Differential effects of exotic Eurasian wild pigs and native peccaries on physical integrity of streams in the Brazilian Atlantic Forest

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Wild pigs (*Sus scrofa*) native to Eurasia and Africa, are one of the world's most widely distributed invasive species. Their impacts on terrestrial environments have been well documented, however little is known about effects on aquatic environments. We used standardized physical habitat surveys to compare the use of streams by invasive wild pig and native white-lipped peccaries (*Tayassu pecari*) and their effects on the physical structure of four first-order streams in the Brazilian Atlantic Forest. Two of the streams were used solely by wild pigs and two by peccaries. Each stream was subdivided by cross-sectional transects into continuous sections, each 10 m in length, where we measured the intensity of use of species and different variables related to the stream physical habitat. Although both species used the streams, wild pigs altered physical and environmental parameters more, and with greater intensity, than the native peccaries. Wild pigs decreased the stream bank angle and the riparian ground cover, leading to local erosion, increase of fine sediments and wet width, and a decrease in stream depth. We recommend studies to evaluate the biological consequences of the alterations caused by introduced wild pigs that should be conducted with population control plans in environments where the pig is invasive.

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Abstract

Wild pigs (*Sus scrofa*) native to Eurasia and Africa, are one of the world's most widely distributed invasive species. Their impacts on terrestrial environments have been well documented, however little is known about effects on aquatic environments. We used standardized physical habitat surveys to compare the use of streams by invasive wild pig and native white-lipped peccaries (*Tayassu pecari*) and their effects on the physical structure of four first-order streams in the Brazilian Atlantic Forest. Two of the streams were used solely by wild pigs and two by peccaries. Each stream was subdivided by cross-sectional transects into continuous sections, each 10 m in length, where we measured the intensity of use of species and different variables related to the stream physical habitat. Although both species used the streams, wild pigs altered physical and environmental parameters more, and with greater intensity, than the native peccaries. Wild pigs decreased the stream bank angle and the riparian ground cover, leading to local erosion, increase of fine sediments and wet width, and a decrease in stream depth. We recommend studies to evaluate the biological consequences of the alterations caused by introduced wild pigs that should be conducted with population control plans in environments where the pig is invasive.

Key-Words: *Sus scrofa, Tayassu pecari,* Ecosystem Engineer, Feral Hogs, Hotspot.

1 Introduction

The physical and chemical features of streams are good indicators of stream ecological integrity and their biological condition (Casatti et al., 2006). Activities that disrupt stream physical structure may impact aquatic biota diversity and ecosystem processes (Gorman and Karr, 1978; Resh et al., 1988). Many of the disruptions in stream physical habitat characteristics have been caused by anthropogenic land use change (e.g. Kaufmann and Hughes, 2006; Wang et al., 2003). However, other organisms can also disrupt the habitat of streams and affect aquatic community structure (Meysman et al., 2006).

In fresh water, various vertebrates, called ecosystem engineers (Jones et al., 1994), can promote alterations in physical habitats and water quality, including native (e.g. Hogg et al., 2014; Peterson and Foote, 2000; Tiegs et al., 2009) and introduced fish species (e.g. Bain, 1993), but also mammals (Anderson and Rosemond, 2007; Beck et al., 2010; Butler and Malanson, 1995; Coronato et al., 2003; Doupé et al., 2010).

In temperate zones the American beaver (*Castor canadensis*) cuts down trees to build dams, altering the physical structure of rivers, changing water dynamics and homogenizing the substrate. In the Neotropics, the white-lipped peccary (*Tayassu pecari*) may modify streams creating microhabitats for species (Beck et al., 2010). However when the use of streams by exotic species results in alterations, it can lead to negative consequences to the environment by disrupting the trophic dynamics, habitat structure, and/or the frequency and intensity of disturbances and geochemical cycles (Simberloff, 2011).

The wild pigs (*Sus scrofa*), native to Eurasia and northwestern Africa (Long, 2003), are one of the oldest species intentionally introduced by humans (Courchamp et al., 2003; Long, 2003). Wild pigs are recognized as an important alien ecosystem engineer, changing the soil structure (Cuevas et al., 2012; Singer et al., 1981), vegetation cover by suppression of native species (Barrios-Garcia and Ballari, 2012; Cuevas et al., 2012), causing alteration in the structure of the seed bank (Bueno et al., 2011; Ickes et al., 2001) and the spread of exotic grasses (Dovrat et al., 2012; Sanguinetti and Kitzberger, 2010). However, there is no consensus about the effects of wild pigs on aquatic environments.

Doupé et al. (2010) reported negative changes in the aquatic plant community and water quality and Arrington et al. (1999) observed an increase in the aquatic plant diversity in water bodies used by wild pigs. Therefore their foraging behavior, which consists of rooting (Barrios-Garcia and Ballari, 2012), and their need for body temperature regulation, promotes the formation of large bogs in water bodies (Barrett, 1978; Coblentz and Baber, 1987; Cuevas et al., 2013).

In the Neotropics the white-lipped peccary *Tayassu pecari* can be considered the native ecological equivalent of the wild pig (Novillo and Ojeda, 2008). The white-lipped peccary is one of the largest Neotropical mammals (Fragoso, 1999) and in their natural range the populations are declining due to habitat fragmentation and poaching (Altrichter et al., 2012; Reyna-Hurtado et al., 2009, 2010). However unlike wild pig, the white-lipped peccary does not seem to have become a problematic invasive species where it has been introduced (Mayer and Wetzel, 1987).

The Serra da Mantiqueira is a mountain range extending for 500 km along southeastern Brazil and one of more important areas of the Brazilian Atlantic Forest Biome, considered to be an area of global importance for biodiversity conservation (Le Saout et al., 2013; Myers et al., 2000). According to local residents, in 2006, six individuals of pigs that had been kept enclosed on a commercial breeding site, were intentionally introduced next to Itatiaia National Park (INP), one of the largest protected areas of the Serra da Mantiqueira. The pigs established feral populations that now have a population in the Serra da Mantiqueira estimated at 199±1.38 individuals with a density of 15,8 ind./km² (Puertas, 2015) and no control effort have been made.

Both the wild pig and white-lipped peccary use streams in their daily activities and have rooting and wallowing behavior and the potential to alter the stream physical habitat structure of streams (Arrington et al., 1999; Beck et al., 2010; Doupé et al., 2010). To better understand the potential effect of wild pigs on aquatic environments of Brazilian Atlantic Forest, we compared the use of streams by the alien wild pig and the native white-lipped peccary and their consequences on the physical structure of first-order streams. We hypothesized that stream use by wild pigs may potentially cause a harmful disturbance to the aquatic ecosystem of the Brazilian Atlantic Forest because such use have a potential to disrupt the physical structure of streams more intensely than the use by white-lipped peccaries

2 Material and Methods

2.1 Study Area

The Itatiaia National Park (INP) is the most representative of a patchwork of protected areas in the Serra da Mantiqueira. The INP has a lower region (22°26'14"S/44°36'3"W), between 600 and 1,500 m of altitude, locally called the Lower Part (LP) which has a Cwb climate type, mesothermal with a rainy season in summer (Köppen, 1936); and the other (22°20'23"S/44°43'17"W) between 1,500 and 2,791 m called the Higher Part (HP) which has a Cfb climate type, mesothermal without a dry season (Köppen, 1936). The area covered by INP has 12 important regional watersheds that drain into two main basins: the Grande River, a tributary of the Paraná River, and the Paraíba do Sul River.

Since 2013 we have been conducting a continuous monitoring program of the mammal's activities in our study area with automatic cameras and there has been no evidence of sympatry between white-lipped peccary and wild pig. The wild pig occurs only in the HP while the white-lipped peccary occurs only in the LP (Rosa et al., unpublished results). Thus, we selected four headwater streams (first and second orders); two in the LP areas and two in the HP areas (Fig. 1). Their riparian vegetation cover was represented by forest in advanced succession stage, with canopy height between 15 and 20 meters.

2.2 Data Collection

To determine the use of streams by wild pigs and peccaries and the consequences on the physical structure of first-order streams we carried out an observational study during the dry season between October and November 2013. For this we performed a standardized physical habitat survey adapted from the methodology of Peck et al. (2006) and Hughes and Peck (2008) that uses physical, chemical and biological variables to assess the integrity of streams.

We surveyed four streams used by the species; two in the LP area (with peccaries and without wild pigs) and two in the HP area (with wild pigs and without peccaries) (Fig. 1). Each stream was subdivided by cross-sectional transects into continuous sections of 10 m in length each (Fig. 2) as recommended by Peck et al. (2006) and Hughes and Peck (2008). Both species occurred over the area sampled, thus we could not find streams that are not used by at least one species in all their extension. But we could find stream sections with different use intensities (eg, footprints, rooting), or even without use by the species. To set the control points and evaluate how different use intensities of species can alter the physical integrity of streams, we employed a use intensity score from the presence or absence of footprints and rooting every 1 meter in each

10m section. Each 1 meter accounted for 10% of the total 10 m section, resulting in a use intensity ranging from 0 to 100% in each 10m section (Fig. 2). The control sections were those in which the use intensity scores were 0%. In total we measured in HP 16 sections used by wild pigs and 12 control sections, and in LP 13 sections used by white-lipped peccaries and 24 control sections. Field experiments were approved by the Research Council of Instituto Chico Mendes para a Conservação da Biodiversidade (number 44164).

To measure the effects of use intensity of species in stream conditions in each 10m-section we measured physical variables associated with morphology and type of substrate of streams that could be altered by ecological engineers such as wild pigs and peccaries from previous field observations. At each of the cross-sectional transects we measured depth (DEPTH) and visually examined substrate type (bedrock, concrete, boulders, cobbles, coarse gravel, fine gravel, sand, silt and clay, hardpan, fine litter, coarse litter, wood, roots) along five equidistant points. Based on substrate type we calculated the mean substrate diameter (SIZE_CLS), the percentage of substrate smaller than fine gravel (SEDIMENT) and larger than boulder (LARGER). Transect characterization also included bank full width (BANKWID), mean wetted width (WT_WID), undercut bank distance (UNDERCUT), and bank angle (ANGLE). We assessed habitat complexity at each transect in 10 m length plots inside the stream channel, using semi-quantitative visual estimates (%) of the surface cover of leaf packs, roots, large woody debris >30cm diameter, brush and small woody debris, overhanging vegetation <1 m above the water surface, undercut banks, boulders, and artificial structures. These variables were used to estimate the number of woody debris pieces (PIECES), riparian ground cover (RIP_GC) and shelter for aquatic organisms (SHELTER).

2.3 Data Analysis

We divided the sampled sections into four groups: (1) points in HP not used by wild pigs (control points); (2) points in the HP used by wild pings; (3) points in LP not used by peccaries (control points); and (4) points in LP used by peccaries. The variables describing the stream conditions were examined using principal component analysis (PCA). Differences among the four groups were tested by discriminant correspondence analysis (DCA) using the software Statistica 6 (StatSoft Inc., 2001).

For each stream variable we tested normality using the Shapiro-Wilk test and compared its mean values between Groups 1 and 2 and between Groups 3 and 4, using the Kruskal-Wallis test for non-normal data and the Student's t-test for normal data using the software Bioestat 5.0 (Ayres et al., 2007).

3 Results

We recorded differences of stream physical characteristics in sampled sections used by wild pigs and peccaries. When ordered, these differences were most evident along the first axis of the PCA (Fig. 3). In general both species were associated with shallower stream depths (DEPTH), and replacement of the larger substrate (LARGER) by fine gravel (SEDIMENT) (Table 1). However, while all sections with any use intensity by wild pigs showed these characteristics, only those with high use intensity values by peccaries (>50% of use intensity) followed this pattern. In sections used by wild pigs, stream characteristics related to the second axis of the PCA were altered (Fig. 3), in particular by reducing the undercut bank distance (UNDERCUT) (Table 1).

When evaluated on its own set of variables, the four groups differed ($p < 0.05$), mainly due to the amount of larger substrate (LARGER) and riparian ground cover (RIP_GC) (Table 2). In stream sections used by either species, we noted the cover of large substrate by silt and removal of riparian ground cover.

In sections used by wild pig the bank distance (UNDERCUT), mean wetted width (WT_WID), woody debris pieces (PIECES) and shelter (SHELTER), did not differ between control and streams-section used by species (Fig. 4c and 4f). However, bank angle (ANGLE), sediment larger than boulder (LARGER), riparian ground cover (RIP_GC), mean substrate diameter (SIZE_CLS), fine gravel (SEDIMENT) and bank full width (BANKWID) were altered (Fig. 4a, 4b, 4d, 4e and 4g). In areas were white-lipped peccaries occurred, bank distance (UNDERCUT), mean wetted width (WT_WID), woody debris pieces (PIECES) and shelter (SHELTER), also did not differ between control and stream sections used by species (Fig. 4c and 4f). However, bank angle (ANGLE), sediment larger than boulder (LARGER), depth (DEPTH) and riparian ground cover (RIP_GC) were altered (Fig. 4d, 4e, 4g and 4h).

4 Discussion

In sections used by wild pigs or peccaries, the physical structures of streams were altered. The main effect included decreasing stream depth by sedimentation due to replacement of the larger substrate by fine gravel. The fact that both species are associated with fine sediments could demonstrate a habitat preference. However, since our control sections presented larger substrates and the sections with predominance of fines were always associated with the bank collapse, these section features must be related to the use by one of the two species

Even with abundance six times lower than white-lipped peccaries (Rosa et al., unpublished results), any use intensity of streams by wild pigs caused bank erosion, reflecting also in a decrease of the stream bank angle and the riparian ground cover. These results support our hypothesis that wild pigs change the physical structure of streams more intensely than peccaries, characterizing them as an agent of alien disturbance to the aquatic ecosystem of the Brazilian Atlantic Forest.

Significant effects of wild pigs on the physical structure of the soil, leaf litter, seed and land plants in terrestrial environments have previously been reported (e.g. Bueno et al., 2011; Cuevas et al., 2012; Wirthner et al., 2011). Their rooting behavior makes the soil less compact and wetter, which reduces the vegetative cover making the soil more susceptible to wind erosion (Cuevas et al., 2012). Such rooting can also reduce ground vegetative cover and leaf litter, which in turn eliminates the presence of some small mammal species that are dependent upon those microhabitat parameters of the forest floor for their survival (Singer et al., 1984).

We found no studies that had evaluated the use of wild pigs or white-lipped peccaries and their effects on stream physical habitats structure. However, Beck et al. (2010) showed that pools created and maintained by white-lipped peccaries are wider and hydrologically more stable over time than other pools, especially during times of drought, increasing the diversity of anurans. For wild pigs, Doupé et al. (2010) noted increased turbidity, changes in chemical composition and reduction of macrophyte coverage on an ephemeral flood plain lagoon used by species. Arrington et al. (1999) did not assess the effect of wild pigs on the physical structure of wetlands, but noted increased vegetation in these areas due to the creation of microhabitats for this species. These authors point out that because of the wet ground, the ability of wild pigs to modify wetlands in wet periods is limited, providing an opportunity for the vegetation to recover, leading to an increase in plant species diversity in these areas.

In the terrestrial environment, wild pigs root and graze to a greater extent than do peccaries because of differences in cranial anatomy of the species (Ilse and Hellgren, 1995; Sicuro and Oliveira, 2002). In the Brazilian Pantanal, where peccaries and wild pigs coexist, morphological differences between the species have been related to a higher soil rooting performance by the wild pigs that allows soil excavation up to 50 times deeper than peccaries (Sicuro and Oliveira, 2002). We believe that these same cranial differences can have a relation to the wild pig's ability to modify aquatic environments.

Where it is an invasive species, the wild pig create new habitats for exotic species increasing their diversity (Cushman et al., 2004; Kotanen, 1995). However, where it is native, it is possible to observe resiliency in the native herbaceous plant community, probably due to their mutual evolutionary history (Dovrat et al., 2014). The same occurs with the white-lipped peccary through its wallowing behavior that creates pools that are used for reproduction by different frog species, leading to an increased density and diversity of frogs in the Peruvian Amazon (Beck et al., 2010). Native or exotic ecosystem engineers can alter the frequency regime of disturbances (e.g., grazing and fire), as well as being the source of disturbance itself (Crooks, 2002), and this may increase the alpha (Arrington et al., 1999) and beta diversity (Astorga et al., 2014). Thus, the effects of ecosystem engineers are a matter of scale and context, depending on the landscape and the regional species pool in which the activity is located. The effects on species diversity vary depending on the scale of influence on the resource and its influence on the increase or decrease in diversity as the heterogeneity is reduced or increased (Crooks, 2002). Thus, the ecosystem engineers may be crucial for maintaining biodiversity in some landscapes, especially those where the disturbances regime and frequency have been altered due to other human activities (Badano and Cavieres, 2006).

In the case of wild pigs, our study shows that the presence of an exotic ecosystem engineer modifies the physical structure of streams; however, we do not know the ultimate consequences. Although the disturbance can increase the number of habitats, we must remember that in tropical environments heterogeneity of substrates is critical for fish diversity, including sympatric congeners (Leal et al., 2010), and we do not know the consequences of stream physical habitat changes caused by wild pigs on fish and other aquatic organisms

The Itatiaia National Park is recognized as a fundamental area for water resources and biodiversity preservation, but suffers with domestic and exotic species such as wild pigs, feral dogs, cattle and domestic horses, whose synergy can enhance the impact of each species individually (Simberloff, 2011). As an immediate solution to reduce the effects of wild pigs on streams, the fencing of streams can be carried out, which has already proved to be a success in Australia (Doupé et al., 2010). However, without a wild pig population control program, the fencing of streams would be a palliative solution.

Brazilian law results in great limitations for wildlife management strategies, mainly regarding the lethal control of populations. Recently, wild pigs were recognized as a risk for the Brazilian economy and biodiversity, and their population control by hunting techniques has been allowed (Instrução Normativa Ibama 03/2013). Therefore we recommend that Protected Areas include the control of this invasive exotic species in their management plans, and that the control techniques and management of exotic species must be extended to the surrounding area and be strategically evaluated in conjunction with the local community.

5. Conclusion

Our results show that both native white-lipped peccary and alien wild pig modified the physical structure of streams causing its sedimentation. The effects of wild pigs can be observed in more environmental variables and even when there is low use intensity of streams. So we believe that this streams' modification leads to an alien process to Brazilian Atlantic Forest environments and the ultimate consequences for biodiversity need to be evaluated.

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Figures Captions

Fig. 1. Study area showing the sampled streams in the Higher Part (square), the *Sus scrofa* area, and in the Lower Part (circle), the *Tayassu pecari* area, of Itatiaia National Park. The line indicates the division of the Brazilian states where the Higher Part (Minas Gerais) and Lower Part (Rio de Janeiro) of Itatiaia National Park are located.

Fig. 2. Sampling design showing the 10m-section used to measure the use of streams by *Sus scrofa* and *Tayassu pecari*.

Fig. 3. PCA showing the effects of *Sus scrofa* (in black) and *Tayassu pecari* (in gray) in the sampled points. Black crosses indicate the control points of *Sus scrofa* area (Group 1); black balls indicate points used by *Sus scrofa* (Group 2); Gray crosses indicate the control points of *Tayassu pecari* area (Group 3); gray balls indicate points used by *Tayassu pecari* (Group 4). The bubbles represent the use intensity (%) of each species, where the larger the ball, the higher the use intensity of the species.

Fig. 4. Mean, standard deviation and maximum and minimum values of the physical streams variables measured in the sampled streams (1) control points of *Sus scrofa* area; (2) points used by *Sus scrofa*; (3) control points of *Tayassu pecari* area; (4) points used by *Tayassu pecari.* Different letters indicate significant differences ($P < 0.05$), with *a* and *b* representing the Groups 1 and 2 and *c* and *d* for Groups 3 and 4.

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Table 1 (on next page)

Stream attributes, PCA scores and contribution to the first three PCA components of the variables measured in streams used by *Tayassu pecari* and *Sus scrofa*.

Highest scores of each axis are in bold and scores between -0.3 and 0.3 are presented only with a positive or negative sign.

Table 1. Stream attributes, PCA scores and contribution to the first three PCA components of the variables measured in streams used by *Tayassu pecari* and *Sus scrofa*. Highest scores of each axis are in bold and scores between -0.3 and 0.3 are presented only with a positive or negative sign.

	PCA 1	PCA 2	PCA 3
DEPTH	**0.74**	-	-0.31
SIZE_CLS	0.46	0.39	0.32
SEDIMENT	**-0.71**	+	-0.52
ANGLE	0.64	0.32	-
WT_WID	0.51	-0.44	-0.49
BANKWID	-	-0.69	-0.32
SHELTER	0.48	0.30	-0.57
PIECES	-0.51	-	+
RIP_GC	0.69	-0.41	+
UNDERCUT	+	**0.77**	-
LARGER	**0.83**	-0.19	+
Eigenvalues	3.63	1.91	1.34
Variance explained (%)	32.99	17.33	12.14
Cumulative variance (%)	32.99	50.31	62.45

Table 2 (on next page)

F and exit values of the model and tolerance of the discriminant correspondence analysis, and p value for variance analysis of variables measured in streams used by *Tayassu pecari* and *Sus scrofa*.

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Table 2. F and exit values of the model and tolerance of the discriminant correspondence analysis, and p value for variance analysis of variables measured in streams used by *Tayassu pecari* and *Sus scrofa*.

	F-exit	Tolerance	P (DCA)	P (variance)
DEPTH	1.30	0.65	0.2844	<0.0001
SIZE_CLS	2.13	0.67	0.1082	<0.0001
SEDIMENT	1.83	0.60	0.1530	<0.0001
ANGLE	1.99	0.71	0.1267	<0.0001
WT_WID	1.39	0.57	0.2560	0.0395
BANKWID	2.31	0.53	0.0877	0,0218
SHELTER	1.76	0.60	0.1657	0.0152
PIECES	0.50	0.82	0.6823	0.0158
RIP_GC	3.03	0.68	**0.0378**	<0.0001
UNDERCUT	0.44	0.65	0.7237	0.2260
LARGER	6.63	0.76	**0.0007**	<0.0001

Figure 1 (on next page)

Study area showing the sampled streams in the Higher Part (square), the *Sus scrofa* area, and in the Lower Part (circle), the *Tayassu pecari* area, of Itatiaia National Park.

The line indicates the division of the Brazilian states where the Higher Part (Minas Gerais) and Lower Part (Rio de Janeiro) of Itatiaia National Park are located.

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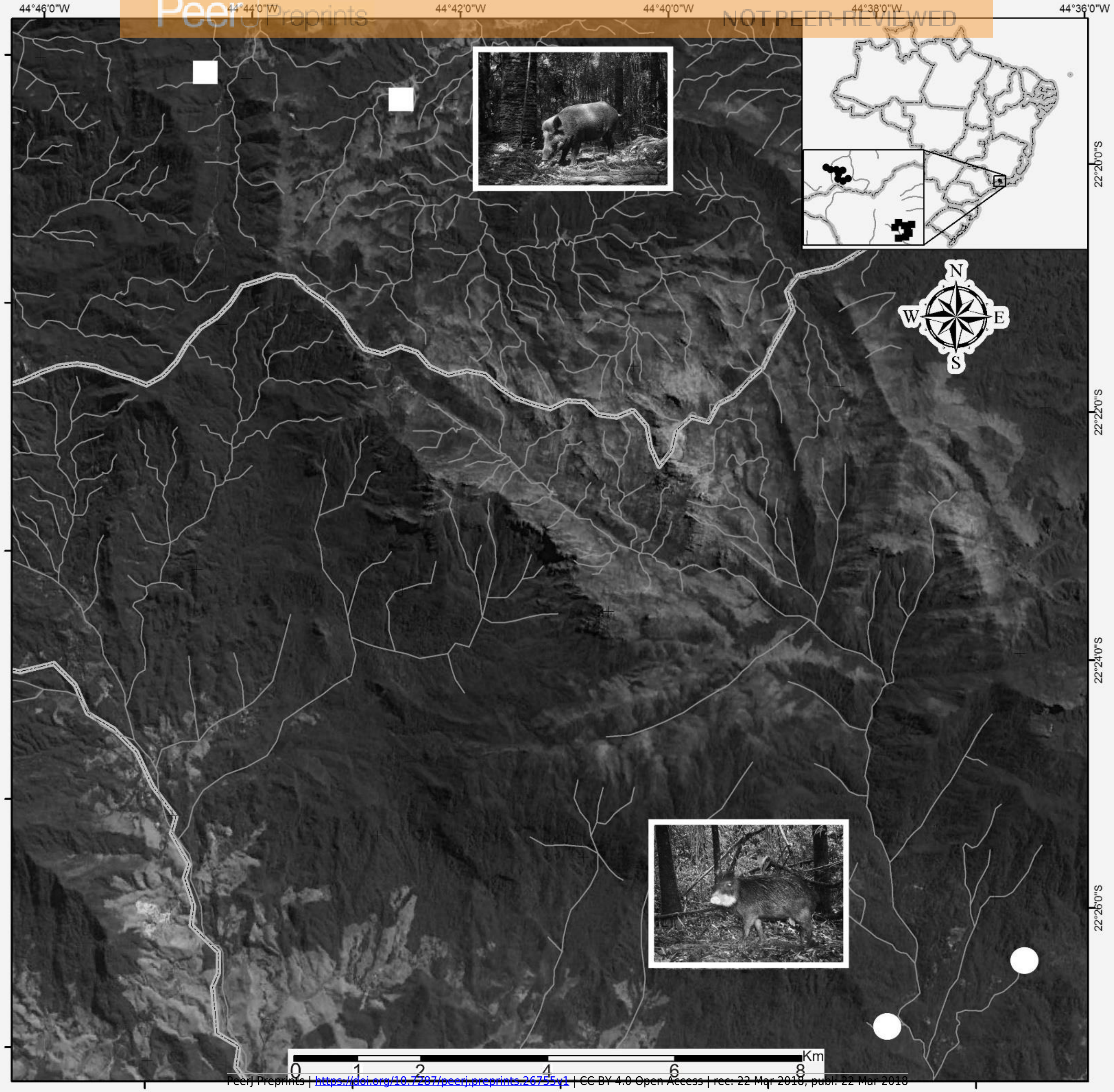
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Figure 2 (on next page)

Sampling design showing the 10m-section used to measure the use of streams by *Sus scrofa* and *Tayassu pecari*.

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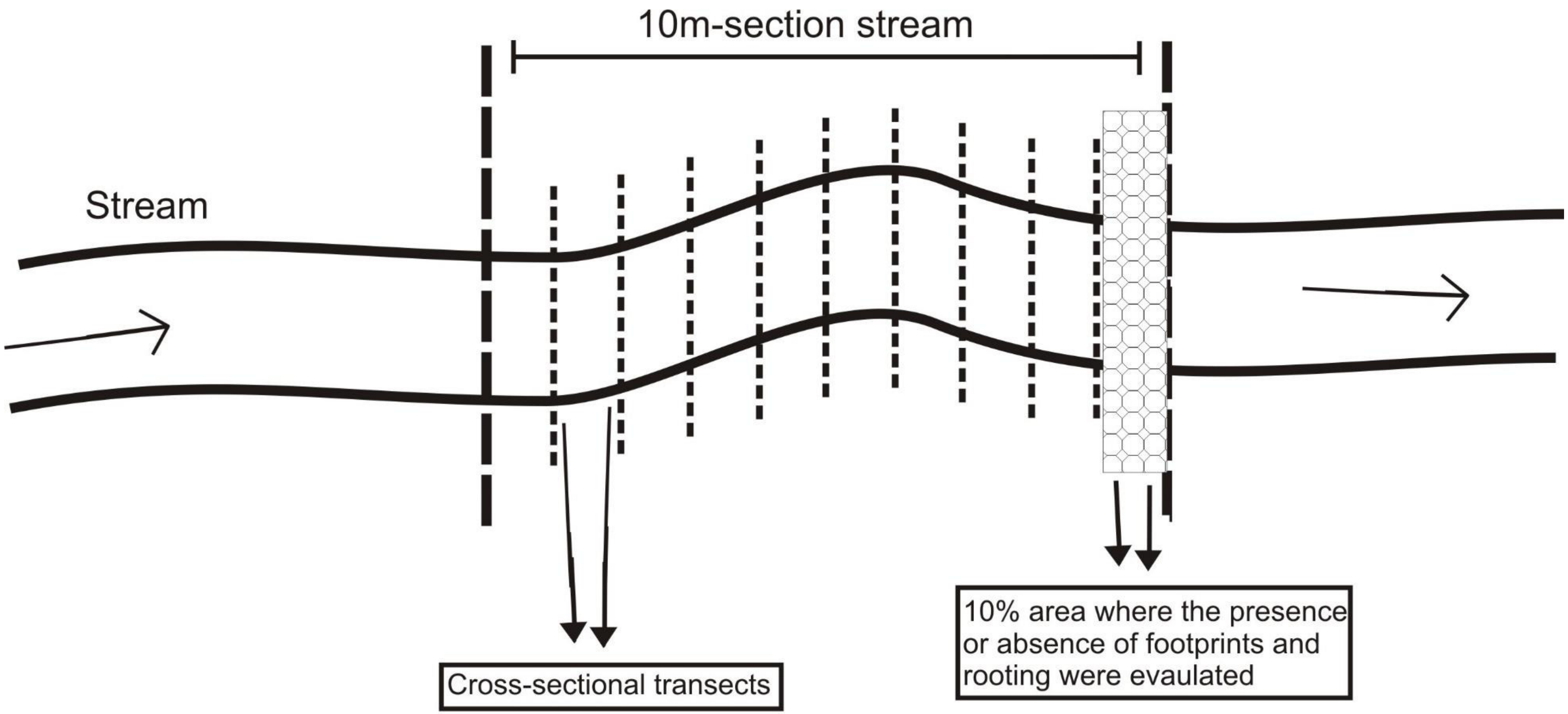

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Figure 3(on next page)

PCA showing the effects of *Sus scrofa* (in black) and *Tayassu pecari* (in gray) in the sampled points.

Black crosses indicate the control points of *Sus scrofa* area (Group 1); black balls indicate points used by *Sus scrofa* (Group 2); Gray crosses indicate the control points of *Tayassu pecari* area (Group 3); gray balls indicate points used by *Tayassu pecari* (Group 4). The bubbles represent the use intensity (%) of each species, where the larger the ball, the higher the use intensity of the species.

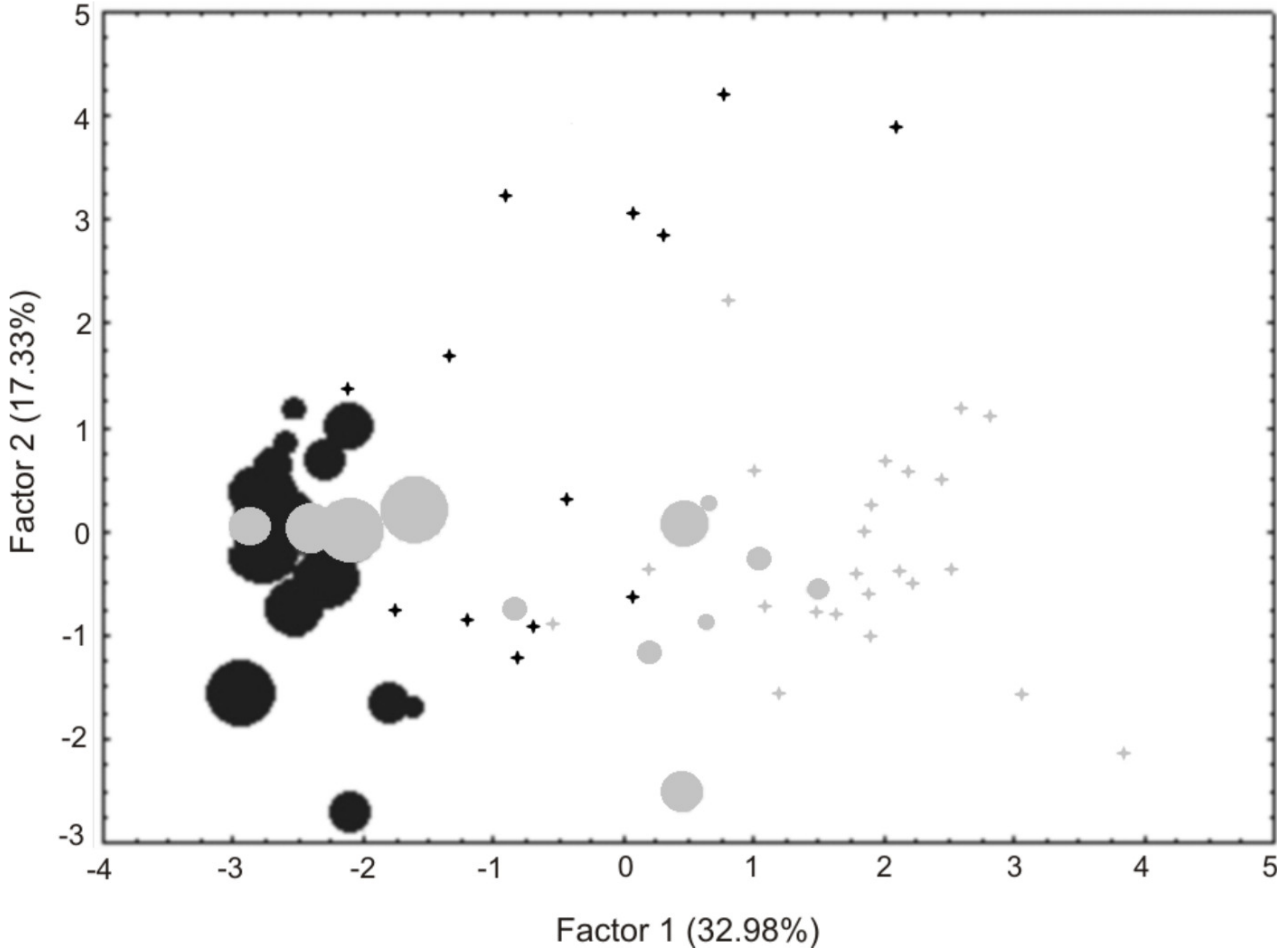
Factor 2 (17.33%)
Factor 1 (32.98%)
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Figure 4(on next page)

Mean, standard deviation and maximum and minimum values of the physical streams variables measured in the sampled streams

(1) control points of *Sus scrofa* area; (2) points used by *Sus scrofa*; (3) control points of *Tayassu pecari* area; (4) points used by *Tayassu pecari.* Different letters indicate significant differences (P <0.05), with *a* and *b* representing the Groups 1 and 2 and *c* and *d* for Groups 3 and 4.

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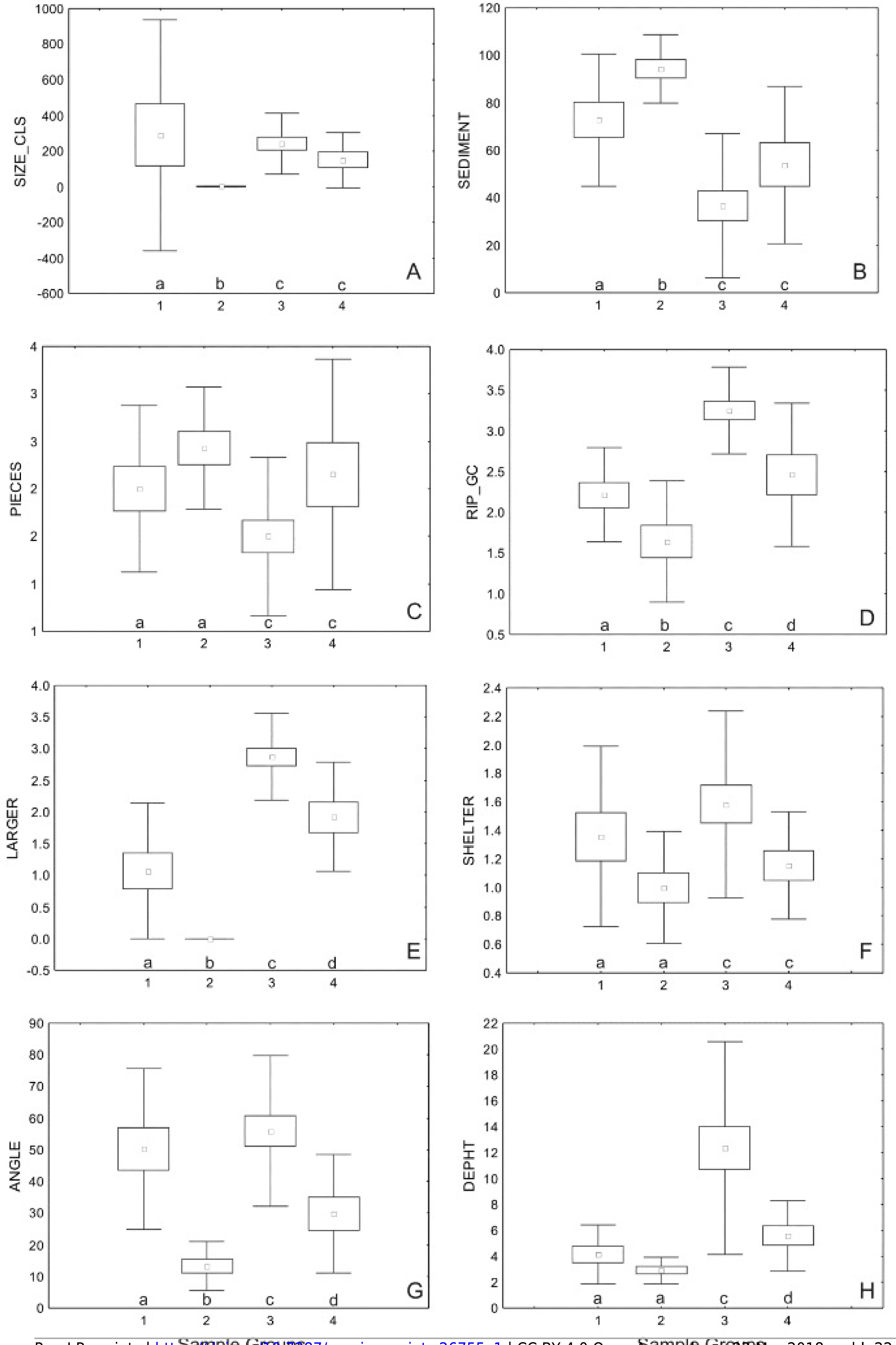
SIZE_CLS
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Sample Groups
Sample Groups