Chapter 3
Effects of Agricultural Expansion on Lotic Benthic Macroinvertebrate Communities: A Review and Case Study from Brazil

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3.1 Introduction

Despite high biodiversity and its importance in provisioning ecosystem services (Corbera et al. 2007; Vörösmarty et al. 2010), Neotropical lotic ecosystems rank among the most threatened in the world (Barlow et al. 2018). The conversion of native land cover, typically forest but also grassland, to human-centered land use represents a primary driver of Neotropical biodiversity loss due to a disproportionately large degree of species richness and land conversion (Barlow et al. 2018).

The loss of native land cover especially in riparian zones exerts a strong impact on lotic ecosystem structure and function (Haddad et al. 2015) due to energetic coupling of streams and rivers with terrestrial vegetation (Webster and Benfield 1986; Marcarelli et al. 2011). Resource subsidies from riparian vegetation provides an important organic matter base to aquatic food webs and physical substrate for benthic aquatic macroinvertebrates. Physical and chemical effects result as elevated solar radiation exposure following vegetation loss increases water temperature (Webster and Benfield 1986; Martins et al. 2017) on lotic macroinvertebrates. Sediment and nutrient concentrations also often increase following vegetation conversion and both environmental stressors typically reduce macroinvertebrate biodiversity (Ferreira et al. 2015). Although the effects of agricultural expansion on the physical, chemical, and macroinvertebrate community properties of stream ecosystems are now well-documented, most studies are concentrated in temperate

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climates. Here, we review studies exploring the effects of native terrestrial ecosystem conversion to agriculture in the Neotropics with an emphasis on lotic macroinvertebrates.

3.2 Review: Agricultural Expansion and Benthic Macroinvertebrates in Neotropical Streams

Loss of natural cover to agricultural expansion is particularly acute in tropical and subtropical ecosystems due to an increased demand for agricultural products coupled with population growth and advancing economies (Millennium Ecosystem Assessment 2005; Laurance et al. 2014). In the Neotropics, these transformations in land use for agricultural expansion have been extensive. In Brazil, the Colombia Andes, and the Ecuadorian Andes, for example, vegetation loss to agriculture remains a critical threat to lotic ecosystems and loss of megadiversity (Iniguez-Armijos et al. 2014; Chará-Serna et al. 2015; Strassburg et al. 2017).

In this chapter, we conducted a qualitative review of studies investigating how agricultural expansion impacted benthic macroinvertebrate communities in headwater Neotropical streams between 23.5° N and 23.5° S. Our review included published studies that quantified entire communities, multimetric indices, and/or those with a focus on focal taxa, most commonly aquatic insects such as Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Diptera - EPTOD that were identified to various taxonomic levels (order, family, genera) (see Table 3.1). We analyzed 34 papers that met geographic and scope criteria. The survey revealed that most studies reflect recent efforts, with the most papers published between 2014 and 2019. Furthermore, studies were unevenly distributed geographically, with study sites primarily located in: Brazil (n = 25) and Ecuador (n = 5) (Figs. 3.1 and Table 3.1). Most Brazilian studies were focused on the southeastern region of the country, where universities and biodiversity researchers are concentrated (Clarivate Analytics, Research in Brazil 2017). Large Neotropical countries, such as Mexico and Peru, apparently lack recent investigations of how agricultural land use conversion impacts lotic macroinvertebrates.

Such geographic disparities also reflect ecological concentrations of effort. Among ecosystems covered, Atlantic tropical moist forest (= 11) and the Brazilian savanna (Cerrado biome) (=10) constituted the study sites for over half of those surveyed. The Atlantic Forest and Cerrado are considered biodiversity hotspots with high endemism (Myers et al. 2000) and rank among the most threatened ecosystems globally (Beuchle et al. 2015; Hunke et al. 2015). Agriculture and pasture cattle grazing converted 88% and 80% of native vegetation in the Atlantic Forest and Cerrado, respectively (Ribeiro et al. 2009; Ferreira et al. 2012; Strassburg et al. 2017). The large number of studies may be related to the need for knowledge about the effects of landscape conversion on streams in these ecosystems (Roque et al. 2021; Albuquerque et al. 2021).

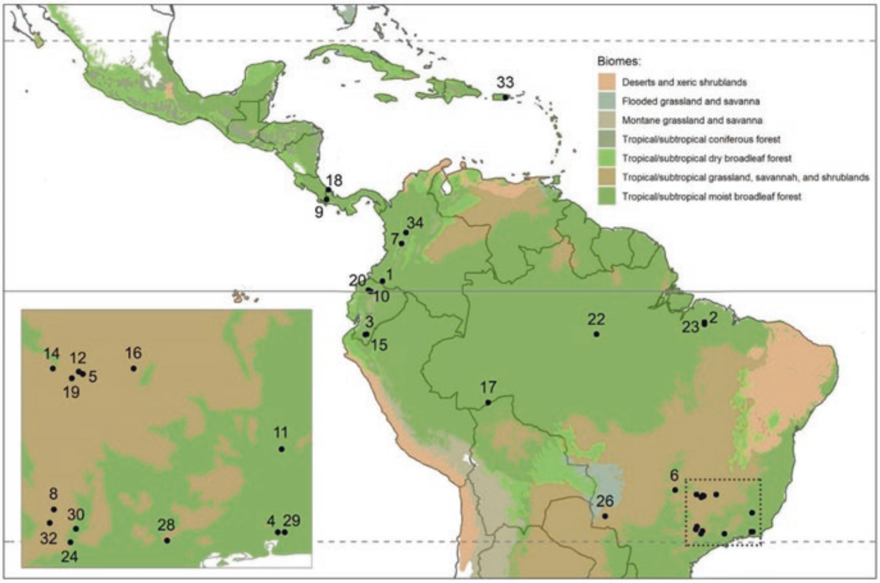

Fig. 3.1 Map showing the distribution of the studies in the Neotropical region

Streams in the Atlantic Forest are under a long and historic degradation due to landscape conversion and many fish and aquatic macroinvertebrates have been largely reduced in this biome (Dala-Corte et al. 2020). Likewise, the Cerrado is the second largest biome in Brazil (after the Amazon) and represents about 23% of the country (Ratter et al. 1997) and has been strongly altered by pasture and crop agriculture (Hunke et al. 2015). It harbors many important large rivers, and its network of headwater streams contain a large diversity of species and ecosystem services (Strassburg et al. 2017).

The impacts of agriculture on Neotropical streams have also been documented in studies in the Brazilian Amazon, montane rainforest, and the tropical moist forest in the Ecuadorian Choco (Chará-Serna et al. 2015; Brito et al. 2019; Morabowen et al. 2019; Lima et al. 2020). In the Brazilian Amazon, for example, agriculture expansion has resulted in the loss of about 18% of the native forest ecosystems (Ferreira et al. 2012) and had considerable impacts on the habitat structure and community composition of many small Amazon streams (Leal et al. 2016).

Similar to related efforts in other regions, a strong majority of studies in Neotropical streams indicated that the loss of native vegetation associated with agricultural practices consistently impacts the structure and composition of aquatic invertebrate communities (Table 3.1). As many studies from temperate zones have demonstrated (e.g., Lammert and Allan 1999; Sponseller et al. 2001; Sweeney et al. 2004), multimetric indices, diversity, and richness tend to decline as agricultural land cover increases in Neotropical watersheds (i.e., Nessimian et al. 2008; Siegloch et al. 2014; Chará-Serna et al. 2015). Community structure also tends to shift toward

Table 3.1 Summary of findings from studies investigating how the loss of native vegetation cover impacts macroinvertebrate communities in Neotropical streams

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
1	Ecuador	Amazon rainforest	Macroinvertebrate densities were > 3 times higher in deforested sites (mean canopy cover 23%) versus forested sites (77%) because opening the canopy increased periphyton biomass. α and β diversity declined with periphyton biomass and increased with canopy cover due to changes in density. Baetidae, Psephenidae, Elmidae, and Tricorythidae increased with canopy loss. Temporal variability of densities was elevated in deforested sites	Family	12	1 to 3	Bojsen and Jacoben (2003)
2	Brazil	Amazon rainforest	Analyses suggested low thresholds of community change at around 9% catchment forest loss and 12% 100 m riparian buffer forest loss but higher values (57% and 75%, respectively) for thresholds where richness declines. Thresholds were much lower than expected, indicating that macroinvertebrates are very sensitive to forest loss	Genus	51	1 to 2	Brito et al. (2019)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
3	Ecuador	Montane cloud forest	Macroinvertebrate densities were higher in deforested (disturbed) sites, possibly due to higher periphyton driven by increased light. Taxonomic richness was comparable among streams, but evenness was lower in deforested streams. Ephemeroptera were more abundant while Odonata were far less abundant in deforested streams	Genus	6	1 to 2	Bücker et al. (2010)
4	Brazil	Atlantic rainforest	Taxonomic richness, but not density, declined by about 20% between reference and disturbed streams. Macroinvertebrates were strongly associated with leaf litter abundance	Genus	7	3 to 4	Buss et al. (2004)
5	Brazil	Savanna (Cerrado)	Taxonomic richness of EPT taxa did not decline from least to most disturbed sites. Functional richness, diversity, and dispersion all decline with loss of native vegetation	Genus	160	1 to 3	de Castro et al. (2018)
6	Brazil	Savannah (Cerrado)	Sites with pasture or sugarcane watersheds supported fewer scrapers, more trophic generalists, and broader niche overlap among taxa. A non-native shrimp (*Macrobrachium amazonicus*) exploits novel niches in disturbed sites	Family	9	2 to 3	de Castro et al. (2016)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
7	Colombia	Montane rainforest	Agricultural land use was associated with significant reductions of a macroinvertebrate multimetric index. A SEM model indicated that the mechanistic pathway was through increases in NH_3-N associated with agriculture	Genus	30	1	Chará-Serna et al. (2015)
8	Brazil	Savanna (Cerrado)	Did not explicitly examine how macroinvertebrate communities change along a gradient but how taxonomic resolution affects assessment indices among watersheds disturbed by agriculture. Identification to family may be sufficient to assess land use impacts	Species	9	1	Corbi and Trivinho-Strixino (2006)
9	Panama	Montane rainforest	Impacts to two macroinvertebrate multimetric indices were largely explained by nutrient enrichment and sedimentation. Pesticide concentrations explained less variation in macroinvertebrate index variability. Macroinvertebrate abundance and richness were not impacted by nutrient enrichment but were reduced by high pesticide concentrations	Family	13	1 to 4	Cornejo et al. (2019)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
10	Ecuador	Montane rainforest	Leaf-shredding macroinvertebrate richness and diversity were comparable between forest and pasture sites, but shredder abundance was much higher in forested sites. Leaf processing by shredders was also lower in pasture reaches. Scrapers were more abundant in pasture reaches	Genus	6	1	Encalada et al. (2010)
11	Brazil	Atlantic rainforest	Odonata assemblages were comparable between agricultural and natural watersheds	Species	10	–	Ferreira-Peruquetti and De Marco Jr (2002)
12	Brazil	Savanna (Cerrado)	Ephemeroptera taxa, the focus of study, responded most negatively to sedimentation. Land use metrics assessed using TITAN included only urban land use, which limits the ability to summarize how natural cover loss affected communities	Genus	183	1 to 3	Firmiano et al. (2017)
13	Brazil	Savanna (Cerrado)	Study explored trait and taxonomic groups associated with multiple gradients, including land use. The group most associated with disturbed watersheds was comprised of obligate aquatic Mollusca and Diptera taxa. Odonata did not appear to be strongly affected by land use gradients	Genus or family	183	1 to 3	Firmiano et al. (2019)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
14	Brazil	Savanna (Cerrado)	Taxonomic richness, community composition, and FFG composition did not differ among pasture, agricultural, and natural landscape streams. Riparian buffers successfully prevented biodiversity loss and changes to communities	Family	13	1 to 3	Guimarães-Souto et al. (2021)
15	Ecuador	Montane rainforest	Detected strong positive linear relationships between multimetric indices and % native vegetation cover at catchment and riparian buffer scales. Dominant taxa linearly negatively increase with natural vegetation loss. Scrapers and shredders both increased with vegetation cover. A threshold of 70% natural cover at the catchment scale was proposed to retain ecological integrity	Genus	23	1 to 3	Iñiguez–Armijos et al. (2014)
16	Brazil	Savanna (Cerrado)	Study aimed to identify land use scale most important in structuring macroinvertebrate communities. Land use disturbances quantified at the catchment scale were far more effective in predicting impacts to macroinvertebrate communities than metrics at the local scale	Genus	80	1 to 3	Ligeiro et al. (2013)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
17	Brazil	Amazon rainforest	Macroinvertebrate community composition and diversity changed as pasture replaced natural cover, with lower collector densities and % EPT in disturbed streams	Family	14	1 to 3	Lima et al. (2020)
18	Costa Rica	Lowland rainforest	Comparisons between forest and pasture reaches suggest that deforestation, even at a very local scale, alters benthic macroinvertebrate communities, reduces diversity, and eliminates sensitive taxa. Riparian forest buffers significantly reduce such effects	Genus or family	12	–	Lorion and Kennedy (2009)
19	Brazil	Savanna (Cerrado)	Benthic macroinvertebrate richness was moderately negatively correlated with wetland and agricultural land use	Family	80	1 to 3	Macedo et al. (2014)
20	Ecuador	Tropical moist forest	Macroinvertebrate species richness was considerably lower in palmito monoculture farmlands than in the other two types of land use (pristine montane cloud forest and organic farms).	Genus	8	1	Morabowen et al. (2019)
21	Brazil	Atlantic forest	There was a significant difference in macroinvertebrate composition among riparian buffer widths. This study showed that riparian buffer widths <15 m altered the macroinvertebrate community	Family	9	4 to 5	Moraes et al. (2014)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
22	Brazil	Amazon rainforest	Aquatic insect richness and Ephemeroptera, Plecoptera, and Trichoptera richness were significantly lower in pasture streams, and their taxonomic composition differed significantly from streams in forested areas	Species	20	1 to 3	Nessimian et al. (2008)
23	Brazil	Amazon rainforest	The occurrence of odonate species was strongly associated with the configuration of the riparian vegetation. Agricultural activities appear to have changed in the composition of odonate assemblages and these insects can act as indicators of the ecological consequences of riparian habitat loss and disturbance	Species	50	1 to 3	De Oliveira-Junior et al. (2015)
24	Brazil	Atlantic forest	Invertebrate richness was strongly correlated with land use index	Family	9	4 to 5	Ometo et al. (2000)
25	Brazil	Atlantic forest	This study demonstrated that variables at different scales (stream and riparian zone) structure stream insect assemblages	Genus	18	1 to 2	Ongaratto et al. (2018)
26	Brazil	Savanna (Cerrado)	Six species showed evidence of nonlinear response in sites with a loss of native vegetation loss between 40% and 60%.	Species	98	1 to	Rodrigues et al. (2016)

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Table 3.1 (continued)

No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
27	Brazil	Atlantic forest	Local scale (stream), landscape attributes and large scales (drainage basin and riparian buffer) generated significant effects on the Chironomidae fauna	Genus	18	2	Sensolo et al. (2012)
28	Brazil	Atlantic forest	The results showed that agricultural and forestry land use has a strong negative effect on the structure of Ephemeroptera assemblages	Genus	29	1 to 2	Siegloch et al. (2014)
29	Brazil	Atlantic forest	Aquatic invertebrate diversity has decreased, and community metrics have changed with deforestation	Genus	4	2 to 3	Silva-Araújo et al. (2020)
30	Brazil	Atlantic forest	The study showed that landscape modification by agriculture, pasture, and silviculture reduced beta diversity by limiting the colonization of potential aquatic insect species, and, ultimately, causing taxonomic homogenization	Genus	32	–	Siqueira et al. (2015)
31	Brazil	Savanna (Cerrado)	The abundances of Elmidae, Chironomidae, and total macroinvertebrates increased along the forest remnant, while the abundance of Baetidae, proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT), rarefied taxonomic richness, and diversity decreased. Taxon richness and EPT abundance did not vary along the forest remnant	Family	12	1	Suga and Tanaka (2013)

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No.	Nation	Ecosystem	Conclusions	Taxonomic resolution	Sample size	Stream orders	References
32	Brazil	Atlantic forest	The study found higher total nitrogen concentrations and electric conductivity in streams with land use dominated by pasture and narrower riparian forests, higher diversity of macroinvertebrates and dissolved oxygen concentrations in streams with higher cover and width of riparian forests although land use was dominated by sugarcane	Family	12	–	Tanaka et al. (2016)
33	Puerto Rico	Tropical forest	The study found little evidence for an insect aquatic effect on leaf breakdown. Results suggested that land use is an important factor affecting leaf litter processing in streams	Family	9	1 to 3	Torres and Ramírez (2014)
34	Colombia	Rainforest	The results suggested that agricultural activity has a higher impact on the diversity of aquatic insects, which may be associated with the loss of riparian vegetation	Genus	10	–	Villada-Bedoya et al. (2017)

more homogeneous assemblages dominated by tolerant individuals (Macedo et al. 2014; Brito et al. 2019; Firmiano et al. 2019). Such findings are consistent with works conducted elsewhere, suggesting that the ecological impacts of converting natural cover to agriculture are globally consistent. We also found that in many Neotropical streams, total macroinvertebrate abundance often increases following forest cover loss (Buss et al. 2004). Most studies attributed greater abundance to an increase in light that elevated primary production, allowing grazers to thrive (Bojsen and Jacobsen 2003). Unlike in temperate regions, primary production in Neotropical streams in most cases is not limited by low temperatures and seasonal fluctuations in light.

Although agricultural land use conversion consistently alters macroinvertebrate assemblages in Neotropical streams, a notable minority of studies did not detect changes in taxonomic composition or richness along changes in spatial and temporal gradients of agricultural cover. Examples span diverse ecological settings, such as karstic forest streams in Brazil (Corrêa et al. 2018, 2019), high-elevation montane forests of Ecuador (Ordóñez 2011; Bücker et al. 2010), and the coffee-growing region of Colombia (Chará et al. 2007). Although works that do detect richness and diversity loss are more common, findings of resilience are encouraging because they suggest that biodiversity can persist despite land cover conversion. Many watersheds (e.g., karstic streams) or ecological attributes could help to diminish the effects of land use conversion (Omernik and Bailey 1997).

Scientific recommendations have been made to conserve lotic ecosystems and to reduce threats to biodiversity (Azevedo-Santos et al. 2021). Given the high degree of landscape change by agriculture, pasture, and other land uses in the Neotropical region. Such recommendations have emphasized the need to create stream conservation strategies and the rehabilitation of disturbed areas, particularly those altered by agricultural activities and ranching. Studies emphasize that governmental agencies need to enforce environmental laws to ensure that riparian vegetation is preserved, maintenance and rehabilitation of the ecological condition of water bodies, and the conservation of aquatic biodiversity (Noss 1999) as well as national and international efforts to safeguard the freshwater life of this hyperdiverse region.

3.3 Case Study: Bodoquena Plateau, Brazil

To illustrate how stream ecosystem responses can be context-specific and nuanced, we present a brief case study of macroinvertebrate community changes in a karstic watershed of tropical Central-West of Brazil. Study sites typify severe land use change in the region, yet we detected limited community structure changes in macroinvertebrates even within streams with radically altered watersheds. Although the effort was part of a larger study designed to explore how macroconsumers such as fish and shrimp induce trophic cascades (see Correa et al. 2018, 2019), the design also allows for comparisons of macroinvertebrate communities along a gradient of native vegetation in riparian buffers.

The Bodoquena Plateau (19° 45′ e 22° 15′ S, 57° 30′ e 56° 15′ W) has an area of 890,68 km^2 and is located in the transition between Cerrado and Atlantic Forest. The hydrography is partially underground with sinks, calcareous tuff, and cave formations, resulting in clear water with high levels of dissolved calcium and bicarbonate. These karst aquatic systems are extensive in Brazil (Sallun-Filho and Karmann 2007). The rivers of the Bodoquena Plateau drain the karst watersheds into the Miranda River, a subunit of the Upper Rio Paraguay Basin, which includes the Pantanal; one the most biodiverse wetlands in the world (Junk et al. 2011). Native vegetation has been rapidly fragmented by cattle ranching and agriculture with predominance of grain monoculture (soybeans and maize), resulting in a mosaic of land cover that ranges from dense riparian vegetation to deforested pasture (Roque et al. 2016).

In May 2015, we selected seven streams within a gradient of remaining forest cover (20–100% of the remnant forest cover) and were distributed across the Bodoquena region. To investigate potential effects of native vegetation loss on benthic aquatic macroinvertebrates, we deployed ten substrate baskets (20 × 20 × 10 cm with mesh opening of 50 mm) in a single pool along gradients of elevation and vegetation cover among seven karst streams with similar substrate composition. Baskets were filled with limestone to promote colonization.

Most of the chemical water parameters, such as temperature (21.0–22.8 °C) ($p = 0.43$), pH (7.2–8.1) ($p = 0.04$), dissolved oxygen (60.0–77.0 mg l^{-1}) ($p = 0.140$) were similar between the sampled sites. Total nitrogen (1.87–0.85 lg/l) ($p = 0.38$), total phosphorous (0.179–0.102 lg/l) ($p = 0.47$), and turbidity (80–100 NTU) ($p = 0.63$) were also not correlated with the vegetation cover gradient.

We found a total of 2465 benthic macroinvertebrates comprising 25 families in the stream sampling along the gradient of vegetation cover. Macroinvertebrate abundance varied more than twofold across sites, with a minimum of 224 individuals found at the Taquaral stream (100% vegetation cover) to a maximum of 600 at the Serra stream (79% vegetation cover). Leptophlebiidae (with 934 individuals), Chironomidae (682), Hydrobiidae (177), and Elmidae (124) were the most abundant families along the gradient cover vegetation. Collector-gatherers-scrapers comprised 56% of total invertebrate abundance, followed by collectors-filterers-gatherers (33%) and predators (11%). Permutational multivariate analyses of variance (PERMANOVA) suggested that benthic macroinvertebrate community composition was unrelated to the vegetation gradient in Bodoquena Plateau.

Our results showed that the vegetational loss gradient had no influence on the macroinvertebrate community composition (Fig. 3.2), in contrast with the results found in other studies involving Neotropical streams (Moretti et al. 2007; Silva-Araujo et al. 2020). Similar studies of multitaxa communities in Bodoquena Plateau streams also did not find detectable responses between terrestrial and aquatic insects across a riparian cover gradient (Roque et al. 2017), and comparisons of fish communities along of the land cover gradient also demonstrated weak or no effects (Casatti et al. 2010). The lack of effect on macroinvertebrates could be attributed to mosaics of vegetation in the Bodoquena Plateau, which may maintain functional connectivity despite land conversion. In karstic systems, the watershed or forest cover delimitation is particularly challenging because surface water does not drain directly into surficial channels. Such a hydrogeomorphic settings likely could decouple the effects of landscape degradation from ecological processes in receiving waters.

Findings from our case study plus collective findings from studies in our qualitative survey suggest that while land use conversion can be expected to impact macroinvertebrate communities in Neotropical streams, observed impacts are likely to be context-specific. Landuse conversion that increases light to stream channels can increase productivity, resulting in elevated macroinvertebrate abundance for grazing

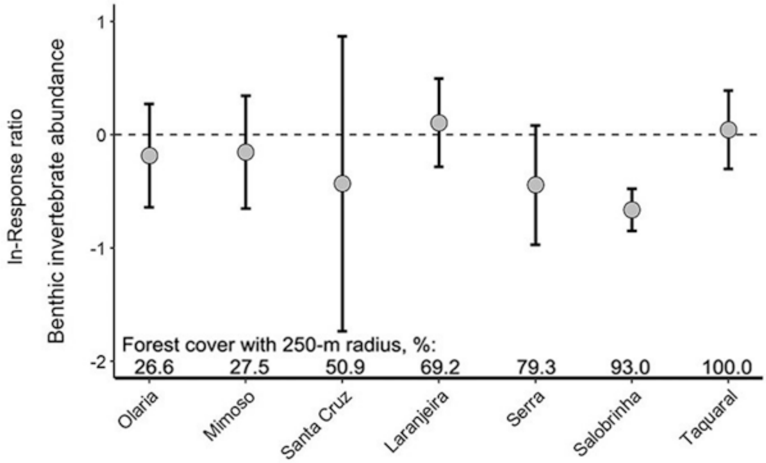

Fig. 3.2 Site-specific ln-response ratio (LRR) of total invertebrates' abundance with respect to the forest cover gradient. Shown are the means of treatment divided by control values ±1 standard error. Sites are ordered from least to most forest cover

taxa (Casatti et al. 2010; Silva-Araújo et al. 2020). Tropical streams are likely to consistently show such patterns because they experience high light and warm temperatures year-round (Boulton et al. 2008). Local hydrogeologic attributes might buffer macroinvertebrate communities from becoming severely degraded, a concept that likely extends beyond tropical regions. Finally, another potential mitigation strategy for minimizing land use effects in streams is maintaining sufficiently wide riparian buffer zones (Azevedo-Santos et al. 2021).

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