

## Watershed services of smallholder agriculture in the Eastern Amazon

Ricardo de O. Figueiredo <sup>a\*</sup>, Jan Börner <sup>b</sup>, and Eric A. Davidson <sup>c</sup>

<sup>a</sup> Embrapa Meio Ambiente, Rodovia SP-340, Km 127.5, Jaguariúna, SP, 13820-000, Brazil. Phone: +55 (19) 3311-2778, Fax: +55 (19) 3311-2640. E-mail: ricfig@cnpma.embrapa.br

<sup>b</sup> Center for International Forestry Research (CIFOR), Rua do Russel 450/601, Rio de Janeiro, RJ, Brazil. E-mail: j.borner@cgiar.org

<sup>c</sup> The Woods Hole Research Center, 149 Woods Hole Road, Falmouth, MA 02540-1644, USA. E-mail: edavidson@whrc.org

\* Corresponding Author

### ABSTRACT

Several hydrobiogeochemical research activities have been conducted in the Eastern Amazon, contributing to the understanding of how changes in forests and agro-ecosystems affect ecosystem service provision. Findings have demonstrate that good agricultural practices and the presence of natural secondary vegetation favored by smallholder farm management are important factors for hydrobiogeochemical cycling, aquatic ecosystem conservation, soil conservation, and mitigation of trace gases emissions from biomass burning in Amazonian small catchments. Two challenges for watershed service management arise in this context. First, low population densities and the relatively flat landscape mean that a critical mass of downstream beneficiaries of such services - a prerequisite for public intervention - is more difficult to identify than in more densely populated mountainous areas. Second, although watershed service providers (farmers) are also to considerable extent service beneficiaries, conflicts over land and cultural heterogeneities among settlers inhibit local collective action to safeguard stream water quality. Including smallholders in carbon payment schemes that

24 compensate for the maintenance of riverbank vegetation would appear as a cost-effective means to  
25 secure watershed services as co-benefits of forest-based climate change mitigation.

26 *Keywords:* Stream water quality, hydrobiogeochemical, good agricultural practices, watershed  
27 management, payments for ecosystem services.

28

## 29 **1. Introduction**

30 Agricultural frontiers in the Brazilian Amazonia are expanding into the forest, compromising  
31 terrestrial and aquatic ecosystem structure and function, including fluxes of nutrients, carbon and  
32 water in small catchments. These first and second order streams comprise 80% of the total riverine  
33 habitat throughout this region (McClain and Elsenbeer, 2001). Several hydrobiogeochemical research  
34 activities have been conducted in the Eastern Amazon, contributing to the understanding of how  
35 changes in forests and agro-ecosystems affect ecosystem service provision.

36 Water cycling, besides carbon storage and biodiversity maintenance, is an important  
37 environmental service provided by the conservation of the Amazonian forests. The magnitude and  
38 value of these services are poorly quantified (Fearnside, 2005). Among other urgent policy actions,  
39 Fearnside (2001) suggested to fortify family agriculture contrary to the current policy focus on large  
40 landholders. In this sense, among other measures, it is suggested that consideration should be given to  
41 the possibility of payments for environmental services as a source of support.

42 In the Eastern Amazon in Brazil, the use of fire for land preparation is still a widespread practice  
43 in many traditional agricultural systems. Reducing the use of fire could be an important step towards  
44 sustainable smallholder agriculture and conservative practices, such as mulching in combination with  
45 zero tillage have shown promising results in experiments (Sommer, 2001). Innovative policy  
46 programs, such as payments for environmental services could help to promote the introduction of this

47 and other alternatives to slash-and-burn agriculture by compensating farmers for additional watershed  
48 services, including forest conservation. The development of payments for watershed services schemes  
49 currently hinges on a better understanding of the biophysical determinants of hydrological service  
50 provision, especially in the Amazon region.

51

## 52 **2. Hydrobiogeochemical Aspects**

53 Large scale agriculture, such as cattle ranching and row crops, tends to radically change the  
54 natural characteristics of small rivers and streams, whereas small holder agriculture, characterized by  
55 secondary forest mosaic landscapes, has a less disturbing effect on small rivers and streams, especially  
56 when slash-and-burn land preparation practices are avoided. Research has demonstrated that good  
57 agricultural practices and the presence of natural secondary vegetation favored by smallholder farm  
58 management are important factors for hydrobiogeochemical cycling, aquatic ecosystem conservation,  
59 soil conservation, and mitigation of trace gases emissions from biomass burning in Amazonian small  
60 catchments (Davidson et al., 2008). In Table 1 we present a calculation for two different systems in  
61 eastern Amazonia which shows that the GWP (Greenhouse Warming Potential) CO<sub>2</sub> (dioxide carbon)  
62 equivalents from soil emissions, fertilizer use, and diesel fuel use in the chop-and-mulch system were  
63 not trivial, but they were nearly six times smaller than the total GWP CO<sub>2</sub> equivalents of slash-and-  
64 burn system extensively used by smallholder farming in the region

65 Other biogeochemical catchment studies more specifically related to water resources have  
66 shown pasture stream channels were deeper and had a lower cover of sandy bottom habitat and a  
67 higher cover of aquatic grass habitat than the forest streams, as well as lower concentrations of  
68 dissolved oxygen and nitrate (NO<sub>3</sub><sup>-</sup>) and higher concentrations of dissolved iron (Fe<sup>2+</sup>) and phosphate  
69 (PO<sub>4</sub><sup>3-</sup>) (Neill et al., 2006). The stream chemistry of these two pairs of forest and pasture watersheds  
70 can be checked in Table 2.

71 In a related article the authors suggest that some links among deforestation, soil  
72 biogeochemistry and the amount of nitrogen (N) and phosphorus (P) reaching small streams have the  
73 potential to influence the structure of these aquatic ecosystems (Neill et al., 2001). The authors point  
74 out that lower ratios of inorganic and total dissolved N:P in pasture streams suggest a switch from P  
75 limitation in forest streams to N limitation in pasture streams. In addition periphyton bioassays in these  
76 forest and pasture streams confirmed that N limited algal growth in pasture streams where light was  
77 available. Figure 1 serves as an illustration of the dimension and environmental aspects of these  
78 studied streams.

79 Whereas the overland flow production is negligible in Amazon forests, overland flow represents  
80 a significant pathway for additional loss of phosphorus and other elements from pastures to the  
81 streams (Biggs et al., 2006). A photograph (Figure 2) of a pasture hillslope in this study area  
82 illustrates the importance of this component of the hydrological cycle in the catchment, where we can  
83 see the cattle trail conveying the water of the overland flow. In the same region Ballester et al.,  
84 (2003), testing the effects of the landscape characteristics on river water chemistry, performed a  
85 multiple linear regression analysis and estimated a threefold increase of phosphate concentration in  
86 stream water due to an increase of 10% in the pasture area of a river basin.

87 Identifying the sources and mechanisms of solute contribution to Amazonian streams is  
88 necessary for understanding nutrient cycling processes in mature tropical forests and the long-term  
89 effects of land use change in the region. Regarding this objective Markewitz et al. (2001) observed in  
90 a particular watershed, where forest clearing and burning 30 years previously enriched the soils in  
91 cations, an increase of leaching of cations during the wet season which increased the input of these  
92 elements into the streams.

93 In contrast to pasture streams, where crops were grown near the stream, increases in steam  
94 concentrations of nitrate, sodium, chloride, and turbidity have been observed to increase with

95 increasing crop cover area (Figueiredo et al., 2010). In this evaluation land use change affected water  
96 chemistry and other measures of streamwater quality in the eastern Amazon catchments. Box plots  
97 graphs in Figure 3 illustrate upstream-downstream trends for pH, nitrate (as  $\text{Ln NO}_3^-$ -N), and  
98 dissolved oxygen (DO) in three streams (IG54, IG7 and IGP). Upstream-downstream trends in pH are  
99 decreasing for IG54 while pH increases downstream in IG7 and IGP, being attributed to impacts in  
100 the headwaters of IG54. On the other hand nitrate upstream-downstream declines were associated  
101 with decreasing percent forest area, while agricultural inputs are suspected of promoting the observed  
102 nitrate spike and dissolved oxygen collapse in station 4 of the IG54.

103 The benefits of smallholder production systems in term of watershed services are strongly  
104 related to the amount of secondary forests available in the landscape. Secondary forests may become  
105 increasingly important as moderators of hydrologic cycles in the Amazon Basin as agricultural lands  
106 are abandoned and often later cleared again for agriculture (Vieira et al. 2003). In catchments  
107 primarily occupied by smallholders, large areas of secondary forest, together with good agriculture  
108 practices that avoid slash-and-burn land preparation, resulted in the conservation of almost natural  
109 stream characteristics (Figueiredo, 2009).

110 In a watershed study (drainage areas < 30 ha), in the eastern Amazonia, Wickel (2004) observed  
111 that, in a catchment where fire is used to prepare land to small crops or pasture renovation compared  
112 to a catchment mainly occupied by secondary forests or chop-and-mulching to agriculture  
113 management, there are additional nutrients losses from soils to streamwater. In Table 3 we observe  
114 the mean chemical composition of baseflow streamwater of this two different type of watersheds  
115 according to land preparation and ratio of concentrations in baseflow to the concentration in rain. This  
116 approach demonstrates larger losses of potassium, calcium, magnesium, sulfate, and nitrate from  
117 slash-and-burn agriculture watershed soils compared to chop-and-mulching watershed soils losses to  
118 streamwater.

119 Larger catchment output of calcium was also in the study of Barroso (2011) analysing  
120 streamwater chemistry in nine watersheds in the eastern Amazonia. In Figure 4 we can see larger  
121 concentrations due to slash-and-burn agriculture in the M4, M5 and M6 watersheds.

122 Even stream fish communities studies in the eastern Amazonia have shown that agricultural  
123 catchments dominated by smallholder farmers can bear a reasonable stream fish diversity. After nine  
124 monthly collections Corrêa (2007) identified forty-three fish species in three streams of such  
125 agricultural catchments, while Brejão (2011) in seven streams of the same agriculture region  
126 registered seventy-three species distributed in six orders, twenty six families and sixty three genera  
127 (Figure 5).

128 Moreover, a few of these studies have surveyed sustainable indicators that can be measured in  
129 Amazon soils and streams, using rapid field measurements that would allow their use by  
130 environmental regulatory agencies. Turbidity, temperature, pH, and dissolved oxygen appear to be the  
131 simplest and most indicative parameters for detecting effects of land-use change on water quality in  
132 this region (Figueiredo et al., 2010). These measurements could be used as indicators for the payment  
133 of watershed services in this region. But further steps are needed specially those related to the values  
134 of these environmental services.

135 It can be conclude from the studies shown above and other studies that the small-holder  
136 agriculture, when not using fire for land management and when preserving large areas of forest  
137 (secondary or mature forests), including riparian zones, can help to mitigate impacts to water quality  
138 in small stream in the Amazonia. This opens a discussion of the possibility of paying for watershed  
139 services to the smallholders who use conservative agriculture practices in the region, or even  
140 compensating large-scale farmers in some way for the same environmental service.

### 141 **3. Challenges of Setting up Payments for Ecosystem Services Schemes in the Amazon**

142 As for the hydrobiogeochemical aspects previously discussed we can infer that, if we want to  
143 assure streamwater quality in the Amazonian small catchments, we need to help producers make the  
144 transition from the traditional slash-and-burn agricultural practices that currently prevail in the  
145 Amazon frontier toward more diversified and sustainable agricultural and extractive practices.  
146 Payments for Environmental Services (PES) could be an effective tool for this purpose (Carvalho et  
147 al., 2004). In a watershed study in the Peruvian Amazonian, McClain and Cossío (2003) state that  
148 resource management efforts should move quickly to implement programs that reinforce good  
149 practices of local people, further educate local people on the ecosystem services provided by riparian  
150 areas, and strengthen the institutional framework for maintaining these practices into the future.

151 A fundamental precondition for PES to be feasible is that ecosystem service beneficiaries are  
152 willing to pay for at least the costs of setting up and running a given PES scheme. In the case of  
153 watershed services, these beneficiaries are typically spatially clustered downstream water users. Many  
154 other ecosystem services, such as carbon capture and species habitat provision result in benefits to the  
155 society as a whole. In the context of the Amazon, two important challenges arise for PES  
156 implementers:

157 1. *Identifying beneficiaries:* Low population densities and the relatively flat landscape mean that  
158 a critical mass of downstream beneficiaries of such services - a prerequisite for public intervention - is  
159 more difficult to identify than in more densely populated mountainous areas.

160 2. *Promoting local collective action:* Second, although watershed service providers (farmers)  
161 are also to considerable extent service beneficiaries, conflicts over land and cultural heterogeneities  
162 among settlers inhibit local collective action to safeguard stream water quality.

163 With regard to the first challenge, a crucial bottleneck is thus to identify a sufficiently large  
164 group of service beneficiaries. Experiences from PES schemes around the world show that watershed  
165 services can often piggyback in PES schemes that address other more globally valued ecosystem

166 services, such as carbon capture and habitat conservation. Mechanism that link several services are  
167 called bundling or layering (Wunder and Wertz-Kanounnikoff, 2009). Economic analyses of  
168 conservation opportunity costs of smallholders in the eastern Brazilian Amazon suggest that the costs  
169 of setting aside an additional hectare of secondary deforestation lie between roughly R\$ 10-20 per ton  
170 of CO<sub>2</sub> (Figure 6). This is slightly higher than cost-estimates for the retirement of extensive pastures  
171 (Bowman et al., 2012; Nepstad et al., 2009; Wunder et al., 2008).

172 For many reasons, including transport infrastructure quality and land tenure security, however,  
173 PES schemes may be more competitively established in the eastern Amazon setting than at today's  
174 agricultural frontiers, where the transaction costs of implementing local interventions tend to be high.  
175 Based on the existing Brazilian Forest Law carbon payment schemes in the Brazilian Amazon could  
176 be optimized in terms of watershed service provision, e.g. through higher rewards for the  
177 conservation and restoration of riparian vegetation.

178 With regard to the second challenge, everywhere in the Amazon the need is evident for the  
179 analysis community conflicts generated by smallholder's own economics needs and interests versus the  
180 environment aspects of fulfilling legal requirements. Plans for sustainable development must come  
181 together with environmental education components and perception and with economic return for the  
182 poor agriculture communities as well as dialogue between conflicting interest groups in target  
183 watersheds. The perception of voluntary groups and institutions that work in support these rural  
184 people is that dialogue and mutual confidence are essential for the success of such development plans.  
185 Plus a considerable amount of work has also to be done to identify who the stakeholders are in this  
186 development process (Grimble & Wellard, 1997).

187

188

#### 189 **4. Outlook and Conclusions**



190 We show that there is a: 1. clear differences in water quality indicators between traditionally and  
191 fire-free managed watershed; 2. clear difference between smallholder versus large-scale producer  
192 managed watershed.

193 Watershed services alone, however, are unlikely to evoke sufficient local demand for  
194 establishing PES schemes in most Amazonian settings. Optimizing carbon payment schemes, for  
195 example, in the context of currently mushrooming REDD+ schemes in the region could represent an  
196 opportunity to improve watershed service provision through ecosystem services bundling.

197 The high degree of dependence of the local population on stream water resources may,  
198 nonetheless, also justify public interventions purely based on replacement cost criteria. The potential  
199 costs of establishing and maintaining decentralized water treatment facilities as natural watershed  
200 services degrade are likely higher than investments in promoting improved community watershed  
201 management schemes.

202

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206

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263

264 **Table 1**

265 Comparison of greenhouse warming potentials (GWP) for a 100-year time frame of emissions from  
 266 slash-and-burn and chop-and-mulch cropping systems over approximately a 2-year cycle.

	Slash-and-burn		Chop-and-mulch	
	Flux	CO <sub>2</sub> equivalents	Flux	CO <sub>2</sub> equivalents
Soil CH <sub>4</sub> efflux	-5.0	-120	16	370
Fire CH <sub>4</sub> emissions	630	14 000	0	0
Soil N <sub>2</sub> O-N efflux	2.9	1300	4.2	2000
Fire N <sub>2</sub> O-N emissions	12	5600	0	0
N fertilizer	0	0	90	370
P fertilizer	0	0	60	37
K fertilizer	0	0	30	13
Diesel fuel for mulching	0	0	300	780
Total CO <sub>2</sub> equivalents		21 000		3600

267 All values are in kg ha<sup>-1</sup>, except for diesel fuel, which is in L ha<sup>-1</sup>. All values are rounded to two significant figures.  
 CH<sub>4</sub>, methane; N<sub>2</sub>O, nitrous oxide; N, nitrogen; P, phosphorous; K, potassium.

268 Source: Davidson, E.A. et al (2008). An integrated greenhouse gas assessment of an alternative to slash-and-burn  
 269 agriculture in eastern Amazonia. *Global Change Biology* 14, pp.1003.

270

271 **Table 2**

272 Nutrient, cation and total suspended sediment concentrations in forest and pasture streams at Nova  
 273 Vida Ranch, Rondônia, Brazil, during the period of low flows in August to September of 1998 and  
 274 1999. Different superscripts indicate that forest and pasture means within each stream pair were  
 275 significantly different (t-test,  $p < 0.05$ )

Parameter	Units	Watershed 1		Watershed 2	
		Forest	Pasture	Forest	Pasture
Dissolved oxygen	mg l <sup>-1</sup>	6.9 <sup>a</sup>	0.1 <sup>b</sup>	6.7 <sup>a</sup>	0.1 <sup>b</sup>
NO <sub>3</sub> <sup>-</sup>	μM	10.7 <sup>a</sup>	6.5 <sup>b</sup>	8.1 <sup>a</sup>	3.5 <sup>b</sup>
NH <sub>4</sub> <sup>+</sup>	μM	4.5 <sup>a</sup>	6.9 <sup>a</sup>	4.9 <sup>a</sup>	4.0 <sup>a</sup>
PO <sub>4</sub> <sup>3-</sup>	μM	0.2 <sup>a</sup>	1.8 <sup>b</sup>	0.5 <sup>a</sup>	0.8 <sup>a</sup>
DIN : DIP		76	7	26	9
Ca <sup>2+</sup>	μM	87 <sup>a</sup>	104 <sup>a</sup>	112 <sup>a</sup>	110 <sup>a</sup>
Mg <sup>2+</sup>	μM	79 <sup>a</sup>	95 <sup>a</sup>	126 <sup>a</sup>	109 <sup>a</sup>
K <sup>+</sup>	μM	84 <sup>a</sup>	189 <sup>b</sup>	64 <sup>a</sup>	209 <sup>b</sup>
Na <sup>+</sup>	μM	63 <sup>a</sup>	85 <sup>b</sup>	67 <sup>a</sup>	104 <sup>b</sup>
Fe <sup>2+</sup>	μM	19 <sup>a</sup>	956 <sup>b</sup>	15 <sup>a</sup>	411 <sup>b</sup>
Total suspended sediments	mg l <sup>-1</sup>	11.4 <sup>a</sup>	13.5 <sup>a</sup>	6.0 <sup>a</sup>	19.2 <sup>b</sup>

276

277 Source: Neill, C. et al (2006). Deforestation alters the hydraulic and biogeochemical characteristics of small lowland  
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279

280 **Table 3**

281 Mean chemical composition (in mg L<sup>-1</sup>) of baseflow water of the two watersheds, and ratio of  
 282 concentrations in baseflow to the concentration in rain (Q/P ratio). WS1= 25.5 ha chop-and-mulching  
 283 agriculture watershed; WS2= 28.6 ha slash-and-burn agriculture watershed.

	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>	PO <sub>4</sub> <sup>3-</sup>	NO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>
<b>WS 1</b>								
<b>Mean</b>	1.45	0.09	0.16	0.20	0.41	0.03	0.02	2.63
<b>WS1/Rai</b>	<b>2.37</b>	<b>0.56</b>	<b>1.31</b>	<b>3.34</b>	<b>2.32</b>	<b>0.75</b>	<b>1.74</b>	<b>2.51</b>
<b>n</b>								
<b>WS 2</b>								
<b>Mean</b>	1.40	0.20	0.61	0.29	0.81	0.02	0.04	2.58
<b>WS2/Rai</b>	<b>2.30</b>	<b>1.21</b>	<b>4.99</b>	<b>4.83</b>	<b>4.65</b>	<b>0.57</b>	<b>4.47</b>	<b>2.46</b>
<b>n</b>								

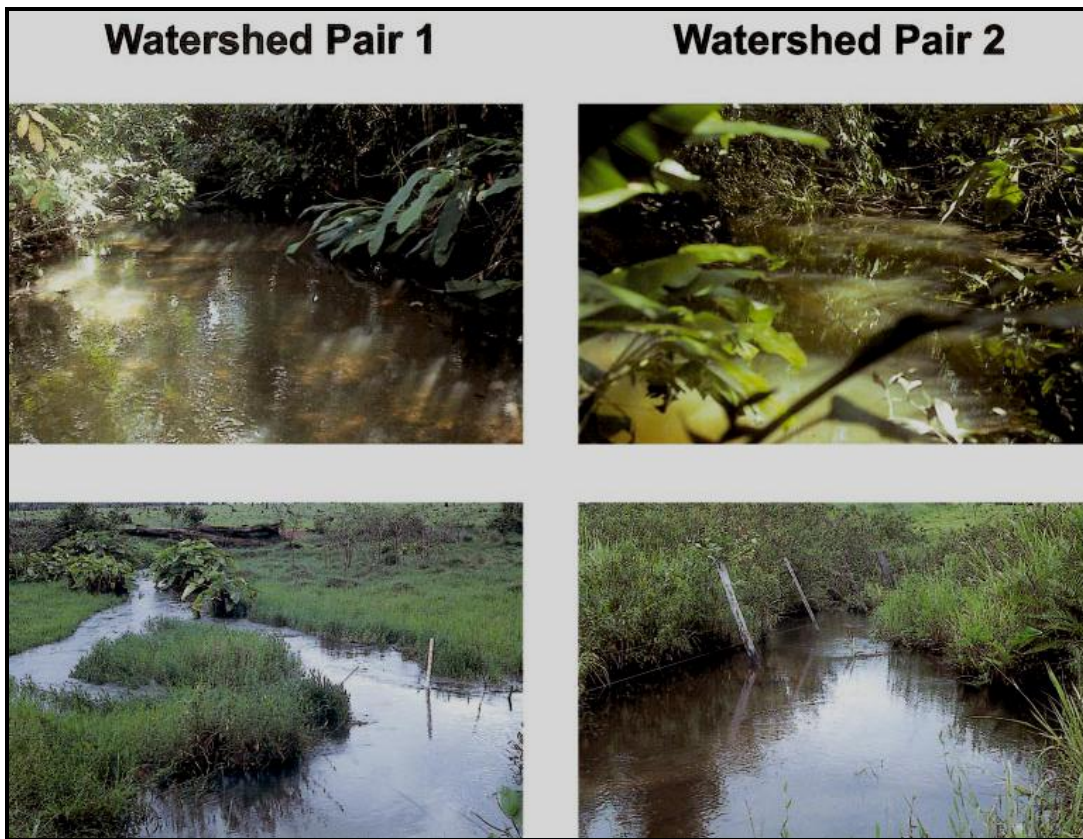
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290 Source: Neill, C. et al. (2001). Deforestation for pasture alters nitrogen and phosphorus in small Amazonian streams.

291 Ecological Applications 11, pp. 1819.

292

293 **Figure 1**

294 Photos of (top) forest and (bottom) pasture studied streams.

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296



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298 Source: Biggs, T.W., Dunne, T, Muraoka, T. et al., 2006. Transport of water, solutes and nutrients from a pasture  
299 hillslope, southwestern Brazilian Amazon. *Hydrological Processes* 20, pp. 2530.

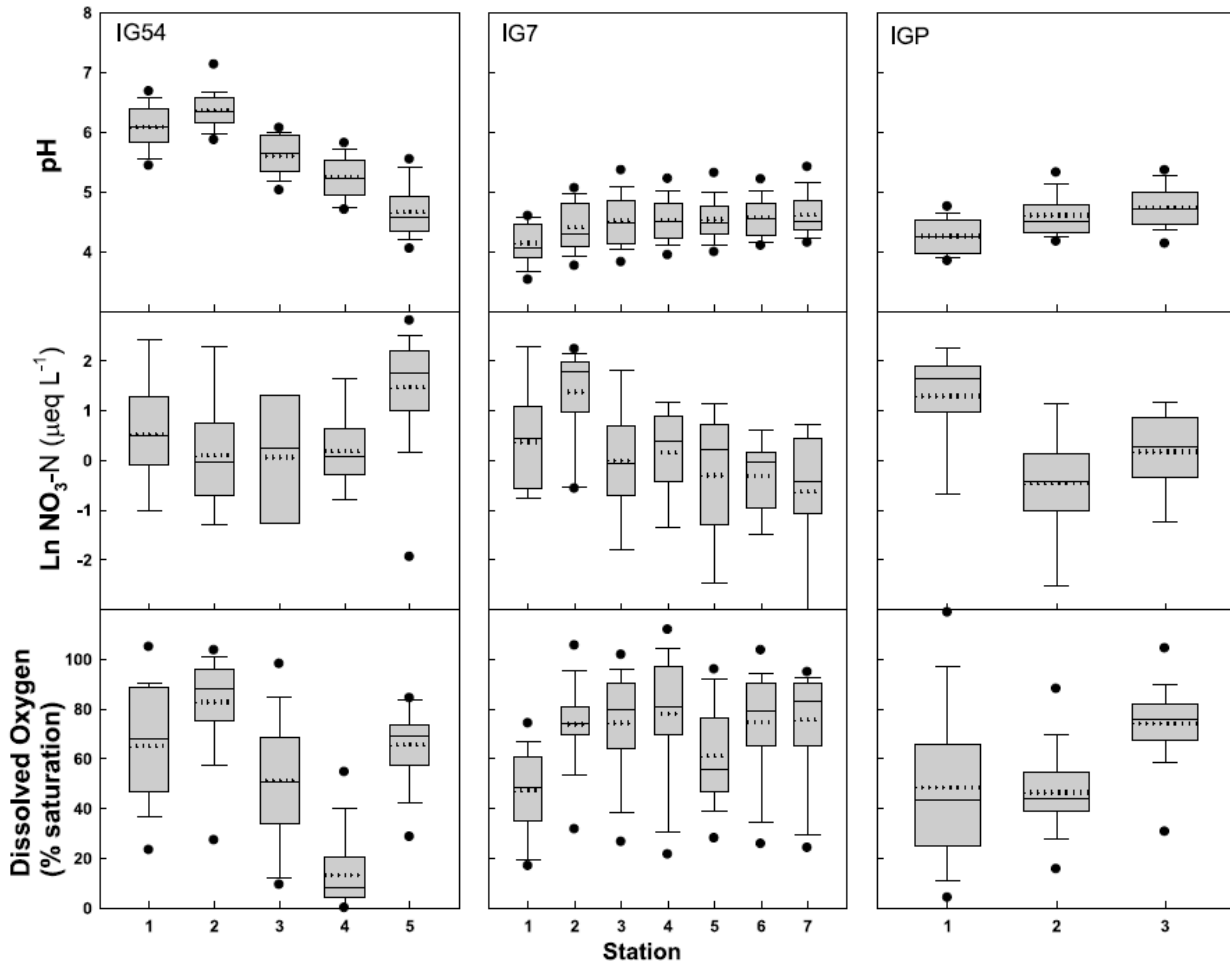
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301 **Figure 2**

302 Photograph of a pasture hillslope as viewed from the overland flow sampling location, with runoff at  
303 the end of an 11-mm rainstorm. In the photo we can see the cattle trail conveying the water.

304

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306

307 Source: Figueiredo, R.O. et al., 2010. Land-use effects on the chemical attributes of low-order streams in the eastern  
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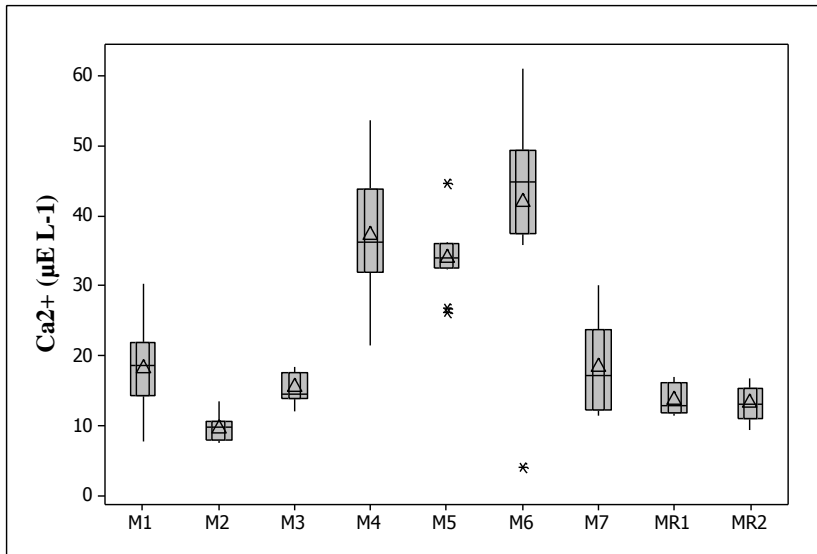
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### 310 **Figure 3**

311 Upstream-downstream trends for pH, nitrate (Ln NO<sub>3</sub><sup>-</sup>-N), and dissolved oxygen (DO) in three  
 312 streams of eastern Amazonia (IG54, IG7, and IGP). Lower and upper boundaries of the box are 25th  
 313 and 75th percentile, dots are 5th and 95th, solid line is median, and dotted line is mean for samples  
 314 that were collected monthly from April 2003 to October 2005.

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318 Source: Barroso, D.F.R., 2011. Fluxos hidrogeoquímicos em águas fluviais de microbacias do Nordeste paraense e a sua  
 319 relação com o uso da terra. Universidade Federal do Pará, Belém, pp.68.

320

#### 321 **Figure 4**

322 Box plot graph of calcium ( $\text{Ca}^{2+}$ ) concentrations along one year period (n=12 ) in streamwater at nine  
 323 catchments in the Marapanim River Basin, eastern Amazonia.

324

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326

327 Source: Gabriel Lourenço Brejão files.

328

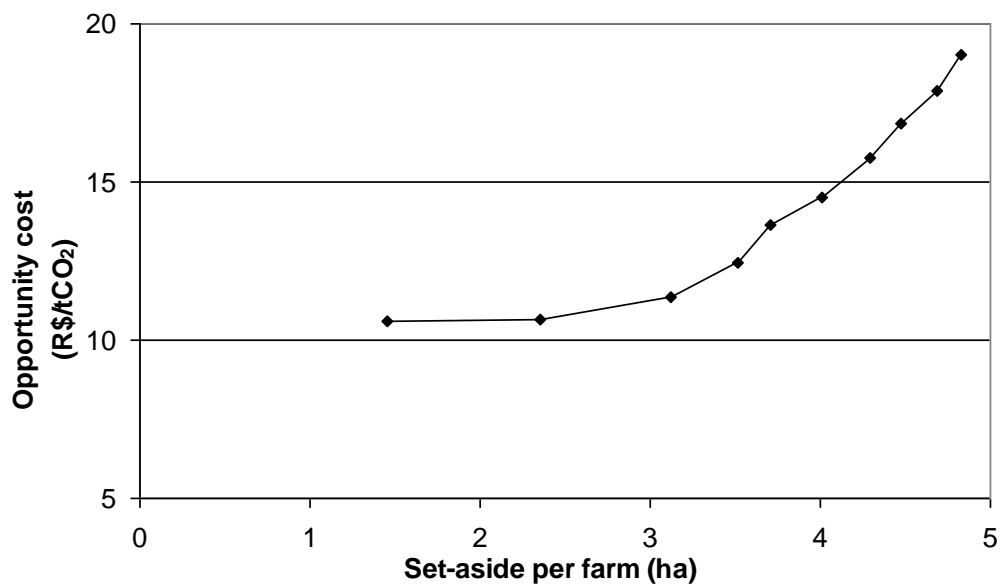
329 **Figure 5**

330 Two of the seventy-three species registered by Brejão (2011) in seven streams of the same agriculture

331 region.

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333



334

335 Source: Modified from Börner, J. et al., 2007. Ecosystem services, agriculture, and rural poverty in the Eastern  
336 Brazilian Amazon: Interrelationships and policy prescriptions. *Ecological Economics* 64, pp.362.

337

338 **Figure 6**

339 Opportunity costs per unit of avoided CO<sub>2</sub> emission in smallholder systems in the eastern Brazilian  
340 Amazon.

341