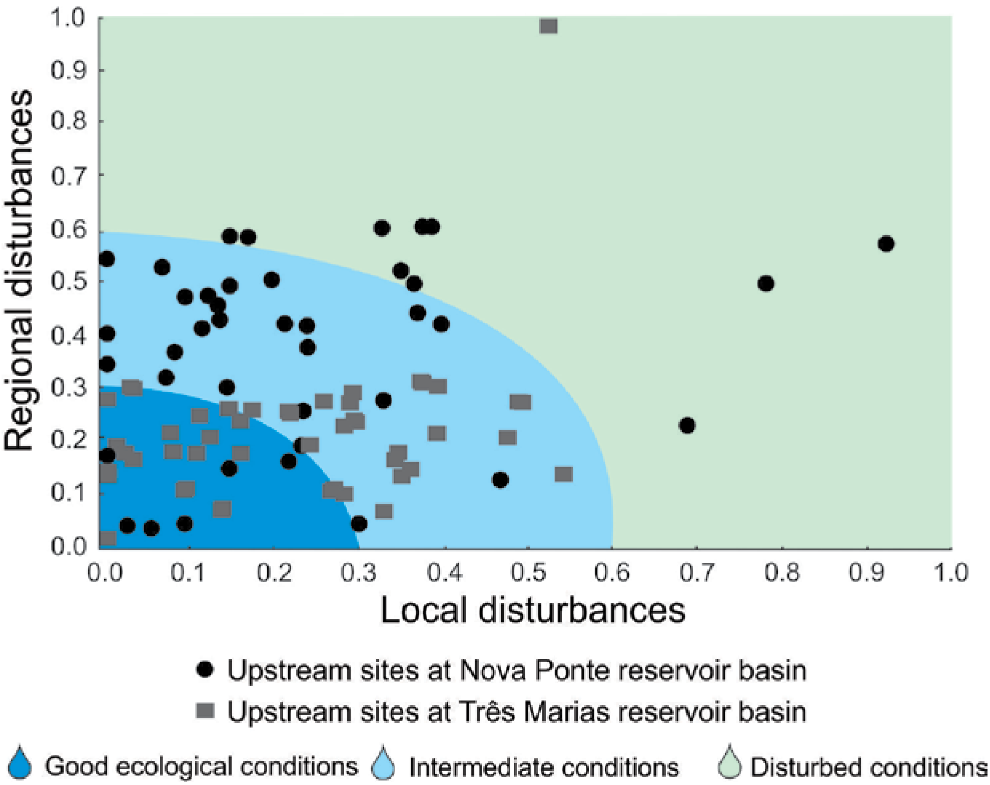

FIGURE 1. Anthropogenic disturbance plane representing local and regional scale disturbance levels of sites. The further from the origin of the plane (zero on both axes), the more disturbed the site. Sites located in the blue, light blue, and green ellipses represent sites with low, intermediate, and high anthropogenic disturbance, respectively.

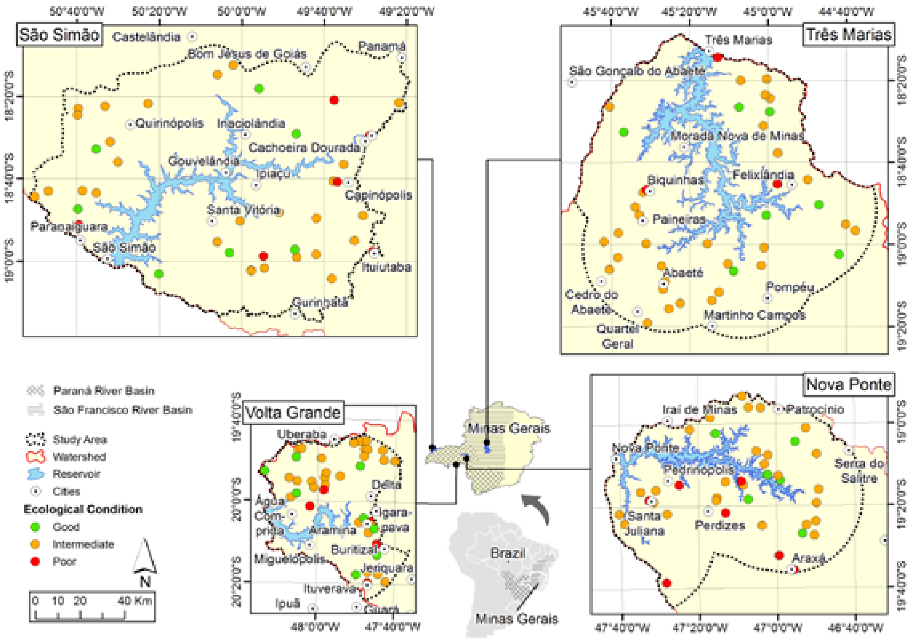

FIGURE 2. Locations of the most- and least-disturbed sites in the Nova Ponte, Três Marias, Volta Grande, and São Simão drainages.

FIGURE 3. Example of a disturbed site in poor ecological condition (Nova Ponte drainage).

2.3 Stream Fish Assemblages

Overall, we collected 19,229 individuals and 144 species, ranging from 38 species in the Nova Ponte drainage to 64 species in the São Simão drainage (Table 1; Leal et al., THIS VOLUME). Those totals represent from 14% to 21% of the known species richness for the drainage basins. *Characidium zebra* and the *Astyanax scabripinnis* species complex were the most abundant. Most of the collected species were native to the basins studied. The three exceptions were the barrigudinho *Poecilia reticulata*, collected in all regions and the tilapias, *Tilapia rendalli* and *Oreochromis niloticus*, collected from the Volta Grande and São Simão drainages, respectively. Overall, we found ten new species: *Astyanax* sp.n. (gr. *scabripinnis*), *Astyanax* sp.n. 2 (gr. *scabripinnis*), *Characidium* sp.n., *Characidium* sp.n. (gr *fasciatum*), *Rhamdiopsis* sp.n., *Trichomycterus* sp.n. 1, *Trichomycterus* sp.n. 2, *Trichomycterus* sp.n. 3, *Hisonotus* sp.1, and *Hisonotus* sp.2. In addition to these, another ten species (of the genera *Astyanax*, *Characidium*, *Harttia*, *Hisonotus*, *Hypostomus*, *Neoplecostomus, Rineloricaria, Serrapinnus,* and two genera of the Hypoptopomatinae and Glandulocaudinae subfamilies) are still being evaluated as potentially new species. These results indicate that even in relatively well-studied drainages, probability stream surveys can increase aquatic biodiversity knowledge. However, we failed to collect most of the basins' species because they are large-sized and large-river species that do not naturally occur in headwater streams, and we only sampled 40 sites per basin.

Our results also indicate that even in highly altered landscapes it is possible to find watercourses with a wide range of stream habitats and a rich stream ichthyofauna. The among-site (or beta) diversity was responsible for much of the total (gamma) diversity in both the Upper Paraná River Basin (39.7%) and the Upper São Francisco River Basin (88.3%), indicating the importance of habitat differences to regional diversity and conservation planning at basin scales.

TABLE 1: Ichthyofauna of Nova Ponte (NP), Três Marias (TM), Volta Grande (VG), and São Simão (SS) stream sites.

Metric	NP	TM	VG	SS
Total number of individuals	4,330	5,910	3,472	5,627
Average number of individuals/ site	113	151	89	144
Number of species	38	58	44	64
Average number of species / site	6	6	6	10
Number of species of commercial interest	3	4	4	8
Number of introduced species	1	1	2	2
Number of species new to science	3	2	3	1

2.4 Stream Benthic Macroinvertebrate Assemblages

For macroinvertebrates, we collected an average of 584 to 1915 individuals and 24 to 26 families per site (Table 2; Ligeiro et al., THIS VOLUME). Três Marias sites had the greatest total family and EPT (mayfly, stonefly, caddis fly) richness, and we found no introduced mollusks at the Nova Ponte sites. Volta Grande sites had markedly fewer EPT and Volta Grande and São Simão sites supported substantially more chironomids and oligochaetes than did the sites of the other two drainages. Together, these metrics suggest that the Volta Grande and São Simão drainages are more disturbed than the Nova Ponte and Tres Marias drainages.

TABLE 2: Benthic macroinvertebrate biodiversity in Nova Ponte (NP), Três Marias (TM), Volta Grande (VG), and São Simão (SS) stream sites.

Metric	NP	TM	VG	SS
Number of individuals	23,356	72,973	76,582	56,410
Number of families	70	80	71	71
Average number of families / site	24.2	26.5	24.4	24.7
% EPT	26.8%	22.1%	18.4%	24.8%
Number of EPT individuals	6,264	16,162	14,070	14,013
% Chironomidae + Oligochaeta	42.8%	47.4%	58.4%	56.3%
Invasive mollusks	-	*Melanoides* sp.	*Corbicula fluminea* *Melanoides* sp.	*Melanoides* sp.
Physical habitat metric that influence EPT genera richness	Bankfull width % cobble Shelter and wood debris Slope % agriculture % pasture	Smooth flow + pool Relative stability of stream bed (critical diameter of substrate) Wetted width mean area Dissolved oxygen	Smooth flow + gravel / Stones Smooth flow + leaves	
Number of EPT families	19	20	17	16
Number of EPT genera	62	65	63	56

2.5 Reservoir Benthic Macroinvertebrate Assemblages

Reservoir sites were dominated by chironomids (nonbiting midges) in all cases but Volta Grande, which were dominated by introduced mollusks and tolerant taxa (Table 3; Morais et al., THIS VOLUME). Nova Ponte also supported a substantial percentage of introduced individuals. The prevalence of resistant taxa resulted from the dominance of chironomids in all four reservoirs. The Chironomidae occupy a diversity of habitats because of their capacity to exploit different food resources, reproduce rapidly under a variety of conditions, and tolerate fine sediments, a common characteristic of the reservoirs studied. The greater percentages of introduced and tolerant taxa in Volta Grande indicate that it is more disturbed than the other three reservoirs.

2.6 Reservoir Fish Assemblages

We collected fewer fish species and families from Nova Ponte and substantially more species, migratory species, and introduced individuals from São Simão, although Três Marias produced the most individuals (Table 4; Sanches et al., THIS VOLUME). Seventy percent of the individuals we collected from both São Simão and Volta Grande were introduced species, indicating potential biological disruption of the native fish fauna and supporting the macroinvertebrate results.

TABLE 3: Benthic macroinvertebrate biodiversity in Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) reservoirs.

Metric	NP	TM	VG	SS
Number of individuals	1,116	976	3,737	3,725
Number of families	18	23	17	14
Number of Chironomidae genera	21	24	23	26
% Chironomidae + Oligochaeta	80	74.18	17.7	96
% introduced mollusks	0.16	1.2	80.7	0.01
% introduced individuals	10.5	1.3	80.8	0.01
% tolerant taxon distribution	50	62.5	90	57.5

TABLE 4: Ichthyofauna of Nova Ponte (NP), Três Marias (TM), Volta Grande (VG), and São Simão (SS) Reservoirs.

Metric	NP	TM	VG	SS
Number of individuals	2,463	3,843	1,488	2,843
Number of families	12	17	14	18
Number of species	29	37	30	48
Number of migratory species	4	5	4	9
Number of introduced species	5	3	7	9
Number of introduced individuals	222	769	1,042	1,990
Percent introduced individuals	9	20	70	70

2.7 Environmental Predictors of Fish and Macroinvertebrate Taxa Richness

Stream habitat metrics related to flow, slope, substrate, site width, and dissolved oxygen explained most of the EPT richness variability (Macedo et al., 2014; Ligeiro et al., THIS VOLUME). In brief, our study demonstrated the importance of local physical habitat factors on the structure and distribution of EPT assemblages, and in the feeding of *Phylloicus* larvae in Cerrado streams (Ferreira et al., 2014).

Reservoirs are altered systems, which makes it difficult to apply the reference area concept. Only Nova Ponte and Três Marias Reservoirs had sites with a large proportion of natural ground cover (non-cultivated areas; Morais et al., THIS VOLUME). In addition, as a general rule, the presence or proximity of tributaries had a positive effect on fish species richness and abundance (Sanches et al., THIS VOLUME). Therefore, such sites could be classified as the least disturbed. On the other hand, sites close to the dam produced the lowest richness and fewest individuals, suggesting that they were the most-disturbed sites. At Três Marias, however, we observed most-disturbed sites along the entire reservoir, without a clear concentration in the area close to the dam.

2.8 Sampling Recommendations

We sampled 40 randomly selected stream sites in each drainage to assess fish and benthic macroinvertebrate assemblage condition. That number of sites was sufficient for estimating macroinvertebrate family and EPT richness in the drainages (Ligeiro et al., THIS VOLUME), but still underestimated total family richness. For fish, we found that greater site lengths could produce meaningfully more species; however, even more species could be obtained by adding new sites, especially in larger rivers (Leal et al., THIS VOLUME). Therefore we recommended sampling 40 sites across a range of stream sizes for basin-wide ecological assessments, but a much greater number for completing biodiversity inventories of aquatic taxa.

We also sampled 40 randomly selected sites in each reservoir. We obtained meaningful estimates of macroinvertebrate family richness with that level of effort, but additional families could be collected by sampling more sites (Morais et al., THIS VOLUME). However, as with streams, sampling more reservoirs would yield even more taxa. In addition, because reservoir sites are not independent and show limnological patterns in different portions of the reservoir (Sanches et al., THIS VOLUME), fewer than 40 sites may suffice for making meaningful ecological assessments of a reservoir (Molozzi et al., 2011; Kaufmann et al., 2014). Finally, because kick nets usually produced more macroinvertebrate taxa (Morais et al., THIS VOLUME), and because boat electrofishing is commonly used for sampling reservoir littoral areas (Miranda & Boxrucker, 2009), we recommend employing these techniques in a standard manner in Brazilian reservoirs.

3 – ACKNOWLEDGMENTS

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SÉRIE PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 2
BENEFITS OF INTERNATIONAL COLLABORATIONS

ROBERT M. HUGHES
& PHILIP R. KAUFMANN

HUGHES, R.M. & KAUFMANN, P. R. Benefits of international collaborations. In: CALLISTO, M.; HUGHES, R. M.; LOPES, J.M. & CASTRO, M.A. (eds.), *Ecological conditions in hydropower basins.* Belo Horizonte: Companhia Energética de Minas Gerais, p. 35-45, 2014. (Série Peixe Vivo, 3).

1 – INTRODUCTION

In this chapter, we share what we have learned from working with our Brazilian colleagues on a multi-university, multi-year, and multi-basin ecological assessment and how those experiences were transmitted more broadly. These lessons (each of which is described in subsequent paragraphs) included 1) learning about markedly different ecosystems; 2) values to the U.S. Environmental Protection Agency (USEPA) of testing monitoring protocols in those ecosystems; 3) applying lessons from the Cemig (Companhia Energética de Minas Gerais) project to research on other continents and elsewhere in Brazil; 4) advantages of academic team research; 5) benefits of corporate-sponsored research and federal student scholarships; 6) communicating with the general public; 7) the research web that has developed out of our work in Brazil; and 8) experiencing Brazilian culture.

2 – TROPICAL ECOSYSTEM RESEARCH

Although we both had lived and worked previously in tropical and subtropical ecosystems, we had not had the opportunity to conduct fieldwork in those systems or to prepare manuscripts on our research regarding what we had learned about them. We found stream reference sites in Brazil that were less disturbed by humans than those that we typically encountered throughout the USA, except for those in remote wilderness areas and in USA national parks. The aquatic biotic communities inhabiting those sites and others generally appeared to be more intact than those we encountered in the USA. Nonetheless, at the site scale, we found about the same number of taxa in streams as in many USA sites, with much of the diversity occurring among sites. That among-site diversity was greater than that in all but the richest biotic regions of the USA. Other differences that struck us were the smaller amount of large woody debris, and the greater amount of leaves, in forested streams than we find in forested USA streams. Also there apparently was a greater tolerance of riparian forest removal by fishes in Brazilian streams. Thus, despite many similarities between subtropical and temperate streams, understanding their ecological differences is also key to effective conservation and rehabilitation.

Although economic development came later to Brazil than to the USA or Europe, the recent rapid development of hydroelectric systems, agriculture, urbanization, and mining in Brazil are now seriously threatening Brazilian ecosystems, sustainable economies, and the quality of human life. Thus it is critically important for Brazil to act rapidly to protect its terrestrial and aquatic ecosystems to avoid the massive ecosystem destruction and widespread species extinctions that population growth and economic growth have produced elsewhere (Limburg et al., 2010).

3 – USEPA PROTOCOL TESTING

A basic goal of all ecological sciences is to arrive at global laws, theories, and generalizations. To do so, it is essential to be able to sample ecosystems in a globally consistent or comparable manner. Therefore it has been of considerable value to the USEPA, as well as aquatic ecosystem science, to be able to implement essentially the same field protocols in Brazilian streams and reservoirs as we use in surveys of streams, lakes and reservoirs in the USA. In fact, the entire suite of USEPA protocols for both streams and reservoirs (including fish sampling) were first implemented as a combined set in Brazil during the Cemig project. We were impressed by how rapidly and carefully our English-language field protocols were translated, learned, and implemented by students who had had no prior experience with such methods. Also the protocols were carefully modified when necessary. The applicability of the USEPA field protocols in Brazil and other countries also led to their greater acceptance by state agencies within the USA. We often stated that if four Brazilian students could sample stream sites under very difficult tropical conditions, a crew of USA state employees should be able to do so as well.

The fact that we could apply the USEPA field protocols in the Cerrado (savanna) ecosystem streams of Brazil gave us confidence that we could do likewise in eastern Amazon (Gardner et al., 2013), Atlantic Forest (Terra et al., 2013b), and eastern Chinese (Chen et al., 2014; Li et al., 2014) streams. After demonstrating our Cerrado results to senior Chinese scientists and students, they were more willing to implement our protocols and subsequently publish their results than if we had only showed them our USA results.

4 – ACADEMIC TEAM RESEARCH

In most of our research careers, we have worked in a USEPA laboratory as contractors, university grantees, or federal employees on an interdisciplinary research team. As we enter further into the Anthropocene, it will become increasingly necessary to collaborate across disciplines and political jurisdictions if we are to make our research politically and socially, as well as scientifically, useful. In other words, we must think and act both locally and globally (or regionally) if our science is to be globally (or regionally) applicable. Whenever possible, this collaborative team approach should be implemented with our graduate and undergraduate students so that they learn the team and data sharing skills early in their careers (Hughes, 2013; Hughes et al., 2014).

We were impressed by the team approaches among professors and graduate and undergraduate students from different universities that we worked with in Brazil (e.g., Pinto et al., 2009; Molozzi et al., 2011; Oliveira et al., 2011; Gardner et al., 2013; Ligeiro et al., 2013a,b; Terra et al., 2013a;b; Jimenez-Valencia et al., 2014; Macedo et al., 2014; Ferreira et al., 2014; Ferreira et al., In Press a; Silva et al., 2014; Tupinambás et al., In Press). We especially enjoyed observing how Brazilian students collaborated on fieldwork, data sharing and analyses, and manuscript preparation, exemplifying a team spirit versus a competitive spirit. The Cemig and RAS (Rede Amazônia Sustentável) projects allowed students to undertake much more complex and extensive research projects than any single student or principal investigator could approach alone. And those projects appear to be leading to institutional changes in Brazil. We also have observed this teaming approach among graduate students in Austria (Trautwein et al., 2012; Schinegger et al., 2012; Mostafavi et al., 2014), Bolivia (Ibanez et al., 2009; Moya et al., 2011), China (Chen et al., 2014; Li et al., 2014; Wang et al. In Press), France (Marzin et al., 2012) and Portugal (Oliveira et al., 2009; Seguradao et al., 2011). Clearly, university researchers in Brazil and these other countries are more willing to experiment and try new approaches than are government agencies in the same countries.

5 – RESEARCH FUNDING

In the USA, we have not observed or participated in research funded by a corporation such as Cemig. Thus, this has been an eye-opening experience, and we were impressed by the research funding and freedom provided by Cemig. Similarly, the existence of, and access to multiple field stations supported by corporations and open to universities offers opportunities unavailable to USA university students.

To a greater extent than in the USA, the Brazilian government funds university student scholarships and post-doctorate study outside Brazil via the Coordenação de

Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) Science without Borders program. In the USA, few ecology students are funded to study abroad and many have to take out substantial loans to fund their educations. Education in research universities will pay positive benefits as these students develop their own research careers in other institutions.

6 – PUBLIC COMMUNICATION

Both Projeto Manuelzão (see below) and the Cemig project support presentations and publications designed to communicate with the general public (e.g. Macedo et al., 2012). This is very important for at least two reasons: 1) as taxpayers and ratepayers the public has a right to know how those portions of their taxes and rates are being spent; and 2) such publications and presentations are an excellent means of educating the public about aquatic ecology and conservation. Note, Projeto Manuelzão is focused on ecological and public health research, monitoring, public education, publication, and citizen action designed to rehabilitate the Rio das Velhas Basin (http://www.manuelzao.ufmg.br). To date, its activities have contributed to substantial improvements in the water quality of the Rio das Velhas and the return of large migratory fish species. We both remember an incident at a Belo Horizonte café where we were told we did not have to pay for a snack because we were wearing Manuelzão T-shirts. As social media such as Facebook and blogs become more common, it will become increasingly useful to use those communication avenues as well.

7 – RESEARCH WEB

It is critically important to publish research results and present them at meetings—in fact not doing so means the research is incomplete. We became involved with the Cemig project because we both presented research results at a mini-course and a symposium at the 2001 Brazilian Society of Ichthyologists meeting in Sao Leopoldo, where we first met Carlos Alves and learned about Projeto Manuelzão. In 2003, several Brazilian scientists met with us again at the Manaus meeting of the American Society of Ichthyologists and Herpetologists and again in Belo Horizonte. Those meetings led to subsequent presentations and mini-courses at the Universidade Federal de Minas Gerais (UFMG), Universidade Federal de Lavras (UFLA) and Pontificia Universidade Catolica de Minas Gerais (PUC-

Minas) in 2007 and 2009, the initiation of the Cemig project in 2009, Fulbright-Brazil grants in 2007 and 2010, and a Brazil-USA workshop in Corvallis in 2011. The mini-courses also led to collaborative research in Rio de Janeiro (Pinto et al., 2006, 2009; Oliveira et al., 2011; Terra et al., 2013a, 2013b; Jimenez-Valencia et al., 2014), Para (Gardner et al., 2013), Europe (Oliveira et al., 2009; Segurado et al., 2011), and Bolivia (Ibanez et al., 2009; Moya et al., 2011) (Figure 1).

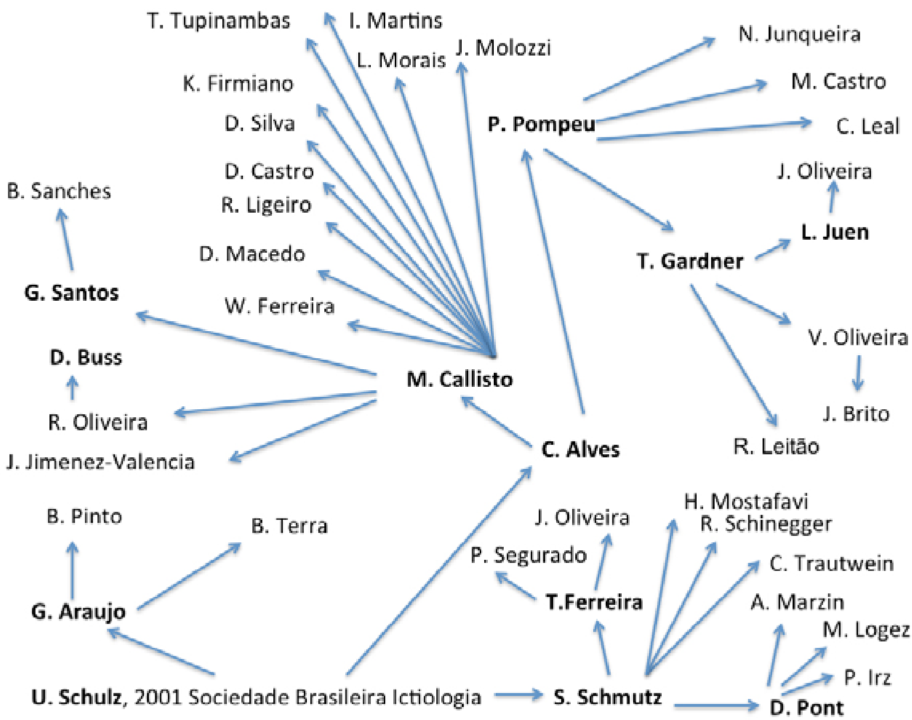

FIGURE 1. The research web emanating from the 2001 Brazilian Society of Ichthyologists meeting in São Leopoldo. Bold fonts indicate professors or senior researchers, during the initial research phases.

8 – BRAZILIAN CULTURE

It is not only the ecological research and the current and planned journal publication efforts that have continued to engage us in the Cemig Project. We have been impressed by the ability of the research team leaders to plan ahead for contingencies that inevitably happen (Plans B, C, etc.). An equally interesting trait is the ability to improvise when equipment fails or does not function properly (jeitinho brasileiro, a little Brazilian way). Even more enjoyable have been the people of the Project; the research group has become like family sharing the challenges, disappointments and joys of our research and our personal lives. In addition to our Brazilian colleagues and friends, we enjoy the Brazilian food, music, dance, celebrations, and adventures, and we relish entertaining and working with those people when they visit us in the USA. This samba atmosphere makes the hazards of fieldwork and the challenges of journal publications fun.

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SÉRIE PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 3
IBI-CEMIG PROJECT RESEARCH NETWORK: CONCEPTION, IMPLEMENTATION, PLANNING, LOGISTICS, SUPPORT, INTEGRATION AND MANAGEMENT

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1 – CEMIG'S MOTIVATION

Cemig Geração generates hydroelectricity at 59 plants, mostly in the state of Minas Gerais. With so many plants, the company owns projects in virtually all the state's river basins, creating a major challenge for managing programs designed to ease environmental impacts of those plants.

The major environmental impacts resulting from deployment of hydroelectric plants involve the fish in the impounded rivers. These impacts are particularly serious for migratory species that have different environmental requirements for completing their life cycles. Impoundment of any river segregates fish populations existing in the area and can separate areas essential for maintaining migratory species such as spawning locales, fingerling development areas, and feeding sites. Non-migratory species are affected by reservoirs also because reservoirs convert lotic systems into lentic systems that are unattractive environments for fish species that have evolved in flowing waters.

Cemig Geração efforts to conserve native fish populations go back 40 years. The first program developed was the fish stocking program, which in Cemig Geração's case began with building the Volta Grande Fish Farming Station in 1974. These programs were of fundamental importance for learning about our native fish species' reproductive mechanisms, and created conditions for mass production of fingerlings that are currently released into most of southeastern Brazil's reservoirs. However, with increased scientific knowledge of the ecology of migratory fish species, several questions arose regarding the effectiveness of stocking programs to conserve native fish populations. Clearly, new scientific strategies and approaches were needed to address fish conservation.

Cemig Geração began discussions with other utilities as early as the 1990s, and these discussions intensified significantly in the 2000s following disclosure of a number of publications relating the success of salmon stocking programs with the environmental quality of receiving environments. In 2007, company technicians took part in a seminar organized by the Universidade Federal de Minas Gerais (UFMG) and the Manuelzão Project (PMz) to revitalize the Velhas River (MG) by incorporating biomonitoring and using Indices of Biotic Integrity (IBI). On that occasion, international researchers presented results, particularly from the United States, where the index was being used as an indicator of river condition nationwide.

Implementing a project to adapt the methodology developed in the United States to

Brazil became a company priority. That was when we noticed the methodology's potential for improving our ability to manage environmental programs developed in river basins affected by company plants. We had special interest in using the information obtained to improve our native fish stocking program, by using areas with better environmental conditions for stocking and, thus, increase fingerling survivorship and integration with wild populations. With the creation of the Peixe Vivo Program in 2007, we made developing Indices of Biotic Integrity for basins in Minas Gerais one of four priorities. Therefore in 2009 we developed a research partnership with the Federal University of Minas Gerais (UFMG), Federal University of Lavras (UFLA), Pontifical Catholic University of Minas Gerais (PUC-MINAS), and Federal Technological Education Center of Minas Gerais (CEFET-MG). Oregon State University (OSU) and the U.S. Environmental Protection Agency (USEPA) were connected to the project through the above universities.

While developing the project we realized that its potential went far beyond what we had thought at first. The project information also could be used to improve management not only of the company's fish stocking program, but also to introduce riparian vegetation, assess water quality, and alleviate erosion and sedimentation in reservoirs. The assessments done in the streams and the reservoir littoral areas provide essential data and analyses to improve the environmental programs implemented. It is now a priority to collaborate with the other hydroelectric generation utilities operating in Minas Gerais and with state environmental management and inspection agencies to incorporate the assessment of biotic, chemical and physical (i.e., ecological) integrity into the monitoring of the state's water resources. Systematically monitoring a number of environmental metrics into the analyses already occurring should bring major gains to environmental management in Minas Gerais. Including new indicators and implementing a more comprehensive method of assessing impacts should pay dividends for the state's water resources and their human users. We believe the company's pioneering initiative to accomplish a project of this nature in the state of Minas Gerais will yield important fruits for our society in the near future. In particular, it will provide a management tool based on our own experiences and our rich biodiversity to boost the conservation status of the rich aquatic ecosystems, which are not only our privilege to enjoy, but also our responsibility to preserve.

2 – INITIAL CONTACTS WITH U.S.A. PARTNERS AND CONSTRUCTION OF CEMIG-UNIVERSITY PARTNERSHIPS

In 1999, a few years after UFMG's Manuelzão Project (PMz) was created, biologists Paulo dos Santos Pompeu and Carlos Bernardo Mascarenhas Alves conducted research on the fish populations in the Velhas River. Their initial aim was to update a species inventory and assess the possibility of the fish returning after treated sewage was released into the river. We had the opportunity to follow the changes in the fish fauna in this basin that resulted from multiple activities implemented by PMz but, from the start it became clear that our approach to the biological integrity of the basin's different environments needed modification.

During the 2001 Brazilian Ichthyology Meeting, Bob Hughes and Phil Kaufmann gave a mini-course entitled "Assessing the Associations among Fish, Habitat and Land Use on a Regional Scale" and presentations on "Tropical and Subtropical Adaptations of an Index of Fish Assemblage Integrity" and "Examining Associations Between Fish Assemblages and Physical Habitat". This was the first contact to attempt a partnership with these two researchers. The idea was to adapt and apply the biotic integrity approach and field protocols widely disseminated in temperate North America for environmental assessments in Brazil.

In step with the fish biomonitoring work in the Velhas River, we invited the Benthic Ecology Laboratory (LEB) team from UFMG to broaden the study approach by incorporating water quality and aquatic invertebrate parameters. This partnership bore fruit with important information obtained on environmental quality in the basin and personnel training involving professional research biologists, Ph.D. students, M.Sc. students, and B.Sc. students. This partnership (PMz/LEB) gave rise to NuVelhas (Transdisciplinary and Transinstitutional Nucleus for Revitalization of the Velhas River basin). A number of environments (streams, major tributaries, the Velhas River mainstem, backwaters) were studied along a gradient between minimally disturbed and severely polluted sites.

After the exchange of hundreds of e-mails, videoconferences, and a visit by Dr. Hughes to Minas Gerais in 2003, we decided to begin research on developing indices of biotic integrity (IBI). While we were seeking funding to implement this approach in the Velhas and São Francisco River Basins, Cemig staff attended one of our outreach seminars and became interested in applying this technology to its reservoir drainage basins. Subsequently an agreement involving the four Minas Gerais universities, two U.S. institutions, and dozens of scientists, with financial support from Cemig's Peixe-Vivo Program, was developed.

Under this project[1], 4 areas were selected for study: the reservoir basins at Nova Ponte, on the Araguari river, Três Marias, on the São Francisco River, Volta Grande, on the Grande River, and São Simão, on the Paranaiba River. Forty sites were chosen on tributary streams in each project and another 40 sites along the reservoir littoral area, totaling 320 sampling sites, an endeavor seldom encountered in Brazilian research work. In addition, 40 Nova Ponte sites were resampled 4 years later to assess temporal and crew variability—information needed for selecting biological metrics.

The new approach broadens environmental assessment, previously limited to collecting water quality parameters, invertebrates and fish, with catchment scale natural variables (geology, vegetation) and land use (urban, agriculture, pasture, silviculture) and local scale data (riparian vegetation, channel morphology, flow types, bed substrate, fish cover, human disturbance etc.).

The adaptations proposed in the aforementioned US-EPA protocols, now translated into Portuguese, can be applied in other Brazilian river basins by scientists to standardize and unify methodologies that make information produced during environmental licensing, monitoring and scientific research comparable.

The progress achieved in the project's first five years has expanded use of the biotic integrity methodology in Brazil via theses, dissertations, monographs, and scientific journal articles. Another outcome of this partnership was Cemig's manifest interest in renewing the agreements through FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais) and Research and Development (P&D ANEEL[2]/Cemig), in 2013.

3 – MANAGEMENT OF THE IBI-CEMIG PROJECT: PLANNING, LOGISTICS, AND INTEGRATION THAT FACILITATED FIELD AND LABORATORY ACTIVITIES

To develop this project's field and laboratory activities, a host of planning, management and logistics actions were needed, including organizing the field and laboratory teams, organizing and procuring materials and services, managing and organizing training and citizen events, and classroom and field instruction. Additionally, airfares, visas and

1 Development of Indices of Biotic Integrity for Environmental Quality Assessment and Support for the Restauration of Habitats in Fingerling Release Areas.

2 ANEEL = Agência Nacional de Energia Elétrica.

accommodations for our U.S. partners were needed for the planned training programs, lectures, workshops, technical meetings, and data analysis activities.

The team coordinators from the four universities (UFMG, UFLA, PUC-Minas and CEFET-MG) participated in periodic action planning meetings. Within each team, scientists from different academic levels were involved in organizing materials and procedures for the field and laboratory activities for the duration of the project. From the start, organizing teams for field and lab work as well as data analyses and manuscript co-authorship in each Brazilian and American institution harmonized responsibilities and competencies. At the Brazilian institutions, associate researchers, Ph.D., M.Sc. and B.Sc. students were selected. On the U.S. side, a Cooperation Agreement was formalized between UFMG (coordinating institution) and OSU.

The field and laboratory material used included a large number of items and specific details that were only determined after the methodology and knowledge of the protocols to be applied had been detailed. Some of the equipment and materials used to assess physical habitat structure was imported from the U.S. To this end, full specifications, quotes and applications to the Imports Department of the Fundação de Desenvolvimento da Pesquisa (FUNDEP) were instituted. FUNDEP is an institution accredited by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under Federal Law no. 8,010/90, which provides for tax exemption on products intended for scientific and technological research. To acquire items on the domestic market, full specifications, quotes and applications to the FUNDEP Procurement Department were also necessary. For items available on the domestic market we accelerated the purchasing process and minimized mistakes by contacting suppliers in advance and negotiating priority materials and minimum delivery time. The partnership and management by FUNDEP facilitated international and domestic purchases in a rapid and economical, manner while ensuring equipment quality, critical features in managing a large project with many researchers and institutions involved.

The project's first action involved joint training of the teams on the new approach to be used in the IBI-Cemig Project, during which the U.S. colleagues also participated. On their first visit, the U.S. partners led a theoretical/practical course at Serra do Cipó (November-December 2007). Acquisition of flights and visas required adjustments to agendas, negotiated at a distance through an intensive exchange of emails. Accommodation at a hotel or at UFMG's student residence (a vacancy arranged with the Post-Graduation

Pro-Deanship) involved students and professors to reduce security risks and difficulties in adapting by the U.S. colleagues. This arrangement also increased personal contacts with several team members and strengthened personal and academic relationships among the research team. The second visit (the start of practical activities using the IBI methodology) was determined after the itineraries of the U.S. researchers were set and in a general meeting (September 2009) during which field team training and the materials needed to perform the methodology to be adopted were established.

Before the first collection, a second theoretical-practical course was administered at UFMG (September 2009), the training program was planned, and the first field campaign was carried out (September-October 2009). The training course was held at the Galheiro Environmental Station, with support from Cemig (owner of the reserve) and from the UFMG Graduate Program in Ecology, Conservation and Management of Wildlife, (PG-ECMVS/UFMG) where the training program's theoretical course was administered. The planning comprised accommodation (lodging and tents) for the entire team (c. 40 people), food (hired in the region), and transportation. Following the Galheiro training, hotel rooms were booked in the Nova Ponte Reservoir drainage area for all four field teams. Hotels were located strategically at central sites relative to several sampling stations, so as to avoid long and unnecessary travel. In addition to the UFMG Benthic Ecology Lab's and the UFLA Fish Ecology Lab's pickup trucks, four-wheel-drive extended-cab vehicles were rented capable of carrying 4 to 5 people and the collection gear.

Before sampling Nova Ponte Reservoir, we held a reservoir training session to ensure that all field personnel were adept at using limnological sampling gear. To sample 40 stations in each reservoir, approximately 15-20 collection days were required. To do that, we established two independent teams, each with two small motor boats. Each team consisted of three biologists and a fisherman. During Três Marias Reservoir sampling, we also used a houseboat from Companhia de Desenvolvimento do Vale do São Francisco (CODEVASF) as our base. We used the houseboat for crew lodging, laboratory, and shelter for the sampling equipment. The CODEVASF support saved us time and greatly facilitated our work in that large reservoir.

To cover the field team a collective life and accident insurance policy was obtained, involving labor, safety and health issues. Travel over secondary and tertiary roads and highways in rural areas, activities in wild and inhospitable environments, and the possibility of falls and encounters with poisonous animals and plants impose inherent hazards that can be minimized by using personal safety protection equipment and practices.

The group formed by the UFMG Benthic Ecology Laboratory; the UFLA Fish Ecology Lab, and the PUC-Minas Vertebrate Zoology Post-Graduate Program selected methodologies, produced primary lists, and organized items for each field team. The material was labeled and separated by colors so that there would be no mixture or missing gear among teams. Besides the complete equipment boxes the material included reserve items to replace possible losses occurring during the fieldwork. In addition to the materials specific to each parameter to be assessed, concern with personal safety gear was an important factor. Such equipment included rubber waders and gloves to avoid contact with contaminated water, life vests for reservoir work, hats, long-sleeved shirts and sunscreen to minimize exposure to UV rays, raincoats, water jugs, and snake protection leggings.

In the office, cost estimates for the field teams' logistics, accommodations, food and travel were determined. Calculations were based on field crew size, periodic crew member substitutes, the number of days needed, indispensable minimum amounts, and a 10% safety factor to offset contingencies.

In addition to project management and logistics, the universities offered classes on the full scope of the Cemig project. In this way, the theory involved in developing indices of biotic integrity was presented, discussed and implemented among professionals and students from the universities involved. In addition to the principles involved in sampling and data analyses, classes included reading pertinent journal articles, interpreting results, presenting at technical and scientific meetings, writing scientific manuscripts, and field projects. For field exercises, transportation (a bus and driver) was provided by the universities, PMz, and UFMG.

The involvement of citizens living in the project areas was guaranteed by presentations at community meetings near the reservoirs studied. These meetings were annual, after preliminary data analyses, and included student presentations of B.Sc. monographs, M.Sc. theses, and Ph.D. dissertations developed during the project. Local companies, Cemig staff, members of regional basin commissions, professional fishermen, students from universities in the areas, and other representatives from the local community were present. Those meetings were important both for communicating the science to citizens and for training future professionals in addressing the public.

To further reach out to the local community and a broader audience, including the university community, medium-sized workshops were held. These workshops included presentations by field professionals from renowned domestic and international institutions as well as discussions and proposals for adapting methodologies. These events enriched the level of discussions and conceptual bases used in this universities-Cemig research partnership. In addition to the Minas Gerais basin workshops a *Workshop on Ecological Assessment: the Foundation for Evaluating Biological Patterns* was held for one week in October 2011 at the USEPA lab in Corvallis, Oregon. This workshop introduced the graduate students and professionals and their research to USEPA and OSU scientists and vice versa. Following the workshop, a Ph.D. and an M.Sc. student from UFMG remained at the lab for one year and one month, respectively, to analyze data and prepare journal manuscripts. The latter student has initiated a one-year Ph.D. internship at OSU to begin in 2015, and two Ph.D. students from UFLA completed one-year OSU internships in 2013.

4 – MANAGEMENT OF THE PROJECT AT FUNDEP

One of the principles of FUNDEP is to enable various projects to be conducted under transparent, safe and innovative administrative and financial management conditions. FUNDEP was established in 1975 as a private entity and duly recognized by the Ministries of Education and of Science, Technology and Innovation as a support foundation, with the goal of supporting UFMG's research, teaching, extension education, and institutional development activities and those of other major teaching and research centers in the country. Working within projects, FUNDEP has helped transform knowledge into fostering education, health and culture, protecting the environment, and enriching Brazilian society. FUNDEP was central to the Cemig project for almost five years of joint work.

Because of its considerable ecological, social and scientific importance, the Cemig initiative was aided by the involvement of multiple universities, the electrical industry, students, professors and researchers, which required FUNDEP's competence in managing a multi-institutional network project. FUNDEP was coordinated by Marcos Callisto (UFMG), Paulo Pompeu (UFLA), and Gilmar Bastos Santos (PUC-Minas).

Working on this project provided FUNDEP the opportunity to broaden its expertise in managing projects and taking part in mobilizing large research teams. That is why multiple meetings were held to present services, align procedures and strengthen bonds with the project coordinators. The network initiative required intensive negotiations with the different partners and systematic follow-up at each phase to ensure that the research team activities were integrated, coordinated, cost-effective, and completed on schedule.

Among project management activities, FUNDEP developed an online interface tool with its partners, which allowed researchers to monitor initiatives via the web from anywhere at any time. The system enabled users to log inquiries and view and generate detailed reports on the project's financial condition. The tool provided high quality service, in line with the partners' needs and in accordance with the legal requirements and rules established by the financing agencies and university administrations.

To manage the Cemig project, subprojects were created and divided into stages for each coordinator. In this way and with the online tool researchers were able to monitor how each step was managed specifically and follow each group's progress and inquiries from basic consumable materials to vehicles. To put the project into practice, FUNDEP implemented hundreds of domestic acquisitions of goods and services apart from importing equipment such as microscopes. Another critical factor was personnel and logistics management, because the teams conducted intensive fieldwork and presentations in four Minas Gerais basins. Field research is susceptible to climatic and environmental factors that can cause sudden cancelations, alterations, and urgent requests. FUNDEP worked quickly to ensure that the scientists' needs were met quickly and efficiently.

FUNDEP provided high quality project management that facilitated project coordinators and research teams being able to focus their attention on essential research issues. FUNDEP provided a key service in helping us to generate scientific results, provide environmental and social benefits, and transfer knowledge produced in universities and research institutes to citizens.

5 – THE CEMIG PROJECT TEAM MEMBERS

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Guilherme Moreira Santos
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CENTRO FEDERAL DE EDUCAÇÃO TECNOLÓGICA DE MINAS GERAIS

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SÉRIE PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 4
SAMPLING SITE SELECTION, LAND USE AND COVER, FIELD RECONNAISSANCE, AND SAMPLING

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MACEDO, D.R.; POMPEU, P.S.; MORAIS, L.; CASTRO, M.A.; ALVES, C.B.M.; FRANÇA, J.S.; SANCHES, B.O.; UCHÔA, J. & CALLISTO, M. Sampling site selection, land use and cover, field reconnaissance, and sampling. In: CALLISTO, M.; HUGHES, R. M.; LOPES, J.M. & CASTRO, M.A. (eds.), *Ecological conditions in hydropower basins*. Belo Horizonte: Companhia Energética de Minas Gerais, p. 61-83, 2014. (Série Peixe Vivo, 3).

1 – INTRODUCTION

Spatially extensive environmental assessments require samples that facilitate associating physical, chemical, and biological site conditions with watershed conditions. Sites must be selected in a random manner to allow statistical inference to the entire population of sites in the study region. Such studies are severely limited by sampling and processing time and human and financial resources (Hughes & Peck, 2008). Reconnaissance is needed before sending entire field crews to the sites to ensure permission from landowners, efficient and safe access, and appropriate site characteristics. To ensure that sites are sampled under the same hydrologic conditions, multiple crews are needed so that sites can be sampled during a short index period (less than one month during the dry season for streams, at the end of the wet season for reservoirs). Sites sampled once per year maximize the number of sites that can be sampled during an index period. Thus, the objectives of this chapter are to describe how we selected sites, reconnoitered and sampled sites, and determined watershed conditions.

2 – STUDY AREA

The Cerrado, with its different phytophysiognomies, covers nearly 20% of Minas Gerais (Carvalho & Scolforo, 2008), where the São Francisco and the Araguari Rivers headwaters are located. The São Francisco River basin covers an area of 645,000 km2, approximately 7.6% of Brazil (Godinho & Godinho, 2003; Sato & Godinho, 2003). The Araguari River, one of the main tributaries on the left bank of the Paranaiba River, runs over 475 km through a drainage basin covering an area of 21,856 km^2 (Baccaro et al., 2004). The Paranaíba River, in turn, meets the Grande River in the Mineral Triangle region to form the Paraná River.

We considered streams located within the area of influence of four hydropower reservoirs owned by Cemig Geração e Transmissão S.A., namely Nova Ponte, São Simão and Volta Grande HPP in the Upper Paraná River Basin, installed on the Araguari, Paranaíba and Grande Rivers, respectively, and that of Três Marias, located on the São Francisco River.

3 – SURVEY DESIGN

Environmental assessments rely on sample sites that aid associating species distributions with site and watershed physical and chemical conditions. Such sites are identified by their geographical location, as opposed to studies in which the variable space is not accounted for (Stevens & Olsen, 2004; Theobald et al., 2007). Spatially balanced sampling, constructed through probabilities, is able to select a network of points that reflect the spatial conditions of the area studied (Theobald et al., 2007). In the USA, this approach is used nationally and regionally (Olsen & Peck, 2008). In Brazil, however, this was a new approach. Therefore studies featuring this type of sampling design are still rare (Ligeiro et al., 2013; Jimenez-Valencia et al., 2014; Macedo et al., 2014).

In our project, we adopted the GRTS (Generalized Random-Tessellation Stratified) approach, in which the sampling design is hierarchically and spatially balanced and applicable to points, lines, and polygons (Stevens & Olsen, 2004). This approach is based on the conversion of all the objects (for example, stream kilometers or reservoir shorelines) along a unidimensional vector. This vector is like a long avenue, and each site is like a hierarchically distributed address on that avenue (Stevens & Olsen, 2004). We developed a spatially balanced sampling design for the Nova Ponte, Três Marias, Volta Grande and São Simão reservoir margins and their wadeable stream reaches (Kaufmann et al., 1999) located < 35 km upstream from the reservoirs.

To select stream sites we used the IBGE's (Instituto Brasileiro de Geografia e Estatística) and DSG's (Diretoria de Serviço Geográfico do Exército Brasileiro) topographic maps (1:100,000 scale), digitized by the Geominas Project (Vegi et al., 2011). The drainage network was topologically corrected via ArcGis Desktop and Strahler (1953) stream order was determined through use of the Hydroflow software program (Ramos & Silveira, 2008). We defined the potential site spatial distribution using R (R Development Core Team, 2010) based on the Spsurvey library (Kincaid, 2009). We created a stream network master sample and established a random list of potential sampling points with a minimum of 1 km distance between each. Points within the reservoir and rivers greater than third order were eliminated, and the first forty points (first through third order) were selected for reconnaissance. We sampled streams with a Strahler (1953) order lower than four (Figure 1). The sites covered a diverse range of characteristics and we considered both the land use in the riparian zone and its surroundings (pasture, farming, urban) at different disturbance levels. Similarly, within the streams themselves a diversity of meso-habitats were studied in terms of different types of substrate (boulders, gravel, sand, etc), flow (rapids, glides, pools etc), and variations in channel width and depth. Because one purpose of the IBI-Cemig Project was to assess biotic integrity, we needed to guarantee that some sites were minimally altered and others severely altered (Whittier et al., 2007). Therefore, some sites were hand picked in preserved areas (e.g., the Galheiros/Cemig reserve) and in highly altered urban areas (Figure 2). It is important to note that sites considered as reference sites are those minimally disturbed by anthropogenic activities yet representative of the region in which they occur. These served as controls (Hughes et al., 1986).

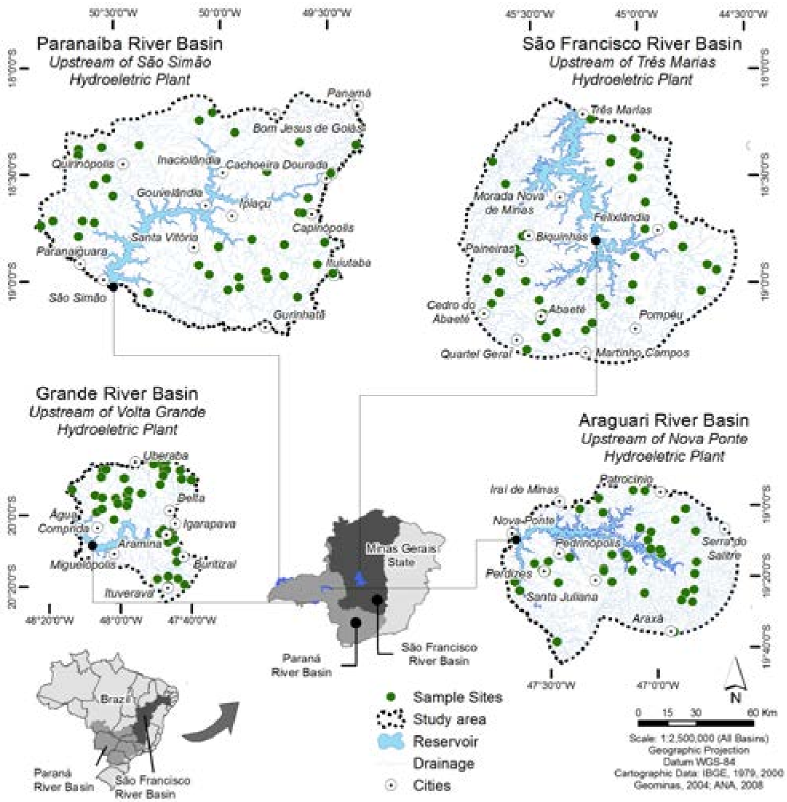

FIGURE 1. Locations of stream sites randomly arranged upstream from São Simão, Três Marias, Volta Grande, and Nova Ponte Reservoirs.

FIGURE 2. Examples of minimally and highly disturbed sites in Nova Ponte, Três Marias, Volta Grande, and São Simão drainages.

We sampled reservoir littoral zones and the reservoir perimeter was established from satellite images. The polygon representative of each reservoir perimeter was extracted from a Landsat image with R7G5B4 composition, eliminating the penetration of light into the water (Jensen, 2006). We used the Maxver classification method to identify the body of water using the Spring/INPE software package (Camara et al., 1996). The randomization process was adapted from Stevens & Olsen (2004) and the routine was implemented using the ArcGis Desktop suite. The perimeter of the reservoir was converted from a line to points; then a point was randomly selected from this group of points and another 39 were positioned equal distances apart along the perimeter (Figure 3).

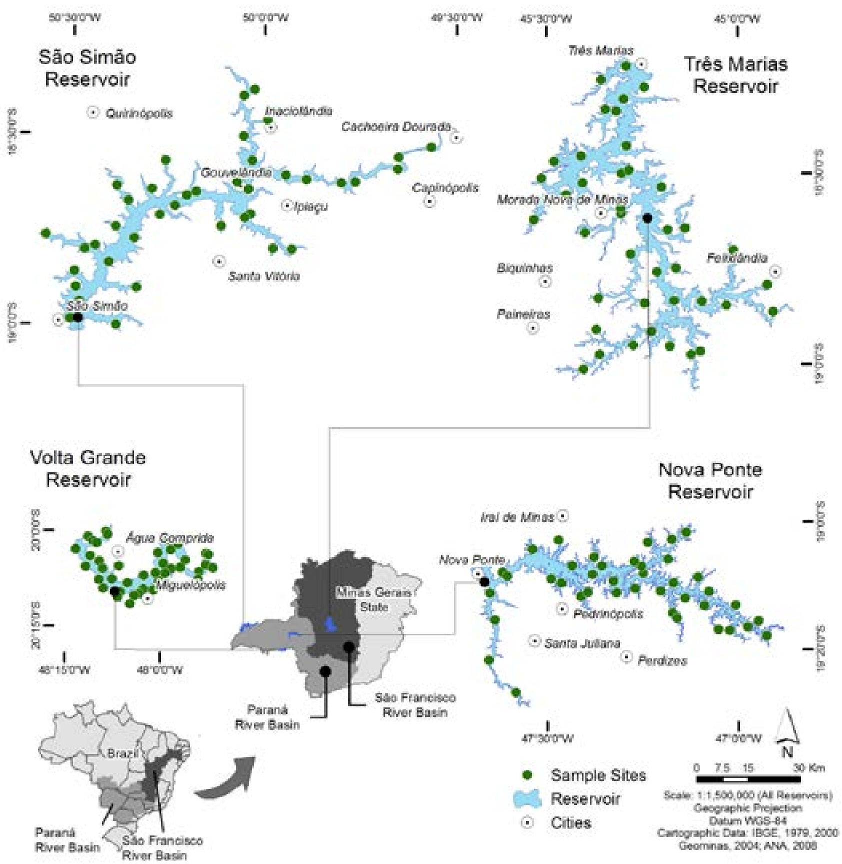

FIGURE 3. Locations of sites in São Simão, Três Marias, Volta Grande, and Nova Ponte Reservoirs.

4 — FIELD RECONNAISSANCE

Once sites had been selected, two-person teams performed field reconnaissance before each sampling campaign. Prior reconnaissance of sampling sites optimized the time required for field sampling, as it ensured that sites were physically and legally accessible and safe to sample. In the case of stream sites, a major purpose was to ensure sites had flowing water and reasonable road access (< 1 km from the site). For reservoirs, the objective was to determine boat access that minimized distances between sites and facilitated sampling multiple sites from a single landing. Following definition of the sampling network, the best access routes were established. We used Google Earth (Google, 2010) software to trace routes (Figure 4) and transferred them to a GPS device connected to a laptop computer (Figure 5) to facilitate navigation and field recognition by the team. At each point, the reconnaissance team recorded useful access information. During field reconnaissance, if site access was excessively difficult or prohibited by land owners, teams were prepared in advance to select new sites, in accordance with the hierarchical rank established using the Master Sample software package. At the end of the field reconnaissance trip, 40 stream sites had been guaranteed for sampling. Reservoir reconnaissance also used Google Earth (Google, 2010) software to locate possible boat access points along the reservoir shore and their respective roads. Distances between points were calculated for sampling points and their respective access points, which aided in planning the sampling sequence (Figure 6).

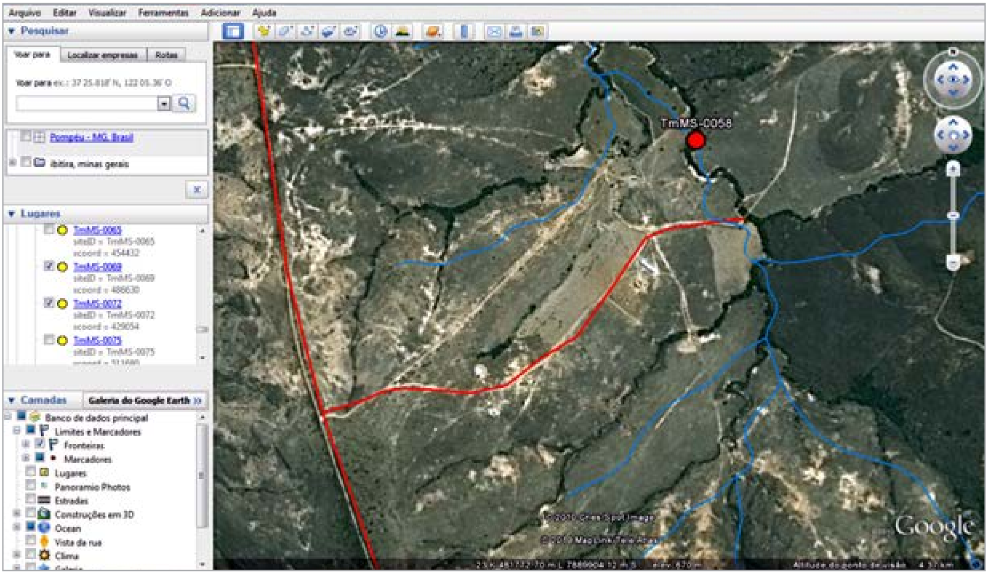

FIGURE 4. Route traced on Google Earth to reach point TMMS-0056, in the Três Marias Reservoir drainage.

FIGURE 5. Field reconnaissance team in the São Simão Reservoir drainage.

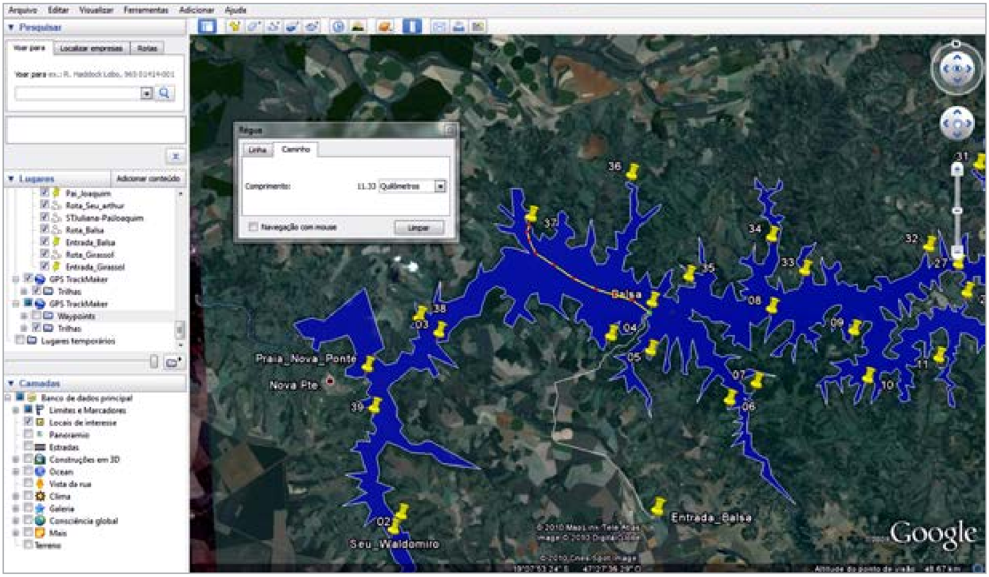

FIGURE 6. Checking distances between sites in Nova Ponte Reservoir through use of Google Earth.

5 – FIELD TEAM GEAR AND EQUIPMENT PREPARATION

The organization of the gear and equipment used by the field teams during the sampling campaigns was undertaken jointly with the partner universities. For stream sampling, when 3 or 4 teams worked simultaneously, all field gear was identified by a different color for each team in advance to avoid confusion. By maintaining several teams in the field at the same time we ensured that sites were sampled under the same hydrologic conditions (within two weeks and one week for streams and reservoirs, respectively), given the fact that each team was able to sample only one stream site per day. Because of differing logistical restrictions for reservoir macroinvertebrate and fish (overnight gill netting) sampling, those two teams worked independently and each specific piece of gear and materials was the responsibility of the UFMG or PUC-MINAS laboratory. Some equipment had to be imported because it could not be found in Brazil. To do so, a market survey was conducted among suppliers and all equipment was acquired according to descriptions made available by the US Environmental Protection Agency (Peck et al., 2006; Callisto et al., THIS VOLUME).

Field teams were established to include representatives of the different skill sets and universities involved. For stream sampling, the labor demand was greater with an average of 12 people required (3 or 4 teams with at least 4 members each). On each crew, there was a person in charge of each function: filling out physical habitat forms, measuring physical and chemical parameters, benthic macroinvertebrate sampling, and fish sampling. Fish sampling in reservoirs required three to four people per team, because they took turns placing gill nets and retrieving them the next morning, seining littoral zones, and sorting and fixing fish. The other reservoir sampling required a three person team with one person in charge of one function: filling out forms, physical and chemical habitat sampling, and benthic macroinvertebrate sampling, with occasional support from another team member. In addition, we hired a licensed boatman familiar with the reservoir for each team. Before any site was sampled, all participants were trained in field safety and to ensure that standard methods and measurements were used in collecting physical, chemical, and biological data.

6 – ENVIRONMENTAL AND BIOLOGICAL CHARACTERIZATION

The length of each stream site was 40 times its wetted width, with a minimum distance of 150 meters (Peck et al., 2006; Hughes & Peck, 2008). The site was divided into 11 cross-sections (A-K) and 10 equidistant measurements were made between each section following the thalweg profile (Figure 7). At the cross-sections, multiple physical habitat characteristics were assessed and macroinvertebrate samples were taken (Ligeiro et al., THIS VOLUME); water samples were collected at the upstream section (K) before all other sampling, (Figure 8). Fish were sampled for proscribed times between each cross section (Leal et al., THIS VOLUME).

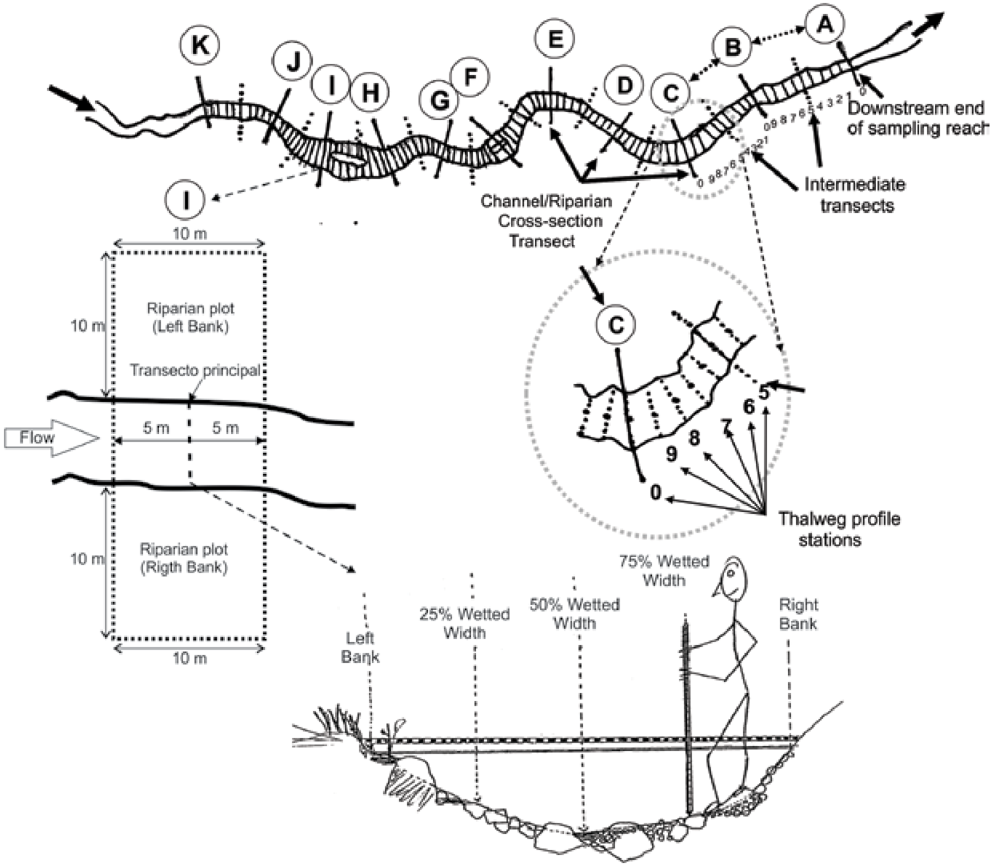

FIGURE 7. Site sampling scheme (from Peck et al., 2006).

FIGURE 8. Photos of field teams sampling streams.

At each of the 40 reservoir sites, we sampled 10 parcels, each 15 meters wide, totaling 150 meters at each sampling site in the littoral region of each reservoir (Figure 9). Each parcel was composed of continuous littoral zones (15 meters wide and 10 meters deep), a riparian zone (15 meters wide and 15 meters deep), and a floodable zone (15 meters wide with a variable depth depending on the degree of reservoir drawdown and the bank slope at the site; USEPA, 2011; Figure 9). Multiple physical habitat characteristics were assessed in each of the three zones; water, sediment texture, macroinvertebrates, and fish were sampled in the littoral zone (Figure 10; Morais et al., THIS VOLUME; Sanches et al., THIS VOLUME).

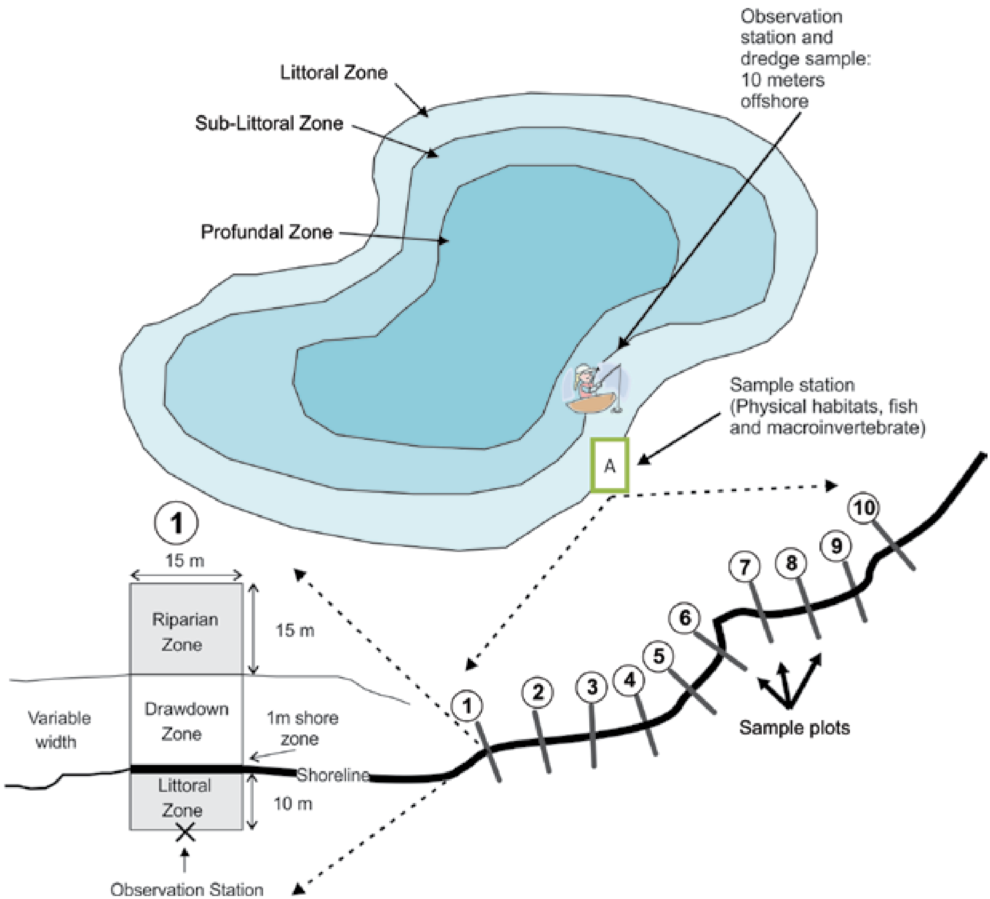

FIGURE 9. Sampling scheme in the reservoir littoral region. Adapted from USEPA (2011).

FIGURE 10. Reservoir sampling. Collecting water samples (A; B; C), applying the physical habitat protocol (D), collecting macroinvertebrates with a kick-net (E), and collecting sediment and macroinvertebrates with an Eckman-Birge dredge (F).

7 – LAND USE AND COVER

Watershed and buffer land use and cover affect the quality of aquatic habitats and, consequently, the aquatic biota. Anthropogenic uses, notably urbanization and agriculture, diminish native vegetation cover, including in the riparian zones, degrading physical habitats, altering hydrology, and increasing sedimentation rates, water temperature, and nutrients (Bryce et al., 2010; Kaufmann et al., 2014). Therefore, it is useful to relate the land use and cover at several different spatial scales with the quality of physical and chemical habitats (Walser & Bart, 1999; Wang et al., 2001).

We determined land use and cover for each stream site catchment and within a 500-meter radius from each reservoir site. To classify land use and cover, we employed manual interpretation of images with fine resolution (0.6 – 5 meters; Google Earth images; Google, 2010) and a set of multispectral images from the TM sensor installed in the Landsat satellite (Figures 11 and 12). Fine resolution images provide the form and texture of elements and the Landsat images produce distinct spectral responses of the targets, facilitating high mapping precision. For example, in the fine spatial resolution featured in Google Earth, vegetation usually appears in the same color (e.g., both forest and sugar cane plantation are green). However, these land uses in a Landsat image look different because foliar structure differences are included (Jensen, 2006). In our study, we mapped four vegetation cover physiognomies (IBGE, 1991): forested savanna, gramineous-woody savanna, park savannah and wet areas. We also mapped four land use types: agriculture, pasture, eucalyptus reforestation, and urban.

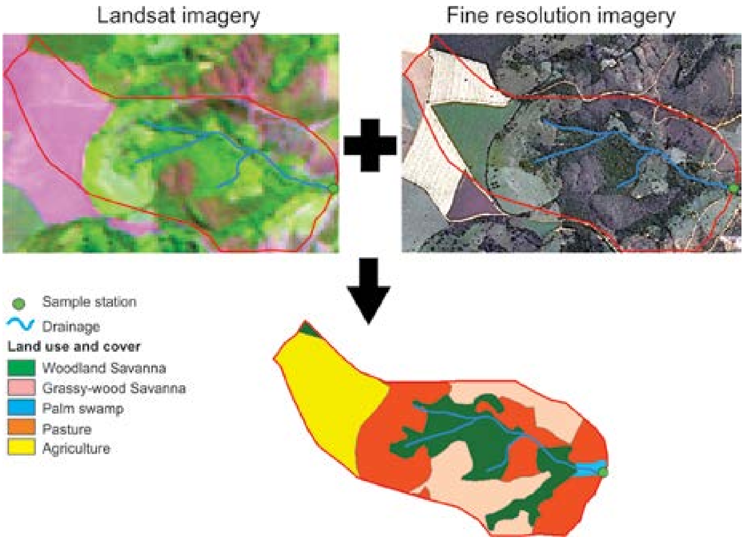

FIGURE 11. Schematic methodology used at site NPMS-00128, Nova Ponte Reservoir drainage.

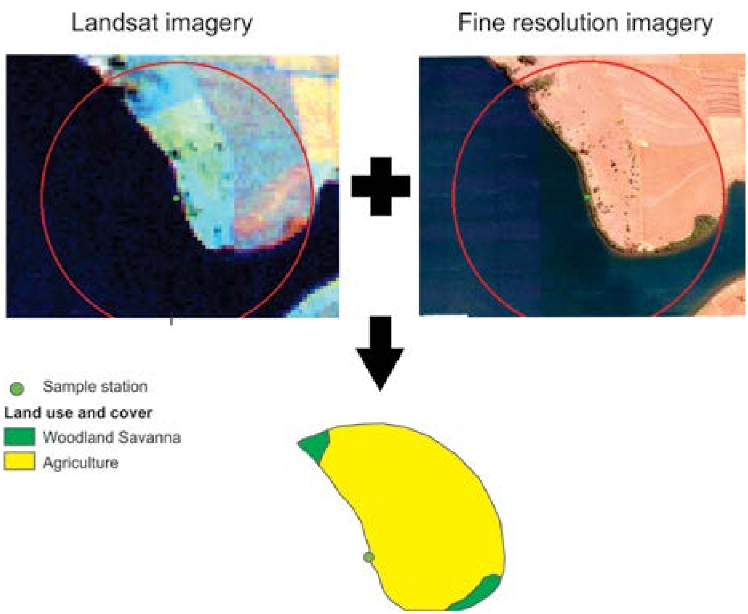

FIGURE 12. Schematic methodology used at site 35, Volta Grande Reservoir.

Agriculture was most predominant in the Volta Grande and São Simão drainages (mean about 70%), followed by Nova Ponte (mean about 50%) and Três Marias, (mean near 0%; Figure 13). Pasture was greatest in the Três Marias drainage (mean near 40%), and the Nova Ponte, Volta Grande, and São Simão drainages were all less than 20%. Regarding natural vegetation cover (forested savanna, gramineous-woody savanna, or park savanna), Nova Ponte and Três Marias were the least altered drainages (natural vegetation means nearly 40%), whereas the other drainages had means of only 10% natural vegetation cover. Mean urban area in all the drainages was lower than 5%, but somewhat higher in Volta Grande and São Simão than the others. These results demonstrate that Nova Ponte and Três Marias watersheds were generally less disturbed than São Simão and Volta Grande watersheds.

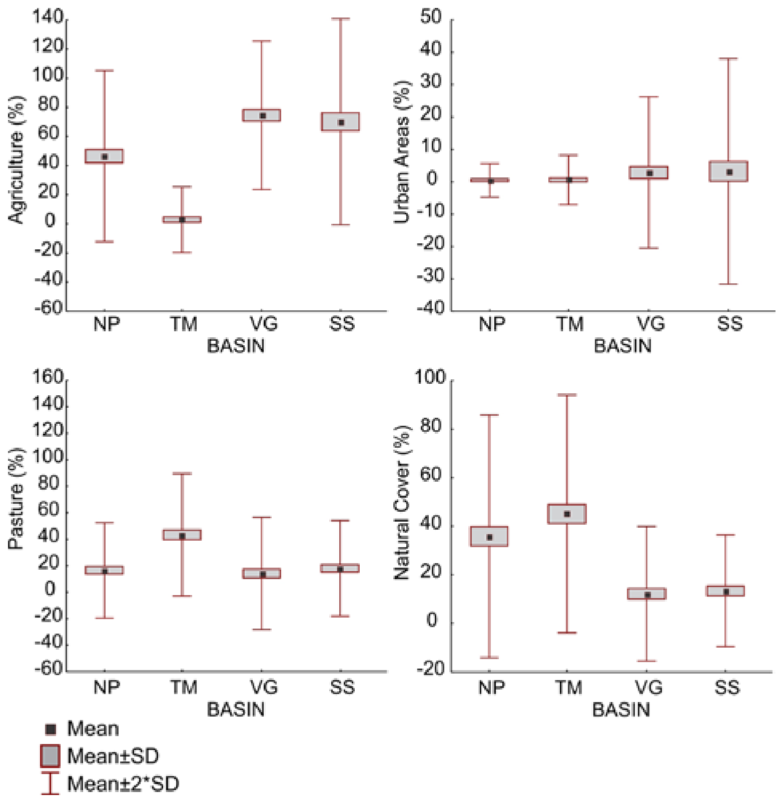

FIGURE 13. Land use in the site watersheds of Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) drainages.

Buffer results for the reservoir sites were similar to those of the drainages' stream sites. The Volta Grande buffers had the highest percentage of agriculture (mean near 85%) compared with São Simão (mean near 20%), and Nova Ponte and Três Marias (means about 10%; Figure 14). Regarding buffer pasture, São Simão had the most (mean near 40%), Nova Ponte and Três Marias pasture means approximated 10%, and the Volta Grande mean was near 0%. Natural vegetation cover was greatest in Nova Ponte and Três Marias buffers (means near 60%); the other reservoirs had means of about 10% of their buffer area in natural vegetation cover. All site buffers had means of less than 5% urban, but Volta Grande and São Simão had slightly more than Três Marias and Nova Ponte. Thus the buffer areas at Nova Ponte and Três Marias were generally less disturbed than those of São Simão and especially Volta Grande.

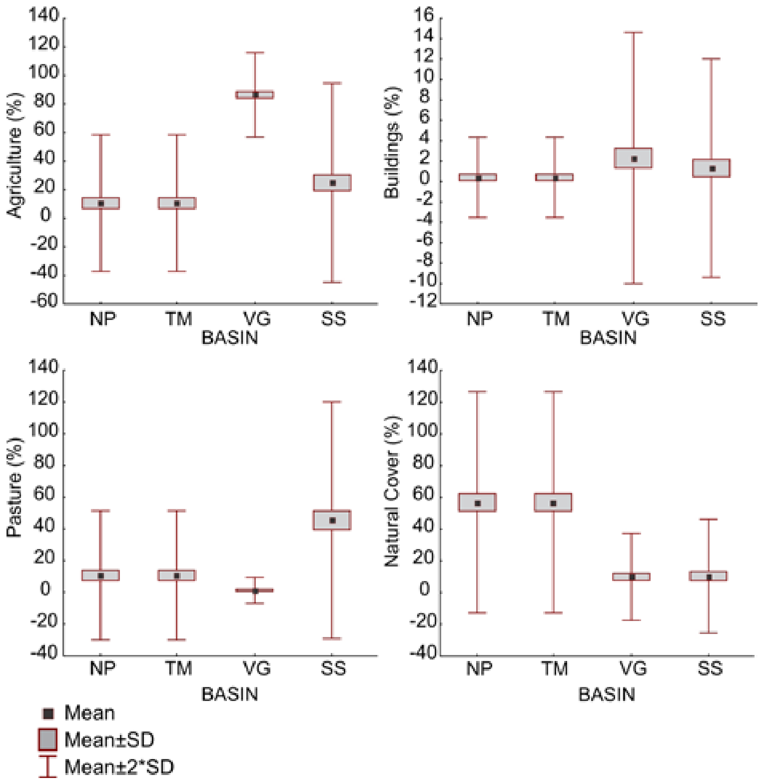

FIGURE 14. Land use in buffers (500 meters) of Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) reservoir sites.

8 – ACKNOWLEDGEMENTS

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SÉRIE PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 5
STREAM SEDIMENTOLOGICAL ANALYSES BASED ON THE USE OF RAPID EVALUATION PROTOCOLS

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1 – INTRODUCTION

Impacts resulting from sediment erosion, transportation, and deposition processes have been severe for decades. The main factors contributing to those processes include anthropogenic alterations to the Earth's surface and climate change (Marengo, 2007; Kaufmann et al., 1999; Rodrigues, 2002; Carvalho, 2008; FISRWG, 1998). Their impacts include degraded physical habitats (Kaufmann et al., 1999; Mazeika et al., 2006), and economic losses resulting from reservoir sedimentation (Carvalho, 2008). Detailed studies of watershed erosion and stream sediment transportation can be used to identify sediment sources and diagnose environmental impacts on rivers (Kaufmann et al., 2008).

Sedimentology studies are particularly important in Brazil, where electricity is predominantly hydraulically generated (Carvalho, 2008). River systems normally function within natural rates of water, sediment, and energy flow, which are called dynamic balance (FISRWG, 1998). Significant changes in erosion rates, transport and sediment deposition alter this balance and impair the quality of surface waters (Kaufmann et al., 1999).

Because of the consequences of river and reservoir sedimentation, government institutions have used rapid assessment protocols to assess river condition with a view to preserving natural transportation and deposition rates (Maddock, 1999; Harding et al., 2009; Oliveira & Cortes, 2005). This idea emerged in the United States in the mid-1980s. Quantitative study of sediment transportation and deposition processes involves ongoing monitoring with costly equipment and methods, which includes operating metering stations and topo-bathymetric surveying (Carvalho, 2008). There are few such sedimentological stations along major Brazilian watercourses. Environmental agencies realized the need to establish qualitative assessment methods based on selected quantitative case studies because of the high cost and time commitment of the latter studies. The rapid assessment protocols also have been used for habitat type mapping of river reaches in a fairly short time (Maddock, 1999; Harding et al., 2009).

The aim of our study was to assess the applicability of a rapid assessment protocol in sedimentology studies, which normally use station-monitored data. We applied those protocols on streams that are tributaries of Nova Ponte, Três Marias, São Simão and Volta Grande Reservoirs, and assessed the principle anthropogenic and morphological factors affecting bed stability and sediment input. In this chapter, we discuss the following:

Contributions of the protocols to sediment management in Brazilian rivers;

The importance of anthropogenic activity in sediment transportation processes;
The extent to which sampled sites were affected by sediment transportation; and
The consequences of these results on the available habitat of local aquatic species.

1.1 Sedimentological Sampling Methods and the Brazilian Stations Network

Sedimentometry studies are normally conducted at a flow station because other measurements, such as current velocity and net flow rate, are also important for this kind of study. There are several methods for sampling suspended, bed, or total sediment loads (Carvalho, 2008). Samples are weighed before processing, then receive granulometric measurement; the concentration of suspended material is determined, as is grain size. In 2000, Brazil had 1,581 primary stream flow metering stations, of which 415 featured suspended solids measurements. Other entities operate a secondary network and also measure suspended solids. The station locations and measurement frequencies leave much to be desired when it comes to properly understanding natural environmental status and trends (Carvalho et al., 2000). Thus, alternative techniques for sediment sampling are needed on a national scale. We stress the importance of understanding sediment transportation processes for the electricity sector, because estimates point to high costs. For example, in the United States, the costs of recovering lost capacity resulting from sediment accumulation in reservoirs total millions of dollars annually (Chow, 1964).

1.2 Theory of Sediment Transportation

Stream bedload starts to move when the stress acting on a given particle is greater than its resistance to movement (VTDEC, 2001). Flow stress is defined as the ratio between the specific weight of water, the hydraulic radius and the channel slope (EQ 1):

(Eq. 1)

$$\tau = \gamma R_h S$$

Where:

t = Bed shear stress (Newtons/m^2);
g = Specific weight of the water (Newtons/m^3);
R_h = Hydraulic radius of the channel (m);
S = Channel slope (m/m)

When flow shear stress equals particle resistance, there is critical bed shear stress (tcr) (EQ 2). Particle resistance varies according to its diameter, the sizes of surrounding particles, the bedding angle, and the percentages of their volumes inserted in the riverbed (VTDEC, 2001). The diameter of the particle relative to the surrounding ones affects its exposure to the flow, which is measured by a protection factor (θ). Based on these principles, Shields (1936) proposed the following expression for the critical bed shear stress needed to move a particle of a given diameter.

(Eq. 2)

$$\tau_{cr} = \theta g(\rho_s - \rho_w)d$$

Where:

t_{cr} is critical bed shear stress (Newtons/m²);
θ is the Shields parameter;
g is gravity acceleration (m/s²);
ρ_s is sediment density (kg/m³);
ρ_w is water density (kg/m³);
d is the diameter of the particle of interest (m);

The quantity of transported material in a river depends on the magnitude of such forces and when they are applied. To estimate the largest particle capable of being transported by a particular flow, the critical bed shear stress must equal flow shear stress, calculated at bankfull flow (Kaufmann et al., 1999):

(Eq. 3)

$$\gamma R_{bf} S = \theta g(\rho_s - \rho_w)d$$

Where:

R_{bf} = the hydraulic radius at bankfull flow (m);

This is justified because hydraulic stream flows during flooding are capable of shifting the largest particles commonly encountered in a river (Lisle, 1982). Thus, a few flood flows significantly alter river channel morphology. Normally, bankfull flow is considered to be the minimum flow capable of altering the shape of the channel and relates to a 1 to 2 year occurrence frequency. Bankfull flow is defined as the limit at which the flow spills over the channel and reaches the flood plain (Harding et al., 2009). When shear stress calculated for the bankfull flow is equal to critical shear stress, the channel is in balance. Stresses higher than critical indicate channel degradation; bed shear stress below critical indicates aggradation. Gauging both types of bed shear stress is crucial to understanding channel adjustments (VTDEC, 2001).

Assessment of stream sediment diameters allows us to analyze their potential for transport; therefore, one way of estimating channel stability is to assess the mean diameter of particles in the bed. The riverbed is unstable when most particles are finer than the mean size the river is capable of moving. This comparison is used to assess the effects of sediment input (Kaufmann et al., 2008). The logarithm of the relative bed stability index (LRBS) is determined by Eq. 4:

$$LRBS = log\left(\frac{D_{gm}}{\left[\frac{\rho_w g R_{bf} S}{\theta(\rho_s - \rho_w)g}\right]}\right) \quad \text{(Eq. 4)}$$

Where:

D_{gm}= mean geometric diameter (m);

All this information can be garnered from Kaufmann et al. (1999) and is an indirect method of assessing stream bedload. Given the operating and financial aspects of the Brazilian sedimentometry system, employing such protocols can provide important and cost-effective information about aggradation and degradation processes in watercourses.

2 – METHODS

2.1 Study Area

We studied 40 sites in each of four reservoir drainages. This enabled the assessment of sedimentology processes that lead to loss of water storage capacity downstream. Each drainage studied has its own peculiarities as to land slope, soil type, rainfall, and land use and cover (Table 1); those factors contribute to different sediment transportation processes in each basin.

TABLE 1: General character of the study drainages (Brazil, 2010).

Drainage	Soil	Slope (%)	Altitude (m)	Annual Rainfall (mm)	Land Use
Nova Ponte	Haplic cambisol Red yellow argisol Red yellow latosol	0-12 >12	50 - 335	>1500	Agriculture Pasture Reserves
Três Marias	Lytholic neosol Red yellow argisol Red Latosol Haplic cambisol	0-12 > 12	520-989	1200-1500	Agriculture Pasture Reserves
Volta Grande	Red Latosol	0-12	50-821	1200-1500	Agriculture
São Simão	Red Latosol Red yellow argisol	0-12	821-1258	Between 1200-1500	Agriculture Pasture

2.2 Sedimentological Aspects of Applying the Assessment Protocols

The USEPA uses rapid assessment protocols in its National Rivers and Streams Assessment (Hughes & Peck, 2008). Several physical measurements are directly related to sediment transport: channel dimensions, gradient, substrate type and size, riparian cover, and anthropogenic alterations. According to Kaufmann et al. (1999), this method is best applied in the dry season. The site length was 40 times the mean wetted width (with a minimum site length of 150 meters). Point measurements were allocated systematically along 21 transects so as to represent the whole site statistically (Macedo et al., THIS VOLUME). Wetted width, cross section depth, substrate, bank characteristics, and riparian cover were measured in 11 transects; width and substrate also were measured at 10 ancillary transects halfway between the 11 main transects (Table 2).

For sediment transportation, other important parameters are stream slope and meander. In USEPA's rapid assessment protocols, the water surface slope is measured between each transect using a water level (flexible water-filled tube). If the site conditions or the tube length preclude measuring the whole transect, it may be split into two or three parts to record the percentage estimate of the corresponding transect length measurement. The mean slope of the site was calculated by dividing the sum of the level differences by the site length. Meander was measured for the entire site. We measured the angle for channel direction (relative to north) with a compass between each transect or transect fraction.

Meandering was calculated as the ratio between the actual site length and the straightline distance between the two ends of the site.

From the on-site measurements, we calculated mean hydraulic and sedimentological metrics for the site. We assessed the following three groups of metrics: 1) bankfull hydraulic radius (described above) and width/depth ratio; 2) sediment size and stability (LRBS, described above); and 3) riparian condition (riparian disturbance, canopy cover).

2.3 Sediment Size and Stability

Stream substrate is a key aspect of the physical habitat of lotic ecosystems (Faustini & Kaufmann, 2007). Because substrate characteristics are sensitive indicators of the effect of human activities (MacDonald et al., 1991), monitoring them is essential to analyzing river condition. The most common sediment-size metrics are D_{50} and D_{gm}. The former is the 50th percentile of the substrate diameter at a site (mm). The D_{50} is the most common statistic for analyzing bed particles; however, D_{gm} was considered the best statistic for use in habitat assessment (Faustini & Kaufmann, 2007). As verified by Kaufmann et al. (2008), D_{gm} describes visually classified stretches more accurately and D_{50} suffers greater influence from large particles. To determine D_{gm}, we assigned to each of the 105 classified particles the geometric mean diameter of the upper and lower bounds of its diameter class (e.g., 5.66 mm for fine gravel), and then determined the geometric mean of those 105 class midpoint values.

TABLE 2: Key components of the USEPA protocol

Longitudinal profile	Thalweg depth, aquatic habitat type, presence of fine sediments, and large woody debris at 100-150 points; meander; slope
Cross-sections	Section and transect length, depth at five points along the transect perpendicular to the stream flow, of which two are at the fringes and three in the middle of the channel; bank height; bank angle; bankfull height and width; riparian cover; wetted width and depth at the midpoint between each section.
	Substrate size classified at the same points where depth was measured and at five points along the 10 ancillary transects; classified as bedrock (>4000 mm), boulder (>250-4000 mm), cobble (>64-250 mm), coarse gravel (>16-64 mm), fine gravel (>2-16 mm), sand (0.06-2 mm), or silt/clay (<0.06)
	Anthropogenic disturbances and their proximity to the channel, including: walls/dikes/revetments; construction; paving; roads/railways; drainpipes; trash/debris; parks/lawns; agriculture; grassland; logging; mining
Discharge	In medium size or large streams, current velocity and depth were measured in a uniform section at 15 to 20 intervals. In small streams, flow was measured by the average time taken to fill a bucket.

Bedrock and fines were given values of 5,660 and 0.0077 mm, respectively. The Dgm was calculated as the antilog of the arithmetic mean of the logarithms of those frequency-weighted class midpoint values (Faustini & Kaufmann, 2007; Kaufmann et al., 2008).

2.4 Riparian Condition

For each site, we sampled the anthropogenic disturbances listed in Table 2. The weighted proximal disturbance index (*W1_hall*) was calculated by counting the presence of those disturbances on each side of the 11 transects (22 potential observations), weighting each observation by its proximity to the stream and averaging them (Kaufmann et al., 1999). Observations observed inside the channel and on the banks were weighted 1.5, those within a 10 x 10 riparian square were weighted 1, and those beyond the square were weighted 0.67. The weighted proximal disturbance index varies from 0 (low) to 5 (high) (Kaufmann et al., 1999).

Riparian vegetation is important for channel structure, nutrient input, large woody debris, shade, and temperature control (Naiman et al. 1988; Gregory et al. 1991). We used a densiometer (convex spherical mirror with 17 gridded points) to measure canopy at each transect. Measurement consisted of counting the number of points occupied by vegetation and occurred in three places: the right and left banks (facing the bank) and midchannel (facing upstream, downstream, right, and left). We calculated *xcdenmid* as the average of the 44 mid-channel measurements and *xcdenbk* as the average of the 22 bank measurements.

2.5 Statistical Analysis

We compared metric variation at the different sites with box plots and used Tukey's test to assess statistical significance at a p-value equal to or less than 0.05. We also conducted a principal component analysis (PCA) for three key variables (*xcdenmid, W1_hall and LBRS*).

3 – RESULTS

Although sites in the four drainages were similar in channel shape, they differed in several sediment characteristics. The width/depth ratios of the sites were very similar, with Nova Ponte and Tres Marias sites having a wider range of values (Fig. 1a). The percentage of fines was significantly lower at Volta Grande sites and significantly higher at Três Marias sites compared with the other drainages (Fig. 1b). Also Três Marias sites had more homogenous and lower sediment critical diameters than sites in the other drainages (Fig. 1c). Although there were no significant differences in mean geometric diameter among the four drainages, the Volta Grande drainage had greater variation and the Nova Ponte drainage was the most homogenous (Fig. 1d) but had sites dominated by fine sediments and large rocks (Fig. 2). Although the Volta Grande sites drainage had a lower level of percent fines, its, bed stability (*LRBS*) was significantly more stable than the *LRBS* of the other drainages (Fig. 3a). Approximately 25% of the sites in the other three drainages had *LRBS* less than -2, and in general, about 75% of the sites tended to be aggrading because the *LRBS* values were predominantly negative. This indicates a tendency towards sediment deposition and movement in the streams of all four drainages.

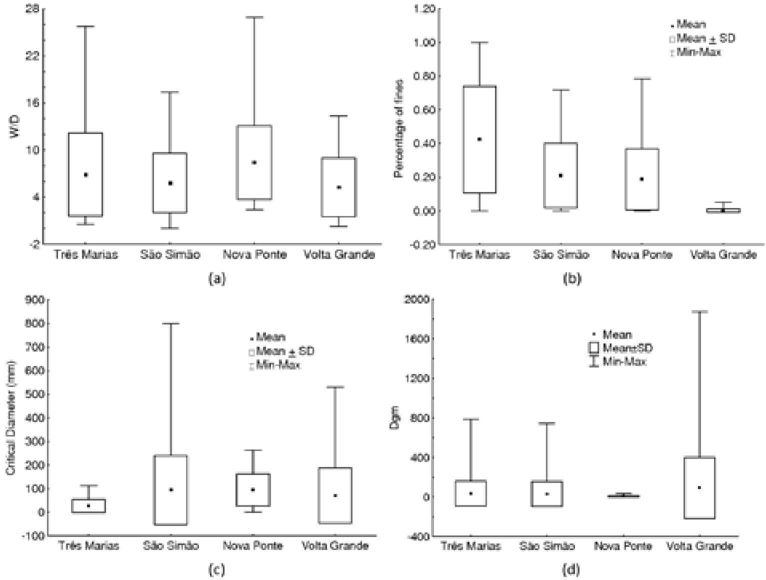

FIGURE 1. Width to depth ratio (a), percentage of fines (b), critical diameter of the sediments (c), and geometric mean diameter of sediments (d) at the sites in the four drainages

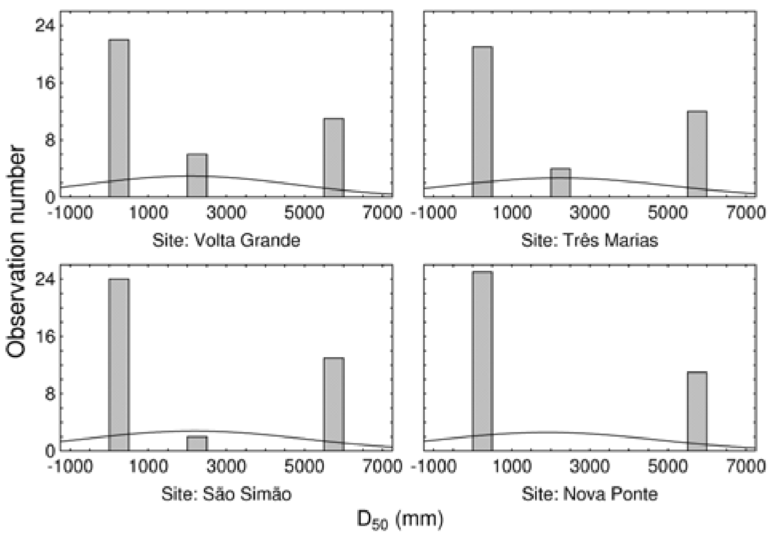

FIGURE 2. D50 of the sediments of sites in the four drainages

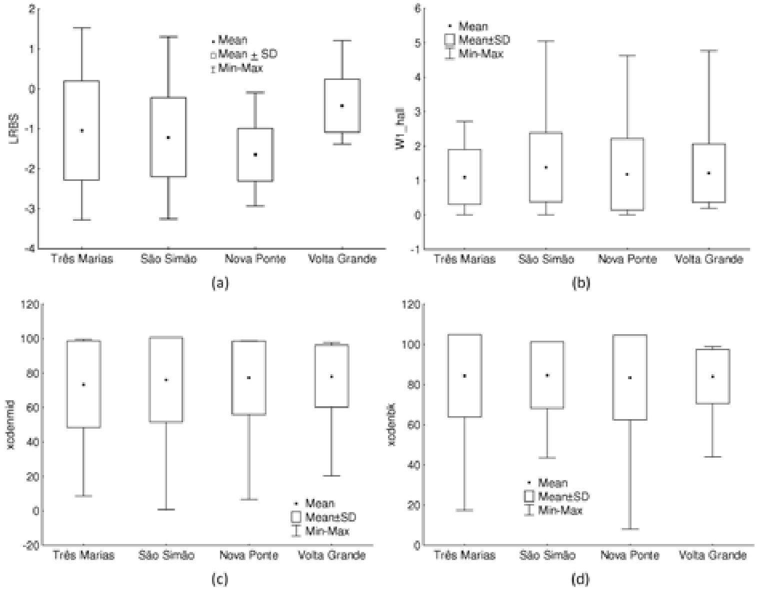

FIGURE 3. Bed stability (*LRBS*) of the sediments (a), weighted proximal disturbance index (b), percent mid-channel riparian cover (c), and percent bank riparian cover (d) at sites in the four drainages

There were no clear patterns between riparian condition and sediment condition at the drainage scale because neither disturbance index values (Fig. 3b) nor riparian cover (Figs. 3c and 3d) differed significantly among the four regions. However, sites in all four drainages averaged some disturbance at each transect (*W1_hall score = 1*), and Tres Marias had fewer high disturbance scores. Sites in all four drainages had fairly high (approximately 80%) median mid-channel and riparian vegetation cover, but Tres Marias and Nova Ponte drainages included more sites with low bank riparian cover. Nova Ponte and Volta Grande sites differed the most in bed stability (*LRBS*), with most of the latter sites being more stable than most of the former sites (Fig. 3a; Fig. 4). Anthropogenic disturbance (*W1_hall*) was inversely related to mid-channel riparian cover (*xcdenmid*) for sites in all four drainages (Fig. 4). The first two PCA axes explained over 80% of the variance among the sites, despite including only 3 variables (Table 3).

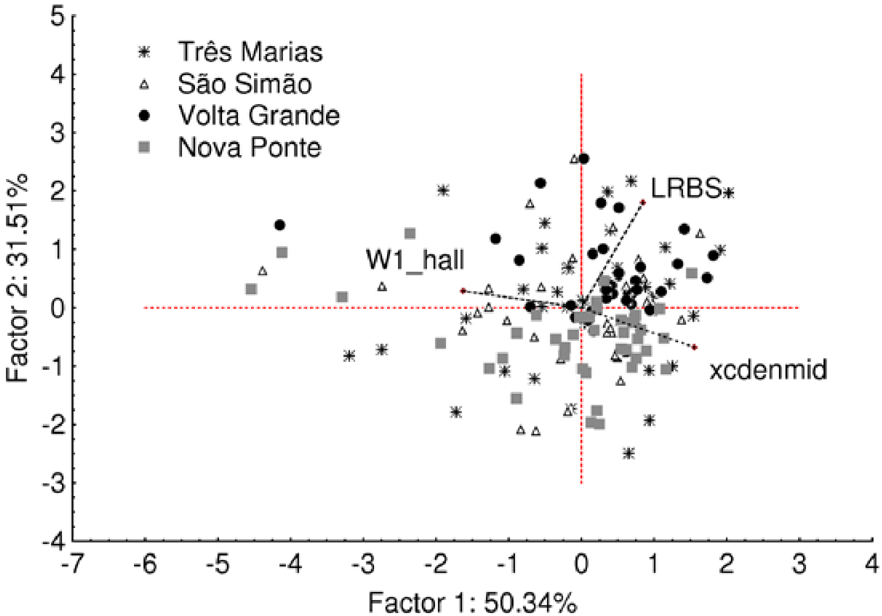

FIGURE 4. Principal component analysis for mid-channel forest cover, log relative bed stability (LRBS) and weighted proximal disturbance (*W1_hall*).

TABLE 3: Factors obtained in principal component analysis

	Factor 1 (50.34%)	Factor 2 (30.64%)	Factor 3 (19.02%)
W1_hall	-0.81	0.14	0.56
Xcdenmid	0.78	-0.34	0.53
LRBS	0.42	0.90	0.11

4 – DISCUSSION

The Nova Ponte, Volta Grande, Três Marias and São Simão drainages differed in several key metrics important to sediment transportation. In general, the Volta Grande drainage had more stable sites regarding erosion and deposition processes. Agriculture is the main land use in the Volta Grande drainage (Macedo et al., THIS VOLUME), whereas the other drainages have a diversity of uses. In addition, the Volta Grande drainage has more homogenous soil, predominantly red latosol. Those soils are quite fertile (Tanaka et al. 1984), which aids agricultural development, as do the lower slopes and lower elevations of the drainage. Riparian forests reduce the quantity of sediments in water bodies, but such forests are reduced by anthropogenic disturbance and can be overwhelmed by watershed erosional processes.

Generally, rapid assessment protocols provide important information regarding sediment transportation when applied in different areas. Information such as that obtained in this study can aid government managers to make decisions regarding riparian forest preservation and land use along streams. However such information is not available in most Brazilian basins, hindering water resource management in Brazil. Therefore, employing rapid protocols in sedimentology studies can provide baseline information about sedimentation and erosion processes and threats to reservoir life and aquatic ecosystem condition.

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SÉRIE
PEIXE VIVO

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CHAPTER 6
ICHTHYOFAUNAL STRUCTURE OF CERRADO STREAMS IN MINAS GERAIS

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1 – INTRODUCTION

Streams are an important component of the Brazilian Cerrado landscape and host considerable biodiversity. In these small-sized water courses, aquatic and terrestrial environments interact through the riparian vegetation, which among other functions, influences solar radiation, sediment interception, and the introduction of organic matter (Pusey & Arthington, 2003; Casatti, 2010). The introduction of allochthonous organic matter such as flowers, fruit, leaves, and branches is essential in these environments. Such allochthonous materials serve as substrate, food, and shelter for aquatic fauna and increase the spatial heterogeneity of water courses (Angermeier & Karr, 1983; Pusey & Arthington, 2003; Brooks et al., 2004). Sunlight penetrating streams influences water quality, such as temperature and dissolved oxygen, as well as cyanobacteria, algae and aquatic plants that provide food and shelter for fish (Tundisi & Matsumura-Tundisi, 2008; Pusey & Arthington, 2003; Casatti, 2010). The retention of particles by riparian vegetation is especially important in landscapes that have been anthropogenically modified and are under pressure from farming and grazing activities, which lead to the transport of sediments, fertilizers and pesticides into water courses. This is the case of the streams in the São Francisco and Upper Paraná Basins, which are partially situated in the Cerrado region, a Brazilian biome that has suffered considerable reduction in its original vegetation (Ferreira, 2007). According to Wantzen (2006), erosion in a single gully may result in the transportation of 60 tons of sediments a day into a stream.

The removal of riparian vegetation is one of the most severe impacts on the integrity of small water courses and may lead to silting, eutrophication, decreased channel stability, and loss of microhabitats that are important for the ichthyofauna (Allan & Flecker, 1993; Pusey & Arthington, 2003; Tundisi & Matsumura-Tundisi, 2008). In drainages threatened by alien species, pollution, and roads, subtraction of this vegetation exposes streams to even further degradation (Casatti, 2010). Along with the physical degradation of streams, the lack of riparian vegetation results in significant changes in fish assemblage taxonomy and function (Casatti et al., 2009; Teresa & Casatti, 2012). The structural complexity of streams, with their mosaic of meso- and micro-habitats, is fundamental for maintaining their biodiversity. Therefore, impacts that lead to structural degradation in these environments are likely to alter the local and regional ichthyofauna, because Cerrado stream fish feature high levels of endemism.

Despite their fragility and importance to biodiversity relative to the effects of land use changes on energy flow and habitat structure, there have been few studies of stream ichthyofauna in the Cerrado region of Minas Gerais. Therefore the objectives of our study were to 1) describe and compare fish assemblage structure in streams located in four different Cerrado drainages in Minas Gerais, 2) estimate adequate levels of sampling effort, 3) determine similarity patterns and beta diversity at multiple spatial scales, and 4) assess the effects of riparian human disturbances on the species richness of stream fish assemblages.

2 – METHODS

2.1 Study Area

The Cerrado, with its different phytophysiognomies, covers nearly 20% of Minas Gerais (Carvalho & Scolforo, 2008). The São Francisco River basin covers an area of 645,000 km2, approximately 7.6% of Brazil (Godinho & Godinho, 2003; Sato & Godinho, 2003). The Araguari River, one of the main tributaries on the left bank of the Paranaiba River, runs over 475 km through a drainage basin covering an area of 21,856 km^2 (Baccaro et al., 2004). The Paranaíba River, in turn, meets the Grande River in the Triângulo Mineiro region to form the Paraná River. We considered streams located within the area of influence of four reservoirs owned by Cemig Geração e Transmissão S.A., namely Nova Ponte, São Simão and Volta Grande HPP reservoirs in the Upper Paraná River basin, installed on the Araguari, Paranaíba and Grande River basins, respectively, and Três Marias HPP Reservoir, located in the Upper São Francisco River Basin.

We sampled streams sites having a Strahler (1957) order lower than four on a 1:100,000 scale map, chosen in accordance with the methodology presented by Macedo et al. (THIS VOLUME). In total, we sampled 155 sites, of which 38 were in the Nova Ponte drainage and 39 in each of the São Simão, Volta Grande and Três Marias drainages. The sites sampled covered a highly diverse range of land uses in their riparian zones and catchments (pasture, farming, urban) at different disturbance levels. Similarly, within the streams themselves a diversity of meso-habitats were studied in terms of different types of substrate (boulders, gravel, sand, etc.), flow (riffles, pools, glides), and channel dimensions (see Macedo et al., 2014 and Santos et al., THIS VOLUME).

2.2 Data Collection

We sampled each site once in September, during the dry season as follows: Nova Ponte in 2009, Três Marias in 2010, Volta Grande in 2011 and São Simão in 2012. The site length was established by multiplying the average width of the stream by 40, with a minimum site length of 150 meters (Peck et al., 2006). Each site was divided into 10 sections separated by 11 equidistant transects.

The fish sampling effort was standardized in terms of the time and number of devices used. Along each section and depending on site width, two or three people used two semicircular hand nets (80 centimeters in diameter, 1 mm mesh) and, whenever possible, a seine (4.0 meters long, 2.0 meters high, 5.0 mm between opposite knots), for a period of 12 minutes, totaling a 2-hour sampling time for each stream (Junqueira, 2011; Figure 1). For the few streams that featured widths > 9 meters, priority was given to sample the maximum number of diversified habitats within the same timeframe, preferably using the seine. In the remaining streams, the 12-minute-interval was sufficient to sample all the available habitats along each section.

Captured specimens were separated by sampling point and section, labeled, and fixed in 10% formaldehyde. At Volta Grande and São Simão, fish were euthanized in eugenol before being fixed in formaldehyde. At the laboratory, fish were rinsed in water, preserved in 70% alcohol, and identified to the lowest possible taxonomic level. Subsequently, they were deposited in the Coleção Ictiológica of the Universidade Federal de Lavras (CI-UFLA).

2.3 Data Analysis

The species collected in each drainage were compared to a list of species known for the whole drainage basin, based on the experience of the research group and on available literature[1]. To this end it was necessary to make some general assumptions regarding the identification of species found in previous works (considering recent revisions), as well as those determined at the genus level (sp.). The percentage of richness collected was then established relative to the total in each whole drainage basin, the relative number of species in common, and single occurrences in each site. For the regional list, we also considered species collected in the four reservoirs studied as part of this project (see Sanches et al., THIS VOLUME).

1 ALVES, 2006a; ALVES, 2006b; ALVES et al., 1998; ALVES et al., 2011; ALVES et al., 1997; ALVES & SANTOS, 1997; BAZZOLI et al., 1991; DERGAM et al., 1999; GODINHO et al., 1991; POMPEU et al.; 2009; SAMPAIO, 2013; SANTOS, 2010; SANTOS, 1994; SANTOS, 1999; VONO & ALVES, 1995; VONO, 2002; VONO et al., 1997.

FIGURE 1. Fish sampling using hand nets and seines in the Cerrado region, Minas Gerais.

To assess similarity in fish assemblage composition (in terms of species, genus, and family) among the four drainages, we performed a non-metric multidimensional scaling (NMDS) through use of the Bray-Curtis similarity scores based on abundance data and the Primer 6.1.13 software package (Clarke & Gorley, 2006). Additionally, we calculated the Jaccard similarity index based on presence and absence data for species, genera, and families in common between pairs of regions. We used the Past 2.17b software package for this purpose (Hammer et al., 2001).

We assessed the representativeness of the samples through use of similarity curves for sites and sections, as described in Schneck & Melo (2010) through use of Sorensen's similarity index and the R software program (R Development Core Team, 2013). This method produced 19 site samples for each drainage and five section samples for each site.

To assess diversity patterns within each basin (Upper Paraná and Upper São Francisco) the total diversity (gamma) was additively partitioned into alpha and beta components. The additive partition considers that the alpha, beta, and gamma diversities are measured in the same dimension (Lande, 1996). Such analysis allows an assessment of diversity patterns along multiple scales in an experimental hierarchical design, where gamma is the sum of the different levels of alpha and beta diversity (Crist et al., 2003). We considered the following levels: alpha (diversity within each section at a site), beta 1 (diversity between sections), beta 2 (diversity between sites), beta 3 (diversity among drainages, exclusively for the Upper Paraná comprising the Nova Ponte, Volta Grande and São Simão drainages). The diversity values observed were then compared with estimated values, obtained through 1,000 randomizations. These analyses were performed using the R software package (R Development Core Team, 2013).

To determine the effect of anthropogenic disturbances on species richness, we calculated Pearson correlations through use of the Statistica 10.0 software package (Statsoft, 2011). We adopted the riparian human disturbance index as an indicator of disturbance in the riparian zone (*W1_Hall*) as proposed by Kaufmann et al. (1999). This index considers the presence of the following disturbance categories: wall, revetment, dam, buildings, pavement, road, railroad, piping for water collection or effluent discharge, landfill, trash, row crop, pasture, silviculture (eucalyptus monoculture), logging and mining. Each impact category is classified in terms of its distance to the water course: more than 10 meters, less than 10 meters, or on the banks. This information is combined into the index, the values of which increase as the number of impacts increase and the distance to the stream decreases (Santos et al., THIS VOLUME).

3 – RESULTS AND DISCUSSION

3.1 Taxonomic Composition

We collected a total of 19,339 individuals, representating seven orders, 23 families, and 144 species (Figure 2, Tables 1 and 2). Of these, 5,910 individuals and 58 species were from the Três Marias drainage of the São Francisco Basin. In the Upper Paraná River Basin, the ichthyofauna was represented by 38 species (4,330 individuals) in Nova Ponte, 44 species (3,472 individuals) in Volta Grande, and 64 species (5,627 individuals) in São Simão. Although featuring different regional richness levels, São Simão was the only drainage to differ significantly from the others in terms of the mean number of species per site, as there were ten in that drainage, compared to six in the others. Nevertheless, we do not recommend comparing these absolute numbers with other studies of the Cerrado or other river basins because other stream studies may use different sampling methodologies.

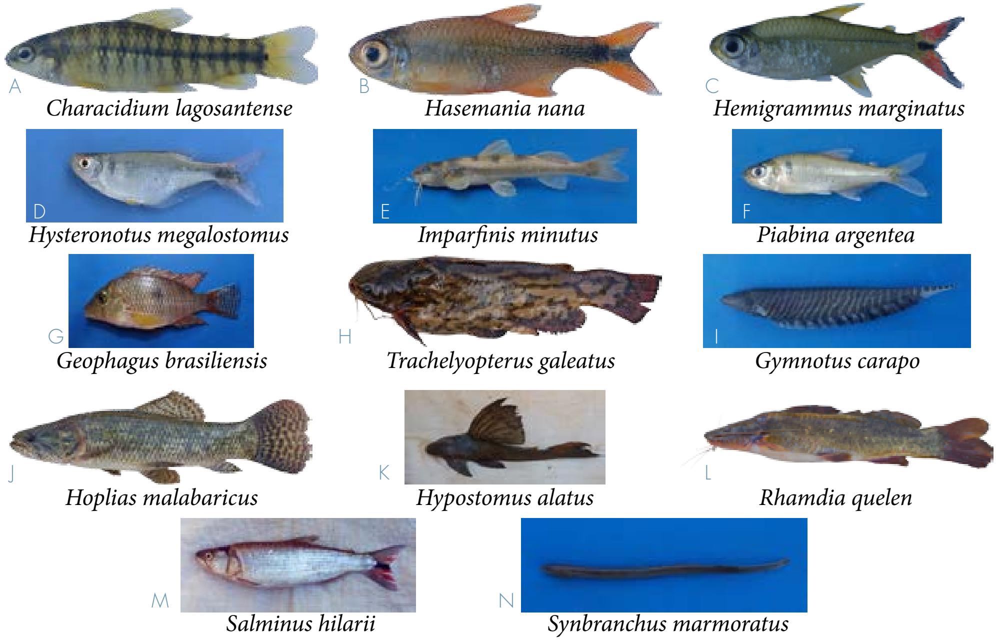

FIGURE 2. Examples of fish species occurring in the sampled streams (Nova Ponte: F, G, I, J, L, N; Três Marias: A to N; Volta Grande: F, G, L, N; São Simão: F, I, J, L, N). Species photos are not scaled. All species are native and with broad geographic distribution. Pictures taken by Carlos Bernardo Mascarenhas Alves from specimens collected in the São Francisco and Paraná Basins but from different streams than in this study.

Fish from Upper Paraná streams can be characterized by their small size, restricted spatial distribution, little or no commercial value, and great dependence on the riparian vegetation for food, reproduction and shelter (Castro & Menezes, 1998), features that can be extrapolated to the streams in the São Francisco River drainage. Larger species of commercial interest, such as the migratory *Salminus hilarii* (Três Marias), *Brycon orbignyanus* (Volta Grande and São Simão), *Leporinus friderici* (São Simão), and *Leporinus obtusidens* (São Simão) and the pirapitinga *Brycon nattereri* (a single specimen recorded in Três Marias and a vulnerable species in Brazil; Rosa & Lima, 2008) were rare in these small streams. Most of the species collected in all four drainages are native to the study basins. The three exceptions were the barrigudinho *Poecilia reticulata*, caught in all drainages, and the tilapias *Tilapia rendalli* and *Oreochromis niloticus*, which were collected in the Volta Grande and São Simão drainages, respectively.

An important component of our collections are the new species and those that are potentially new and still being evaluated by specialists. Although the Upper Paraná Basin is relatively well studied, its cumulative species curve has been exponentially increasing in recent years (Langeani et al., 2007; 2009). However, the São Francisco Basin data suggest more complete taxonomic knowledge of its ichthyofauna. Our study yielded new species in both basins. In the Upper Paraná Basin, we found seven new species: *Astyanax* sp.n. (gr. *scabripinnis*), *Astyanax* sp.n.2 (gr. *scabripinnis*), *Characidium* sp.n., *Characidium* sp.n. (gr *fasciatum*), *Rhamdiopsis* sp.n., *Trichomycterus* sp.n.1, *Trichomycterus* sp.n.2, and *Trichomycterus* sp.n.3. In the São Francisco Basin, experts have confirmed two new species: *Hisonotus* sp.n.1, *Hisonotus* sp.n.2. In addition, at least ten other species (of the genera *Astyanax, Characidium, Harttia, Hisonotus, Hypostomus, Neoplecostomus, Rineloricaria, Serrapinnus,* and subfamilies *Hypoptopomatinae* and *Glandulocaudinae*) from both basins are still being evaluated and are considered potentially new until their identification is confirmed by specialists.

In general, the families were similar among the studied regions, with Characidae, Loricariidae, and Heptapteridae representing most species (Table 2). Three families were recorded in only one region: Pseudopimelodidae (*Microglanis leptostriatus*) in Três Marias, Cetopsidae (*Cetopsis gobioides*) and Rivulidae (*Rivulus apiamici*) in São Simão.

TABLE 1: Number of orders, families and individuals collected in Três Marias (TM), Nova Ponte (NP), Volta Grande (VG) and São Simão (SS).

	TM	NP	VG	SS
No. of orders	5	6	6	6
No. of families	15	15	14	19
No. of species	58	38	44	64
Species per stream*	6 (0-20)	6 (1-16)	6 (1-14)	10 (0-20)
No. of individuals	5,910	4,330	3,472	5,627
Individuals per stream*	151 (0-825)	113 (6-727)	89 (4-356)	144 (0-474)

* Average (minimum-maximum)

TABLE 2: Number of species collected in the orders and families for Três Marias (TM), Nova Ponte (NP), Volta Grande (VG) and São Simão (SS).

Taxon	TM	NP	VG	SS
	Number of species			
CHARACIFORMES				
Parodontidae	3	3	1	2
Curimatidae	-	-	-	2
Anostomidae	2	1	-	7
Crenuchidae	4	3	3	2
Characidae	19	10	11	17
Acestrorhynchidae	-	1	-	1
Erythrinidae	2	2	2	2
Lebiasinidae	-	-	1	1
SILURIFORMES				
Cetopsidae	-	-	-	1
Trichomycteridae	2	3	2	-
Callichthyidae	-	1	3	1
Loricaridae	13	5	6	7
Heptapteridae	7	4	6	8
Pseudopimelodidae	1	-	-	-
Auchenipteridae	1	-	1	1
GYMNOTIFORMES				
Gymnotidae	1	1	2	2
Sternopygidae	1	-	-	3
CYPRINODONTIFORMES				
Rivulidae	-	-	-	1
Poeciliidae	1	2	2	1
SYNBRANCHIFORMES				
Synbranchidae	1	1	1	1
PERCIFORMES				
Cichlidae	-	1	3	4
Total richness	58	38	44	64

The percentage of common species in this study varied from 14% to 21% (Figure 3). The percentage of exclusive species (those added to the regional lists as a result of this study) ranged from 6% in the Três Marias drainage to 15% in the Araguari River Basin (Figure 3). The other species are those that occur in records for the drainage basin that we failed to collect.

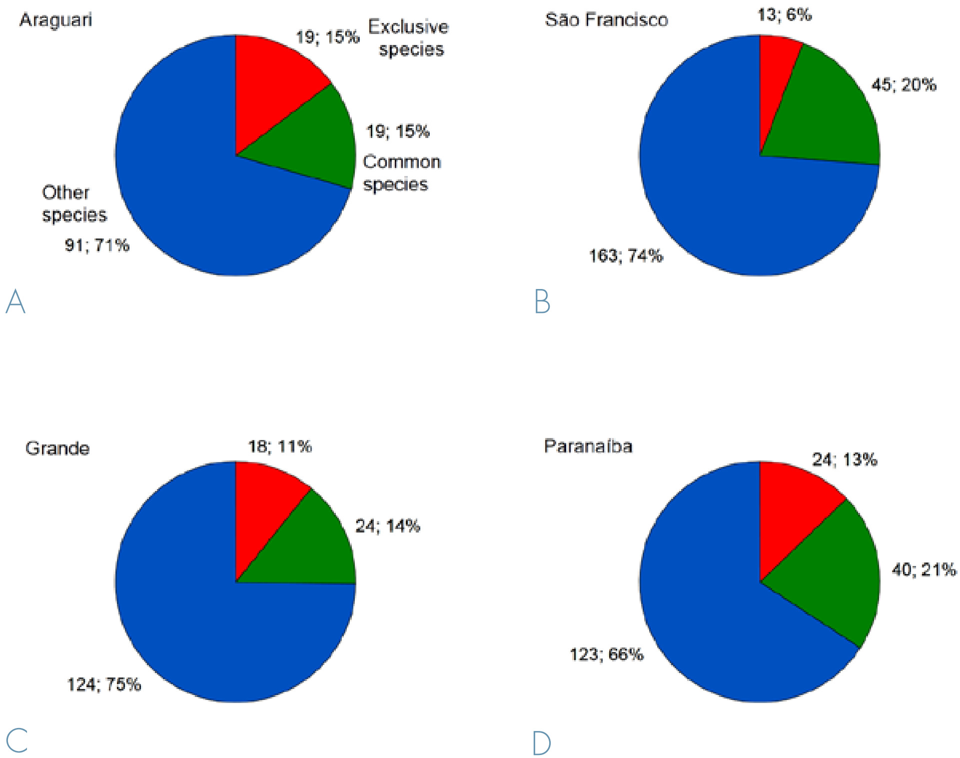

FIGURE 3. Numbers and percent species richness for the sites in each drainage relative to regional richness: Araguari (A, Nova Ponte), São Francisco (B, Três Marias), Grande (C, Volta Grande) and Paranaíba (D, São Simão).

The species abundance pattern for the four drainages indicates fish assemblages composed of a few very abundant species and several species that may be considered occasional or rare (Figure 4). In the four drainages, the 10 most abundant species were responsible for at least 75% of the individuals collected. *Characidium zebra* and *Astyanax scabripinnis* species complex are among them. Besides being abundant, these two species were also well distributed in the area studied and were collected in many different sites. *Characidium zebra* was found in 11 Nova Ponte and Volta Grande sites, 13 Três Marias sites, and 22 São Simão sites. *A. scabripinnis* was found in 4 São Simão sites, 11 Três Marias sites, 26 Volta Grande sites, and 28 Nova Ponte sites. The *Astyanax scabripinnis* species complex is broadly distributed in streams in several Brazilian basins (Bertaco & Lucena, 2006) and study of this species complex in greater detail often leads to the discovery of new species with a more restricted distribution.

Astyanax species are generally well distributed and abundant in streams within a variety of basins in southeastern Brazil. This genus is composed of many generalist species with regard to their feeding habits and habitats occupied, which likely influence their success in colonizating diverse environments. In a recent study conducted in the Três Marias region, Fagundes (2013) observed a great variety of food items consumed by *Astyanax bockmanni, Astyanax fasciatus, Astyanax intermedius* and *Astyanax rivularis*, with no apparent relationship between the diet and the dominant substrate or the level of riparian coverage. In the same region, however, Souza et al. (2014) detected ecomorphological variation in *A. intermedius* and *A. rivularis* in streams with different types of substrate.

In the Upper Paraná sites some cascudo species from the Loricariidae family, Hypostomus genus, were also abundant (*Hypostomus ancistroides* and *Hypostomus aff. nigromaculatus* in Volta Grande, *Hypostomus* sp. in Nova Ponte, *Hypostomus* sp.2 and *Hypostomus* sp.4 in São Simão), contrary to the findings in the São Francisco Basin. The cambeba species, Trichomycteridae family and *Trichomycterus genus*, however, were abundant in all regions except São Simão. Particularly abundant were *Trichomycterus brasiliensis* in Três Marias, *Trichomycterus aff. brasiliensis* and *Trichomycterus candidus* in Volta Grande, and *Trichomycterus* sp.1 and *Trichomycterus* sp.2 in Nova Ponte. In Volta Grande, the alien barrigudinho *P. reticulata* was the second most abundant species and collected in 11 sites. Terra et al. (2013b) reported that *P. reticulata* was a good indicator of anthropogenically disturbed Atlantic forest stream sites. In Três Marias and São Simão, *Knodus moenkhausii* represented 13% and 45% of the total number of specimens, respectively. According to Ceneviva-Bastos & Casatti (2007), *K. moenkhausii* is an opportunistic and efficient species in directing energy to reproduction even in physically degraded environments, which makes it a good stream colonizer.

Some species may be considered rare or accidental in the regions studied, as they were found in low abundance and in few streams. According to Uieda (1984) the incidence of these species may be explained by the fact that they are migratory and, therefore, occur in the assemblage only during a certain time of the year, have low population densities, or occupy areas that are difficult to sample. In this study it is possible that all three factors occurred, in addition to the fact that some species use streams only when they are young. For example, we only collected single specimens of pirapetinga *B. nattereri* and tabarana *Salminus hilarii* in Três Marias, and piracanjuba *Brycon orbignyanus* and piaus *Leporinus friderici, Leporinus lacustres, Leporinus piavussu, Leporinus octofasciatus, Leporinus paranensis, Leporinus striatus* in São Simão. As adults, these species live in larger streams or medium- or large-size rivers and are only occasionally found in small water courses during their juvenile growth stage (Godinho & Pompeu, 2003). Silurliformes, which comprise some species with nocturnal habits, occupy habitats that are less accessible for sampling and avoid swimming in the water column, which may have contributed to our collecting few specimens of, for example, *Tatia neivai* in Volta Grande and São Simão and *Cetopsis gobioides* in São Simão. Finally, for other species, rarity simply might result from low population densities. However, information of this type is scarce for neotropical fish, especially stream species.

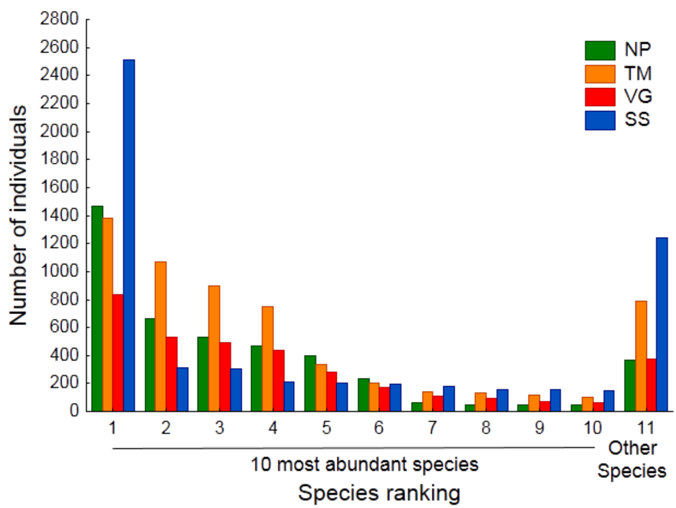

FIGURE 4. Ranking of fish species in descending order of abundance in Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) sites.

3.2 Similarity Between Study Sites and Regions

Regarding the composition of both families and genera, we observed a relatively high degree of similarity among sites in the study regions (Figures 5A and 5B). Comparing pairs of regions, the Jaccard index ranged from 0.6 to 0.8 for family composition and from 0.3 to 0.6 for genera. The São Francisco and Upper Paraná Basins demonstrated a remarkable level of similarity in their ichthyofauna, which suggests a geologically recent connection between them (Buckup, 2011). According to Buckup (2011) the two drainage basins have 63 species in common, which represents 19.6% of the fauna known for the Upper Paraná Basin and 34% for the São Francisco Basin. These figures may be even greater when considering only the Grande Basin, which borders the São Francisco Basin and has 51 species in common.

At the species level, regional differences were much more evident than at higher taxonomic levels (Figure 5C), with Jaccard index scores of 0.1 to 0.3. The first axis separated the São Francisco Basin from the Upper Paraná Basin The second axis separated the two regions within the Paranaíba Basin, the São Simão in the upper part of the axis and Nova Ponte in the lower part.

Different results at different taxonomic levels are expected, given the hierarchical character of taxonomic organization. Yet, they indicate that for conservation planning on broader regional scales, descriptors incorporating not only the taxonomic identity (e.g., richness or diversity of species or families), but also functional characteristics and the ecological role played by species in the environment are strongly recommended and considered better predictors of ecosystem function (Mokanky & Roxburgh, 2008; Mouillot et al., 2011; Teresa & Casatti, 2012) and condition (Marzin et al. 2011). For example, considering the genus or family scale, similarity between sites could lead to a decision based on an underestimation of the contribution of different streams from different sub-basins to the regional functionality of the ecosystem. On the other hand, at the species scale, low similarity between sites in the regions could lead such decisions towards an overestimation of the contribution of each site. Conserving only some sites would be insufficient to preserve the ichthyofauna in streams on a regional scale, but choosing to preserve all sites is economically unfeasible.

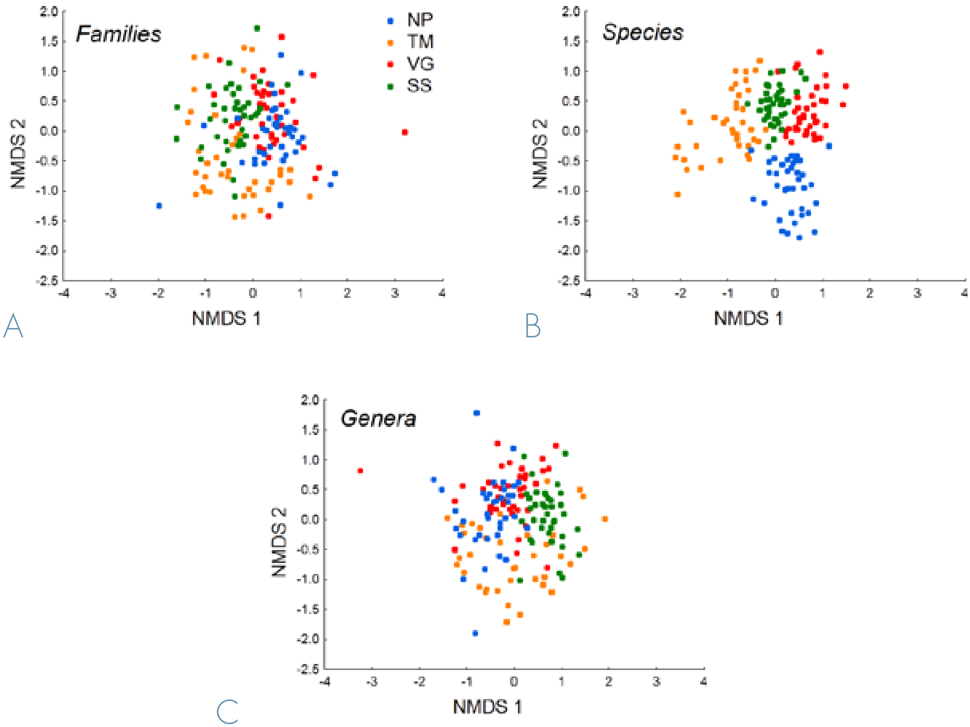

FIGURE 5. NMDS projection of Jaccard scores for stream sites in Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) at three taxonomic levels: families (A), genera (B) and species (C).

3.3 Sampling Effort and Diversity Partitioning

The four drainages had a similar pattern in site similarity curves, with a tendency to stabilize and form an asymptote (Figure 6A). In the case of sampling extent in each site, represented by the number of sections, the curves nearly stabilized in Volta Grande and Três Marias (Figure 6B). For Nova Ponte and São Simão, the lack of curve stabilization indicates that sampling a greater number of sections or a greater distance in each site would result in collecting a meaningfully greater number of species. However, as is evident in the diversity partitioning, an increase in the number of sections sampled would make only a small contribution compared with that obtained by adding new sites or new drainages (Figures 7A and B). In both river basins, the alpha 1 (within-section) diversity and beta 1 (between sections) diversity, were together responsible for 7.7% (Upper Paraná) and 11.7%

(São Francisco) of the regional (gamma) diversity.

An assessment of sampling effort facilitates analyzing how representative a database is for a drainage and, consequently, whether it is appropriate for use in conservation decision making and planning activities at different spatial scales. A robust database is of fundamental importance for guiding the effective allocation of conservation resources (Smith & Jones, 2005). The near stabilization of the sampling effort curves shows that, in terms of the number of sites in each drainage or the number of sections in each site, our field work produced representative samples in terms of species richness, because of the relatively high similarity between any two samples. However, the beta 2 (between sites) diversity for the two basins was responsible for a large portion of the regional diversity: 39.7% for Alto Paraná and 88.3% for the São Francisco drainage basin—meaning that more sites are warranted for assessing beta 2 diversity.

The representativeness of our samples was also reinforced by true richness estimates, which show that the species collected ranged from 70% to 80%: 79% (Jackknife 1) and 73% (Jackknife 2) in Nova Ponte, 78% and 71% in Três Marias, 81% and 78% in Volta Grande, and 77% and 70% in São Simão. More samples would certainly add new species to the list, because the streams host species that are rare and/or restricted in their distributions. Nevertheless, the results show that the database produced over the four years of the project is sufficiently consistent and complete for analysis at different scales.

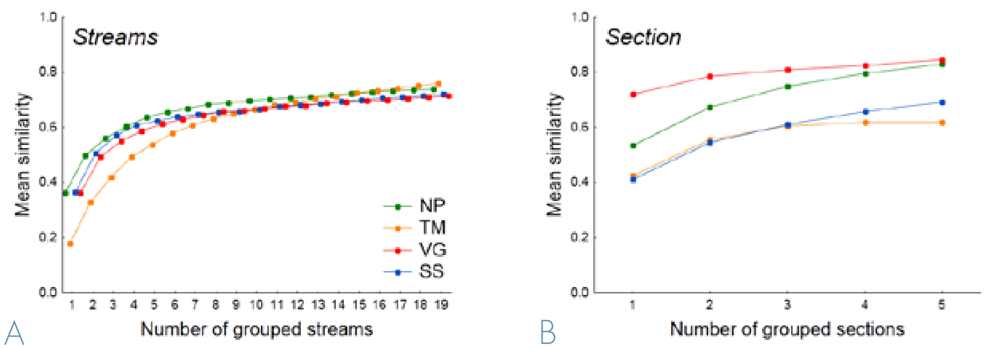

FIGURE 6. Similarity curves constructed based on the Sørensen index for the sites (A) and sections (B) of each sampled drainage (NP: Nova Ponte; TM: Três Marias; VG: Volta Grande; SS: São Simão).

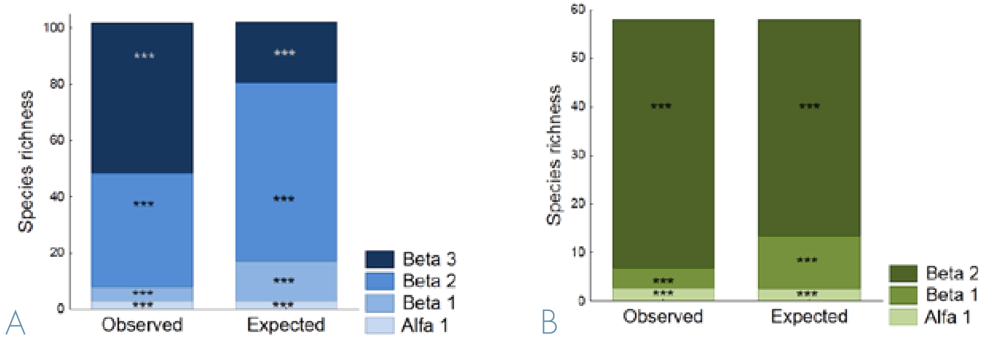

FIGURE 7. Observed and expected diversity partitioning values for alpha 1 (within sections), beta 1 (between sections), beta 2 (between sites) and beta 3 (between drainages) for the Upper Paraná Basin (A; Nova Ponte, Volta Grande and São Simão) and São Francisco Basin (B; Três Marias). *** $p < 0.001$.

3.4 Richness and Anthropogenic Disturbance

The correlation between species richness and the riparian human disturbance index (*W1_Hall*) resulted in very low and insignificant values (Figure 8). This does not mean that the ichthyofauna in the studied regions is unaffected by human activities near the streams, because the role of other variables connected to human use of the drainage basin, such as water quality, substrate composition, and riparian vegetation composition were not considered. However, it does reinforce the idea that richness alone should not be considered a good indicator of ecosystem disturbances in all cases, because the relationship between these two components may show little consistency (Drobner et al., 1998; Terra et al., 2013a; Leal et al., 2014) and must be calibrated for natural variability (Pont et al., 2006; 2009).

The main problem with a strictly taxonomic approach lies in the assumption that all species play the same role in the functioning of the ecosystem (Teresa & Casatti, 2012). Different species have different requirements and interactions with the environment. For this reason, we believe that these descriptors alone fail to detect anthropogenic disturbances. Therefore, the evaluation of functional aspects is recommended, as it is effective in quickly and consistently responding to different disturbances (Pont et al., 2006; Marzin et al., 2011; Mouillot et al., 2013). Similarly, approaches that allow for an understanding of the functioning of the environments on a larger scale, such as an energy and matter cycles and flows, are also recommended.

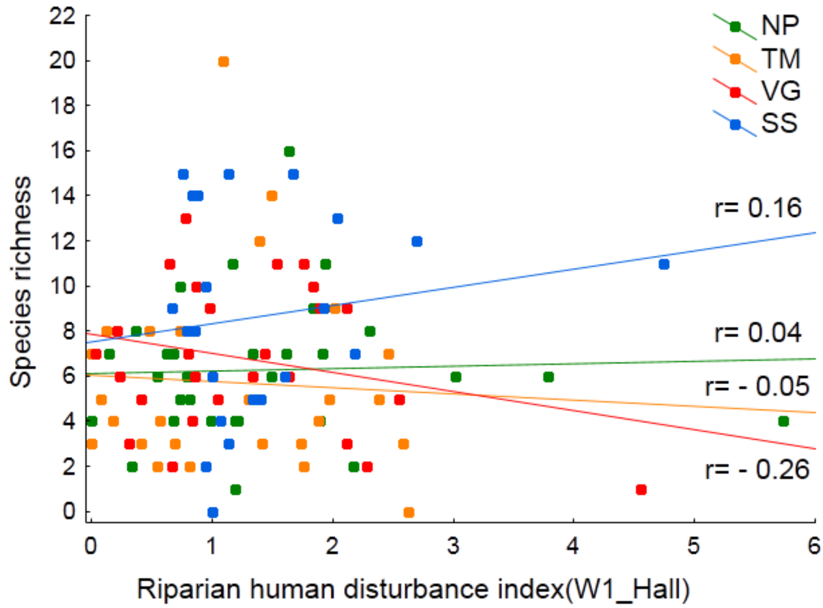

FIGURE 8. Pearson correlation (r) between fish species richness and the riparian human disturbance index (W1_Hall) for Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS).

3.5 Final Considerations

Our study represents an important record of the stream fish fauna in the Minas Gerais Cerrado, which is under heavy pressure from human activities. Because streams are generally neglected from a conservation point of view, studies such as this one represent a considerable advance towards filling the existing knowledge gap for streams. The robust database that we formed following four years of sampling in 155 sites reinforces the importance of these small water courses, as they represent considerable regional species richness, exclusive species, and species that are potentially new to science. New species, in turn, may be of great interest for conservation, as they are endemic and restricted in terms of geographical distribution, locally rare, endangered, and/or indicative of environmental quality. Additionally, the taxonomic similarity and beta diversity patterns found reinforce the remarkable contribution of the different streams and regions to regional diversity.

We observed that the study area as a whole has sites with a broad range of habitat types, which are fundamental for maintaining ichthyofaunal diversity. The protection of these habitats is related to the integrity not only of adjacent riparian forests, but also to that of entire drainage basins (Casatti, 2010; Macedo et al., THIS VOLUME). Therefore, it is imperative that streams be included in assessments that consider a diversity of scales and are aimed at conservation planning for areas hosting dams and other human developments. Our analyses should be expanded, including other approaches, environmental descriptors, and geographical scales, thus facilitating advances in the understanding of the functioning of these environments and of the reactions of the fish assemblages to local and regional anthropogenic disturbances.

4 – ACKNOWLEDGEMENTS

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SÉRIE
PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 7
BENTHIC MACROINVERTEBRATES IN HEADWATER STREAMS: MULTIPLE APPROACHES TO ECOLOGICAL STUDIES IN DRAINAGE BASINS

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LIGEIRO, R.; FERREIRA, W.R.; CASTRO, D.; FIRMIANO, K. R.; SILVA, D. & CALLISTO, M. Benthic macroinvertebrates in headwater streams: multiple approaches to ecological studies in drainage basins. In: CALLISTO, M.; HUGHES, R. M.; LOPES, J.M. & CASTRO, M.A. (eds.), *Ecological conditions in hydropower basins*. Belo Horizonte: Companhia Energética de Minas Gerais, p. 127-158, 2014. (Série Peixe Vivo, 3).

1 – INTRODUCTION

Continental freshwater stream ecosystems host numerous forms of life in different compartments. Some organisms live at the water-atmosphere interface, taking advantage of surface tension to survive (*pleuston* organisms). Others are transported in the water column, whether by drifting (*plankton* organisms) or swimming (*nekton* organisms). Finally, some live at the bottom of aquatic ecosystems and are called benthic organisms (from the Greek word *benthos*, which means bottom). Among these, the benthic macroinvertebrates are animals (e.g., insects, crustaceans, annelids, mollusks) that have a body size greater than 0.5 mm and are usually visible to the naked eye (Esteves et al., 2011).

Benthic macroinvertebrates play important roles in the maintenance of ecological processes in streams in three key ways. 1) Their feeding aids the decomposition of organic matter (dead animal and plant matter) that accumulates on the stream bed. 2) They are important links in the aquatic trophic webs, transferring nutrients and energy from smaller organisms and organic debris to higher trophic levels (for example, fishes, amphibians, aquatic birds, and other invertebrates). 3) They are important for nutrient cycling, releasing nutrients stored in the sedimentary compartment into the water column through bioturbation.

In addition to their ecological importance, benthic macroinvertebrate assemblages also play an important role as bioindicators of the ecological conditions in streams (Callisto et al., 2001). Human alterations to aquatic ecosystems or to their surrounding areas alter the streams' ecological conditions and biodiversity. Studying the composition and structure of macroinvertebrate assemblages facilitates assessments of the condition of ecosystems as a whole (Norris & Thoms, 1999). Benthic macroinvertebrates have four characteristics that make them good indicators of ecological conditions. 1) They feature species with different levels of tolerance to environmental alterations and that respond to a broad gradient of anthropogenic disturbances. 2) They are, for the most part, sessile or have low mobility, thus reflecting the ecological conditions of the sites assessed. 3) They have life cycles ranging from months to one or more years, thus enabling environmental diagnostic studies on annual time scales. 4) They are relatively large and easily sampled.

Benthic macroinvertebrate assemblages act as efficient bioindicators of water quality where a gradient of environmental conditions is considered, ranging from reference sites to severely impaired ones. Some macroinvertebrate groups are sensitive to human alterations, living preferably in stream reaches minimally affected by sewage, toxic chemicals, siltation, nutrient enrichment, and riparian zone disturbances. On the other extreme of the environmental conditions gradient, there are macroinvertebrates that are resistant to alterations in the physical and chemical parameters of water quality and sediments and are thus able to withstand such adverse conditions as hypoxia, anoxia, or very low or very high pH. In an intermediate position in terms of bioindication, some groups are tolerant, thriving in sites where small changes caused by human activity are observed (Figure 1). Studying benthic assemblages as bioindicators is not restricted to indicator species, but also makes use of several diversity metrics, functional traits, and other ecological characteristics of macroinvertebrate assemblages (Figure 2; Davies & Jackson, 2006).

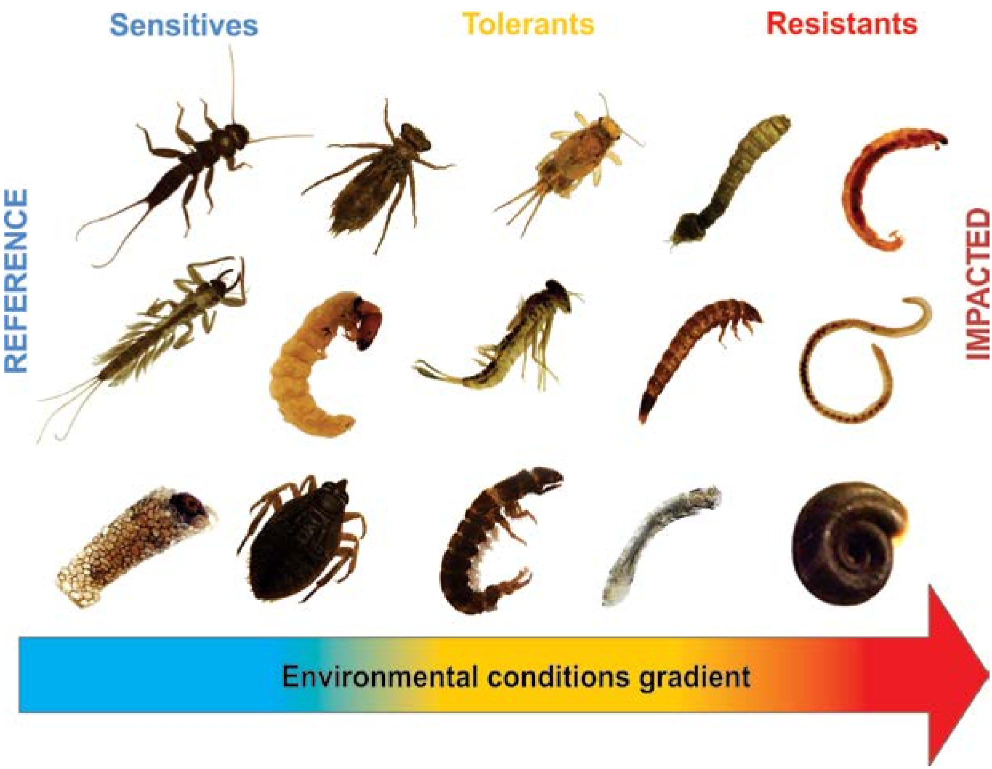

FIGURE 1. Conceptual basis for using benthic macroinvertebrate assemblages as bioindicators along a gradient of environmental condition.

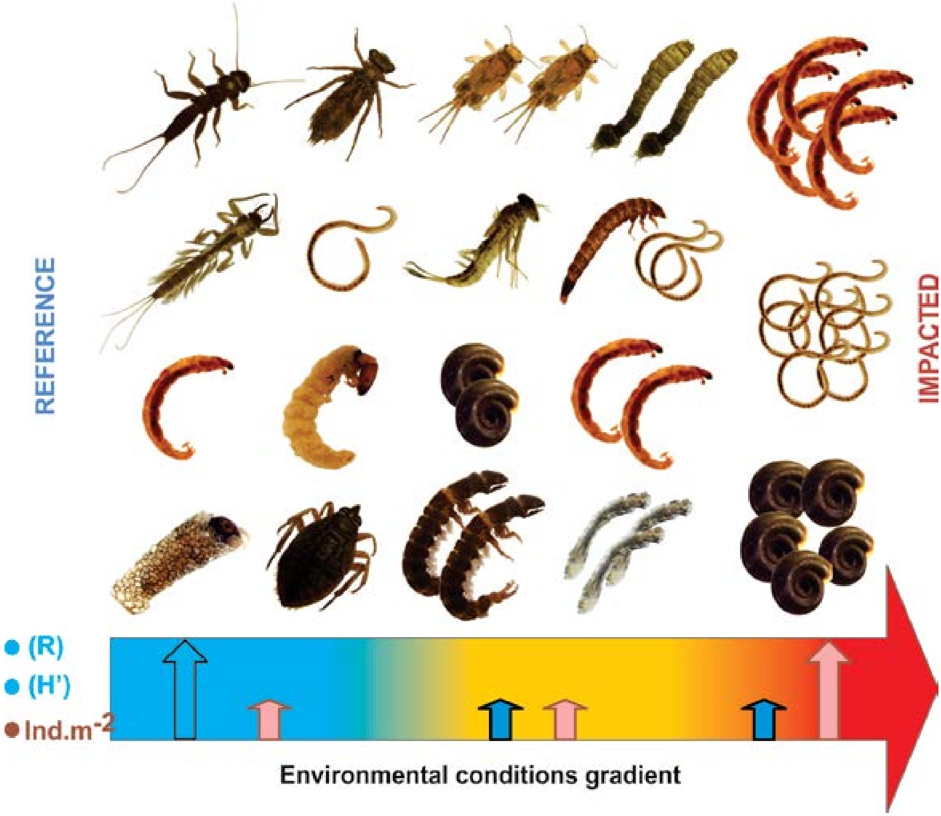

FIGURE 2. Examples of how the richness (R), diversity (H') and density (Ind/m2) of benthic macroinvertebrates may be used as biological metrics in studies assessing environmental conditions.

The objective of this Chapter is to discuss approaches for studying benthic macroinvertebrate assemblages in streams in terms of understanding the interactions between macroinvertebrates and their environment, and concerning the use of macroinvertebrates as bioindicators of environmental quality. The results presented here are from studies conducted between 2009 and 2013 in the drainage basins of Nova Ponte, Três Marias, Volta Grande and São Simão hydropower reservoirs. The description of sampling procedures, data treatment and the recommendation of some commonly used statistical analyses are also included.

2 – METHODS

2.1 Collecting and Processing Samples

In the field, an efficient and standardized sampling methodology was adopted to represent the diversity of local conditions for the sites, including the different types of substrates (e.g., sand, gravel, leaf deposits) and surface water flows (e.g., still water, runs, rapids). Eleven macroinvertebrate samples were collected per site (see Macedo et al., 2014), totaling 1,760 samples from 160 study sites. A kick-net sampler (30-centimeter opening, 500-μm mesh, 0.09-m2 area) was used to collect benthic organisms (Figure 3A). Each sample was put in a plastic bag and fixed in 50 ml of formaldehyde solution at 10%, thus avoiding a loss of organisms due to decomposition or occasional predatory activity. Samples were labeled and taken to the UFMG Benthic Ecology Laboratory, where they were washed through a 500-μm mesh sieve to remove smaller particles (mud, sand and very fine organic particles), thereby facilitating organism sorting (Figure 3B). Macroinvertebrates were placed into trays over a light box (Figure 3C) and then identified through use of a stereoscopic microscope (32x) with the aid of identification keys (Pérez, 1988; Merritt & Cummins, 1996; Fernández & Domínguez, 2001; Costa et al., 2006; Mugnai et al., 2010) (Figure 3D). Organisms were identified to family, except for Bivalvia, Hydrachnidiae, Hirudinea, Nematoda, Collembola. The insects of the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders were identified to genus.

FIGURE 3. Steps in sampling and processing benthic macroinvertebrates: collecting with the kick-net sampler (A), washing fine particles through a 500-μm mesh seive (B), sorting on trays over light boxes (C), identifying organisms through use of a stereo-microscope (D).

2.2 Storage and Treatment of Biological Data

Just as important as appropriate sampling methodologies and careful taxonomic identification is the proper and correct storage and treatment of the biological data. The first data records were usually made in notebooks in which the organisms' taxonomic identities were recorded, as well as the number of individuals of each taxon found in the samples. This information was then entered into digital worksheets. Excel software perfectly supported the volumes of data collected. We entered data in small portions and always by a pair of researchers, thereby ensuring data accuracy and reliability. The integrity of the data was preserved by keeping the original physical copy in a safe place and by periodically storing backups of the digital files (Figure 4).

A characteristic biological worksheet features samples (different sites, transects, etc) displayed as lines and the taxa displayed as columns (Figure 4) The quantities of each taxon for each sample may be expressed as the number, density, or biomass of individuals. Our biological data from the worksheets were subsequently formatted for use in statistical software so that formulas, notes, data transformations and new variables were progressively added to the worksheet as analyses were performed. However, an original copy of the worksheet was saved unaltered for use as a standard and a starting point for all subsequent analyses (Figure 4). Later modifications were saved separately (with different file names) to avoid accidental errors and data losses that could have occured as the data were progressively modified.

2.3 Data Analysis

There are many types of information that may be explored from the biological data sets, and the choice of analyses depends on the ecological study and the questions being asked. We briefly present the basic routines and analyses that were adopted in the IBI-Cemig project, which are frequently seen in other macroinvertebrate studies elsewhere.

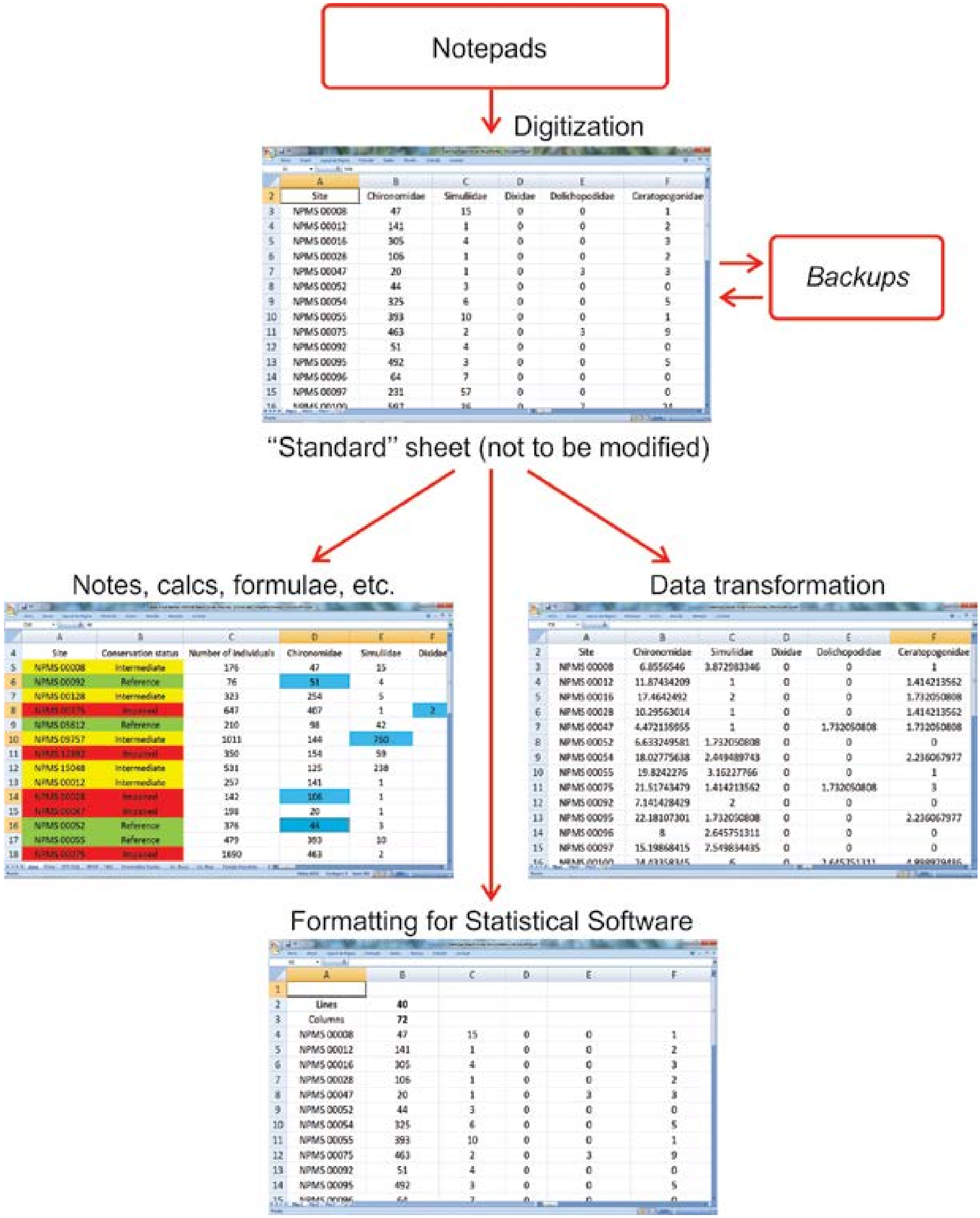

FIGURE 4. Flowchart for data organization, storage, and analyses. Special emphasis was given to preserving the integrity of the data in the different phases of the process.

Statistical procedures are basically divided into *exploratory data analyses* and *statistical inference analyses.* In assemblage ecology studies, the first group of analyses aims to describe the general patterns of the structure and composition of assemblages (Mingoti, 2005). Included in this category are *collection curves*, which assess whether samples are sufficient to represent the existing taxonomic richness, and *relative abundance histograms* of the taxa, which describe dominance and rarity patterns in the assemblages. Classifications such as *multidimensional scaling* (MDS) and *principal component analysis* (PCA), among others, are intended to generate gradients to assess the tendency to form groups in sets of biological or habitat variables. Canonical correspondence analyses, and other similar methods, seek to relate biological data to measured abiotic variables and they are useful for elucidating the factors that govern the composition of biological assemblages.

Statistical inference analyses seek to interpret differences between groups or dependence relationships between variables by testing hypotheses (Gotteli & Ellison, 2004). Several *analyses of variance* models (ANOVAs) and different forms of *regressions* (simple, when they feature only one predictor, or multiple, when they feature two or more predictors) are part of this group, and are all included in the most general category of *linear models*. Hypothesis testing also can be based on similarity / dissimilarity matrices, such as *permutational multivariate analysis of variance* (PERMANOVA) and *analysis of similarity* (ANOSIM), used to differentiate groups defined a *priori* in relation to a set of multivariate data (e.g., taxonomic composition).

3 – RESULTS

3.1 Composition of Macroinvertebrate Fauna

We collected a total of 229,321 individuals, distributed in 96 taxa. The Diptera, Ephemeroptera and Coleoptera were the most abundant across the sites (55.8%, 17.7% and 10.8%, respectively). Diptera (true flies) are found in practically all types of freshwater ecosystems, including shorelines and bromeliads, and therefore have a broad distribution ranging from preserved environments to extremely impaired environments. This group features different adaptations in terms of aquatic respiration, the capacity to exploit a diversity of food resources, and life cycle length, making them efficient colonizers (Ward, 1992). The Chironomidae (a family of Diptera) were numerically dominant in the sites of all four drainages, ranging from 39–47% of the individuals collected. Ephemeroptera (may flies) feature some species that live exclusively in high quality waters (Callisto et al., 2001). The nymphs of this order are exclusively aquatic and the adults have a very short aerial life, which is the characteristic after which the order is named. Coleoptera (beetles) is the largest order of insects in terms of the total number of species globally and it is abundant and diverse in freshwater systems (Segura et al., 2011). Some groups, such as the Gyrinidae and the Hydrophilidae live their entire lives in water (Esteves et al., 2011).

We collected varying numbers of organisms, but similar numbers of taxa from the four drainages. We collected 23,356 organisms distributed in 70 taxa from the Nova Ponte sites (Figure 5), including considerable numbes of Gripopterygidae (Plecoptera). These insects are very sensitive to environmental disturbances and, like Ephemeroptera and Trichoptera species, are indicators of high water quality (Esteves et al., 2011) and they are potential shredders of leaf detritus. In the Três Marias sites, we found 72,973 organisms, distributed in 80 taxa (Figure 6); we found the most families in this basin. We collected 76,582 organisms distributed in 71 taxa from the Volta Grande sites (Figure 7) and 56,410 organisms distributed in 71 taxa from the São Simão sites (Figure 8). We also collected the greatest proportions of Oligochaeta, which are generally tolerant of organic pollution, in these two drainages.

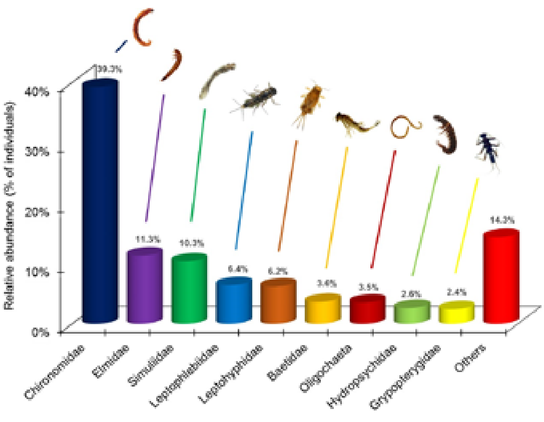

FIGURE 5. Relative abundances of the major taxa groups found in streams draining into Nova Ponte Reservoir.

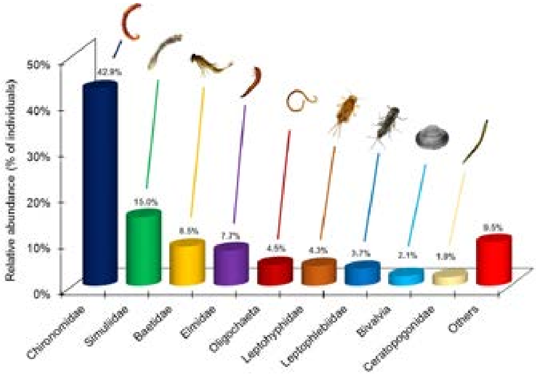

FIGURE 6. Relative abundances of the major taxa groups found in streams draining into Três Marias Reservoir.

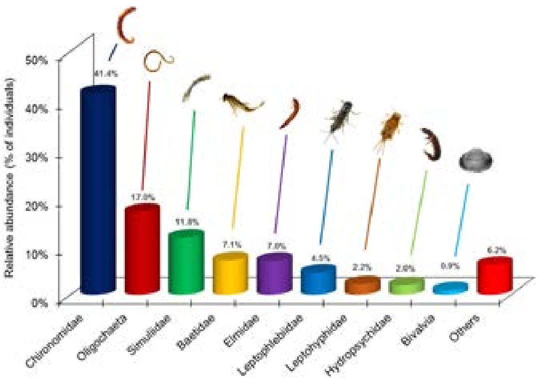

FIGURE 7. Relative abundances of the major taxa groups found in the streams draining into Volta Grande Reservoir.

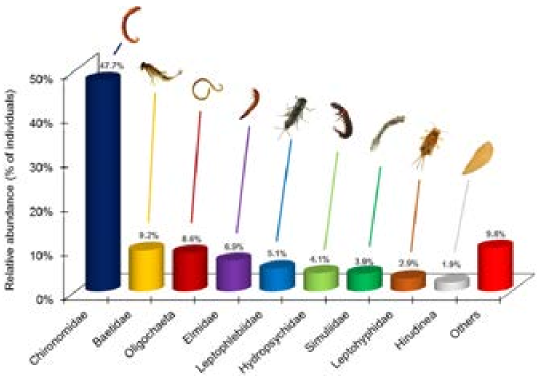

FIGURE 8. Relative abundances of the major taxa groups found in streams draining into São Simão Reservoir.

3.2 Sampling Efficiency

Counting the number of taxa in a certain area is a simple and intuitive way to characterize the diversity of biological assemblages (Gotelli & Colwell, 2001). Taxa richness is influenced by natural variations in the environment and by anthropogenic disturbances (Rosenberg & Resh, 1993). It is a metric widely used in biodiversity studies, is considered an important tool for managing protected areas, and it is a fundamental concept in assemblage ecology (Melo, 2008).

Although it is an important biodiversity measurement, taxonomic richness observed in a given site or region depends on the number of samples and individuals collected. Through species accumulation curves one can obtain a simplified view of how species richness varies as a function of sampling effort (Figure 9). A similar pattern occurred in the Nova Ponte, Volta Grande and São Simão curves, which approached 70 taxa. In the Três Marias drainage, the number of families was greater, as was the rate of taxa accumulation. Because macroinvertebrates comprise an extremely diverse group, have small body sizes and multiple feeding strategies, we did not expect that the collection curves would stabilize. The megadiversity of benthic macroinvertebrates points to the need for extensive and long-term biological inventories.

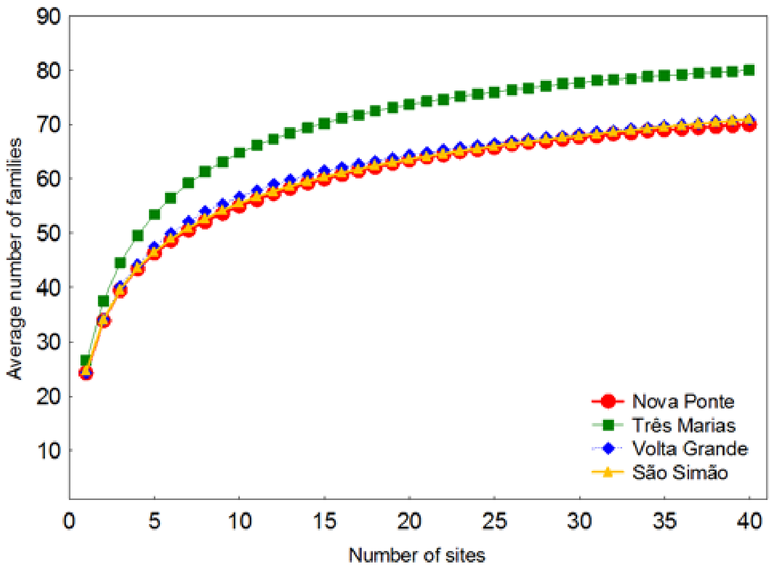

FIGURE 9. Sampling effort curves for 40 Nova Ponte, Três Marias, Volta Grande and São Simão sites.

3.3 Measuring Levels of Anthropogenic Disturbance

Biological monitoring is designed to assess the intensity and rate that aquatic ecosystems are being altered by human activities and it is an important water resource and biodiversity conservation management tool (Marchant et al., 2006). The development of biological indicators of several kinds depends primarily on the determination of those sites minimally affected by human activities that represent reference conditions to be compared with other sites (Hughes et al., 1986). Often it is impossible to find minimally disturbed or nearly pristine sites in a region. In these cases, the least-disturbed sites (best possible) are considered as the regional reference conditions (Stoddard et al., 2006). Comparison between assemblages from the most- and least-disturbed sites in a river basin or region facilitates selection of the biological metrics most affected by human disturbances, thus lending support to the development of biological indices for environmental quality assessment.

Frequently, biological studies that use most- and least-disturbed sites use only subjective definitions, according to the researchers' criteria or the opinion of specialists, using no quantitative criteria. In a study conducted in the headwater streams of the Nova

Ponte and the Três Marias drainaged, Ligeiro et al. (2013) proposed a disturbance index that quantitatively describes the disturbance gradient of a stream site. The Integrated Disturbance Index (IDI) simultaneously analyzes disturbances in the site's catchment (e.g., % agricultural area, % urban area) and locally (e.g., the presence of trash, culverts, buildings in the sites and their riparian zones). Considering both local and catchment scales jointly is important because disturbances acting on both scales may negatively affect site habitats and assemblages of aquatic organisms. The application of the IDI showed that both catchment and local disturbances affected the taxonomic richness of benthic macroinvertebrates in the basins studied (Ligeiro et al., 2013).

The two scales of disturbance can be depicted in a plane in which the axes are the intensities of anthropogenic alterations suffered by the sites at both spatial scales (Figure 10). The IDI was then calculated as the Euclidian distance for each site to the origin of the plane, where the level of disturbance is zero on both scales. Therefore, the more distant from the plane's origin, the more disturbed the site. As can be seen in Figure 10, in general, Nova Ponte sites were more distant from the origin of the plane (they featured greater IDI values) than Três Marias sites, and thus demonstrated greater degradation in ecological condition. This can be explained by a greater amount of agriculture in the Nova Ponte drainage. This human activity is a source of many types of human impacts on aquatic ecosystems. Consequently, anthropogenic disturbance was the main factor explaining taxonomic richness of benthic macroinvertebrates in Nova Ponte sites. On the other hand, in the Três Marias drainage, the natural variability of physical habitats was the main factor structuring macroinvertebrate assemblage richness.

3.4 Physical Habitat Characteristics Structuring EPT Richness

Insects from the Ephemeroptera, Plecoptera and Trichoptera (EPT, Figure 11) orders are sensitive to changes caused by human activities and many genera are indicators of good water quality (Callisto et al., 2001; Ferreira et al., 2011). Therefore, alterations in the physical environment, leading to consequent loss of habitats, may affect them negatively. For example, removing riparian vegetation increases silt loads in streams as a result of bank erosion and sediment flow. This reduces the diversity of habitats and the availability of refuge and food resources for the EPT.

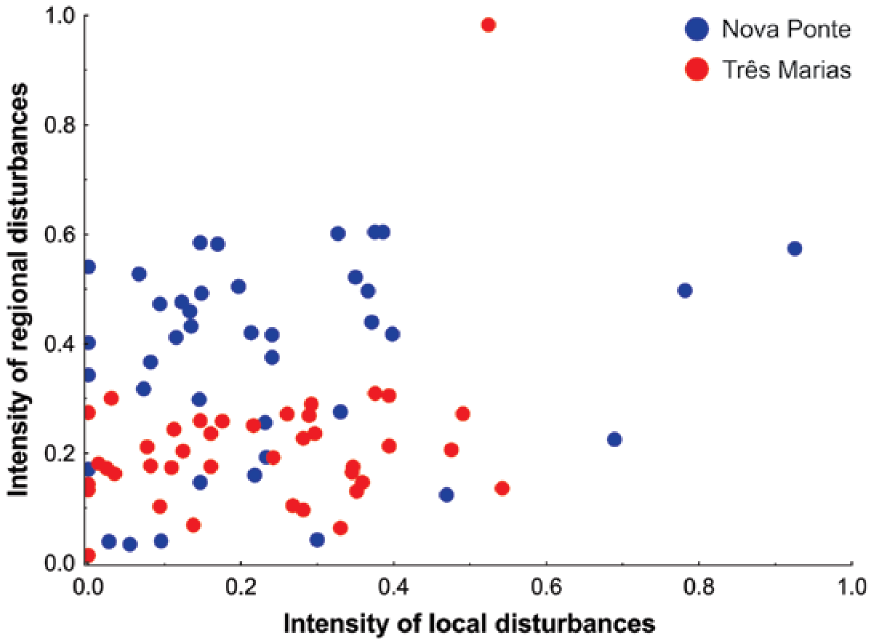

FIGURE 10. Intensity of anthropogenic disturbances of Nova Ponte and Três Marias sites at local and regional (catchment) scales.

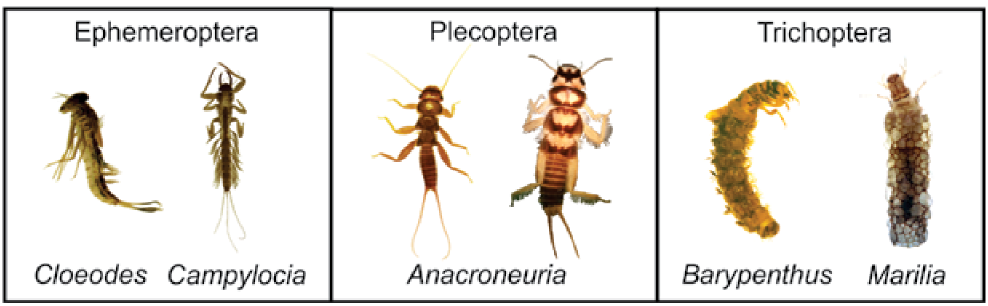

FIGURE 11. Examples of insect genera of the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders.

To protect headwater streams it is important to understand the interactions between environmental factors (e.g., physical habitat structure and water quality) and the assemblages of aquatic organisms. Organisms such as benthic macroinvertebrates are recommended for assessing changes in freshwater ecosystems because they are closely related to environmental factors on several different temporal and spatial scales. Characteristics related to structural components, such as substrate variety in the stream channel, hydraulic variation, and the types of surface flows influence the composition, structure, diversity and temporal stability of aquatic assemblages and are also important for maintaining the integrity of ecological processes (Kaufmann & Faustini, 2012).

In the Nova Ponte and Três Marias drainages the taxonomic composition and richness of EPT genera were studied in relation to the physical habitats and abiotic parameters of water quality (Ferreira et al., 2014). They observed that metrics such as mean bankfull width, the percentage of stones and pebbles, the percentage of slow flows, and dissolved oxygen concentration explained EPT richness in sites in the Nova Ponte and Três Marias drainages (Table 1). Some genera were influenced by habitat metrics related to the types of surface flows (e.g., *Phylloicus, Chimarra, Leptohyphes, Hermanella* and *Camelobaetidius*), to the morphology of the stream channel (e.g., *Hagenulopsis, Varipes, Cynellus, Macronema, Polycentropus* and *Waltzoyphius*), to the type of substrate on the stream bed (e.g., *Triplectides, Asthenopus, Leptonema* and *Itaura*), to water quality parameters (e.g., *Campsurus, Cynellus, Macronema, Polycentropus* and *Waltzoyphius*), to natural shelters (e.g., *Massartela* and *Helicopsyche*), and to riparian structure (e.g., *Cloeodes* and *Polyplectropus*) (Figure 12; Table 2).

3.5 Mesohabitat Components determining EPT Assemblage Composition

Benthic macroinvertebrates have a close relationship with stream substrates and surface flow types, because these are important components of fluvial physical habitats. Mesohabitats are defined as habitat units composed of specific substrates and flow types. Some taxa are adapted for living in conditions with more intense flow, holding on to the substrate and moving between large stones and pebbles. Others have a vermiform body that enables them to live between fine particles of sediment in deposition sites such as still waters and pools.

TABLE 1: Physical habitat and water quality parameters that most influenced EPT richness in Nova Ponte and Três Marias sites.

Drainage Basins	EPT genus richness	Physical habitats and water quality parameters that best explained EPT richness
Nova Ponte	61	Mean bankfull width Percentage of stones and pebbles Proportion of natural shelter Stream slope
Três Marias	65	Percentage of slow flow Relative bed stability Mean wetted width Dissolved oxygen concentration

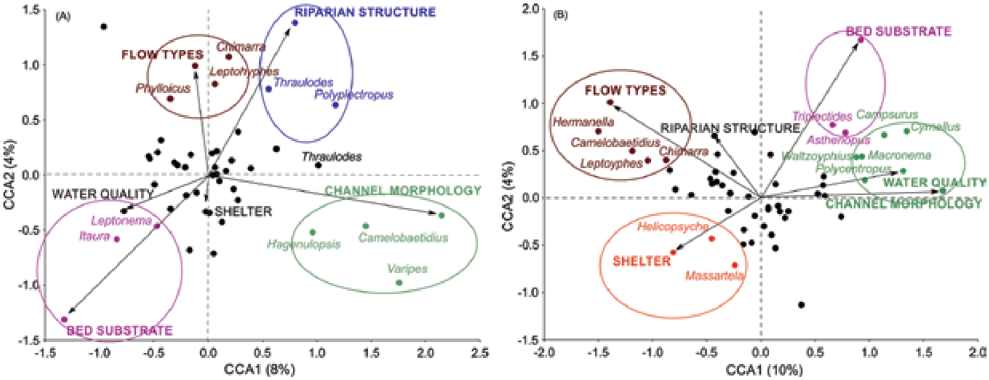

FIGURE 12. Relationship between the composition of EPT genera and physical habitat and water quality metrics in Nova Ponte (A) and Três Marias (B) sites.

TABLE 2: Physical habitat and water quality metrics that influenced the composition of EPT genera in Nova Ponte and Três Marias sites.

Physical habitat and water quality parameters	Description of metrics
Channel morphology	Mean depth and width Slope and sinuosity
Riparian structure	Mean and standard deviation in % canopy Total riparian cover
Bed substrate	Mean % substrate embeddedness % pebbles and gravel
Shelter	Leaf packs Algae and macrophyte tufts Margin undercut Anthropogenic shelter (e.g., tires, bricks etc)
Types of flows	Rapid and slow flows % pools
Water quality parameters	Dissolved oxygen pH Total nitrogen

Substrates

Substrates play an important role for benthic communities, as they provide their habitat, refuge against predators, and food resources (Allan & Castillo, 2007). In particular, substrate characteristics, such as particle size, heterogeneity, compaction, and stability influence resident benthic organisms (Verdonschot, 2001; Figure 13).

Surface Flow Types

Dfferent surface flow types provide different quantities of dissolved gases, determine the quantity of organic matter to be transported, and modify the mesohabitats by means of abrasion and deposition processes (Reid & Thoms 2008). Therefore, they represent a distinct set of relevant conditions for benthic organisms (Figure 14).

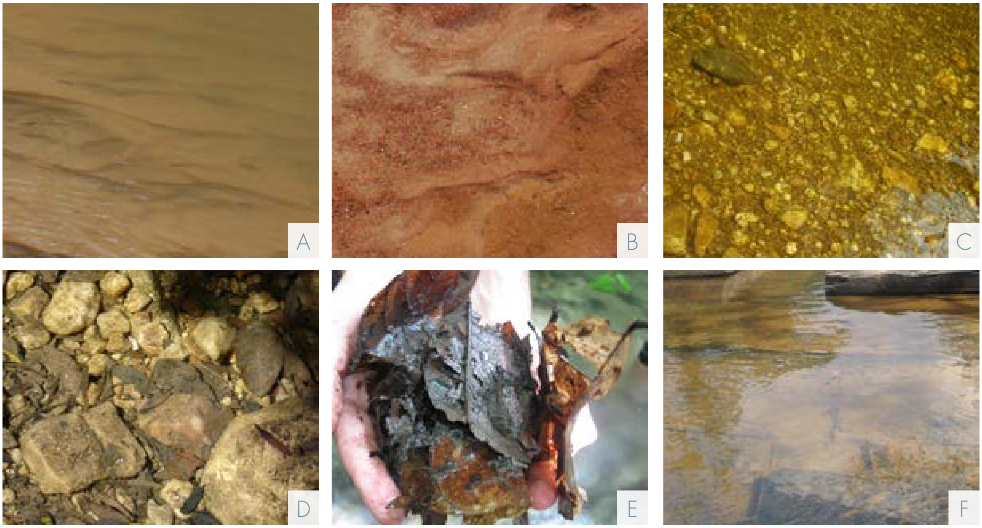

FIGURE 13. Substrate types found at the bottom of streams: fine (silt and clay) (A), sand (B), gravel (C), cobble (D), leaf packs (E), and boulder (F).

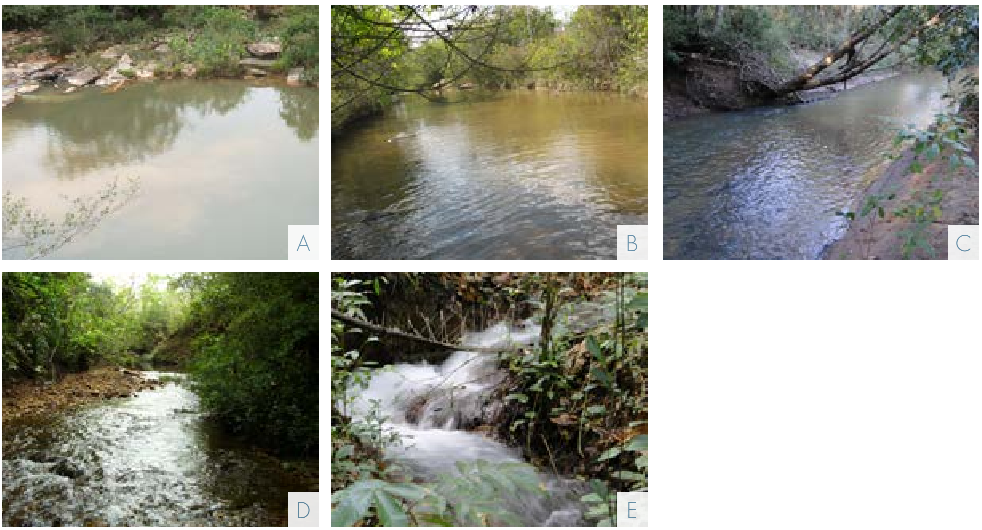

FIGURE 14. Different surface flow types: pool (A), slow glide (B), fast glide (C), riffle (D), and rapid (E).

We assessed the importance of mesohabitats (substrates and surface flows) in determining the composition of EPT assemblages (Silva et al., 2014). Analyses were performed to partition the total variation of the EPT assemblages into fractions related to the mesohabitats and to the spatial factor (represented by the different sites sampled). We observed that mesohabitats explained 16.5% of the variation in EPT assemblages versus 11.3% for the spatial factor and 2% shared by the mesohabitat and spatial factors (Figure 15). The majority of the total variation in the assemblages (70%) could not be explained by the mesohabitats and spatial factors considered.

To determine how much each mesohabitat component (substrates or surface flows) separately influenced the variation of assemblages, the total percentage explained by the mesohabitat in the first test was analyzed separately (Figure 16). We found that surface flow types explained 67.6% of the variation in EPT assemblage composition versus 14.2% for substrate types and 18.2% shared by these two components. Therefore, mesohabitat factors, especially surface flow types, should be carefully considered in studies assessing biodiversity in headwater streams.

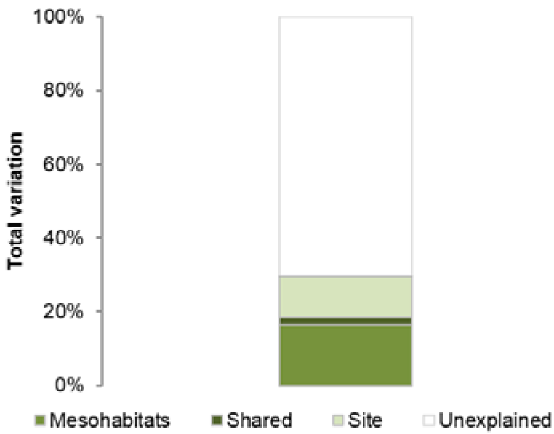

FIGURE 15. Variation in EPT assemblages explained by mesohabitat and site variables.

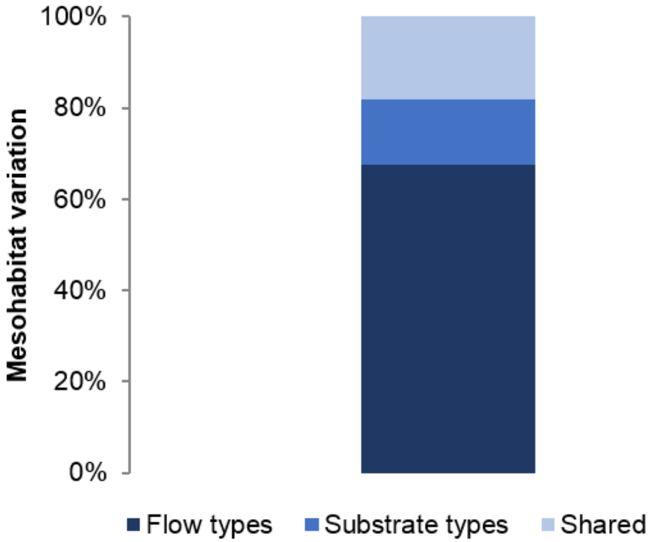

FIGURE 16. Fractions of the pure environmental factor explaining the variation of EPT assemblages, expressed in percentages of the total mesohabitat variation.

3.6 Ephemeroptera Diversity and Sampling effort

Ephemeroptera are sensitive to pollution, live in a wide variety of environmental conditions, and feature high genus and species richness. The total Ephemeroptera richness in the four basins was 41 genera distributed over 7 families (Baetidae, Caenidae, Ephemeridae, Euthyplociidae, Leptohyphidae, Leptophlebiidae, Polymitarcyidae) (Figure 17). This corresponds to 57% of the total genera richness known in Brazil (Salles et al., 2013), and 24 genera were shared by the four basins (Figure 18). We identified 30 genera in Nova Ponte sites distributed over 5 families, 35 genera distributed over 7 families in Três Marias sites, 27 genera distributed over 4 families in Volta Grande sites and 29 genera distribuited over 4 families in São Simão sites. Some genera were found exclusively in Nova Ponte, Três Marias and São Simão sites (2, 6 and 2 genera, respectively). The genera accumulation curves tended towards stabilization, demonstrating that the sampling effort was sufficient for an Ephemeroptera inventory in the drainages studied (Figure 19). Similar to other biodiversity surveys of Brazilian Ephemeroptera, we found few common genera, high abundances and frequencies, and many rare genera (Shimano et al., 2010; Souza et al., 2011; Siqueira et al., 2012) (Figure 20).

FIGURE 17. Ephemeroptera. Leptophlebiidae: *Ulmeritoides* (A), *Thraulodes* (B); Caenidae: *Caenis* (C); Euthyplociidae: *Campylocia* (D); Leptohyphidae: *Traverhyphes* (E), *Tricorythodes* (F): Baetidae: *Camelobaetidius* (G), *Americabaetis* (H). Photos: Kele R. Firmiano.

Genera considered common in the Nova Ponte drainage were: *Thraulodes* (Leptophlebiidae) and *Traverhyphes* and *Tricorythodes* (Leptohyphidae). In the Três Marias drainage they were: *Traverhyphes* (Leptohyphidae), *Americabaetis*, *Callibaetis* and *Cloeodes* (Baetidae) and *Caenis* (Caenidae). In the Volta Grande drainage the prevailing genera were: *Americabaetis* and *Baetodes* (Baetidae) and *Farrodes* and *Thraulodes* (Leptophlebiidae). In the São Simão drainage the most common genera were: *Americabaetis* (Baetidae), *Farrodes* and *Thraulodes* (Leptophlebiidae) and *Traverhyphes* (Leptohyphidae). Most of the common genera found in the Nova Ponte and Três Marias drainages are considered generalists, occurring in sites with varying levels of anthropogenic disturbance (according to the integrated disturbance index of Ligeiro et al., 2013). On the other hand, most of the rare genera were found in streams featuring intermediate or low anthropogenic disturbance (least-disturbed sites).

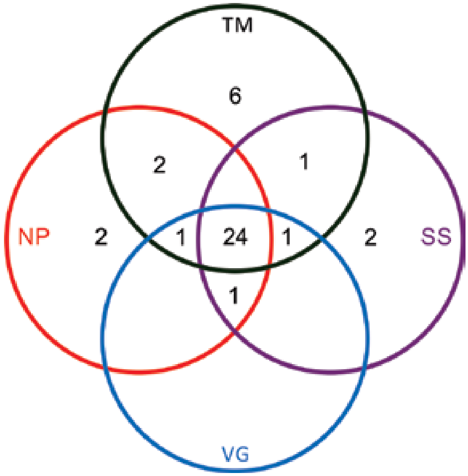

FIGURE 18. Ephemeroptera richness in Nova Ponte (NP), Três Marias (TM), Volta Grande (VG) and São Simão (SS) sites.

3.7 Anthropogenic Disturbance Variables Influence Ephemeroptera Richness

Anthropogenic disturbance metrics measured on catchment and local scales were used as predictors of the Ephemeroptera genera richness in the Nova Ponte and Três Marias sites. On a catchment scale, the predominant types of land use in both basins were agriculture and livestock grazing. These land uses affect streams in different ways and exert a negative influence on Ephemeroptera assemblages. In agricultural areas the natural vegetation is removed and replaced with agricultural crops, along with intense soil manipulation, thus leading to an increase in the nutrient load, an acceleration of erosion processes, and silting of the water bodies (Carpenter et al., 1998). In areas with livestock grazing, soil compaction is the most commonly observed impact resulting from the movement of cattle over the land (Agouridis et al., 2005).

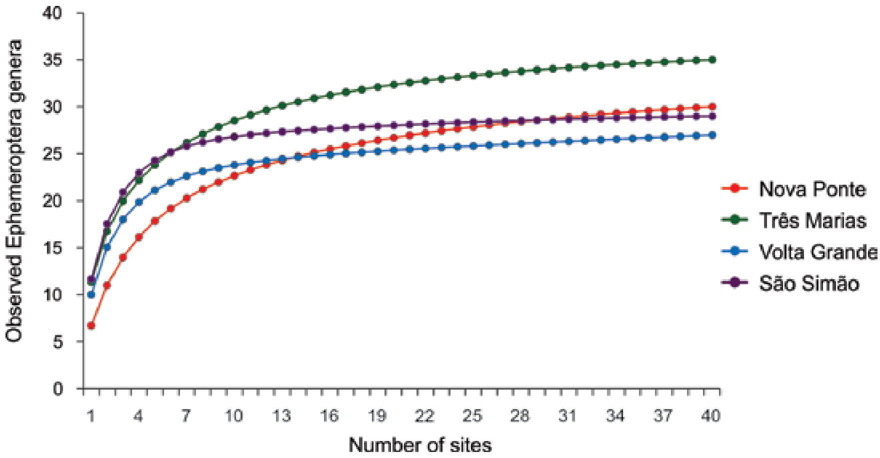

FIGURE 19. Ephemeroptera sampling effort curves for Nova Ponte, Três Marias, Volta Grande and São Simão sites.

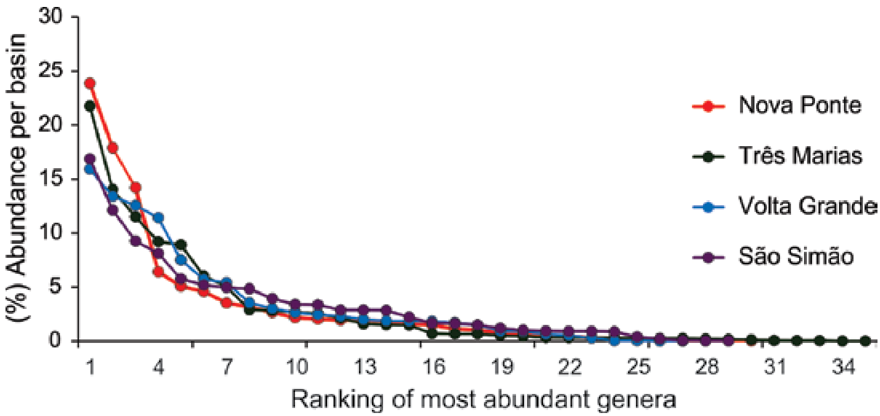

FIGURE 20. Relative abundances of Ephemeroptera genera found in each drainage.

Local anthropogenic disturbances, such as the presence of pipes, bridges, trash and buildings near the margins negatively influenced Ephemeroptera richness. These interventions reduce the availability of habitats for the aquatic biota in several ways. In channelized streams, for example, there is less diversity of substrates and surface flows. Dams reduce water velocity, creating reaches of still water where fine sediments are deposited. The presence of pipes, trash, and buildings are often related to a worsening of water quality, because of the decomposition of waste and sewage effluents directly disposed of into watercourses (Woodward et al., 2012).

The analysis of indicator genera (Dufrêne & Legendre, 1997) demonstrated that out of the 30 Ephemeroptera genera identified in Nova Ponte sites, five were indicators of least-disturbed sites, according to the Integrated Disturbance Index (IDI; Ligeiro et al., 2013). This analysis is based on the relative frequency and abundance of Ephemeroptera in the most- and least-disturbed sites. The indicator genera belong to the Baetidae and Leptophlebiidae families, considered the most diverse in many studies of headwater streams. In previous studies, Baetidae nymphs were considered indicators of good ecological conditions. Although this family as a whole is considered the least sensitive to anthropogenic alterations according to the BMWP index (Junqueira et al., 2000), Buss & Salles (2007) and Souza et al. (2011) found species that were sensitive to environmental degradation. The Leptophlebiidae are usually more sensitive, and genera from this family, assessed as good ecological condition indicators, were classified as collector-gatherers and shredders (Shimano et al., 2012). Shredders are associated with leaf packs deposited on streambeds, which confirms the importance of maintaining riparian vegetation for the conservation of aquatic biodiversity.

3.8 Physical Habitat Characteristics Associated with the Gut Contents of a Typical Shredder

Detritivorous invertebrates play an important role in the decomposition of fallen leaves that accumulate at the bottom of streams (Graça, 2001). Shredding benthic macroinvertebrates feed on these leaves (coarse particulate organic matter or CPOM) and reduce their size, thus making them available to other detritivore and decomposer organisms in the form of fine particulate organic matter (FPOM; Boyero et al., 2011).

Phylloicus (Trichoptera: Calamoceratidae) larvae are usually found in cool or cold, well-oxygenated streams with ample vegetable material. They are considered typical shredders (Pérez, 1988; Merritt & Cummins, 1996; Cummins et al., 2005), feeding on leaves and using them to construct shelters (Figure 21). They are also considered good bioindicators because of their sensitivity to anthropogenic impacts. Because of their close relationship with the physical environment, their feeding habits may vary according to the availability of food resources, either in the form of CPOM or FPOM. Therefore, alterations in the physical environment may affect these animals, both directly and indirectly.

In Nova Ponte and Três Marias sites, *Phylloicus* larval diets were assessed for five larval development stages (I, II, III, IV and V instars) (Figure 21). Gut contents (CPOM, FPOM, algae, plant tissue, animal tissue, mineral) were related to physical habitat metrics assessed in the sites (riparian vegetation, surface flow types, substrate types, leaf accumulation). The two basins differ in their land uses and in the disturbance conditions of the sites. Agriculture is the major land use in Nova Ponte catchments, whereas cattle grazing is the predominant land use in Três Marias catchments (Ligeiro et al., 2013). Associated with differences in physical habitats between the two drainages, the Nova Ponte larvae had a greater proportion of FPOM in their guts (> 90%). Although FPOM also was the predominant food item of Três Marias larvae, III and IV instar larval guts contained elevated proportions of CPOM. The other items (algae, plant tissue, animal tissue, mineral matter) were rare in *Phylloicus* larval guts, suggesting that their consumption was occasional and probably of little importance (Figure 22). The relative importance of FPOM was related to the average width and depth of the streams, as well as to the presence of riparian vegetation. The relative importance of CPOM was associated with riparian vegetation cover and the availability of leaf-accumulating wood debris on the streambeds (Table 3).

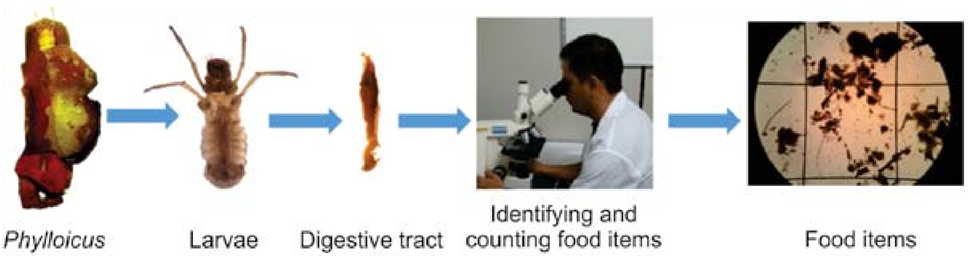

FIGURE 21. Stages in studying gut contents of Phylloicus larvae.

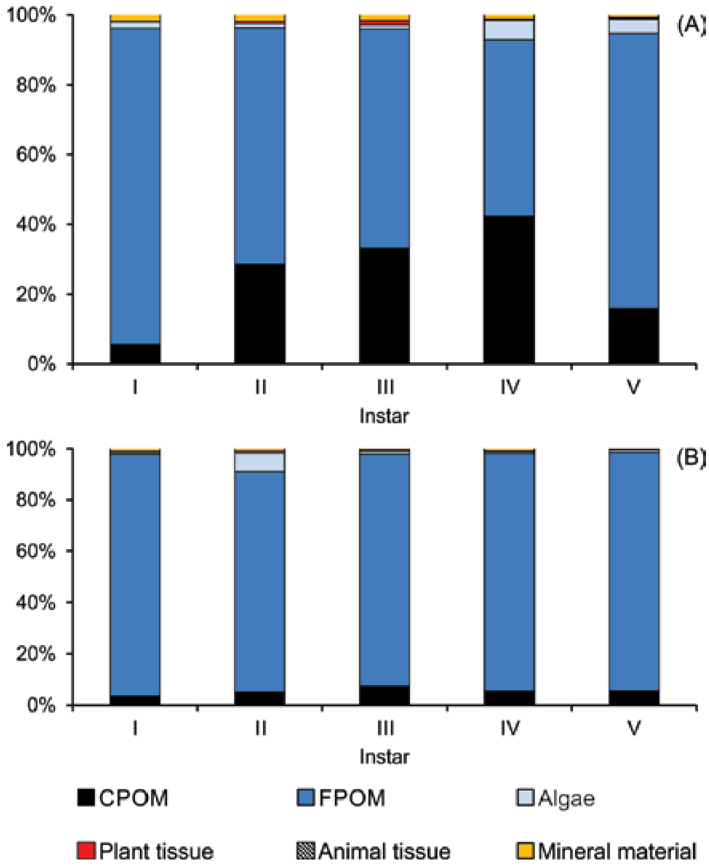

FIGURE 22. Proportion of food items in *Phylloicus* larval guts, by instar, collected from Nova Ponte (A) and Três Marias (B) sites.

4 – SUMMARY

Macroinvertebrate taxonomic composition and richness was related to physical habitat characteristics and anthropogenic disturbances at local and catchment scales. Such results support using benthic macroinvertebrates for understanding the functioning of aquatic ecosystems and for monitoring stream environmental conditions.

TABLE 3: Physical habitat metrics selected by multiple regression models related to the proportions of food items found in *Phylloicus* larval guts for Nova Ponte and Três Marias sites.

Phylloicus (Trichoptera: Calamoceratidae)	Food items	Physical habitats metrics and relationship with food items
	CPOM	Median riparian cover – ground layer; Instream brush and small debris
	FPOM	Mean width x mean depth; Median riparian cover – ground layer.
	Algae	Riparian middle layer herbaceous cover; Median riparian cover – ground layer.
	Plant tissue	Mean bank riparian canopy; Median riparian cover – middle layer.
	Animal tissue	Mean bankfull width; Mean width x mean depth.
	Mineral material	Total organic matter; Riparian middle layer present (fraction reach).

5 – ACKNOWLEDGMENTS

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SÉRIE
PEIXE VIVO

ECOLOGICAL
CONDITIONS

CHAPTER 8
BENTHIC BIOINDICATORS OF ENVIRONMENTAL QUALITY AT CEMIG RESERVOIRS

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1 – INTRODUCTION

Rivers are key parts of landscapes. They mold the land, attract people, supply goods and services that contribute to human well-being, and provide habitat for many species of flora, fauna, and microorganisms. However river connectivity is altered by reservoirs used for storing water, modulating flows, and generating electricity. Damming a river modifies its physical, chemical and biological attributes (Franklin et al., 1995) by altering the natural flows of water, sediments, and biota (Tupinambás et al., 2013; Pelicice et al., 2014). These modifications are so significant that a new and simpler ecosystem arises, producing an artificial reservoir that is distinct from what was previously a river.

The reservoirs formed by hydroelectric dams offer ecosystem goods and services, including hydropower, urban drinking water, irrigation water, flood control, navigation, fishing, tourism, and recreation (Agostinho et al., 2008). According to the Brazilian National Water Agency (ANA), the volume of fresh water in Brazil represents roughly 12% of the available fresh water in the world. Artificial reservoirs are a strategic element in the country's water storage system, especially in areas that are subject to long dry seasons, such as northeastern Brazil.

However, the multiple uses of water produce environmental alterations at a large scale, such as reduced aquatic biodiversity, habitat fragmentation, alien species dispersal, degraded water quality, and reduced environmental quality (Borges et al., 2010; Rocha et al., 2011; Tiemann et al., 2004). Therefore, assessing water quality, biodiversity, and environmental integrity are important for developing the scientific basis for rational reservoir management.

In addition to their immediate effects, large hydroelectric projects affect the landscapes within and outside their drainage basins by stimulating urban sprawl, irrigated agriculture, and road construction. Such changes reduce natural vegetation and alter the biodiversity on land and in watercourses. In Minas Gerais, these land use changes have fundamentally altered the biota of the Cerrado, the second largest neotropical biome and one of the planet's biodiversity conservation hotspots (Myers et al., 2000).

Land use and cover, littoral physical habitat characteristics, limnological conditions, and aquatic assemblage structure can be assessed to determine ecological conditions (Kaufmann & Whittier, 1997). Such information then can be used for developing actions for rehabilitating and conserving aquatic ecosystems. That information is particularly important in basins used for hydroelectric energy generation in Brazil (Macedo & Callisto, 2012). In other words, knowledge of the environmental characteristics of a project's river basin is critical for decision makers and regulatory agencies concerned with conservation and rehabilitation.

Consideration of abiotic and biotic aspects at different spatial scales aids us in assessing the environmental quality of aquatic ecosystems and this chapter presents an example of such an assessment for hydroelectric reservoirs in Minas Gerais. We conducted this study to assess the biological influence of the characteristics of reservoirs and the surrounding areas, using benthic macroinvertebrate assemblages as bioindicators of environmental quality. Our objective was to assess the degree to which land use, littoral physical habitat, and water quality variables influence benthic assemblage structure and composition. To answer this question, we evaluated environmental characteristics at macro (buffer land use) and meso (site riparian) scales.

2 – METHODS

We measured physical, chemical and biological parameters at 40 sites in the littoral region of Nova Ponte, Três Marias, Volta Grande and São Simão Reservoirs at the end of the rainy season in 2010, 2011, 2012 and 2013, respectively (Figure 1). We determined land uses, riparian condition, water quality, and sediment size to characterize the 40 sampling sites in each reservoir. Land use and cover were determined in an area 500 meters in diameter around each sampling site (Macedo et al., THIS VOLUME). Riparian condition was evaluated in terms of riparian vegetation layers (canopy, mid-layer, ground), anthropogenic disturbance (e.g. buildings, trash, pasture, agriculture), and substrate size (e.g. rock, gravel, sand, mud) (Figures 2 and 3). Sampling sites dominated by predominantly natural characteristics were classified as low disturbance, whereas sampling sites dominated by anthropogenic disturbances were classified as high disturbance. Sampling sites where natural characteristics and anthropogenic disturbances were approximately equal were classified as medium disturbance (Figure 4).

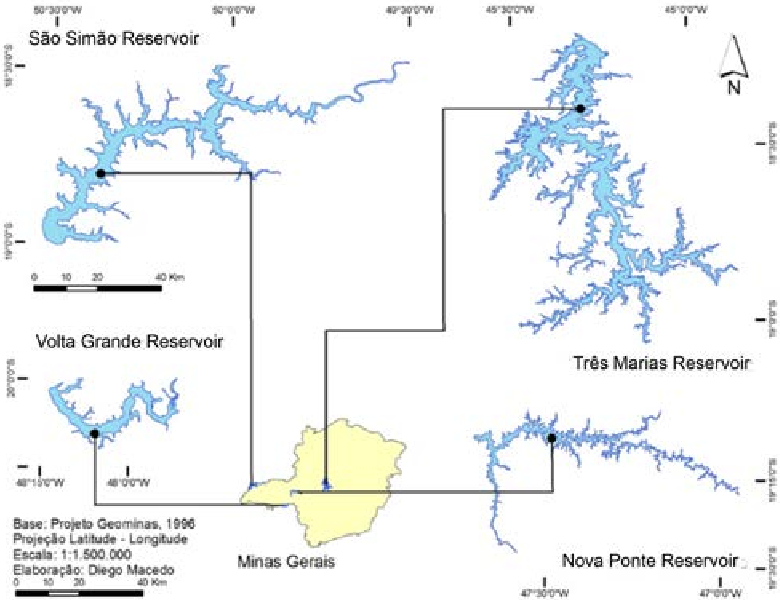

FIGURE 1. Locations of reservoirs in Minas Gerais

FIGURE 2. High disturbance habitat observed at a site scale.

FIGURE 3. Sediment sizes observed at a site scale.

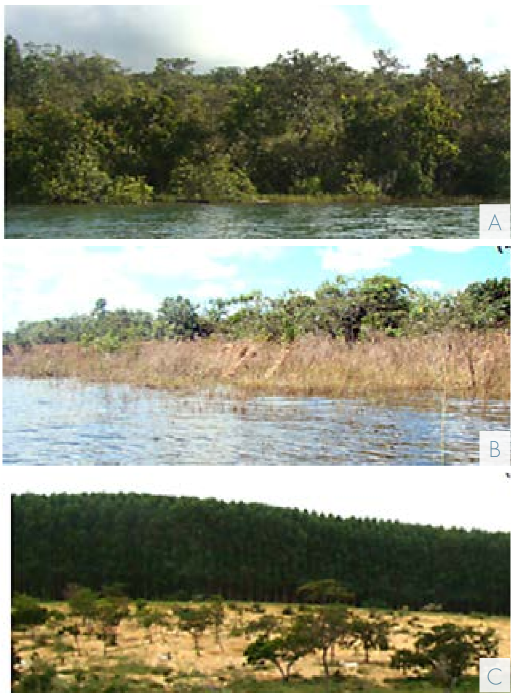

FIGURE 4. Examples of low (A), medium (B) and high (C) disturbance observed at a site scale.

We measured water quality (e.g. temperature, depth, nutrients, dissolved oxygen) and sediment organic matter content and size at each station where we sampled macroinvertebrates. We used two macroinvertebrate sampling gears: an Ekman-Birge grab and a kick-net (Figure 5a,b). The macroinvertebrate samples were returned to the lab where the sediments were washed through a 500 mm sieve and the macroinvertebrates were sorted and identified through use of light tables and dissecting scopes (Figure 5c,d).

FIGURE 5. Collecting benthic macroinvertebrates through use of an Ekman-Birge grab (A) and a kick-net (B) and sample processing at the UFMG laboratory (C, D).

2.1. Application of the Methodology to Semiarid Paraíba Basin Reservoirs

We also assessed three reservoirs (Acauã, Boqueirão, Poções) in the Paraíba River Basin in northeastern Brazil to evaluate the feasibility of applying the same protocols there (Figure 6). The Paraíba Basin has a water deficit over 70% of the year, low mean annual rainfall (600 mm) and long dry seasons (8-9 months of the year).

FIGURE 6. Reservoirs studied in the semiarid Paraíba River basin of northeastern Brazil (Acauã top, Boqueirão middle, Poções bottom).

These characteristics severely limit economic development and produce intense human pressure on scarce water resources (Montenegro & Ragab, 2012). The basin is characterized by caatinga vegetation (deciduous, small thorny trees and shrubs with xeric grasses and cacti as ground cover). Aquatic ecosystems include shallow natural lakes, artificial reservoirs, and temporary rivers and creeks that flow only during the rainy season. Lakes and rivers in this xeric region are subject to prolonged periods of water scarcity and substantial drawdown, and the rivers and creeks are highly variable and subject to short-term and unpredictable flooding (Barbosa et al., 2012). Maintenance of environmental quality is difficult. Thus, tools that can assist in the identification of locations that are a priority for conservation or that require greater management care are of great importance. Despite the different climate and vegetation type, we successfully employed the same field protocols as in the cerrado (savanna) systems of Minas Gerais, indicating the applicability of those assessment tools to xeric northeastern Brazil. Kaufmann et al. (2014) also used similar protocols to assess disturbance and physical habitat condition of conterminous USA reservoirs and lakes occurring in xeric, mountain, subtropical, and temperate forest and grassland ecoregions.

2.2 Data Analyses

We calculated two anthropogenic disturbance indices, based on land use within a 500 m buffer of the site (Macedo et al., THIS VOLUME) and site riparian conditions (Kaufmann et al., 2014). To calculate the BDI (Buffer Disturbance Index), we used the following formula:

BDI = (4 x % constructed area) + 2 x (% agricultural areas + % bare soil) + (% pasture). (1)

We calculated the RDI (Riparian Disturbance Index) as described by Kaufmann et al. (2014):

RDI = (Disturbance Intensity + Disturbance Extent)/2, (2)

Where disturbance intensity is the sum of the mean proximity-weighted tallies of near-shore disturbance types at each station, and disturbance extent is the proportion of the station shoreline with any type of disturbance present. Kaufmann et al. (2014) considered USA lakes with RDI scores > 0.75 as being in poor condition as a result of site-scale disturbance, whereas those with scores < 0.25 were deemed in good condition.

In each index, values close to zero represent sites suffering a minimal degree of influence from human activities and higher values are attributed to sites suffering greater impacts. We calculated the IDI (Integrated Disturbance Index) as the Euclidean distance of the position of the site relative to the origin in a two-dimensional graphical representation with the BDI on one axis and the RDI on the other. The greater the value of the site IDI, the greater its deviation from the origin of the graph and the greater the disturbance level (Ligeiro et al., 2013; THIS VOLUME).

To assess macroinvertebrate condition, we calculated % alien individuals, % sensitive individuals through use of BWMP scores (Junqueira & Campos, 1998), and % EPT (Ephemeroptera, Plecoptera, Trichoptera) individuals. Higher scores for % sensitive individuals and % EPT indicate less-disturbed macroinvertebrate assemblages; higher scores for % aliens indicate more-disturbed assemblages (Plafkin et al., 1989). Given greater analytical time, additional metrics will be evaluated for developing a reservoir macroinvertebrate assemblage index following the protocol Stoddard et al. (2008) used for streams. We also calculated sampling effort curves for macroinvertebrate family and Chironomidae (nonbiting midges) genera richness to determine whether our sampling was adequate for assessing those variables.

3 – RESULTS & INTERPRETATION

3.1 Disturbance

We observed different land use patterns in the areas surrounding the reservoir sites (Table 1). Natural vegetation (forest and fields) predominated around Nova Ponte Reservoir and agriculture was the major anthropogenic use. Similarly, the area surrounding Três Marias Reservoir was mostly natural; the major anthropogenic land uses were *Eucalyptus* plantations, pasture, and agriculture. However, Volta Grande Reservoir was surrounded mostly by agriculture, with little natural vegetation. Likewise, anthropogenic land uses surrounded most of São Simão Reservoir (pasture, agriculture, water level depletions and bare earth) and there was little natural vegetation.

We classified the buffer (BDI) and riparian disturbance index (RDI) scores as low, medium, or high (Figures 7 and 8). At the buffer scale, 45% of Nova Ponte sites had low BDI scores and 17.5% had high BDI scores. Similarly, 42% of Três Marias sites had low BDI scores and 32% had high BDI scores. Conversely, only 15% of Volta Grande sites had low BDI scores and 45% had high scores. Likewise, only 5% of São Simão sites had low BDI scores and 30% had high scores.

At the riparian scale, 52.5% of Nova Ponte sites had low RDI scores and 17.5% had high RDI scores. Similarly 48% of Três Marias sites had low RDI scores and 15% had high scores. However, 70% of São Simão sites had low RDI scores and 17.5% had high scores. Although 42% of Volta Grande sites had low RDI scores, 58% had high RDI scores. In other words, the BDI (buffer) scores and the RDI (riparian) scores were not correlated at the reservoir scale. Nonetheless, Volta Grande had a significantly higher IDI score than the others (Table 2) indicating that its nearshore environment was more disturbed than those of the other reservoirs.

TABLE 1: Percentages of land uses in the reservoir buffers. Eucal. plant. – Eucalyptus plantations; Constr. – Constructions; Inund. veget. – Inundated vegetation;

Reservoir	Land uses								
	Forest	Field	Agriculture	Pasture	Eucal. plant.	Constr.	Bare soil	Inund. veget.	Water level depletions
Nova Ponte	33.6	34.1	21.7	9.4		0.3	0.9		
Três Marias	26.7	30.0	10.6	10.7	16.3	0.4	4.1	1.2	
Volta Grande	6	4	87	1		2			
São Simão	7	3.5	25	45		1.3	8	0.2	10

TABLE 2: Average disturbance scores and biological conditions of Nova Ponte, Três Marias, Volta Grande and São Simão Reservoirs. Bold = substantially different from the other three reservoirs.

Reservoir	IDI	% Aliens	% Sensitive Taxa	% EPT
Nova Ponte	0.4	2.4	1.78	3.1
Três Marias	0.54	1.3	**13.63**	**15.4**
Volta Grande	**1.15**	**80.7**	1.58	**0.6**
São Simão	0.61	**0.01**	5.41	11.3

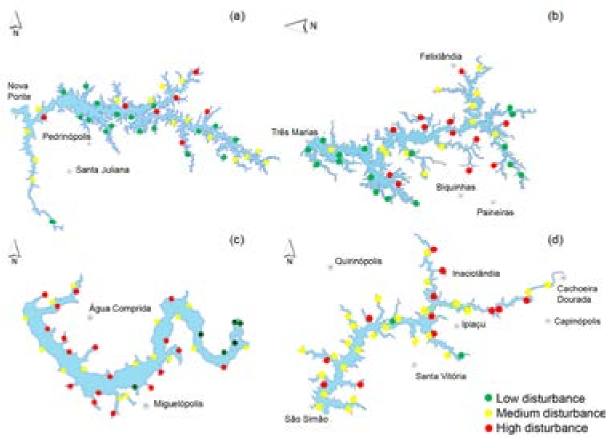

FIGURE 7. Buffer anthropogenic disturbance levels at Nova Ponte (a), Três Marias (b), Volta Grande (c) and São Simão (d) Reservoir sites.

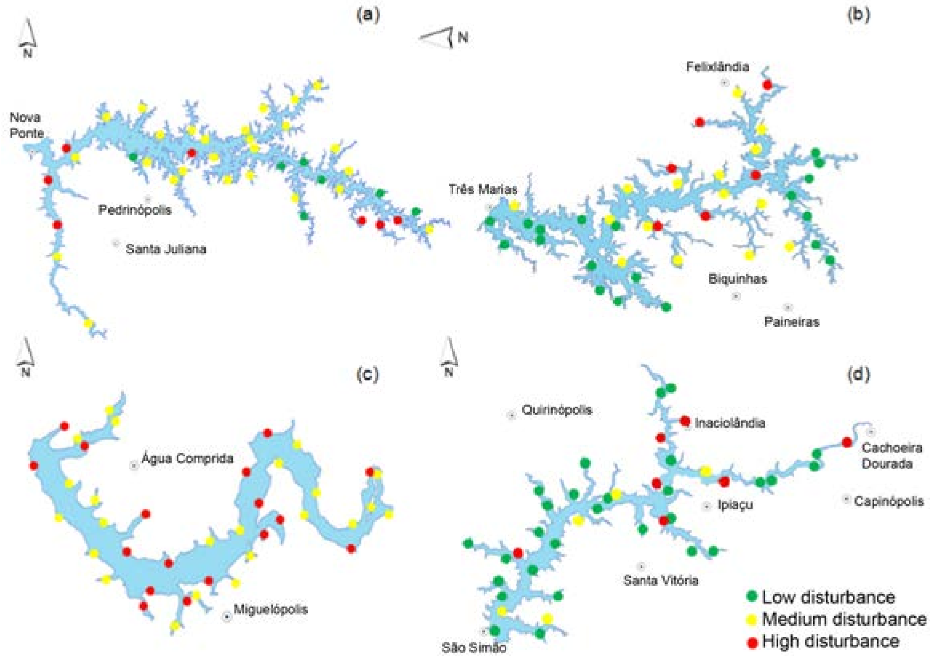

FIGURE 8. Riparian anthropogenic disturbance levels at Nova Ponte (a), Três Marias (b), Volta Grande (c) and São Simão (d) Reservoir sites.

3.2 Biological Conditions

We found a total of 42,513 macroinvertebrates in the four reservoirs. The major taxonomic groups were Chironomidae (61.8%), Oligochaeta (9.5%), and alien invasive species (*Melanoides tuberculatus, Corbicula fluminea, Limnoperna fortunei* and *Macrobrachium amazonicus* – 10.5%). Because of their greater numerical abundance and recognized ecological role in reservoirs and lakes, we identified the Chironomidae larvae to genus, with 21 genera found at Nova Ponte, 34 at Três Marias, 29 at Volta Grande and 26 at São Simão. Benthic macroinvertebrate assemblages differed among the reservoirs, especially in the relative abundance of alien species, % EPT, and % sensitive taxa (Table 2; Figure 9).

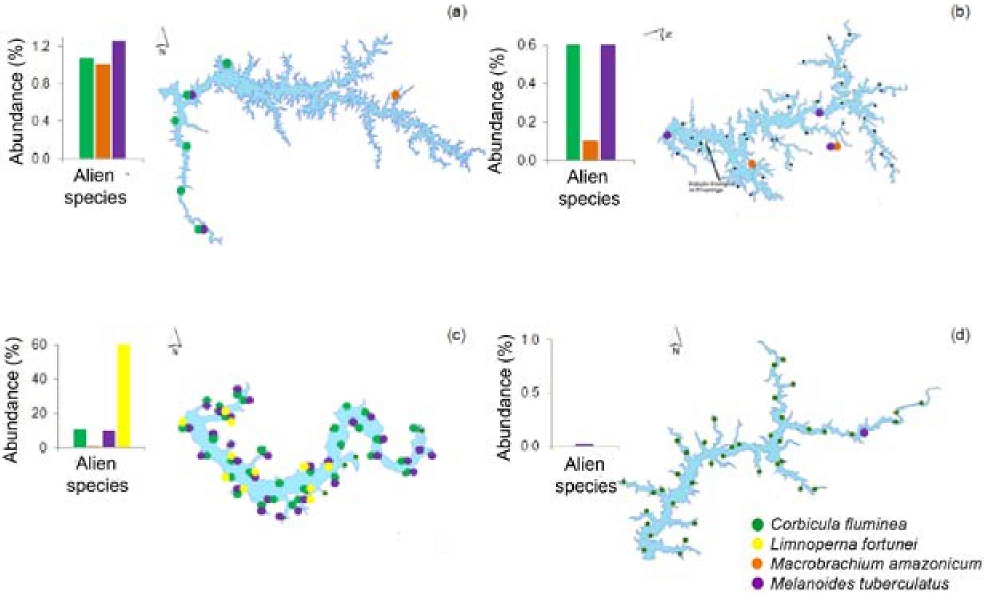

FIGURE 9. Relative abundance and distribution of alien species in Nova Ponte (a), Três Marias (b), Volta Grande (c) and São Simão (d) Reservoirs.

In Nova Ponte, we collected 1,116 organisms and 18 families via an Ekman-Birge dredge. The most abundant groups were Chironomidae (46%) and Oligochaeta (42%), including 462 individuals and 21 genera of chironomids. With kick-nets we collected 15,340 individuals and 36 families, mostly Chironomidae (63%) and Oligochaeta (16%). The alien species *Corbicula fluminea* and *Melanoides tuberculatus* were collected at 6 sites near the dam, and 567 *Macrobrachium amazonicus* were collected at 18 sites.

At Três Marias, we collected 976 individuals (23 families) with the dredge, including 698 (72%) chironomids representing 24 genera. We collected 4,464 individuals (21 families) with kick-nets, including 2,874 (64%) chironomids in 25 genera. We also collected a few alien *Melanoides tuberculatus* (0.6%), *Corbicula fluminea* (0.6%) and *Macrobrachium amazonicus* (0.1%).

With the dredge we collected 3,737 individuals and 17 families from Volta Grande, including only 486 chironomids (14%) in 23 genera. The assemblage was dominated by alien mollusks: *Limnoperna fortunei* (60.85%), *Corbicula fluminea* (9.98%) and *Melanoides tuberculatus* (9.77%). We obtained a different result with the kick-net, with which we collected 4,234 individuals and 40 families, dominated by Chironomidae (28%), Baetidae (14%), Oligochaeta (11%) and the alien *Melanoides tuberculatus* (10%).

At São Simão, the dredge produced 3,693 individuals and 14 families, 96% (26 genera) of which were Chironomidae. The kick-net produced 8,921 organisms and 25 families, again dominated by Chironomidae (81% of individuals), but <1% *Melanoides tuberculatus*.

Sampling effort curves based on dredge sampling indicate that additional samples are needed if one wants to assess total reservoir taxonomic richness in an adequate manner (Figure 10). However, indicators based on percentages (e.g., % aliens, % EPT) are often more robust for making ecosystem assessments as long as 500 individuals are collected per site and depending on the level of site condition discrimination desired (Cao et al., 2002; Li et al., 2014). Sanches et al. (THIS VOLUME) found high proportions of alien fish in São Simão and Volta Grande, suggesting that a combined macroinvertebrate-fish assemblage assemblage assessment may be warranted. The kick-net was generally a more productive sampling gear because it produced more individuals, more taxa, and could be used on all substrates (soft, hard, vegetation, wood). Presumably for this reason, it is used by the U.S. Environmental Protection Agency in its National Lake Assessment program (USEPA, 2009).

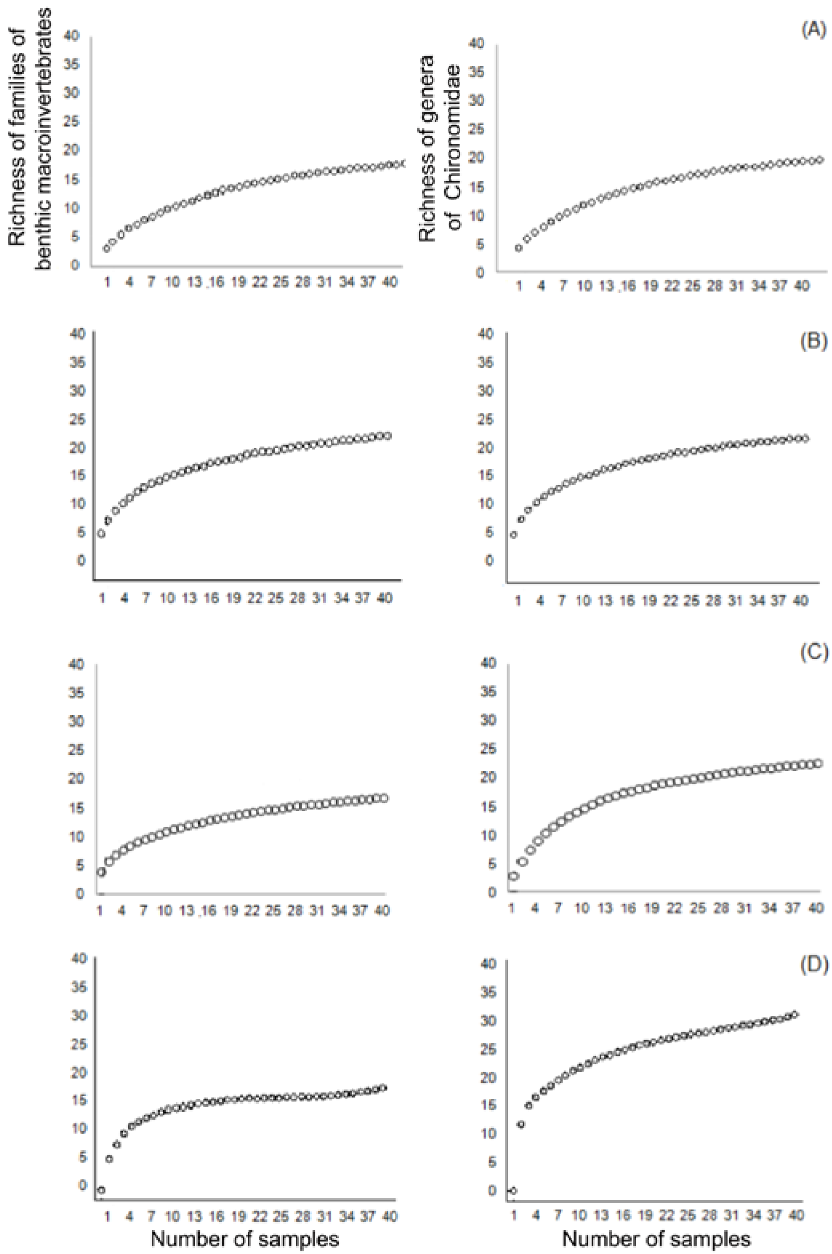

FIGURE 10. Dredge sampling effort curves for benthic macroinvertebrate families and Chironomidae genera in Nova Ponte (A), Três Marias (B), Volta Grande (C) and São Simão (D) Reservoirs.

3.3 Distribution of Benthic Macroinvertebrates versus Disturbance Levels

Reservoir-scale disturbance was associated with reservoir-scale macroinvertebrate assemblage indicators such as % aliens and % EPT; however, further metric evaluations are needed. The site-scale distribution of macroinvertebrates was not explained by the site-scale BDIs, RDIs, or IDIs. Instead, we believe that site distribution patterns are also strongly affected by water level fluctuations and catchment-scale land use. For example, Morais (2013) observed that the water level in Três Marias dropped 10 meters vertically and an average of 113 meters horizontally between the wet season peak and the dry season low. Miranda et al. (2010) cited fluctuating reservoir water levels as a major cause of habitat degradation in 494 USA reservoirs. Allen et al. (1999) and O'Connor et al. (2000) determined that catchment-wide land use were major factors associated with biotic assemblage condition in northeast USA lakes. Macedo et al. (THIS VOLUME) reported that Nova Ponte and Tres Marias catchment conditions explained greater variability in stream macroinvertebrate taxa richness than did site conditions. It is probable that these water level fluctuations and catchment conditions structure littoral benthic assemblages as much or more than local land use and riparian cover conditions. Thus, it is likely that the fauna we found was composed of organisms that colonized the littoral zone during the wet season immediately before we sampled, as well as by those taxa that responded to reservoir-wide and watershed-wide conditions versus only site conditions. Clearly, it is important to evaluate natural and anthropogenic pressures at multiple temporal and spatial scales (Wang et al., 2006; Johnson & Host, 2010) and to consider the entire reservoir as one unit, major reservoir regions (Terra et al., 2010; Sanches, 2014), or both.

4 – DISCUSSION

The introduction of alien species is related to commercial activities (Fernandez et al., 2003) and, in the case of *C. fluminea*, to compete with *Biomphalaria glabrata*, the intermediate host of *Schistosoma* spp. (Giovanelli et al., 2002). However *C. fluminea* clogs pipes and hydroelectric structures (Silva & Barros, 2011), alters the structure and function of ecosystems (Silva & Barros, 2011), and is considered the second leading cause of lost global biodiversity by Coradin & Tortato (2006).

Conservation of riparian areas and regions with low levels of disturbance at hydroelectric reservoirs must be a priority if managers want to maintain that environmental quality at those sites, but catchment-wide conservation and mitigation are also necessary to maximize reservoir quality. Also, alien species control and eradication programs are needed if managers desire to control those species. Such programs should include a risk analysis that takes into account the cost-benefit relationship of any actions, the impacts on natural ecosystems, and the social and economic impacts of species introductions (Cowx et al., 2009; AFS, 2014). In addition to the buffer- and riparian-scale variables that we assessed, additional assessments of watershed-wide land use (as Macedo et al., 2014; THIS VOLUME did for streams) and water level fluctuations are needed. Ideally such assessments would be regional joint efforts by governments, academia, and private enterprises and undertaken over complete hydrological cycles and for long times (e.g. a minimum of 10 years). Investments in the improvement of environmental conditions can improve water quality, conserve biodiversity, and increase the supply of goods and services from hydroelectric reservoirs for the well being of society.

5 – ACKNOWLEDGEMENTS

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SÉRIE
PEIXE VIVO

ECOLOGICAL
CONDITIONS

CHAPTER 9

ICHTHYOFAUNA OF FOUR CEMIG RESERVOIRS: ASSEMBLAGE CHARACTERISTICS AND CONSERVATION PERSPECTIVES

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1 – INTRODUCTION

Hydropower dam construction is one of the most common anthropogenic alterations of Brazilian rivers. Currently, most large rivers in the country are influenced by dams, with a total of 700 large dams having been built (Agostinho et al., 2008). Because many of these dams are located in the São Francisco and Paraná River Basins, the generation potential in the southern, southeastern, and northeastern regions of Minas Gerais has been almost completely exploited (ANEEL, 2002).

The physical and chemical alterations of rivers resulting from reservoir construction alter entire aquatic communities (Cecilio et al., 1997). In oligotrophic reservoirs, the conditions are particularly inhospitable and feature a simplified habitat, low nutrient concentration, high transparency, and thermally and chemically stratified waters. As a result of this new environment, migratory species and species adapted to fluvial habitats are lost (Gao et al., 2010). Although fish passes can move some adult fish past dams, the reservoirs behind the dams are lethal traps for many downstream migrating larval, young, and adult fish (Pelicice & Agostinho, 2008; Agostinho et al., 2011; Pompeu et al., 2012; Pelicice et al., 2014). The restructuring of reservoir assemblages is marked by the extinction of native species and a drastic alteration in the abundance of the majority of species (Gomes & Miranda, 2001), because few species are capable of successfully colonizing the newly formed environment. The remaining native species tend to be restricted to areas with greater similarity to the fluvial environment (Gao et al., 2010), such as the fluvial region and tributaries. Consequently, these locations have the greatest fish species richness (Terra et al., 2010).

In addition, the installation of a hydroelectric plant tends to increase the chances of establishment of non-native species. In heavily modified environments such as reservoirs, many introduced species establish themselves and displace portions of the native ichthyofauna (Gido & Matthews, 2000). Introduced species alter the food chain (Mercado-Silva et al., 2009), prey on native species (Terra et al., 2010), and compete for food resources.

Many studies have been conducted in Brazil to understand the ecology of reservoir fish assemblages. However, most of those studies involved few sites and poor study designs, resulting in little increased knowledge regarding the spatial distribution of reservoir ichthyofaunas. Therefore we sampled 40 systematically selected sites on each of four large reservoirs to evaluate fish assemblage composition, species richness and abundance, and species distribution patterns.

2 – METHODS

2.1 Study Areas

The study area comprised the upper reaches of two large Neotropical basins: the Paraná and São Francisco Rivers. In the Paraná Basin, we selected three major drainages in the state of Minas Gerais: the Paranaíba River, the Araguari River, and the Grande River. Together, these four basins drain approximately 66% of the state of Minas Gerais. In each drainage, we sampled a Cemig hydroelectric power plant (HPP) reservoir: São Simão, Nova Ponte and Volta Grande in the Paraná Basin and Três Marias in the São Francisco Basin. The São Simão HPP was installed on the Paranaíba River in 1978, has an installed capacity of 1,710 MW, and its reservoir holds a useful volume of 5.5 billion m^3 (Cemig, 2013). The Nova Ponte HPP, installed along the middle reach of the Araguari River, began operation in 1994 with an installed capacity of 510 megawatts and a useful reservoir volume of 10.4 billion m3 (Vono, 2002). The Volta Grande HPP was installed on the Grande River in 1974, has a capacity of 380 MW, and its reservoir holds a useful volume of 268 million m^3 (Cemig, 2013). It is one of 12 reservoirs built in series on the Grande River, is the smallest reservoir among the four sampled, and is the only one that lacks a large depletion capacity. The Três Marias HPP began operation in 1962 with an installed capacity of 396 MW and a storage reservoir volume of 15.3 billion m^3. It is the only dam built on the upper reach of the São Francisco River (Godinho & Godinho, 2003).

2.2 Fish Sampling

We collected fish between 2010 and 2013. At the end of the rainy season each year, we sampled one HPP reservoir at 40 littoral zone sites uniformly spread along its perimeter (see Macedo et al., THIS VOLUME). At each site, we set 10 gill nets, each 20-meters long and with mesh size varying from 3 to 16 cm (between opposing knots). Five pairs of nets were set in series at an angle of approximately 45° from the shore and with the smaller mesh net nearest the shore. A distance of 40 meters was maintained between each pair of nets, so the total site length was 200 m. The nets were set in the evening and retrieved in the morning for a soak time of 15 h.

We preserved captured fish in 10% formalin and transported them to the PUC Minas Vertebrate PPG-Zoology laboratory where they were washed and transferred to 70 % alcohol. The species, standard length (cm), and body weight (g) were determined for each specimen at each site. We used taxonomic keys (Britski et al., 1986; Graça & Pavanelli, 2007) to identify species and deposited voucher specimens in the ichthyological collections of the PUC-Minas Natural History Museum, the São José do Rio Preto State University (São Paulo), and the Maringá State University (Paraná). Species originating in other basins or that did not originally belong to the reaches studied were deemed as introduced.

3 – RESULTS

We collected 93 fish species in 21 families and four orders (Appendix 1). Most species were Characiformes, followed by Siluriformes (Três Marias and São Simão), Perciformes (Volta Grande) or both (Nova Ponte). Gymnotiformes were absent in Nova Ponte and uncommon in the other reservoirs. São Simão produced the most species (49), followed by Três Marias (37), Volta Grande (30) and Nova Ponte (29). Três Marias Reservoir yielded the most individuals (3,843), followed by São Simão (2,843), Nova Ponte (2,463) and Volta Grande (1,488) (Table 1).

TABLE 1: Number of individuals, orders, families and species collected per reservoir.

	Upper Paraná River			São Francisco River
	São Simão	Nova Ponte	Volta Grande	Três Marias
Individuals	2,843	2,463	1,488	3,843
Orders	4	3	4	4
Families	17	12	14	17
Species	49	29	30	37

We collected 10 migratory species in São Simão (20% of the species), 4 in Nova Ponte and Volta Grande (14% and 13% of species, respectively) and 6 in Três Marias (16% of species) (Figure 1). In terms of relative abundance, migratory species represented 11% of the individuals in São Simão, 10% in Nova Ponte, 5% in Volta Grande, and 4% in Três Marias. Migratory Anostomidae, Prochilodontidae, and Bryconidae species were collected from all four reservoirs.

We collected 11 introduced species in São Simão (22% of the species), 5 in Nova Ponte (17% of species), 7 in Volta Grande (23% of species) and 3 in Três Marias (8% of species)

(Figure 1). However the relative abundance of introduced individuals was high in São Simão (71%) and Volta Grande (60%) and lower in Nova Ponte and Três Marias (10% and 20% of total abundance, respectively). An introduced species dominated the assemblage in three reservoirs: *Geophagus* cf. *proximus* and *Plagioscion squamosissimus* in São Simão (Figure 2), *P. squamosissimus* in Volta Grande (Figure 3), and (*Cichla cf. piquiti*) in Três Marias (Figure 4). However, in Nova Ponte, native species (*Iheringichthys labrosus* and *Pimelodus maculatus*) were the most abundant and had the greatest biomass (*Schizodon nasutus* and *Prochilodus lineatus*); the 5 most frequently collected species were native (Figure 5).

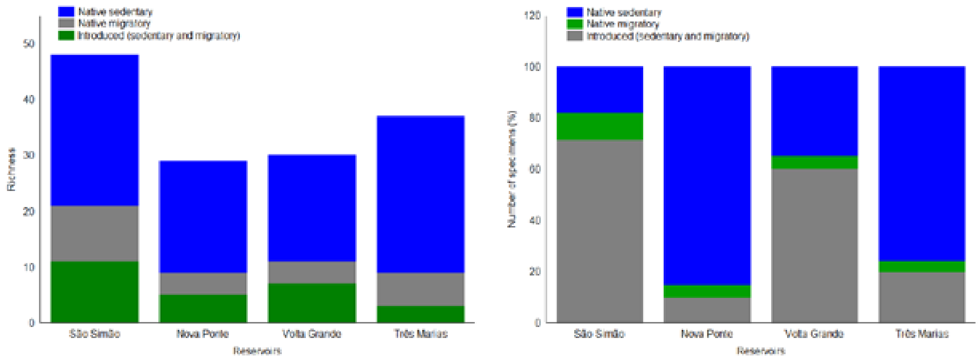

FIGURE 1. Richness and number of specimens (%) of native and introduced fish species collected from four Minas Gerais reservoirs.

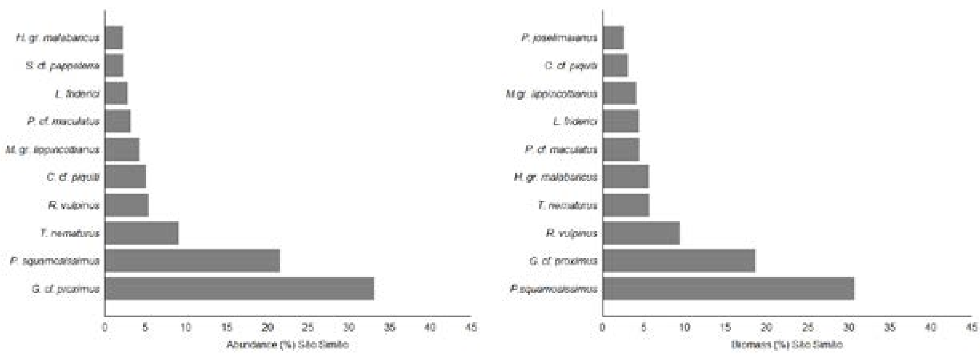

FIGURE 2. Relative abundance and biomass of the ten most common fish species collected from São Simão Reservoir.

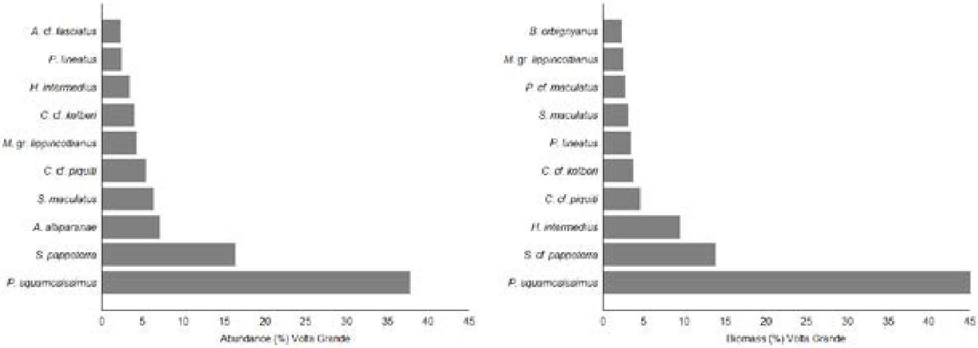

FIGURE 3. Relative abundance and biomass of the ten most common species collected from Volta Grande Reservoir.

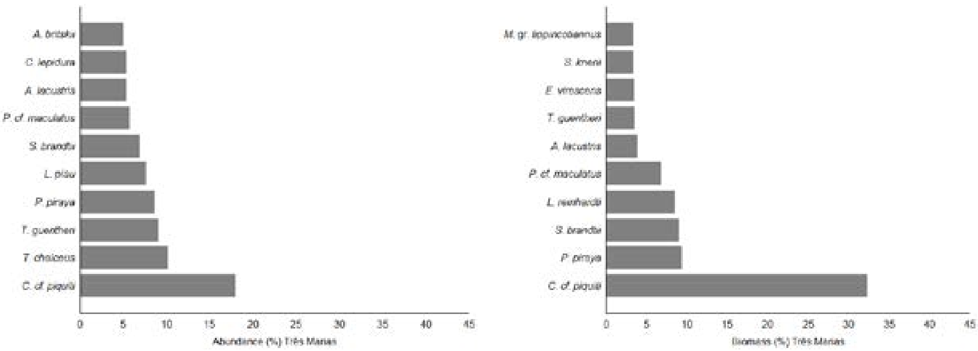

FIGURE 4. Relative abundance and biomass of the ten most common fish species collected from Três Marias Reservoir.

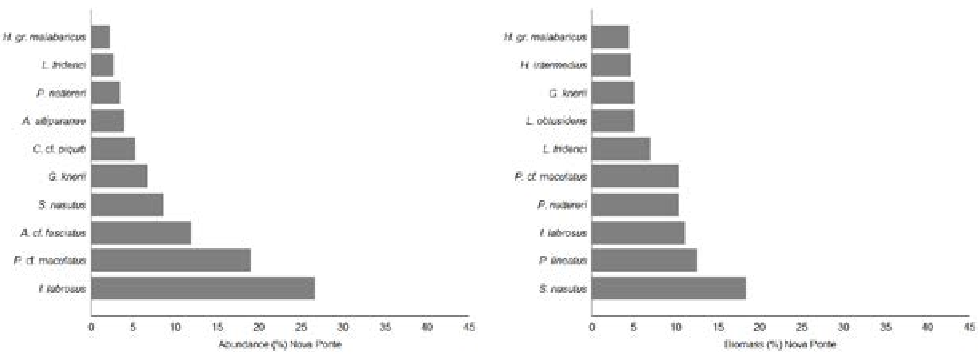

FIGURE 5. Relative abundance and biomass of the ten most common fish species collected from Nova Ponte Reservoir.

Tributaries influenced the distribution of species among sites. At São Simão, sites located near tributaries had greater richness (tributary: 12.2 ±3.7; reservoir: 10.7 ±1.8), greater total abundance (tributary: 20.4 ±9.0; reservoir: 18.7 ±10.9), more migratory species (tributary: 2.4 ±2.2; reservoir: 1.3 ±1.8), and fewer introduced species (tributary: 9.4 ±6.5; reservoir: 18.5 ±6.5). We observed the same pattern in Nova Ponte: greater species richness (tributary: 10.8 ±2.7; reservoir: 9.1 ±2.3), greater total abundance (tributary: 16.1 ±9.3; reservoir: 12.5 ±7.6), more migratory species (tributary: 0.9 ±1.1; reservoir: 0.5 ±0.8), and fewer introduced species (tributary: 1.2 ±0.8; reservoir: 1.5 ±1.3). At Três Marias we found fewer introduced species near tributaries (tributary: 5.0 ±4.0; reservoir: 5.7 ±6.3), but no such patterns in Volta Grande.

4 – DISCUSSION

Hydroelectric projects modify fish species composition and abundance as a result of the proliferation of those with greater trophic and reproductive plasticity and the elimination of those that are most sensitive (Agostinho et al., 1999). The presence of a series of reservoirs and the associated intensification of land use, amplifies the negative impacts on water quality (Linke et al., 2007) and the biota (Capcott et al., 2012; Pelicice et al., 2014).). Small-sized, short-lived, and sedentary species with high reproductive rates that are adapted to semi-lentic environments are favored, while migratory and rheophilic species are eliminated (Agostinho et al., 1995; Pelicice et al., 2014). This situation is amplified as the reservoir ages (Agostinho et al., 2008) and when projects are constructed in series.

We observed few migratory species and individuals in the reservoirs. Agostinho et al. (2008) reported that only 5% of 75 Brazilian reservoirs studied supported over 3 abundant migratory species. The reproductive behavior of these species typically includes long migrations to spawning areas and the drift of eggs and larvae to marginal lakes where juvenile development occurs (Suzuki et al., 2011). Persistence of such species is seriously hindered by the loss of connectivity, transformation of lotic environments to lentic systems, and by agriculture, pasture, and urbanization.

Frequently, the most abundant species in reservoirs are of low commercial value, widely distributed across their ranges, and highly tolerant to environmental disturbance, which facilitates their persistence in modified environments (Brandão, 2007). The presence of such opportunistic species in all four reservoirs is likely related to their physiological tolerance and behavioral plasticity. For example, *P.* cf. *maculatus* was among the most commonly captured species in Upper Paraná and São Francisco reservoirs (Alvim & Peret, 2004; Brandão, 2007), and it is considered a generalist feeder that occurs in widely different environments (Gomes & Verani, 2003).

Some reproductive strategies are advantageous in impaired environments. For example, sedentary species that engage in parental care and do not depend on the seasonal water cycle, such as *Hoplias* and *Cichla*, can colonize regulated environments successfully (Agostinho et al., 2004). Other species may be resistant to damming if they have small quickly developing eggs, a broad feeding spectrum, and the ability to colonize different types of environments (Dias et al., 2005).

Introduced species may compete for resources, predate native prey, interfere with reproduction, and transfer disease and parasites (Petesse et al., 2007). The impacts on local fish faunas may be especially detrimental if introduced species are piscivorous (Moyle & Cech, 1996; Hughes & Herlihy, 2012). In Volta Grande, we collected few native species, which was likely a result of predation by *P. squamosissimus*, which represented 90% of the catch at some sites. Piscivorous species, such as *C.* cf. *piquiti* and *P. squamosissimus*, have been highly successful at colonizing other reservoirs in southern and southeastern Brazil (Agostinho et al., 2008).

We found that tributaries had a positive influence on native species distribution, abundance and richness, which indicates the importance of such habitats for fish population conservation. Relatively well-preserved large tributaries may meet the ecological requirements of certain species even after damming (Pracheil et al., 2013). Such areas produce nutrients and greater fish habitat diversity (Araújo & Santos, 2001). Despite the importance of tributaries for maintaining remnant native species in reservoirs, long lotic stretches uninfluenced by dams is still the ideal scenario for conserving native fish faunas (Pracheil et al., 2013). This is especially important for reservoirs that still have significant free stretches upstream (Nova Ponte, Três Marias and São Simão) or occur in large drainage basins (Três Marias and São Simão).

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APPENDIX 1. Fish species collected from Nova Ponte, São Simão, Volta Grande, and Três Marias HPP reservoirs.

ORDER / Family / *Species*	**Author**	**Common Name[1]**	**Maximum total length (mm)**	**Upper Paraná River**			**São Francisco River**
				Nova Ponte	**São Simão**	**Volta Grande**	**Três Marias**
CHARACIFORMES							
Acestrorhynchidae							
1) *Acestrorhynchus britskii*	Menezes 1969	Peixe-cachorro	160				X
2) *Acestrorhynchus lacustris*	(Lütken 1875)	Peixe-cachorro	280			X	X
Anostomidae							
3) *Leporellus vittatus*	(Valenciennes 1850)	Piau-rola / Solteira	220	X			X
4) *Leporinus amblyrhynchus*	Garavello & Britski 1987	Timburé	105	X			
5) *Leporinus friderici*[2]	(Bloch 1794)	Piau-três-pintas	370	X	X	X	
6) *Leporinus lacustris*	Campos 1945	Corró	230			X	
7) *Leporinus* cf. *macrocephalus*[2, 3]	Garavello & Britski 1988	Piaussu	500		X		
8) *Leporinus obtusidens*[2]	(Valenciennes 1837)	Piau-verdadeiro / Piau	410	X	X	X	X
9) *Leporinus octofasciatus*	Steindachner 1915	Flamenguinho	210	X			
10) *Leporinus piau*	Fowler 1941	Piau-gordura	189				X
11) *Leporinus reinhardti*[2]	Lütken 1875	Piau-três-pintas	192				X
12) *Leporinus tigrinus*	Borodin 1929	Flamenguinho	210		X		
13) *Leporinus geminis*[2?, 3?]	Garavello & Santos 2009	Piau	180		X		
14) *Leporinus* sp.[2?, 3?]	-	Piau	-		X		
15) *Schizodon borellii*	(Boulenger 1900)	Piau-bosteiro	315		X		
16) *Schizodon knerii*	(Steindachner 1875)	Piau-branco	272				X
17) *Schizodon nasutus*	Kner 1858	Timborê	390	X	X	X	
Bryconidae							

ORDER / Family / *Species*	Author	Common Name[1]	Maximum total length (mm)	Upper Paraná River			São Francisco River
				Nova Ponte	São Simão	Volta Grande	Três Marias
18) Brycon orbignyanus[2]	(Valenciennes 1850)	Piracanjuba	400			X	
19) Salminus brasiliensis[2]	(Cuvier 1816)	Dourado	780		X		
20) Salminus hilarii[2]	Valenciennes 1850	Tabarana	340	X	X		X
Characidae							
21) Astyanax altiparanae	Garutti & Britski 2000	Lambari-do-rabo-amarelo	129,2	X	X	X	
22) Astyanax cf. fasciatus	(Cuvier 1819)	Labari-do-rabo-vermelho	102	X	X	X	X
23) Astyanax lacustris	(Lütken 1875)	Lambari-do-rabo-amarelo	134				X
24) Astyanax schubarti	Britski 1964	Lambari	89	X			
25) Galeocharax knerii	(Steindachner 1879)	Dentudo	257	X		X	
26) Moenkhausia costae[3]	(Steindachner 1907)	Lambari	70	X			
27) Orthospinus franciscensis	(Eigenmann 1914)	Lambari	74				X
28) Roeboides descalvadensis[3]	Fowler 1932	Dentudo	89		X		
29) Roeboides xenodon	(Reinhardt 1851)	Lambari-cachorro	95				X
30) Tetragonopterus chalceus	Spix & Agassiz 1829	Piaba-rapadura	86				X
Curimatidae							
31) Curimatella lepidura	(Eigenmann & Eigenmann 1889)	Manjuba	100				X
32) Cyphocharax modestus	(Fernández-Yépez 1948)	Saguiru	132	X			
33) Cyphocharax nagelii	(Steindachner 1881)	Saguiru	165		X		
34) Steindachnerina elegans	(Steindachner 1875)	Saguiru	106				X
35) Steindachnerina insculpta	(Fernández-Yépez 1948)	Saguiru	144	X	X	X	
Cynodontidae							
36) Rhaphiodon vulpinus[2]	Spix & Agassiz 1829	Cachorra-facão	780		X		

ORDER / Family / *Species*	Author	Common Name[1]	Maximum total length (mm)	Upper Paraná River			São Francisco River
				Nova Ponte	São Simão	Volta Grande	Três Marias
Erythrinidae							
37) Hoplias intermedius	(Günther 1864)	Trairão	500	X	X	X	X
38) Hoplias gr. malabaricus	(Bloch 1794)	Traíra	400	X	X	X	X
Iguanodectidae							
39) Bryconops sp.	-	Piaba	120				X
Parodontidae							
40) Parodon nasus	Kner 1859	Canivete	117		X		
Prochilodontidae							
41) Prochilodus argenteus[2]	Spix & Agassiz 1829	Curimatá-pacu / Zulega	440				X
42) Prochilodus costatus[2]	Valenciennes 1850	Curimatá-pioa	420				X
43) Prochilodus lineatus[2]	(Valenciennes 1837)	Curimba	542	X	X	X	
Serrasalmidae							
44) Metynnis gr. lippincottianus[3]?	(Cope 1870)	Pacu-cd	170	X	X	X	
45) "Myleus" micans[2]?	(Lütken 1875)	Pacu	276				X
46) Piaractus mesopotamicus[2]	(Holmberg 1887)	Pacu-caranha	405		X		
47) Pygocentrus nattereri[3]	Kner 1858	Piranha	500	X			
48) Pygocentrus piraya	(Cuvier 1819)	Piranha	340				X
49) Serrasalmus brandtii	Lütken 1875	Pirambeba	212				X
50) Serrasalmus maculatus	Kner 1858	Pirambeba	108		X	X	
51) Triportheus guentheri	(Garman 1890)	Piaba-facão	134				X
52) Triportheus nematurus[3]	(Kner 1858)	Sardinha	183		X		
SILURIFORMES							
Auchenipteridae							
53) "Trachelyopterus" galeatus	(Linnaeus 1766)	Cangati	285	X			X
Callichthyidae							
54) Callichthys callichthys	(Linnaeus 1758)	Tamboatá	150		X		

ORDER / Family / *Species*	Author	Common Name[1]	Maximum total length (mm)	Upper Paraná River			São Francisco River
				Nova Ponte	São Simão	Volta Grande	Três Marias
55) Hoplosternum littorale	(Hancock 1828)	Tamboatá	240			X	X
Heptapteridae							
56) Pimelodella avanhandavae	Eigenmann 1917	Mandi-chorão	236		X		
57) Pimelodella gracilis	(Valenciennes 1835)	Mandi-chorão	184	X			
58) Rhamdia aff. Quelen	(Quoy & Gaimard 1824)	Bagre	410		X		
Loricariidae							
59) Hypostomus ancistroides	(Ihering 1911)	Cascudo	210		X		
60) Hypostomus faveolus	Zawadzki, Birindelli & Lima 2008	Cascudo	206		X		
61) Hypostomus margaritifer	(Regan 1908)	Cascudo	330		X		
62) Hypostomus cf. strigaticeps	(Regan 1908)	Cascudo	150		X		
63) Hypostomus sp.1	-	Cascudo			X		
64) Hypostomus sp. 2	-	Cascudo		X			
65) Hypostomus sp. 3	-	Cascudo				X	
66) Megalancistrus parananus	(Peters 1881)	Cascudo-ab-acaxi	504			X	
67) Proloricaria prolix	(Isbrücker & Nijssen 1978)	Cascudo-chine-lo	450			X	
68) Pterygoplichthys joselimaianus[3]?	(Weber 1991)	Cascudo	305		X		
69) Hemisorubim platyrhynchos[2]	(Valenciennes 1840)	Jurupoca	525		X		
70) Iheringichthys labrosus	(Lütken 1874)	Mandi-beiçudo	240	X	X		
71) Leiarius marmoratus vs Pseudoplatystoma sp. (híbrido)[3]	-	Pinta-do-amazônico / Cachandiá / Jundiara			X		
72) Pimelodus fur	(Lütken 1874)	Mandi-branco	170				X
73) Pimelodus cf. maculatus[2]?	Lacepède 1803	Mandi-amarelo	310	X	X	X	X
74) Pimelodus pohli	Ribeiro & Lucena 2006	Mandi-branco	150				X

ORDER / Family / *Species*	Author	Common Name[1]	Maximum total length (mm)	Upper Paraná River			São Francisco River
				Nova Ponte	São Simão	Volta Grande	Três Marias
75) *Pinirampus pirinampu*[2]	(Spix & Agassiz 1829)	Barbado	680		X		
76) *Pseudoplatystoma corruscans*[2]	(Spix & Agassiz 1829)	Surubim / Pintado	860		X		X
PERCIFORMES							
Cichlidae							
77) *Astronotus* cf. *crassipinnis*[3]	(Heckel 1840)	Apaiari	302			X	
78) *Cichla* cf. *kelberi*[3]	Kullander & Ferreira 2006	Tucunaré	445		X	X	X
79) *Cichla* cf. *piquiti*[3]	Kullander & Ferreira 2006	Tucunaré	280	X	X	X	X
80) *Cichlasoma paranaense*	Kullander 1983	Cará	171	X	X	X	
81) *Crenicichla britskii*	Kullander 1982	Joaninha	176		X	X	
82) *Geophagus brasiliensis*	(Quoy & Gaimard 1824)	Cará	175	X			
83) *Geophagus* cf. *proximus*[3]	(Castelnau 1855)	Cará	200		X		
84) *Oreochromis niloticus*[3]	(Linnaeus 1758)	Tilápia	200	X	X	X	
85) *Satanoperca* cf. *pappaterra*[3]	(Heckel 1840)	Cará	222		X	X	
86) *Tilapia rendalli*[3]	(Boulenger 1897)	Tilápia	170	X	X	X	
Sciaenidae							
87) *Pachyurus francisci*	(Cuvier 1830)	Corvina	297				X
88) *Pachyurus squamipennis*	Agassiz 1831	Corvina	291				X
89) *Plagioscion squamosissimus*[3]	(Heckel 1840)	Corvina	800		X	X	

ORDER / Family / *Species*	Author	Common Name[1]	Maximum total length (mm)	Upper Paraná River			São Francisco River
				Nova Ponte	São Simão	Volta Grande	Três Marias
GYMNOTIFORMES							
Gymnotidae							
90) Gymnotus aff. carapo	Linnaeus 1758	Sarapó	760				X
Sternopygidae							
91) Eigenmannia microstoma	(Reinhardt 1852)	Tuvira	187				X
92) Eigenmannia virescens	(Valenciennes 1836)	Tuvira	320			X	
93) Sternopygus aff. macrurus	(Bloch & Schneider 1801)	Tuvira	550		X		
Riqueza total				29	48x	36	37

1. According to Britski; Sato; Rosa (1988) and Graça & Pavanelli (2007).
2. Species considered migratory, according to Agostinho et al. (2003), Graça & Pavanelli (2007) and Alves & Pompeu (2010).
3. Species considered introduced in the upper Paraná and/or São Francisco river, according to Graça & Pavanelli (2007), Alves & Leal (2010) and Santos (2010).

? - Undefined

Designations: "aff." - (affinis) / "cf." - (confers) / "sp." - (species maintained at the generic level because morphological characteristics do not fit existing descriptions in the literature) / "gr." - (from the group).

APPENDIX 2. Photographs of some of the species collected in this study.

CHARACIFORMES

Acestrorhynchidae

Acestrorhynchus britskii

Acestrorhynchus lacustris

Anostomidae

Leporellus vittatus

Leporinus amblyrhynchus

Leporinus friderici

Leporinus geminis

Leporinus obtusidens

Leporinus octofasciatus

Leporinus piau

Leporinus reinhardti

Leporinus tigrinus

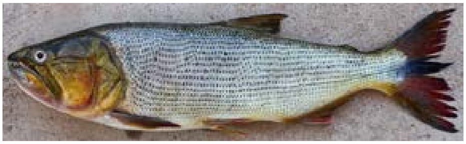
Leporinus sp.

Schizodon knerii

Schizodon nasutus

Bryconidae

Brycon orbignyanus



Salminus brasiliensis

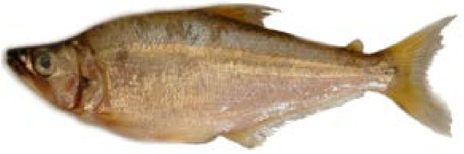
Salminus hilarii

Characidae

Astyanax altiparanae

Astyanax cf. *fasciatus*

Astyanax lacustris



Galeocharax knerii

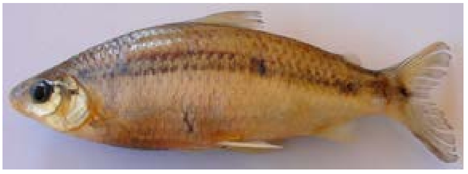
Moenkhausia costae

Orthospinus franciscensis

Roeboides xenodon

Tetragonopterus chalceus

Curimatidae



Cyphocharax modestus

Cynodontidae

Rhaphiodon vulpinus

Iguanodectidae

Bryconops sp.

Erythrinidae

Hoplias intermedius

Hoplias gr. *malabaricus*

Prochilodontidae

Prochilodus argenteus

Prochilodus costatus

Prochilodus lineatus

Serrasalmidae

Piaractus mesopotamicus

Pygocentrus nattereri

Pygocentrus piraya

Metynnis gr. *lippincottianus*

"Myleus" micans

Serrasalmus brandtii

Serrasalmus maculatus

Triportheidae

Triportheus guentheri

Triportheus nematurus

SILURIFORMES

Auchenipteridae

"Trachelyopterus" galeatus

Callichthyidae

Hoplosternum littorale

Pimelodidae

Hemisorubim platyrhynchos

Pimelodus fur

Pimelodus cf. *maculatus*

Pinirampus pirinampu

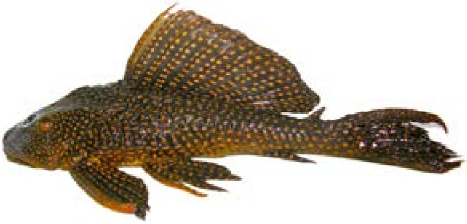
Pseudoplatystoma corruscans

Leiarius marmoratus vs *Pseudoplatystoma* sp. (híbrido)

Loricariidae

Hypostomus ancistroides

Megalancistrus paranaus



Pterygoplichthys joselimaianus

PERCIFORMES

Cichlidae

Cichla cf. *kelberi*

Cichla cf. *piquiti*

Geophagus cf. *proximus*

Oreochromis niloticus

Satanoperca cf. *pappaterra*

Tilapia rendalli

Sciaenidae

Pachyurus francisci

Pachyurus squamipennis

Plagioscion squamosissimus

GYMNOTIFORMES

Sternopygidae

Eigenmannia microstoma

Sternopygus aff. *macrurus*

Photos taken by: Amanda Ribeiro Cocovick, Bárbara Becker, Bárbara de Oliveira Sanches, Gilberto Nepomuceno Salvador, Lorena Cristina dos Santos and Tiago Casarim Pessali.

SÉRIE
PEIXE VIVO

ECOLOGICAL CONDITIONS

CHAPTER 10
PROSPECTS FOR THE INDEX OF BIOTIC INTEGRITY APPROACH WITH FISH AND BENTHOS IN CERRADO DRAINAGE BASINS

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1 – FUTURE CEMIG RESEARCH

We have developed a large database for developing IBIs for Minas Gerais streams and reservoirs via the UFMG, UFLA, PUC-Minas, CEFET-MG, OSU, USEPA, and Cemig/Peixe Vivo partnership. That database and subsequent data analyses and journal manuscripts have led to a set of additional research questions and three new projects:

1) The FAPEMIG/Cemig project entitled, *Development of Indices of Biotic Integrity: Stream Fish as Indicators of Water Quality in Drainage Basins at Cemig's Hydropower Projects in Minas Gerais,* is focused on developing a stream fish IBI based on assemblage composition and functional guilds and assessing energy and nutrient flows.

- Daniela Fagundes will resample the Nova Ponte stream sites to determine the degree to which species composition and functional guilds change with time and sampling crew. That information will be used to help select IBI metrics that are more responsive to anthropogenic disturbance than they are to natural and sampling variability. She also will collaborate with Deborah Silva, Barbara Sanches, and Barbara Becker on their IBI research (see below).
- Debora Carvalho will use stable isotope (^{13}C and ^{15}N) analysis to assess how agricultural practices alter aquatic food webs. Nine streams upstream of São Simão Reservoir will be studied, three draining a sugar cane plantation, three draining grazing land, and three forested. This research will be coordinated with the isotopic macroinvertebrate research of Diego Castro, Anna Aguiar, and Wander Ferreira (UFMG; see below).

2) The ANEEL/Cemig project entitled, *Development of Indices of Biotic Integrity: Benthic Macroinvertebrates as Indicators of Water Quality in Drainage Basins at Cemig's Hydropower Projects in Minas Gerais,* is focused on developing a macroinvertebrate IBI, but includes a total of seven complementary studies.

- Deborah Silva will develop an IBI by assessing responses of benthic macroinvertebrate assemblages to anthropogenic alterations of 160 sites in four drainages. She also will assess how land uses at local and catchment scales alter physical and chemical habitat and link those patterns with poor IBI scores in a relative risk framework.
- Rafael Ligeiro will study the effects of differing degrees of anthropogenic disturbances on the spatial and temporal components of benthic macroinvertebrate beta diversity

in headwater streams of the Nova Ponte drainage, including the effects of those disturbances on stream substrates. To assess the temporal component, he will test the effects of those disturbances on the variation between 2009 and 2013/2014 samples and coordinate with Wander Ferreira.

- Wander Ferreira will examine the partitions of alpha, beta, and gamma diversity for the macroinvertebrate assemblages collected from the 160 Nova Ponte, Três Marias, Volta Grande, and São Simão sites. Additionally, he will use ^{13}C and ^{15}N to elucidate the sources of leaf litter and fine particles eaten by *Phylloicus* larvae. This research will be coordinated with Debora Carvalho's, Diego Castro's and Anna Aguiar's research.
- Diego Castro will assess anthropogenic disturbance gradients and riparian plant cover to assess stream energy flows to evaluate causal mechanisms, differentiate anthropogenic impacts from natural variability, and develop a trait-based IBI through use of ^{13}C and ^{15}N. This research will be coordinated with that of Debora Carvalho, Wander Ferreira, and Anna Aguiar.
- Anna Aguiar will examine the trophic dynamics of macroinvertebrate assemblages by assessing their relationships with riparian floristic composition, allochthonous organic matter inputs, and autochthonous production through use of on-site experiments and ^{13}C and ^{15}N measurements.
- Maria Anacleto will assess the effects on macroinvertebrate assemblage structure of environmental quality at macro-, meso- and micro-scales in Nova Ponte Reservoir by focusing on areas with maximum ecological potential versus areas severely altered by anthropogenic disturbance. Likely indicators will include the occurrence and abundance of alien mollusks and shrimp.
- Ariadine Almeida will examine the population dynamics of *Macrobrachium amazonicum,* which is an extremely abundant alien in Nova Ponte Reservoir, and important to its trophic dynamics.
- Through use of high spatial resolution images and multispectral TM sensor images, Diego Macedo will determine the environmental frailty of the four Cemig drainages by mapping catchment land use and vegetation cover of the sites sampled in the preceding research projects. He also will aid the research teams in locating sampling sites and setting routes and access points.

3) We intend to develop a reservoir fish assemblage index (RFAI) via the ANEEL/Cemig project: *Medium Term Spatial Variations and Index of Fish Assemblages for Reservoirs as Indicators of Habitat Quality in Cemig's Hydropower Projects in Minas Gerais.* The RFAI is an alternative name for an index of biotic integrity (IBI) because reservoirs are highly altered ecosystems lacking natural reference sites, which hinders IBI development.

Barbara Sanches and Barbara Becker will direct this project, including fish sampling, specimen identification, metric screening and selection, and index scoring. They will collect data during the dry and wet seasons along a disturbance gradient at 20 Volta Grande Reservoir sites: 6 on the Buriti and Carmo Rivers (the Reservoir's two major tributaries), 12 on the reservoir's central axis, and 2 immediately below the Volta Grande Dam. They will collaborate with Robert Hughes and Philip Kaufmann and train three scholarship students in all phases of this project.

2 – FURTHER APPLICATIONS

In addition to the new research outlined above and in the preceding book chapters, we believe that the Cemig project results are applicable for drainage basin management throughout Minas Gerais and Brazil. Drainage basin committees, state agencies such as the Minas Institute of Water Management (Instituto Mineiro de Gestão das Águas), and the National Water Agency (Agência Nacional de Águas) can use these approaches to obtain comparable data and ecological insights. Past results from the Cemig -Peixe Vivo Project and presumed results from the ANEEL/Cemig and FAPEMIG/Cemig projects indicate the technical capability and methods to assess streams and reservoirs. They also qualify the research group to begin planning, testing and implementing ecological monitoring and assessment initiatives for large (boatable) rivers, as has occurred in temperate nations (e.g., Mebane et al., 2003: Hughes & Peck, 2008; Flotemersch et al., 2011).

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