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Giulia Baldaconi da Silva Bispo

Serviços Ecossistêmicos Hídricos em paisagens savânicas sob gradiente de florestas naturais e plantios de eucalipto

Water Related Ecosystem Services in Brazilian savannas, in landscapes of natural vegetation and eucalyptus plantations

São Paulo

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Dissertação apresentada ao Instituto de Biociências da Universidade de São Paulo para obtenção do título de Mestre em Ecologia. Área de concentração: Ecologia de Ecossistemas Terrestres e Aquáticos

Orientação: Profª Drª Rozely Ferreira dos Santos

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Dr[a] Elaine Cristina C. Fidalgo	Dr[a] Carolina Bozzeti Rodrigues

Para ser grande, sê inteiro: nada
Teu exagera ou exclui.
Sê todo em cada coisa. Põe quanto és
No mínimo que fazes.
Assim em cada lago a lua toda
Brilha, porque alta vive.

Odes de Ricardo Reis. Fernando Pessoa, 1933

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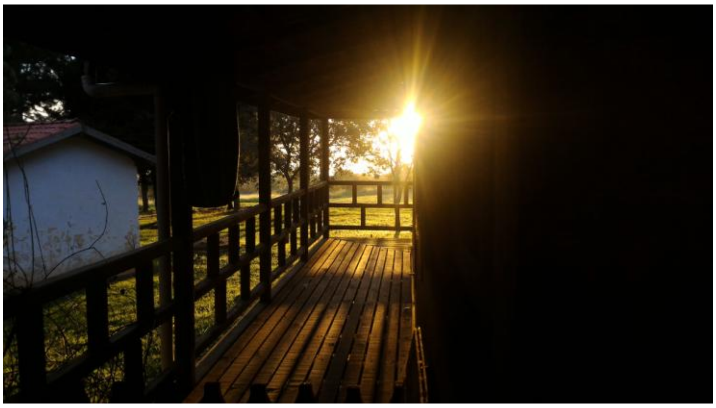

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RESUMO

Baldaconi S. Bispo, Giulia. “Serviços Ecossistêmicos Hídricos em paisagens savânicas sob gradiente de florestas naturais e plantios de eucalipto”

A abordagem dos serviços ecossistêmicos aumentou ao longo dos anos, tornando-se uma ferramenta poderosa para o planejamento ambiental, guiando a tomada de decisão sobre o manejo de recursos naturais. Mudanças no uso/cobertura da terra são os principais impactos sobre os ecossistemas naturais, o que implica diretamente na provisão de serviços, e na capacidade do ambiente de sustentar esses benefícios. A água fornece diversos serviços ecossistêmicos hídricos, vitais para a sobrevivência humana. Então, neste contexto, paisagens submetidas a vastas mudanças de uso e cobertura representam uma séria ameaça aos serviços hídricos, como é o caso das áreas em domínio de Cerrado brasileiro. Prever e valorar as conseqüências da conversão de áreas naturais para usos da terra sobre os serviços hídricos pode se tornar uma forma de evitar sua perda e diminuir as incertezas nos processos de tomada de decisão territorial. Com esse propósito, objetivamos mensurar e definir limiares em relação às mudanças na disponibilidade de sete serviços essenciais de água em paisagens savânicas do Estado de São Paulo que sofreram conversão de florestas nativas para reflorestamentos. Analisamos recursos hídricos de onze bacias hidrográficas de pequena ordem, que compreendem composições de sistemas florestados em contato com florestas plantadas de eucalipto. As amostras de água foram avaliadas por meio de treze parâmetros físico-químico-biológicos, presumidos como indicadores de sete serviços hídricos. Os resultados ressaltaram a importância de Turbidez, pH e condutividade elétrica como elementos indicadores da provisão dos serviços. Os melhores ganhos potenciais na provisão ocorreram a partir de 45% de cobertura florestal. Paisagens com menos do que 20% de florestas naturais tendem a tornarem-se menos sustentáveis para a provisão de todos os serviços somados.

Palavras chaves: serviços ecossistêmicos, qualidade de água, LULC, planejamento ambiental, ecologia de paisagens.

ABSTRACT

Baldaconi S. Bispo, Giulia. *“Water Related Ecosystem Services in Brazilian savannas, in landscapes of natural vegetation and eucalyptus plantations”*

The ecosystem services approach has increased throughout the years, becoming a powerful tool for environmental planning as well as guideline for resources management and decision-making. Changes in land use/cover are the main human-driven impact over natural ecosystems, which implies directly in ecosystem services provisioning capacity and the ability to sustain those benefits. Water resources are strongly related to human well-being and survival, as one of the most valuable benefits humans acquire from nature. In this regard, landscapes suffering from extreme or vast changes in land use/cover represent threats over water resources, as is the case for Brazilian *Cerrado* savannas. The prediction of impacts of land cover exchanges over water-related ecosystem services may become one way to avoid its loss, diminishing uncertainties in decision making of land uses. In this sense, our work aimed the measurement and recognition of thresholds that indicates changes in the availability of seven essential water-related ecosystem services, within Cerrado landscapes of São Paulo State, that are facing the conversion of native forests into eucalyptus plantations. We analyzed water resources at 11 low order catchments which comprised a gradient of forested savanna and eucalyptus plantations. Stream water quality data were obtained for 13 physical-chemical-biological parameters, previously known as indicators for seven water-related ecosystem services. Results highlight the importance of monitoring Turbidity, pH, electric conductivity as indicators of services provision. Best potential gains of the seven services occurred above 45% of natural forest coverage. Landscapes with less than 20% of forest tend to become too unsustainable.

Keywords: Ecosystem services; water quality; LULC, environmental planning; landscape ecology.

INTRODUCTION

The Ecosystem Services (ES) approach has been highly regarded throughout the years. Nowadays several organizations and initiatives are dedicated to this subject, such as TEEB (The Economics of Ecosystems & Biodiversity), CICES (Common International Classification of Ecosystem Services), IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), and more recently BPBES (Brazilian Platform on Biodiversity and Ecosystem Services). The ES approach is becoming a powerful tool for environmental planning as well as guideline for resources management and decision-making (MEA, 2003; VIGLIZZO et. al. 2011; BALVANERA et al., 2012).

The ES has experienced faster and broader impact than any other time in human history (DOHERTY et al., 2014). However, often the importance of ES only comes to public knowledge after jeopardized or after irreparable loss of natural resources due to environmental degradation, gaps in monitoring, and lack of research (DAILY et al., 2009). Changes in land use/cover (LULC) are the main human-driven impact over natural ecosystems, which implies directly in ES provisioning capacity (FOLEY et al., 2005; METZGER et al., 2006; TURNER; DONATO; ROMME, 2013) and the ability to sustain those benefits (LIANG, LIU, 2017). Several authors recognize the importance of improving evaluation regarding the impact of LULC exchanges over ES and trade-offs (DE GROOT et al., 2010; FENG et al., 2012; JONES et al., 2017). In addition, researchers emphasize that the main problem lies within difficulties in transposing ES knowledge to actual public policies (DE GROOT et al., 2010; BENNETT, 2017). In this regard, we must take into account the trajectory of changes that incurred in losses to human well-being (COSTANZA et al., 1987; HAINES-YOUNG; POTSCHIN, 2012; FERRAZ et al., 2014; BOEREMA et al., 2016).

Water resources are strongly related to human well-being and survival, it stands out not just for its condition as an indicator of landscape sustainability, but also for being one of the most valuable benefits humans acquire from nature (BRAUMAN et al., 2007; FRAGOSO, 2008; MARTIN-ORTEGA, 2015; LA NOTTE et al., 2015; HACKBART et al 2017). Water quality (WQ) is often misrepresented as a final ES, meanwhile it is most likely to be an important contributor to many different services (KEELER et al., 2012), since it involves several ecologic processes and combination of those (HACKBART et al. 2017). It affects human well-being in several ways, each of which can be interpreted as specific benefits, therefore evaluated as distinct water-related ecosystem services (ESw) (HACKBART, 2016).

It becomes certain that changes in LULC can alter water conditions by changing concentration of its natural components (i.e., water quality parameters: WQp), therefore causing ecological malfunctions and altering ESw supply (KEELER et al., 2012). In this regard, landscapes suffering from extreme or vast changes in LULC represent threats over water resources, as is the case for *Cerrado* forested savannas.The Cerrado biome originally covered 23% of the Brazilian territory. By 2013, 43% of this domain was already taken by antropic LULC exchanges (MMA, 2015). As a biodiversity hotspot, Cerrado savannas present fundamental importance to a variety of ecosystem services supply (MYERS et al., 2000, Lehmann et. al. 2014). Sadly, it has been less monitored in comparison to other biomes, such as the Amazon, meanwhile faces intense pressure for land cover exchanges (PENNINGTON et al., 2006). Recently, only 8.3% of this biome is officially set as protected areas (CNUC, 2019). Therefore, Cerrado can be pointed as one of the most threatened biomes nationwide (PENNINGTON et al., 2006; BEUCHLE et al., 2015, KLINK; MACHADO, 2005). Assessing the intensity of land cover exchanges in Cerrado savannas can be challenging, due to its vast coverage, and the complexity of ecosystems within the Cerrado domain (DURIGAN; et al, 2007 Pivello 2011, Beuchle *et al*, 2015). Within its vast territory, we find water springs that feed three of the biggest watersheds in Brazil, as well as important aquifers such as *Guarani* (LIMA; SILVA, 2007). These characteristics make Cerrado preservation fundamental to the hydrological balance of this country (MMA, 2006). Land cover exchanges in these conditions are particularly dangerous if not monitored.

In the past thirty years of agriculture expansion over Cerrado landscapes, over 50 million hectares were taken by livestock pastures, 14 million hectares for annual farming and over 2 million hectares of forestry and perennial cultivars (EMBRAPA, 2016). Eucalyptus species prevail on forest plantations in Brazil, one of the 10^{th} biggest planted areas in the world. These are heavily concentrated in the states of Minas Gerais (24%), São Paulo (17%) and Mato Grosso do Sul (15%) (IBA, 2017). Most of the plantations are of fast growth, highly productive and with short periods of harvesting. The intensive management increases concerns over water quality impacts (RODRIGUES, 2017) and ESw supply (HACKBART, 2016).

The São Paulo State has got specific conditions regarding savannas and transitioning Cerrado/Semideciduous Forest (RUGGIERO et al., 2002). Due to historical reasons, natural coverage exchange occurred mainly over “cerrado sensu lato” physiognomies, avoiding hilly terrain, which resulted in several forest savanna remaining patches (“cerradão” and semideciduous forests). Until mid-XX century, the Cerrado covered up to 14% of São Paulo State, mostly preserved, and only disturbed by pasture and wildfire (DURIGAN et. al. 2004; Beuchle et. al. 2015). During the 1970’s, agriculture took space over Cerrado landscapes, incentivated by the Federal Government through “ II Plano Nacional do Desenvolvimento, II PND” - the Nacional Plan for Development, with an specific program for the Cerrado savannas, “Programa de Desenvolvimento dos Cerrados (polocentro)”, from 1974 to 1979 (MMA, 2015). By the beginning of the XXI century, intense deforestation had diminished it to only 17% of the original Cerrado land cover in the State. In the year 2000, eucalyptus plantations, specifically, expanded due to the “National Forests Program” (“Programa Nacional de Florestas” - PNF).

Eucalyptus plantations possible impact on water resources includes reduction of water yield, siltation, increase in soil loss during harvesting and changes in water and nutrient cycling (LIMA, 1996; OLIVEIRA; et al, 2015; FOELKEL, 2005; VITAL, 2007; MOSCA, 2008). Even though management improvements were made over the years, stigma still remains amongst rural populations (MOSCA, 2008; LIMA ET AL., 2013). Practices on soil protection, roads and forest management are known to be capable of diminishing possible impacts (FERRAZ et al., 2007; MOSCA, 2008; RODRIGUES, 2017), amongst those, the increase in riverside natural forest area is indicated (AQUINO et al., 2012; CASSIANO et al., 2013).

Natural forests are responsible for several eco-hydrological functions, such as regulation of water quantity, erosion control, nutrient loss, and, therefore, are reflected on WQp (LIMA, 2013). By easing the water passage through the soil, natural forests improve water quality (BRAUMAN et al., 2007; Fiquepron 2013; CASSIANO, 2017). Thus, water quality tends to increase in watersheds at least partially covered by natural forests, in comparison to other LULC (FERRAZ et al., 2013; CASSIANO, 2017). Even when landscapes present fragmented patters, studies show their importance in assuring ES supply (CASSIANO et al., 2013; LITTLE et al., 2015, HACKBART, 2016; Bitencourt, 2017) or reducing further impacts to water resources (DING et al., 2016; MELLO et al., 2018; CASSIANO, 2017). The intensity of ESw provision is likely related to the amount, configuration and the quality of the forests (FERRAZ et al., 2014). From this perspective, we need to settle a safer bridge between water quality and combined anthropogenic/natural elements (URIARTE et al., 2011), using indicators that establish the contribution of landscape components to the ESw provision (MAES et. al. 2012).

The prediction of impacts of LULC exchanges over ESw may become one way to avoid its loss or even help obtaine improvements, by tracking changes in specific landscape characteristics linked to the maintenance of the service itself. Thus, demands on a broader and diversified approach, from ecologic processes to valuation (RIEB et al., 2017). Also, aiming the recognition of thresholds that indicate the intensity of human interferences beyond the point where a different state establishes, possibly resulting in adverse conditions at the local scale (RIEB et al., 2017). The answer to these issues gives room for decision makers to improve alternatives in land use and conservation, in order to preserve water resources.

Several studies have tried to identify and measure gains or losses in water services to get realistic sceneries with high-quality data (KEELER et al., 2012; OJEA, MARTIN-ORTEGA, 2015, LA NOTTE et al., 2015; ZHENG et.al, 2016; DING et al., 2016), many present monetary valuation techniques aiming at better policy choices (DI SABATINO et al, 2013; OJEA, MARTIN-ORTEGA, 2015, LA NOTTE et al., 2015). Other researches preferred the ecological assessment based on water quality indexes, acquiring information on water quality and deducing ESw supply (KEELER et al., 2012; PESCE, WUNDERLIN, 2000).

Encouraged by this background, we chose to evaluate changes in the availability of seven ESw, in landscapes of the Cerrado domain within São Paulo State that presents different quantities of natural forests coverage and short rotation eucalyptus plantations. Our approach evaluates trends and implications regarding WQp and possible thresholds on ESw supply. To assign values, we followed an approach based on HACKBART, (2016), in order to incorporate the dependence of ecological processes and functions, LULC exchanges, and its consequential changes in ESw, as a way to diminish uncertainties in the decision process, pointed as a major issue (GRIZZETTI et al., 2016, HACKBART, 2017).

MATERIAL AND METHODS

Study area and landscapes selection

Fieldwork was carried out within Cerrado domain, at four municipalities of São Paulo state, Brazil (Figure 1). These landscapes are covered by forested savannas, in altitudes ranging from 600m to 880m and over Red Latossol and Red-Yellow Latosol soils types (more details in SM-1). It presents tropical climate, Koeppen classification “Cfa” (ÁLVAREZ-CABRIA; et al 2016), dry season occurs from April to the end of September (mean temperature of 17.4 °C and mean rainfall below 75 mm) while rainy season from October to March (mean temperature of 21.6 ° C and average precipitation over 75 mm). This region has been undergoing major land use exchanges, yet, it contains a few remaining patches of the savanna ecosystems.

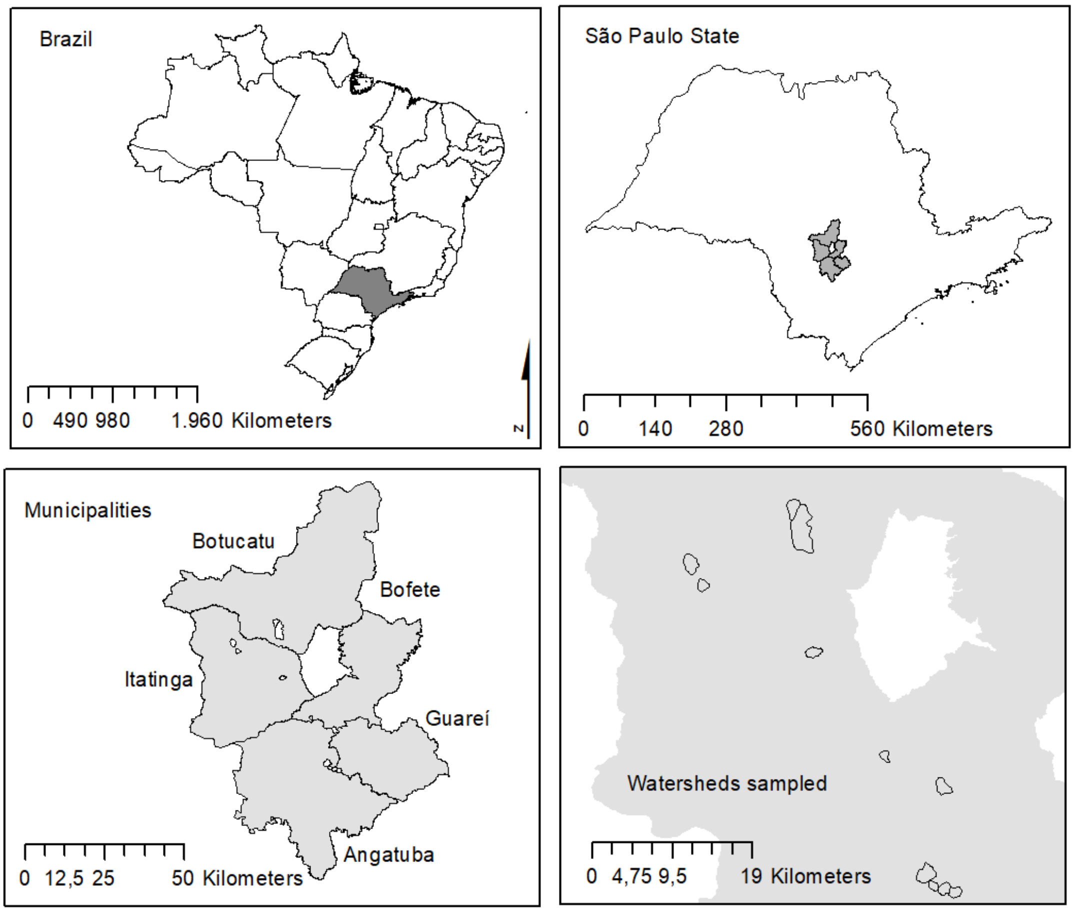


Figure 1 - Study region: municipalities of Botucatu, Itatinga, Bofete, Guareí and Angatuba SP - Brazil.

We mapped the land use/cover of this region employing images from Google Earth. The shapefiles of the hydrography, topography, soils, and slope were obtained from Brazilian Agencies, referenced in Supplementary Material SM-1. The geo-referenced database was developed using the coordinate projection system UTM, Datum SIRGAS 2000, zone 23S. We selected 51 catchments of second and third orders, which would represent a gradient between 0 and 100% of forest cover and silviculture, restraining slope and soil type conditions as similar as possible. Conditions of accessibility and permission by the landowners were checked on field, and only 11 catchments remained. The no-native forest areas were occupied by eucalyptus plantations with a maximum possible margin of 6% for other land uses. Three catchments with more than 97% of native forest coverage represent the best conditions of the land cover capacity of ESw provisioning. In addition, we investigated the morphologic characteristics of each catchment (soil type, slope, drainage density, road density, and approximate ages).

ESw and Water Quality parameters selection

We selected seven ecosystem services (Table 1) following the systematic literature review made by HACKBART (2016), which links the provision, regulation and cultural ESw with water quality indexes, by combining several WQp related to the maintenance of the service itself (Table 2). The parameters measured were: pH (pH); EC (µg/cm²): conductivity; TDS (ppm): total dissolved solids; TSS (mg/L): total suspended solids; Turb (NTU): turbidity; DO (ppm): dissolved oxygen; T (ºC): temperature; COLF (CFU/10ml): fecal coliforms; COLT (CFU/10ml): total coliforms; NH_4 (µg/L): ammoniacal nitrogen; NO_2 (µg/L): nitrite; NO_3 (µg/L): nitrate; P (µg/L): total phosphorus. In order to adjust the chemical parameters concentrations, we also measured the streamflow (Q L/s).

Table 1 - Classification of ESw based on TEEB (2008); modified from HACKBART, 2016.

Category	Basis	ESw	Description
ESw provisioning	Includes all ecosystem products intended for direct human use, such as food and energy, which may be placed on the market, consumed or directly used.	Fishing	The ability to contribute to the presence of river fish through the water quality natural maintenance.
ESw regulation	Benefits acquired from nature due to the regulation of natural processes	Water for human use	The ability to provide water quality for different human uses, such as domestic or industrial, not necessarily drinkable water.
		Agriculture	The ability to provide quality water for agricultural production.
		Drinking water	The capacity of water purification, of maintaining a quality condition that allows human consumption.
		Erosion control	The control of suspended materials in the water due to the surrounding erosion that interferes directly with water quality.
		Disease	The capacity to control disease

		control	transmission.
ESw cultural	Intangible benefits that people acquire from ecosystems in the form of spiritual, religious, contemplative and educational experiences	Recreational purposes	The ability to provide conditions for direct and prolonged contact with water.

We collected water samples in each stream following water-preservation protocol every two months for seven times, from December 2017 to December 2018. The separation of field samples into dry or rainy hydroperiods was made based on daily precipitation official bulletins from two different pluviometers close to all sampling spots. All parameters needed as input for calculation of the seven ESw were measured, leading to 938 gross data (SM-10). Streamflow measurements were obtained by the float method (PALHARES et al., 2007), and the mean-section method (British Standard, 2007). Details for the procedures of data collection, sampling and water analysis can be checked on supplementary material 2. All water bodies belong to the same class according to the national classification, specified as class 1 (BRASIL, 2005).

Table 2: Water parameters detected by HACKBART, 2016 as indicators of ESw described below. Cells marked with an "x" indicate combination of parameters that were used to calculate the ESw.

Classified as	ESw	T	pH	EC	DO	TDS	COLF	COLT	TS	TURB	P	NO2	NO3	NH4	References for WQp HACKBART, 2016
Provisioning	Fishing	**x**	**x**	**x**	**x**			**x**		**x**		**x**	**x**	**x**	Bascarón, 1979; Koçer & Sevgili 2014; Xu *et. al.* 2010; Sutadian *et. al.* 2016
Regulation - Maintenance	Human use water		**x**	**x**	**x**	**x**	**X**	**x**	**x**	**x**	**x**			**x**	Mojahedi & Attari, 2009; Sutadian *et. al.* 2016
	Agriculture	**x**	**x**		**x**	**x**	**X**		**x**	**x**					Xu *et. al.* 2010; Sutadian *et al.* 2016
	Potable water	**x**	**x**		**x**	**x**	**X**		**x**	**x**			**x**	**x**	Mojahedi & Attari, 2009; Sutadian *et. al.* 2016
	Run-off control			**x**	**x**	**x**			**x**	**x**					Sutadian *et. al.* 2016
	Disease control		**x**	**x**	**x**	**x**		**x**		**x**	**x**	**x**	**x**	**x**	Avigliano & Schenone 2016
Cultural	Recreational	**x**			**x**	**x**	**X**		**x**	**x**		**x**			Nemerow & Sumitomo 1970; Sutadian *et. al.* 2016

Data analysis and ESw estimate

Overview

A previous evaluation was carried out to identify the behavior of acquired data to annual, drier and rainy hydroperiod (details in SM-3). We tracked and removed outliers from total sample and established the WQ parameters that best suited to variations in native forest quantity. In this regard, data were normalized per variables using the Z-score method (values from 0 to 1). The Mardia's multivariate normality test (KORKMAZ; et al, 2019) was applied (SM-4). The outliers were verified by the coefficient of variation (>3 times the coefficient) of the annual average values, and for dry and rainy hydroperiods. The outliers were replaced with the average attribute value to avoid abnormalities in data distribution and avoid interfering in the interpretation of the statistical tests and results (GOTTELI, 2009). Simple regression analysis was applied to identify trends in parameters that presented a significant relation to the amounts of natural forests. Second-degree polynomial functions were applied, since they were able to improve the representation of the complexity in WQp (GOTTELI, 2009). We also verified the behavior of the coefficients of variation along the gradient, once the increase on variation may indicate impacts over WQp.

Estimate of ESw

Our study approach was to identify seven ESw as a response of combined WQp. Researchers who have built up water quality indices for individual or global actions/activities defined them as simple sums of specifics parameters, most of them using the normalized data (ABBASI; ABBASI, 2011, 2012). We decided for Random Forest hierarchical method (BREIMAN, 2001) - efficient in working non-linear data and able to relate parameters of different natures - to develop indexes that consider the relative contribution of each parameter for a specific ESw, in an expression of landscape forest quantity.

To develop the index for each one of the seven water services ($ESwI_i$), the normalized parameters for each quality condition (wpq_i) were multiplied by the respective relevance values (*rvi*) identified by Random Forest and then formulated by the simple summation, according to Table SM-1 and Equation 1.

$$ESwI_i = \sum(wpq_i \times rv_i) \qquad (1)$$

In order to compare the indices of the seven services, we converted all $ESwI$ in a series of 0–100 by Equation 2, where $ESwIi_{0,100}$ represents the distributed values on a scale of 0 to 100; y_{max} refers to the maximum possible value assigned to $ESwI$ on a scale; y_{min} refers to the minimum possible value assigned to $ESwI$ on a scale (0,1); x_n is the value of $ESwI_i$ obtained for each landscape by equation 1; x_{min} is the minimum value of $ESwI_i$ among all landscapes; and x_{max} is the maximum value of a $ESwI_i$ among all landscapes.

$$ESwI_{0,100} = \frac{[(y_{max}-y_{min})-(x_n*100)]}{\left[(y_{max}-y_{min})-\left(\frac{x_{min}*100}{x_{max}}\right)\right]}100 \qquad (2)$$

We applied the Piece-Wise model to evaluate the relationship between ESw and forest cover, to validate the occurrence of thresholds throughout possible breakpoints (TOMS, LESPERANCE 2003). Statistical analyses and graphs were built in R software 3.5.2 and Matlab 2017a (R Development Core Team, 2013; MathWorks, 2017).

RESULTS

The eleven low-order catchments selected were mapped for LULC compositions, and are presented in Figure 2, with more details in SM 1. Six catchments resulted in <31% coverage of native forests, two settled between 45% and 55%, and three resulted in >97% preserved native forests, taken as our reference for ESw supply (Figure 2). We noticed that natural forest coverage distribution along the landscapes follows similar patterns within all catchments we sampled, as vegetation components of "*cerradão*"/ semideciduos forests usually covers higher and drier areas rather than the riverside. Most land covers were taken by plantations while smaller zones alongside the streams are protected, concentrating most sampling spots below 30% natural forest coverage. Intermediate situations of more than 45% natural forest coverage could be found when the relief restrains or make plantations unaffordable, which isn't the case for most landscapes in this area (SM-1). Intermediate situations such as 55% or more could also be found within the vicinities of protected areas. Drainage densities were considered regular (CARVALHO, SILVA, 2006), and ranged from 0.73 (B21) to 1.45 (B99) km/km², with mild slope (SM-1). Road densities ranged from 3.4 (B99) to 55.5 (B21) m/ha (SM-1), most eucalyptus plantations were considered densities of regular / high pressure, while preserved areas had low pressure of road density (PRADO, 2015).

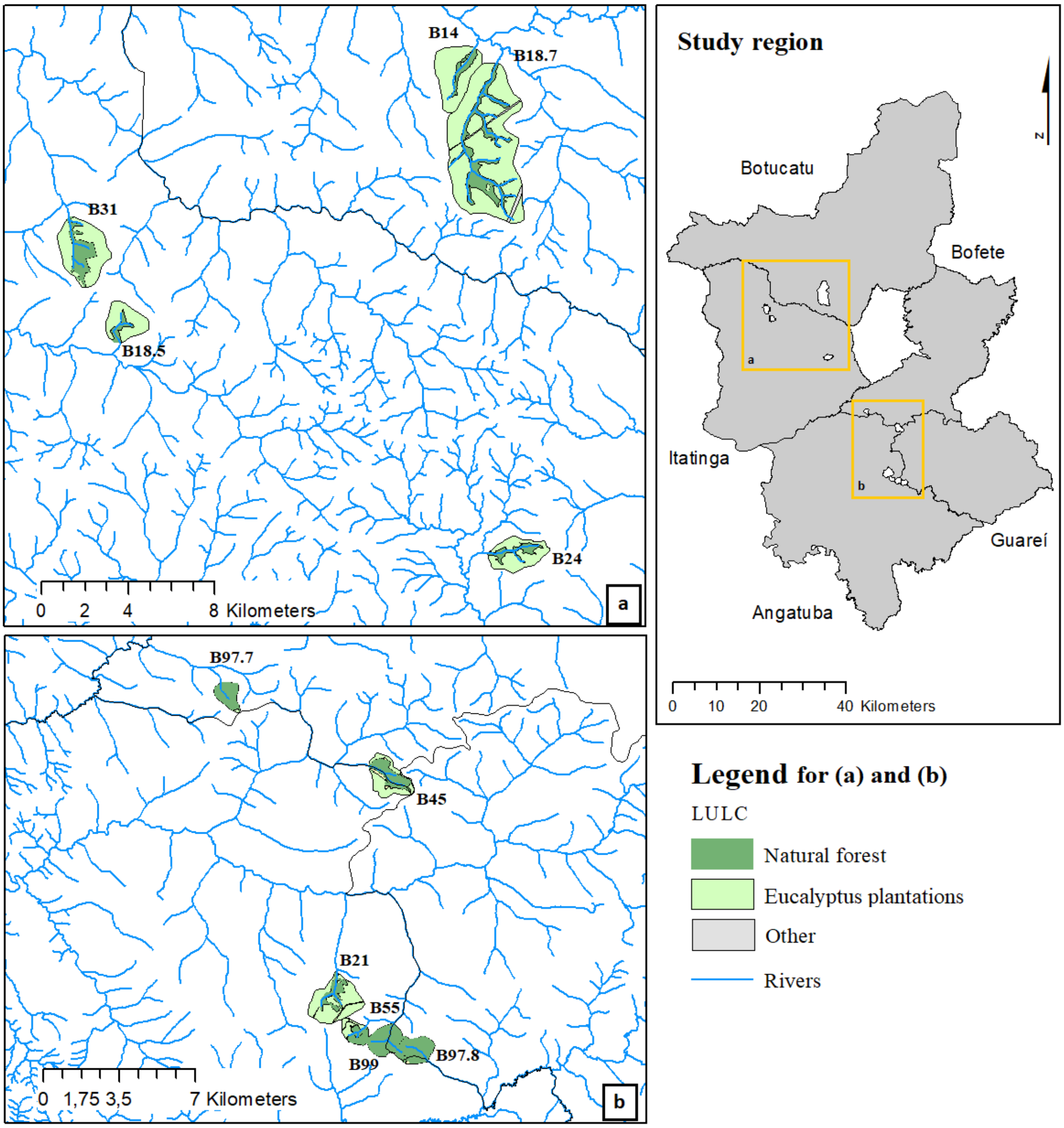
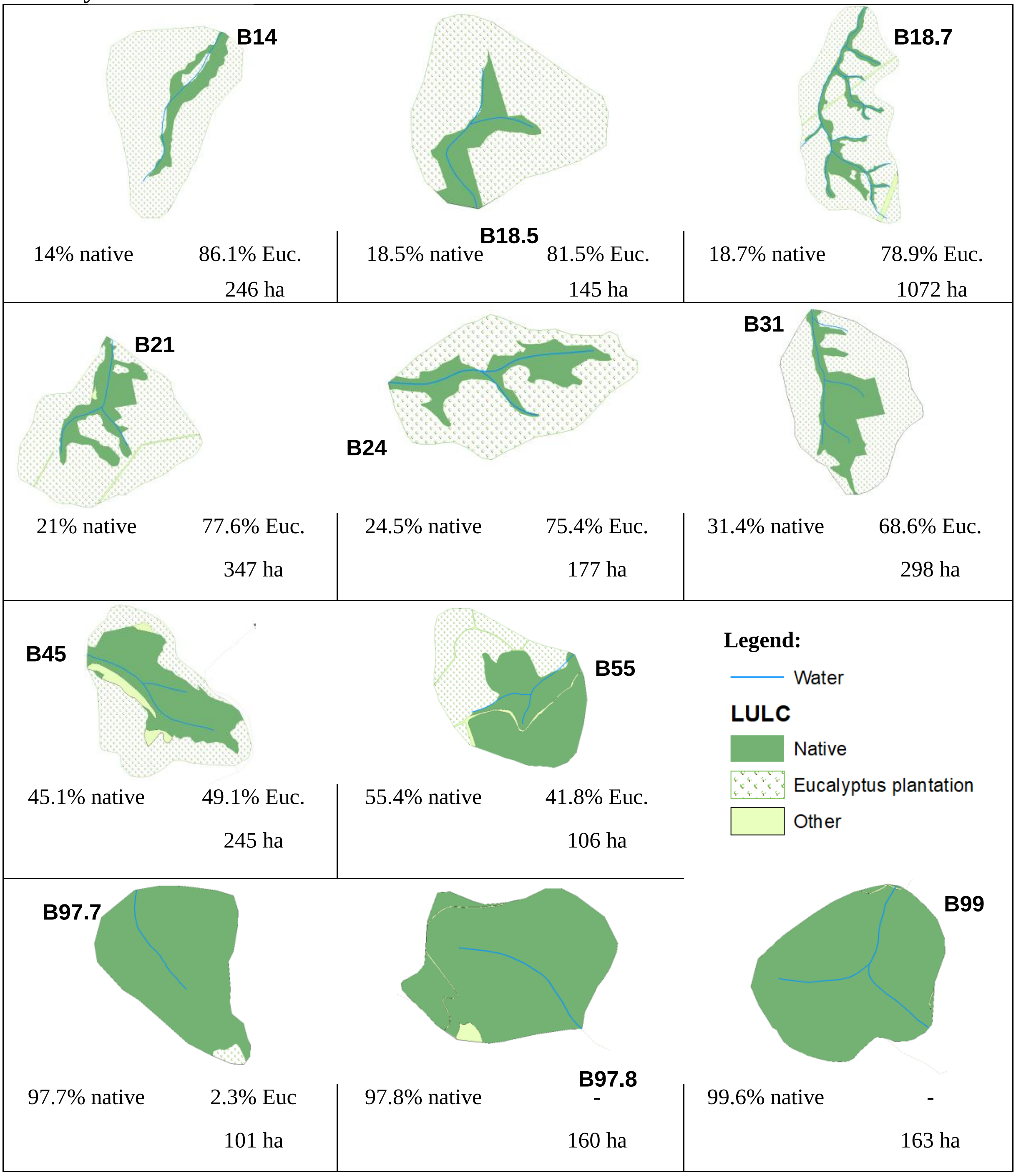


Figure 2 – LULC mapping for all catchments and their location in the study region zoomed in (a) and (b) for closer details. See more in SM 1.

Catchments' were surrounded by either eucalyptus plantations or natural forests only, not facing other land use changes nearby.

Table 3– Details of LULC mapping for each of the 11 catchments; percentage of native forest, of eucalyptus plantation, and total area (ha). All native remaining patches are >34 years old.

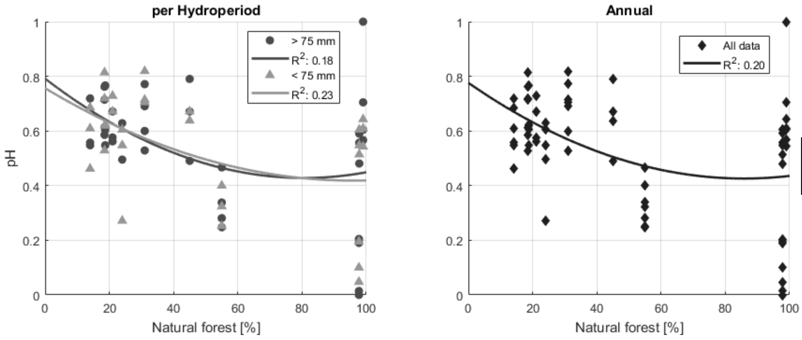


Behavior of WQp according to Native Forest percentage

Statistic results regarding normality and homoskedasticity of data obtained from monitored WQp can be found in SM-4, for annual, rainy and drier hydroperiods. The majority of our data had non-normal distributions and resulted in no multivariate normality, as expected (VON SPERLING, 2014; SCHMALZ et al. 2016). For that reason, we proceeded with non-parametric tests to investigate differences between the hydroperiods. Kruskal-Wallis test showed that the majority of WQp had no significant differences regarding the hydroperiods. Statistical multivariate differences between the hydroperiods were tested by ANOSIM non-parametric test. Disparities over hydroperiods were very low.

The pH showed a similar range along the gradient, but B55 and B97.7 presented lower measurements in general, EC and TDS presented higher values for B14 and B18.5, as well as B99 (SM-5). TSS and Turb data presented wider range for natural forest coverage below 20% (SM-5, Figure 3). DO and Temperature presented scattered data (SM-6). Coliforms had very low counting, if present at all, COLT presence in water was more frequent than COLF (SM-10). Nitrogen series showed very low discharge. NH_4, and NO_2 were frequently below detection limits. NO_3 presented slightly higher values in B99; and P was detected in all landscapes, but presented higher values in B14 and B99.

We identified trends throughout the gradient, even though the regressions for WQp showed $R^2 < 0.5$ (Figure 3; SM-6). In general, Turb, TSS, pH, EC and TDS showed negative tendencies in response to the increase in native forest (Figure 3). Among this group of variables, Turb and TSS are likely to be most appropriate to reflect the forest quantity in stream water, at least for this region.



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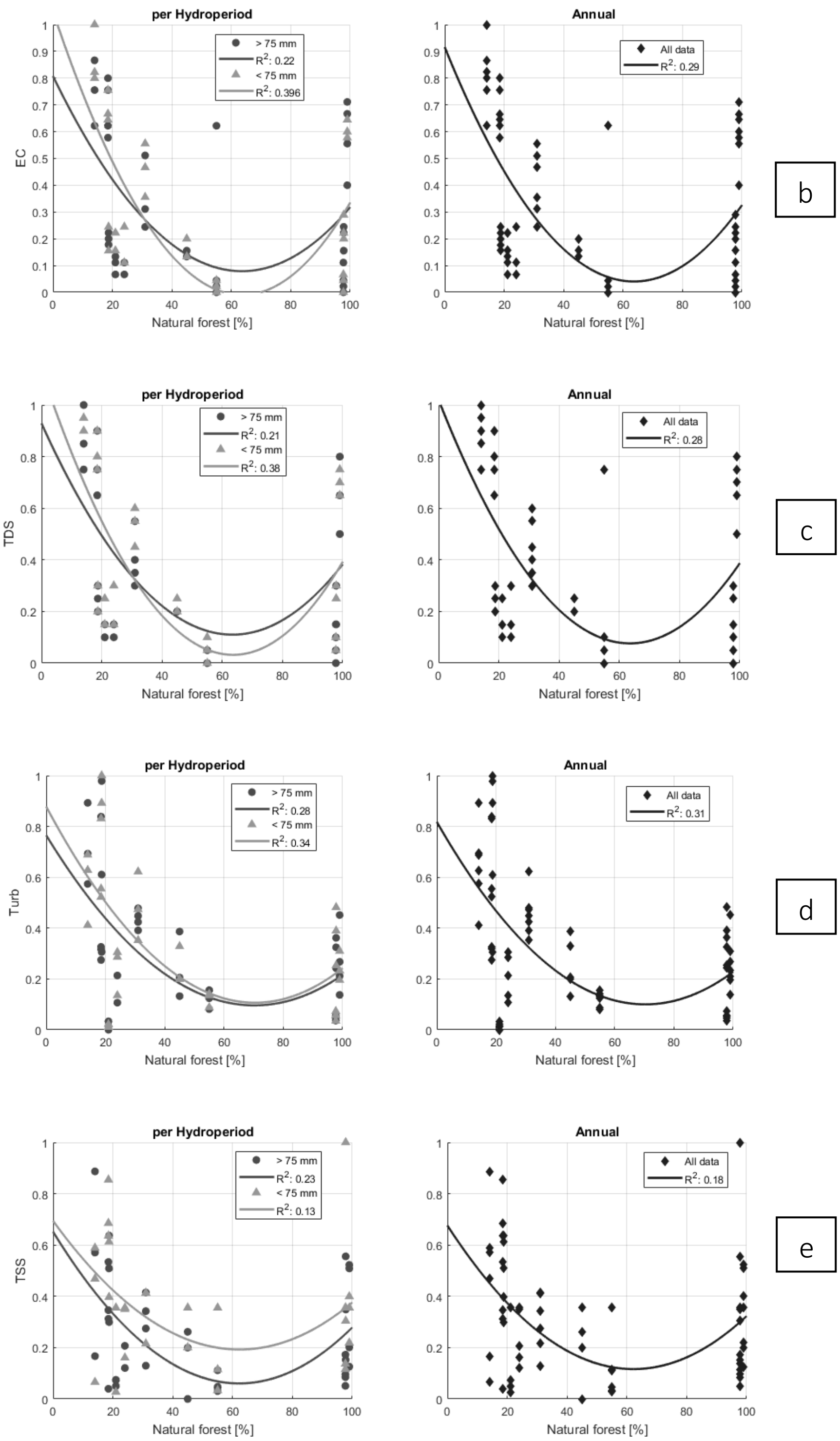

Figure 3 – Trendlines for most significant parameters (a) Turb (b) TSS (c) pH (d) EC (e) TDS

Regarding the coefficient of variation (CV), higher amplitude and asymmetry were observed in landscapes between 14 and 31% of natural forest, for Turb, TDS and EC (Figure 3).

The separation of hydroperiod showed higher fit during the drier hydroperiod for seven parameters (pH, EC, TDS, 1-DO, COLT, TURB and P). While this separation for the coefficients of variation also indicated that four parameters had a higher fit during the drier hydroperiod (EC, TDS, COLT and TSS), while two (NO3 and P), during the rainy hydroperiod.

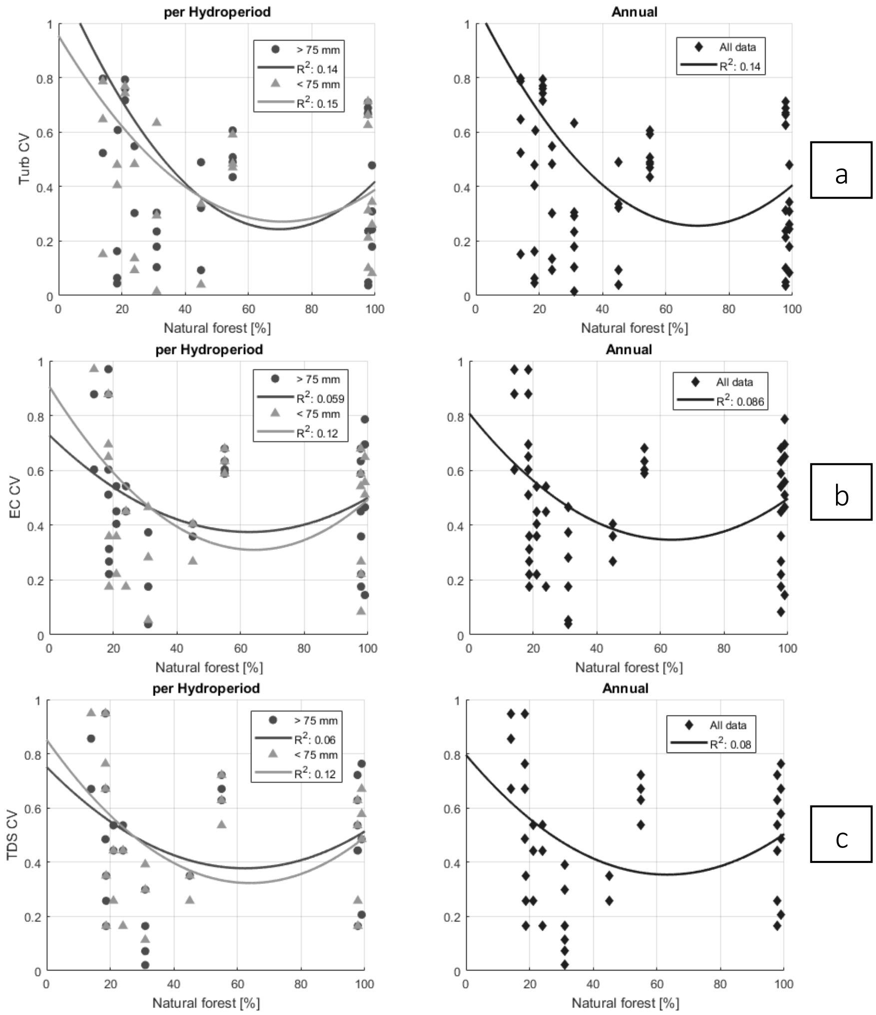

Figure 4 - Trendlines for the coefficients of variation along the gradient of natural forest for (a) Turby (b) EC and (c) TDS.

The boxplots and trendlines were able to show that B99 had different behavior when compared to the other preserved landscapes, giving us the hint that it could possibly be responding to other characteristics rather than the percentage of natural forests.

As new tecnologies are developed, we expect the expansion of eucalyptus plantations into areas now taken by natural forests (MMA, 2015), which will likely develop into landscapes with no more than 50% natural forest coverage. Due to this expectation, we applied the simple linear regression into our data up to 55% natural forest coverage. We can easily check that for this spectrum, seven measured parameters presented the best response to the increase in natural forests (SM-7).

ESw supply and the increase in natural forest coverage

From all WQp that entered Random Forest algorithm (Table 1) to estimate each of the seven ESw, Turbidity (rvι = 1) and pH (rvι >0.9) showed the highest values of impact along cumulative presence of natural forests. These results accompanied trends detected by simple regressions (Figure 2). NO3 (rvι > 0.7) presented high impact values for two ESw, followed by P (rvι > 0.65).

The indices to seven ESw calculated by equation (1) are presented in SM-8. Trendlines for the ESw display service gains as natural forest percentage increases in the landscape, in all cases. B99 presented results of ESw supply lower than other preserved landscapes. It’s likely that its behavior brings information about specific conditions other than the percentage of native forests itself. These specificities might cause very particular WQp values not comparable to the other samples obtained in this study, for that reason, we chose to investigate the total ESw supply (SM-9) with all samples and also a reduced sample (Figure 5), removing B99 to better understand general trends on ecosystem services. Mean values of the preserved landscapes were used as reference for best ESw supply conditions. Trendlines showed higher fit for the reduced sample (SM 9).

Table 4 - Random Forest for seven ESw, considering different combinations of relevant WQp. rvι: relevance factors (normalized scores) obtained through the relation between percentage of forest and WQp.

Erosion control		Agriculture		Recreation		Drinking water		Fishing		Direct human use		Disease control	
WQp	rvι	WQp	rvι	WQp	Rvι	WQp	Rvι	WQp	rvι	WQp	rvι	WQp	rvι
Turb	1.00	Turb	1.00	Turb	1.00	Turb	1.00	Turb	1.00	Turb	1.00	Turb	1.00
EC	0.59	pH	0.90	TDS	0.51	pH	0.97	pH	0.95	pH	0.95	pH	0.94
DO	0.51	TDS	0.54	DO	0.48	NO3	0.75	NO3	0.74	P	0.75	P	0.66
TDS	0.50	DO	0.46	TSS	0.47	TDS	0.54	EC	0.62	EC	0.62	NO3	0.63
TSS	0.45	TSS	0.46	T	0.33	OD	0.46	DO	0.44	TDS	0.53	EC	0.60
		T	0.30	NO2	0.23	TSS	0.42	T	0.32	DO	0.43	TDS	0.52
		COLF	0.16	COLF	0.17	TgC	0.31	NO2	0.27	TSS	0.42	OD	0.44
						NH4	0.23	NH4	0.23	COLT	0.24	NO2	0.24
						COLF	0.16	COLT	0.23	NH4	0.21	COLT	0.22
										COLF	0.17	NH4	0.20

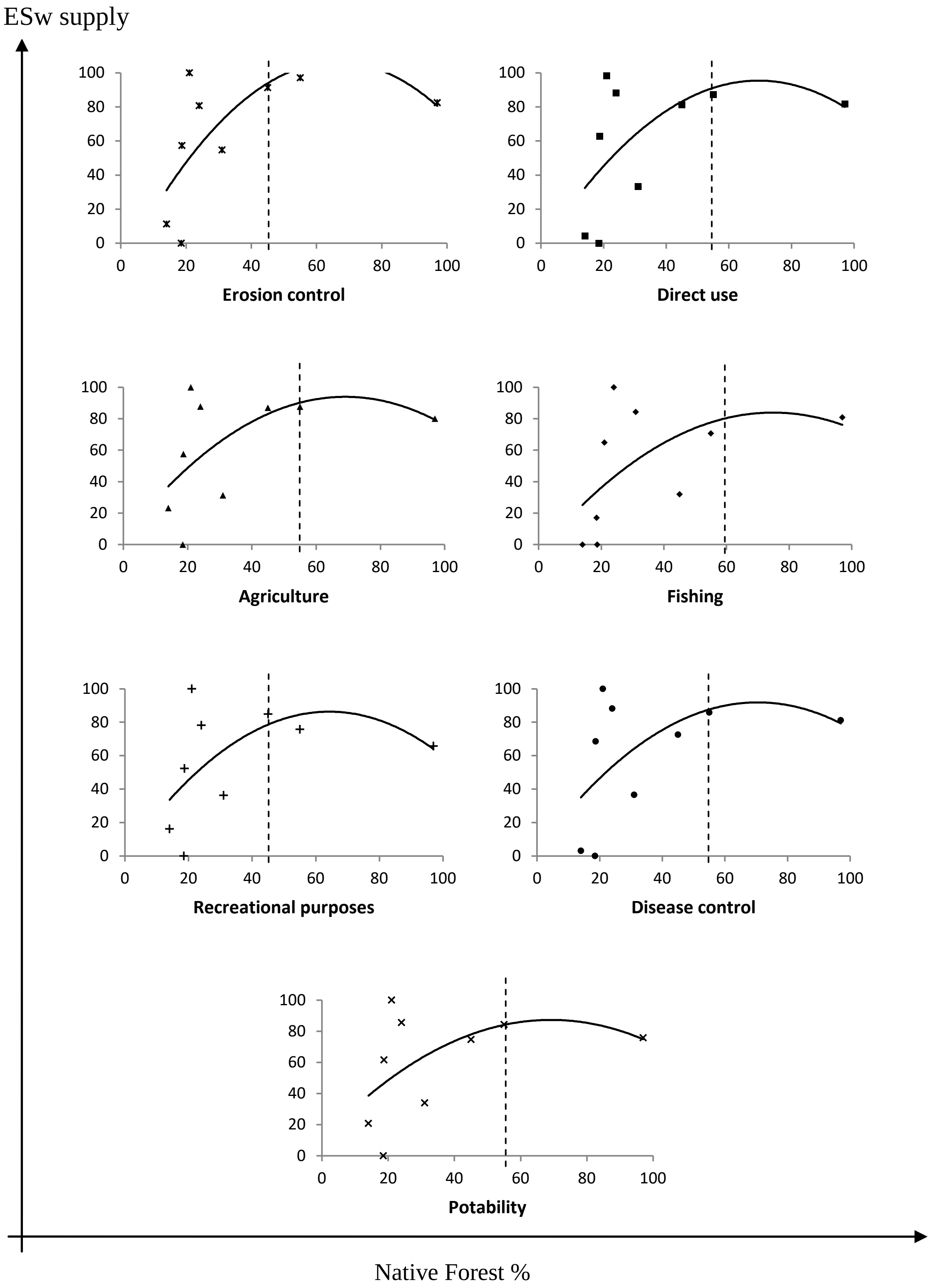

Figure 5– Trendlines of ESw supply x Native forests (%). Reduced sample. Dashed lines indicate potential changes in the ESw provision trend.

Trendlines indicate that all ESw provisioning increased with the percentage of natural forests, Erosion control presented the best fit (R^2=0.45), followed by Direct Use (R^2=0.31), Agriculture (R^2=0.28), Fishing (R^2=0.27), Recreational purposes (R^2=0.27), Disease control (R^2=0.26) and Potability (R^2=0.23). The quadratic regressions indicated that ESw supply for landscapes of lower natural forest percentages becomes more unstable. At situations of less than 40% - 55% natural forest, the curves presented the sharpest angle, indicating a quick loss in ESw supply.

In order to assess landscape provision capability for all seven ESw summed, we generated the trendline for the reduced sample (Figure 5), resulting in general increase in ESw supply along the gradient (R^2= 0.29).

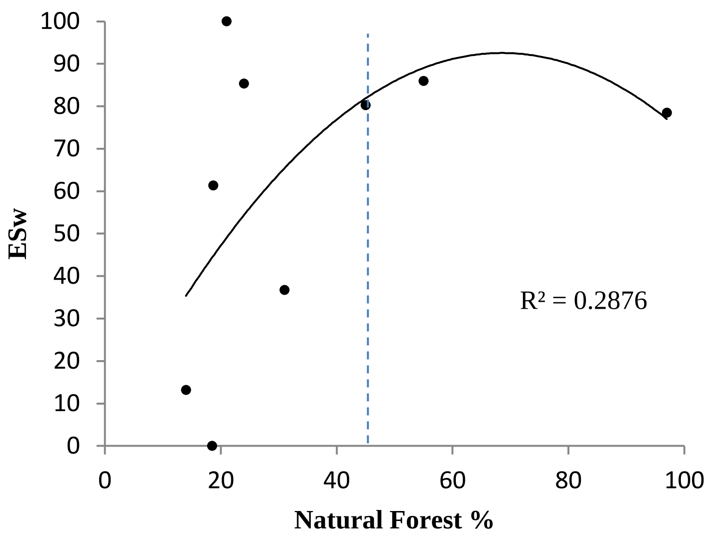

Figure 6 –Trendlines for summed ESw indexes normalized into ESw supply (reduced sampling). Dashed line indicates potential changes in ESw provision.

Once the ESw results presented normal distribution detected by Shapiro-Wilk test (SM-4), we proceeded with the Piece-Wise model to estimate the presence of potential breakpoints in ESw supply depending on quantity of natural forest coverage, in order to define possible thresholds. The threshold was estimated between 14 and 31% natural forest coverage, with one breakpoint at 20% (R^2= 0.5; Adjusted R^2 = 0.21). It is crucial to point out that the reduction to only 20% of natural forest leads to fast decrease in ESw supply (Figure 6).

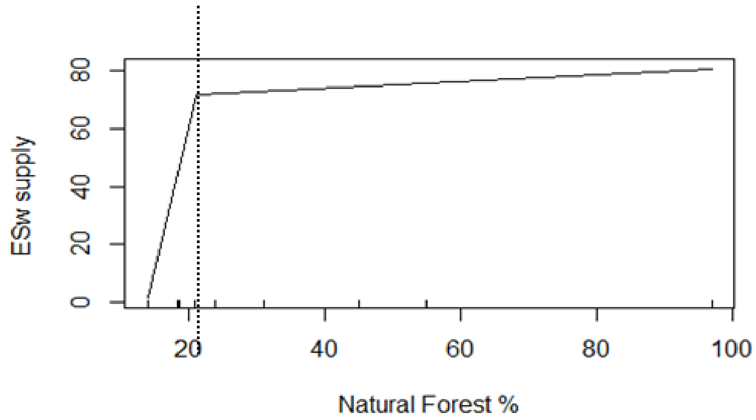

Figure 7 - Piece-wise model for ESw in relation to the percentage of forest cover. The vertical line highlights estimated threshold value.

DISCUSSION

We analyzed thirteen WQp in stream water assuming that measurements are related to native forest quantities of low-order catchments, thus, that their combinations with eucalyptus plantations are fair representations of ESw supply in these landscapes (HACKBART, 2016). When observed individually (Figure 2), we detected that Turb, TSS, pH, EC and TDS showed higher contribution to the detection of stream quality related to native forest coverage. Similar results on the importance of Turb, TSS, EC and TDS for landscapes of native forests and eucalyptus plantations were also identified by HACKBART (2016), in the Atlantic Forests. In addition, MOSCA (2008) detected increase in values of Turb and EC for two low-order streams, due to harvesting event in a short rotation eucalyptus plantation. CASSIANO, 2017 evaluated two low-order catchments with eucalyptus plantations of 39% natural forest coverage (M2) in comparison to a 12.5% natural coverage condition (M3). Her results showed that turbidity levels were lower for M2, and TSS results were two times smaller in M2, most likely due to the presence of larger preserved area, indicating possible benefits acquired by the larger percentage of riparian forests. All findings allowed us to indicate that these WQp can bring important information regarding the response to increase in natural forest coverage, as well as eucalyptus plantations impacts on water resources. Regarding other land uses, several studies have investigated the effects of land-use conversion as a key factor on ecohydrological processes and water quality changes. TDS and Turbidity are also usual referral parameters (AMIRI, NAKANE 2009; DING et al., 2016; Sutadian et al. 2016; AVIGLIANO, SCHENONE 2016; CLÉMENT et al. 2017; TANIWAKI et al. 2017; ULLAH et al. 2018; MELLO et al., 2018).

Despite the low discrepancies detected by ANOSIM test, differentiating the hydroperiods allowed us to identify that Turbidity, pH and EC can be informative regardless of rainy/drier periods, thus contributing to general information throughout the year. On the other hand, trendlines and coefficients of variation showed some differences between hydroperiods. The results achieved by HACKBART (2016) for eucalyptus plantations in the Atlantic Forests highlighted significant differences between rainy and dry seasons. Then, it can be recommended monitoring throughout both periods since many studies assume annual values and camouflage the seasonal variability possibly covering-up relevant information (HACKBART, 2016).

Parameters that presented the best relation to natural forest percentage (Turb, TSS, pH, EC and TDS) and also presented higher coefficient of variation in the lower percentages of natural forest coverage (Turb, EC e TDS), are related to the erosion of dissolved particles (EC, TDS, pH), and bigger particles as well (Turb, TSS), which indicates soil loss impacts. These results are fair to the reality of eucalyptus plantations, once soil loss is often pointed as a frequent impact over water resources (Lima et al. 1996, FERRAZ et al., 2007, MOSCA, 2008, Foelkel 2005, CASSIANO, 2017, RODRIGUES, 2017). Crucial events in this regard are the clear cut, due to trucks and heavy machinery transit; the first years after planting or after coppice, once the canopy formation is strictly necessary to soil protection; and the presence of dirt roads to the transport of logs, pointed by several authors as important sediment sources (GARCIA et al., 2003, FERRAZ et al., 2007; MARTINS FILHO, 2014; PRADO, 2015; RODRIGUES, 2017). Its effect can be worsened depending on the positioning of the roads across the watershed relief, and also during the construction of new roads (FERRAZ et al., 2007). From another perspective, the results obtained in our search reassure the role described by some researchers of preserved forests in the protection of low order streams (FERRAZ et al., 2014, CASSIANO, 2017, MELLO et al., 2018, FIQUEPRON; GARCIA; STENGER, 2013), as the increase in forest coverage followed lower values of these important parameters.

The same methodology on ESw supply here presented was applied in the São Paulo State’s forested savannas by Bitencourt (2017), to investigate gains in ESw with the increase in natural forest percentage in face of pasture land use. WQp of high importance ranked by Random Forest in his study were DO, EC, TDS and COLT, and parameters that presented higher linear fit were DO, NH4 and P, suggesting there is higher input of organic matter into stream when compaired to eucalyptus plantations in the same region. Results may differ not only due to land use discrepancies, but as well regarding protected forests position in the landscape: meanwhile eucalyptus plantations may not necessarily gain benefits from planting too close from water streams, cattle owners do prosper from removing riparian vegetation to ease cattle access to water, which may as well contribute to the disparities. FERRAZ et al., 2014 highlight the importance of natural forests configuration within the landscape to assure gains in stream protection. In the work of MELLO et al., 2018, the authors discuss the relative importance of the riparian zones vs watershed LULC in the contribution to water quality parameters. In their results, the riparian forests had a significant role in increasing DO, while, TSS and Turb were linked to the land use at the watershed level. Investigation is still needed to better understand how the position of the preserved forests within the catchments explains WQp and possible impacts over ESw supply.

ESw Provision: Outcomes to Environmental Planning and Management

Low order streams (1st to 3rd orders) contribute to the function, health, and biodiversity of the entire river networks (Vannote et al., 1980), and thus, directly contributing to ESw supply downstream. We conclude that the quality of this contribution may change in catchments below 45% natural forest coverage combined with eucalyptus plantations, while tends to become too unpredictable in situations of less than 20%.

Our results pointed out that the provision of the seven ESw decreased with the percentage of eucalyptus plantations, in all cases. WQp combinations to ESw indexes reflected the relative importance of each parameter in response to the increase in natural forest coverage. It is worth highlighting that erosion control presented the highest R^2 value (0.45) for the quadratic regression, and the combined parameters related to this service were composed by variables that presented higher fit in relation to the increase in natural forests. The productivity of eucalyptus planted forests heavily depends on a healthy water cycle and sustainable management that avoids ecosystem damages at the local scale. Two major stages of management are particularly challenging in this regard: Soil preparation and site harvesting, as well as the presence of dirt roads (GARCIA et al., 2003, Foelkel, 2005, CORRÊA, 2005; FERRAZ et al., 2007). Soil and nutrient loss are the main problems, easily impacting water streams (MARTINS FILHO, 2014). Despite of the diminishment in ESw provision, the plantations in this area do not present correlation as high as detected by HACKBART (2016) for the Atlantic Forests with steep slope.

In general, losses in the seven measured ESw were not as intense as they were for pastures within the same region (Bitencourt, 2017). Studies show that the presence of eucalyptus canopy is crucial in reducing the speed and impact with which the rainfall reaches the soil, decreasing particulate loading into streams, also due to the litter deposition and the presence of woody roots, protecting the soil surface (Foelkel, FERRAZ et al., 2013; MARTINS FILHO, 2014). RANZINI & LIMA (2002) indicate the importance of leaving litter, branches and barks for soil protection. PADILHA et al. (2018), in their study, showed that the eucalyptus trees played an important role in soil protection, regardless of the tillage types they tested. These characteristics added with the mild slope and might enhance the protection of the eucalyptus plantations over soil and nutrient loses in this region.

Studies presented the linkage between landscape increase in natural forest proportions and lower soil losses into streams (CASSIANO, 2017, LITTLE et al., 2015; SWEENEY, NEWBOLD 2014). The provision of ESw could be partially explained by the increase in natural forests, but low R^2 values indicated the complexity of this response, as more factors must also be relevant. Soil types and textures presented some variation within our sampling spots (SM-1), it is expected that soil types are reflected in streamwater parameters values (LIMA et al., 2013). This variation might have diminished the adherence of our model. Increasing the amount of sampling spots may be one way to addresss this issue. RUGGIERO et al., (2002) also highlights that parameters vary depending on the species compositions and structure within the natural forests areas, which might as well explain some of the variation of our data. FERRAZ et al., 2013 emphasizes the importance of the quality and composition of the natural forest patches in ES provision. Future studies on the species composition of the preserved areas in these landscapes might bring important information in this regard.

The trendline for general ESw provision was made to address possible outcomes for decision makes interested in preserving more than one specific service. For the summed seven ESw, provisioning increases along the gradient and the estimated threshold pointed that situations below 20% natural forest coverage tends to lose provision, indicating these landscapes may become too unstable. The pasture landscapes studied by Bitencourt (2017) required at least 50% natural forest preservation in order to maintain 70% of ESw provision. The author points out that less than 20% forest coverage creates circumstances where ESw loses provision, and at this point the catchments can be considered unsustainable. When compared to eucalyptus plantations, the threshold of 20% natural forest coverage presented similar outcomes. Likewise, in the results achieved by HACKBART (2016) regarding the ecosystem services supply, 20% of natural forests preservation were able to ensure good ESw provision at first sight, but harvesting events throughout the whole landscape dropped the ESw provision in landscapes of 20-60% coverage, pushing the threshold up to 70% of preservation needed to ensure ESw supply. These results rise awereness over better management practices in these landscapes.

CONCLUSION

Our results allow us recommending stakeholders to watch for Turbidity, pH and EC as important parameters to monitor water resources in landscapes of eucalyptus plantations, given the results found by the present study as well as supported by other studies. Regarding the ESw supply, our results showed higher correlation between plantation land use and natural forest coverage for the Erosion Control ESw. All services provisions increased with higher percentages of forest cover, endorsing the importance of increasing natural forests percentages within catchments by no less than 20%, if possible keeping 45%, in order to assure the ESw supply by diminishing potential impacts of this land use and instabilities.

Future studies may achieve better outcomes by increase the number of sampling catchments. Colecting data on species composition, structure and quality of preserved forests is also recommended, as an approach to the variability found on WQp, and the varialibity of ESw supply in landscapes with similar percentages of natural forests, potentially increasing the adherence of the model.

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SUPPLEMENTARY MATERIALS

SM - 1: Details of Mapping.

We mapped LULC by visual interpretation, employing up-to-date Google Earth images available and ARCGIS 10.5 *basemap* available. Shapefiles of topography (DEM), soils, and slope data we obtained from Brazilian Institute of Geography and Statistics (IBGE: www.ibge.gov.br), Brazilian Environment Ministry-MMA (http://mapas.mma.gov.br) and National Institute for Space Research - INPE (http://www.dsr.inpe.br/topodata/) (1:50.000). UTM, Datum SIRGAS 2000, zone 23S. The hydrography of the study area was obtained from CETESB (1:25.000). Altimetry data (Shuttle Radar Topography Mission) obtained from the National Institute of Space Research (INPE) (20 meters). First, we considered different types of land use and coverage of the region and identified the protected areas. Most results for land use in the area were related to either pasture, *Eucalyptus*, orange orchards or sugar cane plantations. We proceeded investigating and mapping only eucalyptus plantations for this work.

The catchments were defined according to the Strahler method, based on the hierarchy of the tributaries, considering 2nd and 3rd order. We delimited 51 catchments that included all characteristics related to our goals. All landscapes were visited, in order to check the accessibility to the sites, achieve authorization of land owners to collect and analyze the water samples and assure the possibility to commute and take all samples in a week, so that there would be no disparity of hydro-periods within the same sampling campaign. This procedure resulted in the selection of 11 landscapes, location can be found in Table SM-1.1. For those, we procedded with the investigation of physical characteristics (Table SM-1.3), soil types and other information sources were SMA, 2003, SMA, 2009, GONÇALVES et al., 2012 and SMA, 2017.

Table SM-1. 1- Coordinates for each sampling spot.

Catchment	Latitude	Longitude
B14	22 59,03081996 S	048 31,74150000 W
B18.4	23 04,74665996 S	048 38,61294000 W
B18.7	22 59,32517996 S	048 31,30422000 W
B21	23 23,87909996 S	048 22,68750000 W
B24	23 08,81525996 S	048 31,51590000 W
B31	23 02,28635996 S	048 39,60714000 W

B45	23 17,37293996 S	048 22,62666000 W
B55	23 23,87471996 S	048 22,69470000 W
B97.7	23 16,37459996 S	048 26,26656000 W
B97.8	23 24,76787996 S	048 21,15324000 W
B99	23 23,83331996 S	048 22,01322000 W

Table SM-1. 2: Description of the land uses and forest cover, morphologic characteristics and details regarding the eucalyptus plantations and preserved landscapes.

	Morphological characteristics						Other land uses		Eucalyptus plantations characteristics		
	Soil		Slope	Altitude		Drainage					
Catchment	Predominant soil type	Soil type at the sampling spot	Mean (degrees)	Maximum	Minimum	Density (km/km2)	Grass field	Dirt roads (m/ha)	Age of implantation	Approxim. Euc. ages within the catchment**	Type of mgmt
B14	Red Latosol	Red Latosol + Nitisol	3.4	780	840	0.88	0%	39.6	>34 years	66 months	Coppice
B18.5	Red Latosol	Gleysol	1.2	820	840	1.19	0%	43.3	>34 years	0 - 56 months	Plantation
B18.7	Red Latosol	Red latosol + Nitisol	4.3	780	880	1.40	0.94%	47.3	>34 years	0 - 12 - 42 - 66 months	Coppice
B21	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Latosol + Quartzarenic Neosol	4.5	640	740	**0.73**	0.24%	55.5	>34 years	32 - 51 - 90 months	Coppice
B24	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Argisol	5.6	640	720	1.36	0%	54.9	>34 y.o. Smaller areas planted between 1988 - 2009	0 - 24 - 96 months	Coppice
B31	Red Latosol	Gleysol	3.7	780	840	1.15	0%	46.5	>34 years	0 - 11 - 20 - 56 months	Plantation
B45	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Latosol + Quartzarenic Neosol	5.3	640	720	0.95	5.73%	39.8	>34 y.o. Smaller areas planted between 2008-10	7 - 19 - 39 months	Coppice
B55	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Argisol	4.7	680	740	1.12	0%	25.9	Half >34 y.o. - half between 1994 – 2007	90 months	Plantation
B97.7	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Latosol + Quartzarenic Neosol	4.9	640	720	0.89	0%	3.7	>34 years	32 months	Plantation
B97.8	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Argisol	6.9	660	780	0.78	1.47%	9.6	-	-	-
B99	Red/Yellow Latosol + Quartzarenic Neosol	Red/Yellow Argisol	**10.2**	660	800	1.45	0%	3.4	-	-	-

** The *Eucalyptus* age set as “zero” denotes the presence of harvesting event.

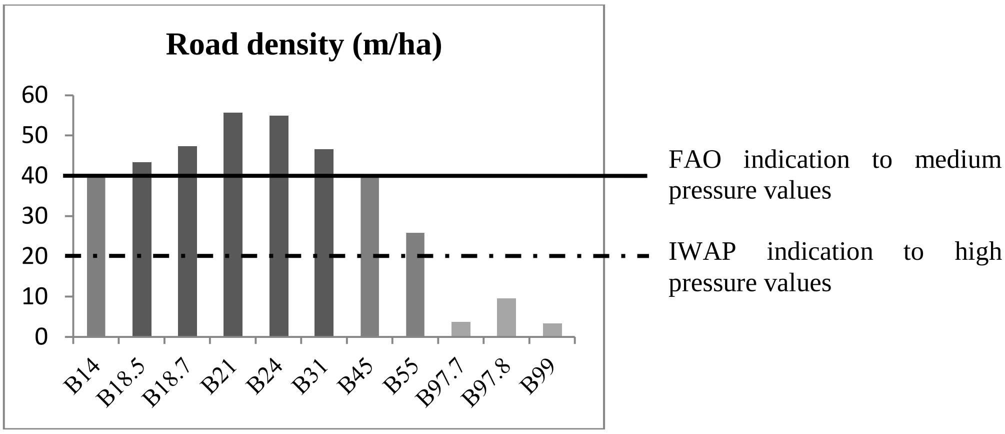


Figure SM-1. 1: Road densities (m/ha) for each sampled catchment. Continuous line shows FAO indications to medium pressure of road density; dashed line shows IWAP indications of high pressure of road densities (PRADO, 2015).

SM - 2: Methods of data collection, sampling and water analysis.

Parameter	Measurement	Methods
Electrical conductivity (EC)	*In situ* - Probe	Hanna HI 98129. Detection limits: 1µS/cm;
pH (pH)		0.01 pH;
Temperature (T)		0.1 °C;
Total Dissolved Solids (TDS)		0.01 ppm
Dissolved oxygen (DO)	*In situ* - Probe	Hanna HI 9146. Det. lim. 0.01 mg/L
Turbidity (TURB)	Same day - Probe	Hanna HI 98703 portable Turbidity meter. Det. lim. 0.01 NTU when <9.9; 0.1 NTU when from 10.0 to 99.9, and 1 NTU when >100
Coliforms – fecal/total (COLF/COLT)	Same day - AlfaKit ColiPaper + portable incubator	Microbiological carts "ColiPaper" will turn COLF colonies into blue dots and COLT into pink dots after 12h inside 35°C incubators
Suspended Solids (TSS)	Same day - 2x2L bottled* samples kept <5°C	Samples filtered with 0.45µm millipore filters (Baumgarten *et.al*. 1996)
Ammonio (NH_4)	3x500ml bottled* samples; H_2SO_4 10% added until pH<2; kept <5°C until analysis	Korroleff (1976)
Nitrite (NO_2)		Mackereth et.al. (1978)
Nitrate (NO_3)		HACH powder pillows Nitriver 3 Nitraver 6 for Cadmium reduction (cf. US EPA, 2011)
Total Phosphorus (P)		Valderrama (1981)
*All water bottles were previously soaped with Extran 1%, washed in purified water, soaked in HCl 10% and then rinsed with purified water. They were dried and kept closed until sampling. On the field, all bottles were rinsed with water from the stream before taking samples. (ANA, 2011)		

SM - 3: Hydroperiods.

Streamflow (Q) measurements were obtained by the float method (PALHARES et al., 2007), and applied to calculate the stream discharge for all nutrients addressed.

Regional rainfall data were obtained from two sources (DAEE; and the Experimental Station of Forest Sciences of Itatinga) close to all sampling spots, to both accumulated monthly rainfall and daily precipitation. No samples were taken on rainy days. We also monitored 3 days-accumulated rainfall before field samples were taken, and only October 2018 (15mm) and December 2018 (6mm) had rainfall events. Historical data (1939 – 2018) were obtained from DAEE, rainy season (October – March) showed mean monthly accumulated rainfall of >75mm, while dry season (April – September), < 75 mm.

When assuring that ESw loss responds to LULC and landscape compositions, we must assume that rainfall will be the main vector to transport sediments and nutrients into the stream, therefore we divided our samples in hydro-periods of more than and less than 75 mm accumulated rainfall, for each month sampled (Figure SM-3).

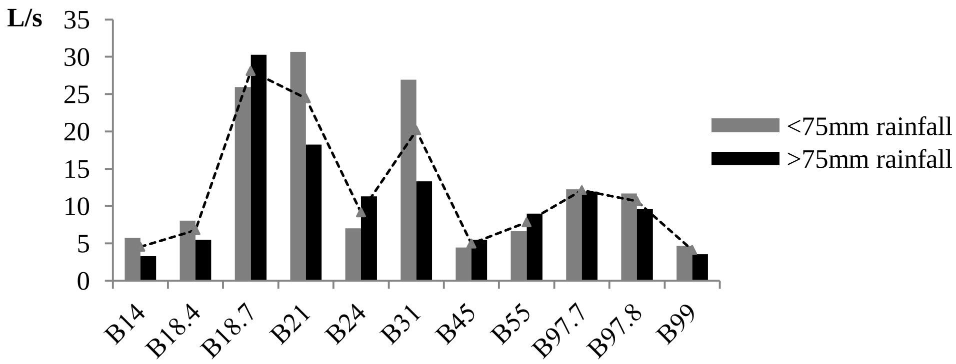


Figure SM-3. 1. Mean values of Q for the hydro-periods <75mm rainfall (orange) and >75mm (blue) rainfall, for each low-order catchment.

SM - 4: Statistics.

Table SM-4. 2. Shapiro-Wilk normality test for each WQp, the majority resulted in non normal distribution. Non-parametric Kruskal-Wallis tests were applied to check if the hydroperiods have significant differences. MARDIA test of multivariate normality was applied and resulted in non-multivariate normality. Non-parametric ANOSIM test was applied to identify multivariate Bray-Curtis dissimilarities between the hydro-periods. The closer to 0 is the R value, the more groups can be considered similar. Dissimilarities were very low.

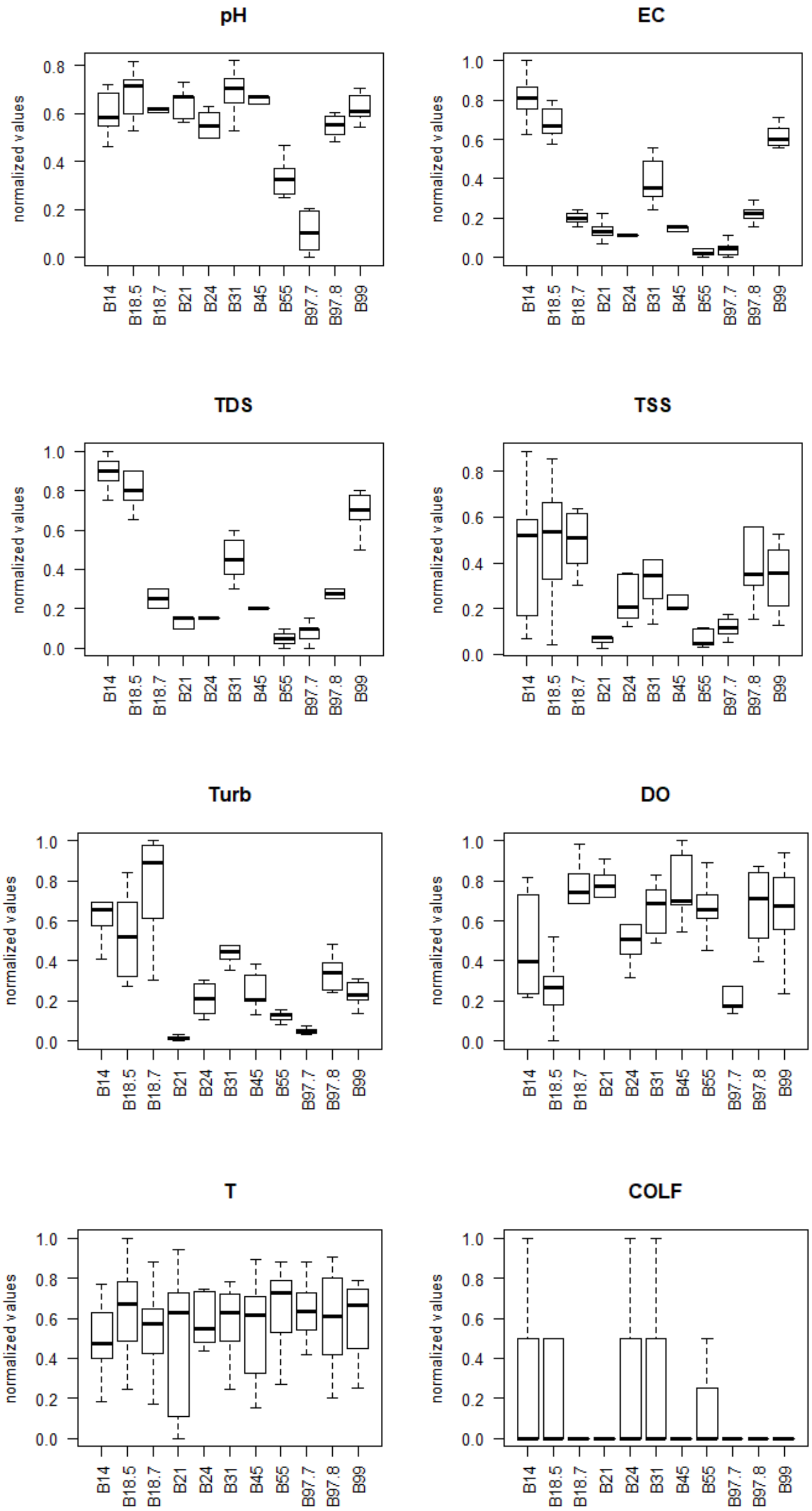
WQp Outliers removed	**Shapiro-Wilk**		**Kruskal-Wallis**	
	Normality?	p-value	Hydro-periods differs?	p-value
pH	NO	0.000269	NO	0.66
EC	NO	$2.5\ 10^{-5}$	NO	0.89
TDS	NO	$1.4\ 10^{-5}$	NO	0.88
T	NO	0.028	NO	0.59
DO	YES	0.053	NO	0.51
COLT	NO	$6.17\ 10^{-7}$	NO	0.27
COLF	NO	$3.8\ 10^{-13}$	YES	0.03
TURB	NO	0.0003	NO	0.47
TSS	NO	0.0007	NO	0.27
NH_4	NO	$3.2\ 10^{-14}$	NO	0.38
NO_2	NO	$1.2\ 10^{-12}$	NO	0.48
NO_3	NO	$3.1\ 10^{-8}$	NO	0.38
P	NO	$1.8\ 10^{-8}$	NO	0.47

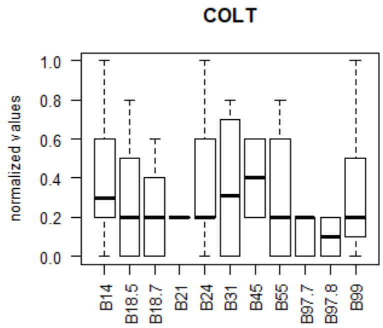
Multivariate normality?			
MARDIA results		**p-value**	**Results**
Mardia Skewness	NO	1046.3	$1.49\ 10^{-48}$
Mardia Kurtosis	NO	7.25	$4.27\ 10^{-13}$
MVN?	**NO**		
Multivariate Hydro-periods differ?			
	R	**Significance**	**Permutations**
ANOSIM results	0,012	0,26	9999

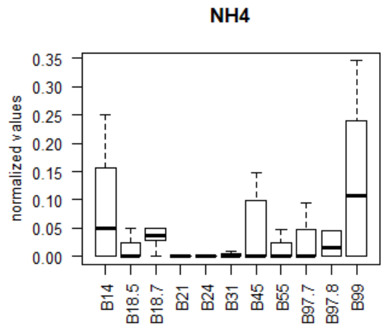
Table SM-4. 3: Shapiro-Wilk statistical results for normality distribution of the normalized ESw indexes: total sample and reduced sample:

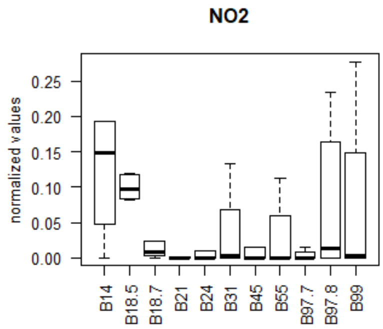
ESw	Total sample P value	Reduced-sample P-value	Normality?
Fishing	0.29	0.26	YES
Direct Use	0.13	0.05	YES
Agriculture	0.26	0.15	YES
Potability	0.41	0.32	YES
Erosion Control	0.09	0.10	YES
Disease Control	0.11	0.08	YES
Recreational Purposes	0.85	0.66	YES
Summed ESw	0.29	0.16	YES

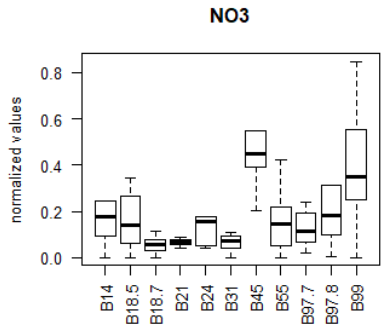
SM - 5: Boxplots**:**

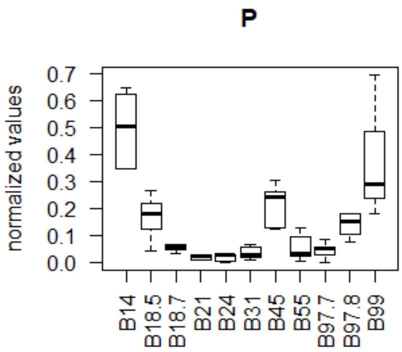



COLT
normalized values
0.0
0.2
0.4
0.6
0.8
1.0
B14 B18.5 B18.7 B21 B24 B31 B45 B55 B97.7 B97.8 B99

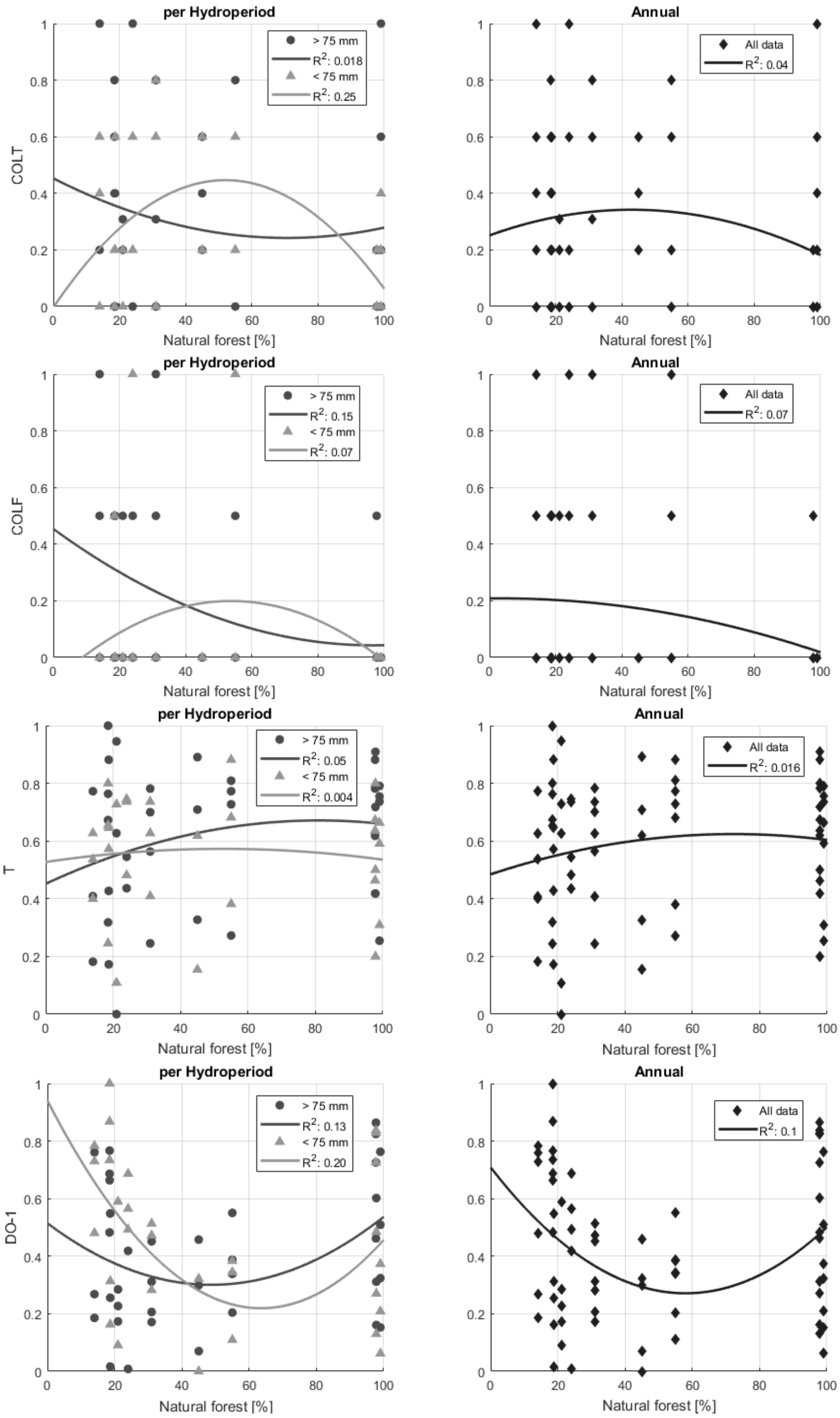

NH4
normalized values
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
B14 B18.5 B18.7 B21 B24 B31 B45 B55 B97.7 B97.8 B99


NO2
normalized values
0.00
0.05
0.10
0.15
0.20
0.25
B14 B18.5 B18.7 B21 B24 B31 B45 B55 B97.7 B97.8 B99


NO3
normalized values
0.0
0.2
0.4
0.6
0.8
B14 B18.5 B18.7 B21 B24 B31 B45 B55 B97.7 B97.8 B99


P
normalized values
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
B14 B18.5 B18.7 B21 B24 B31 B45 B55 B97.7 B97.8 B99

SM - 6: Quadratic regressions.



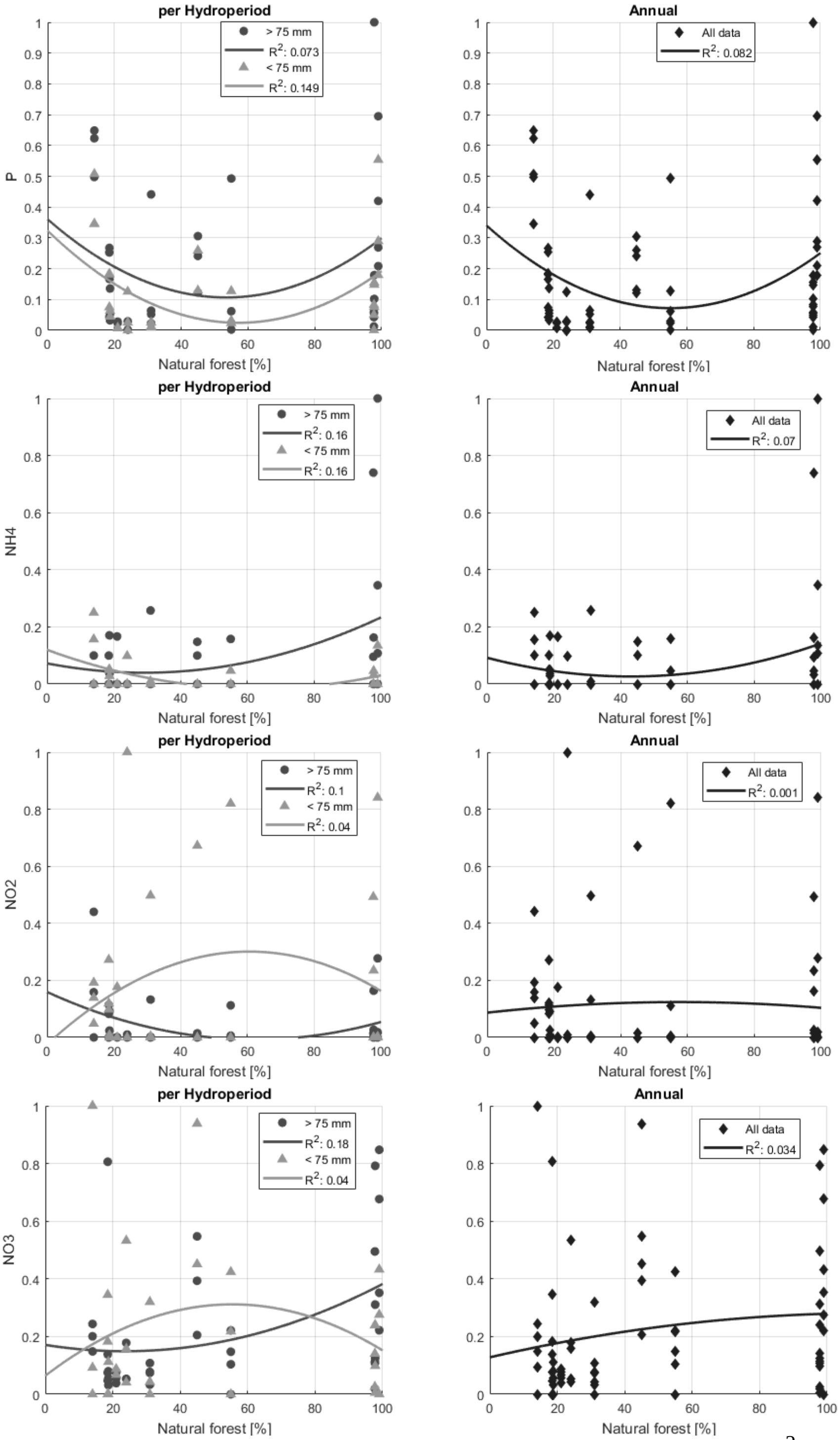
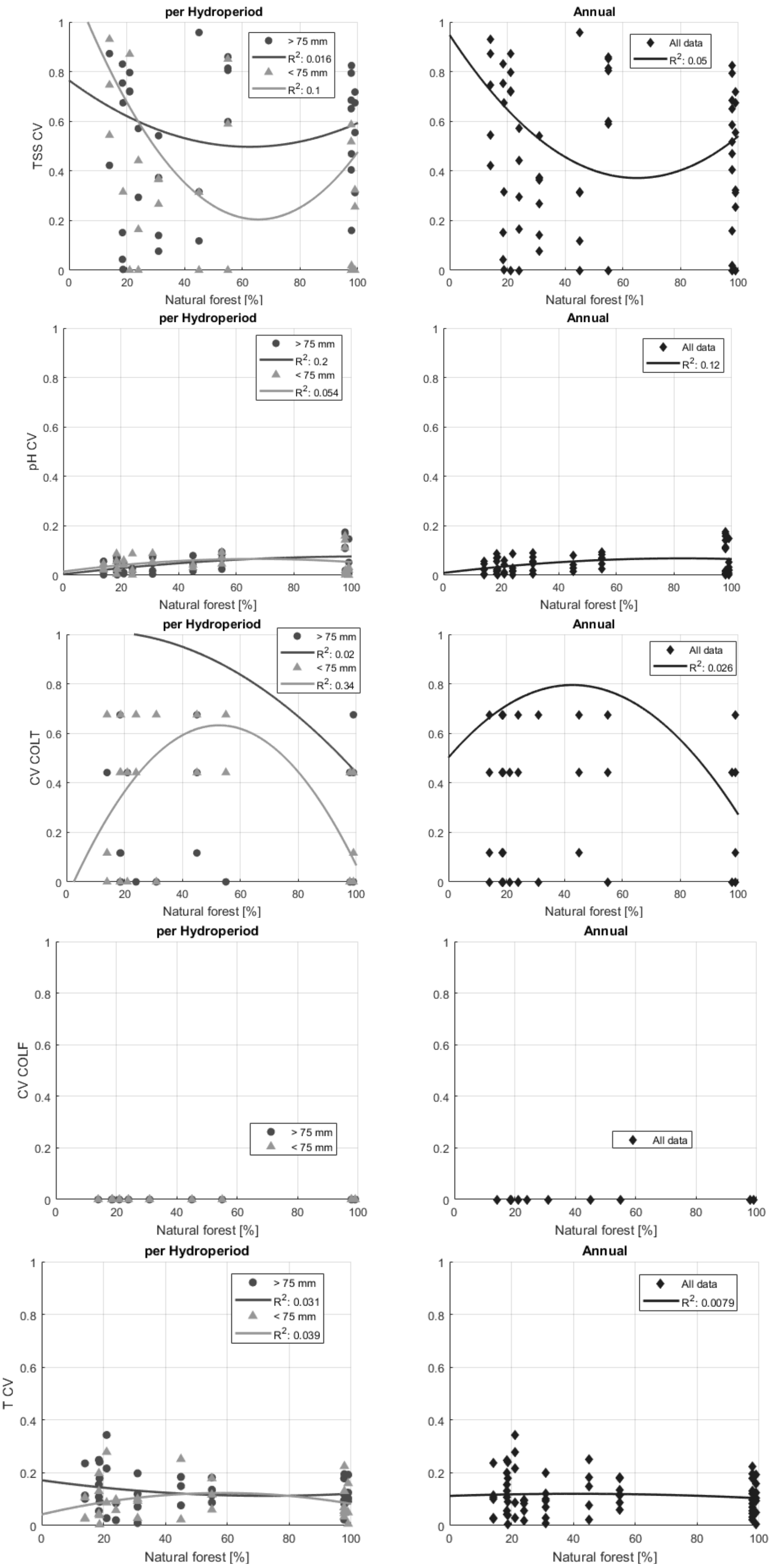


Figure SM-6. 1. Trendlines for WQ parameters that presented lower R^2: annual data, drier (<75mm) and rainy (>75mm) hydroperiods.


per Hydroperiod
Annual
TSS CV
> 75 mm
R2: 0.016
< 75 mm
R2: 0.1
All data
R2: 0.05
pH CV
R2: 0.2
R2: 0.054
R2: 0.12
CV COLT
R2: 0.02
R2: 0.34
R2: 0.026
CV COLF
T CV
R2: 0.031
R2: 0.039
R2: 0.0079
Natural forest [%]

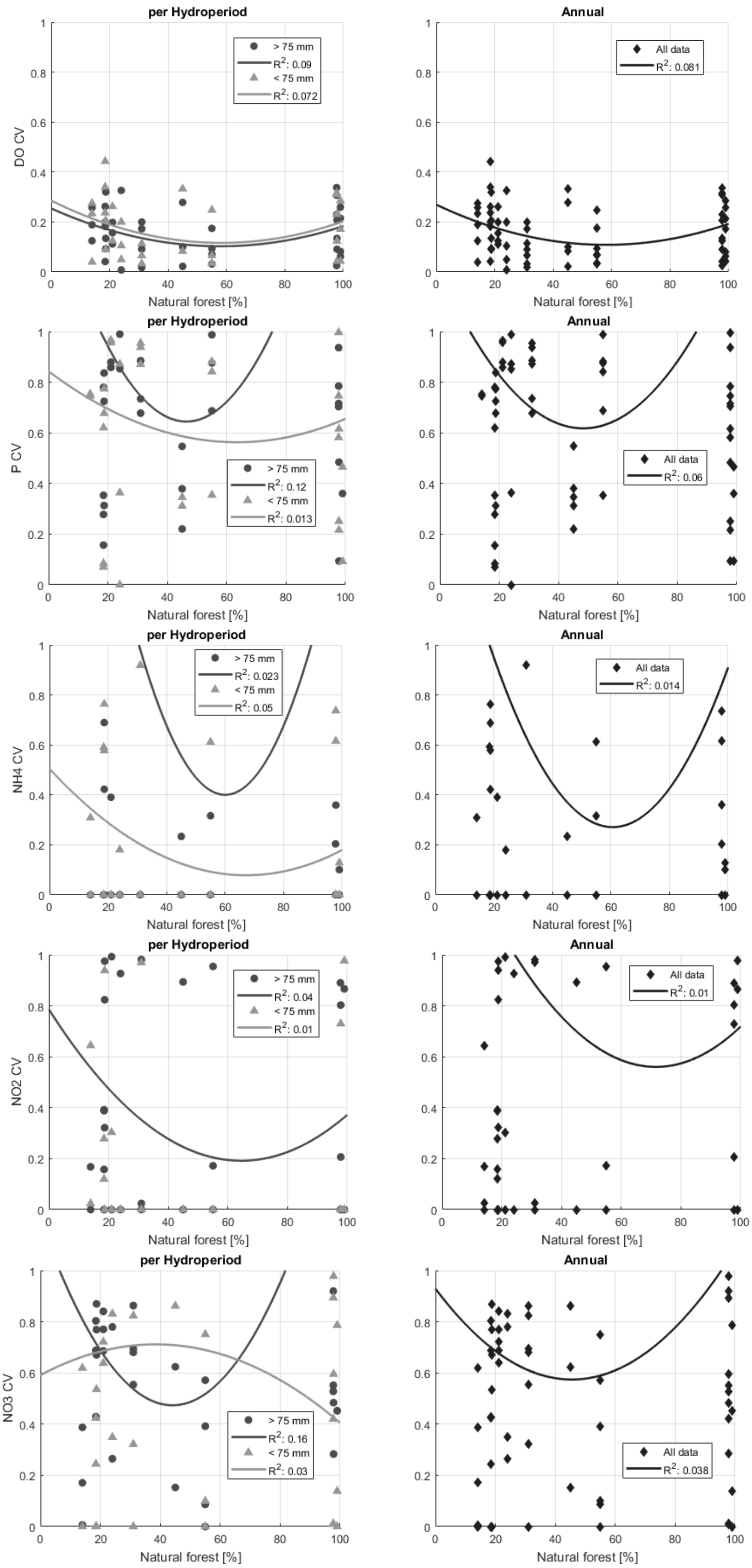
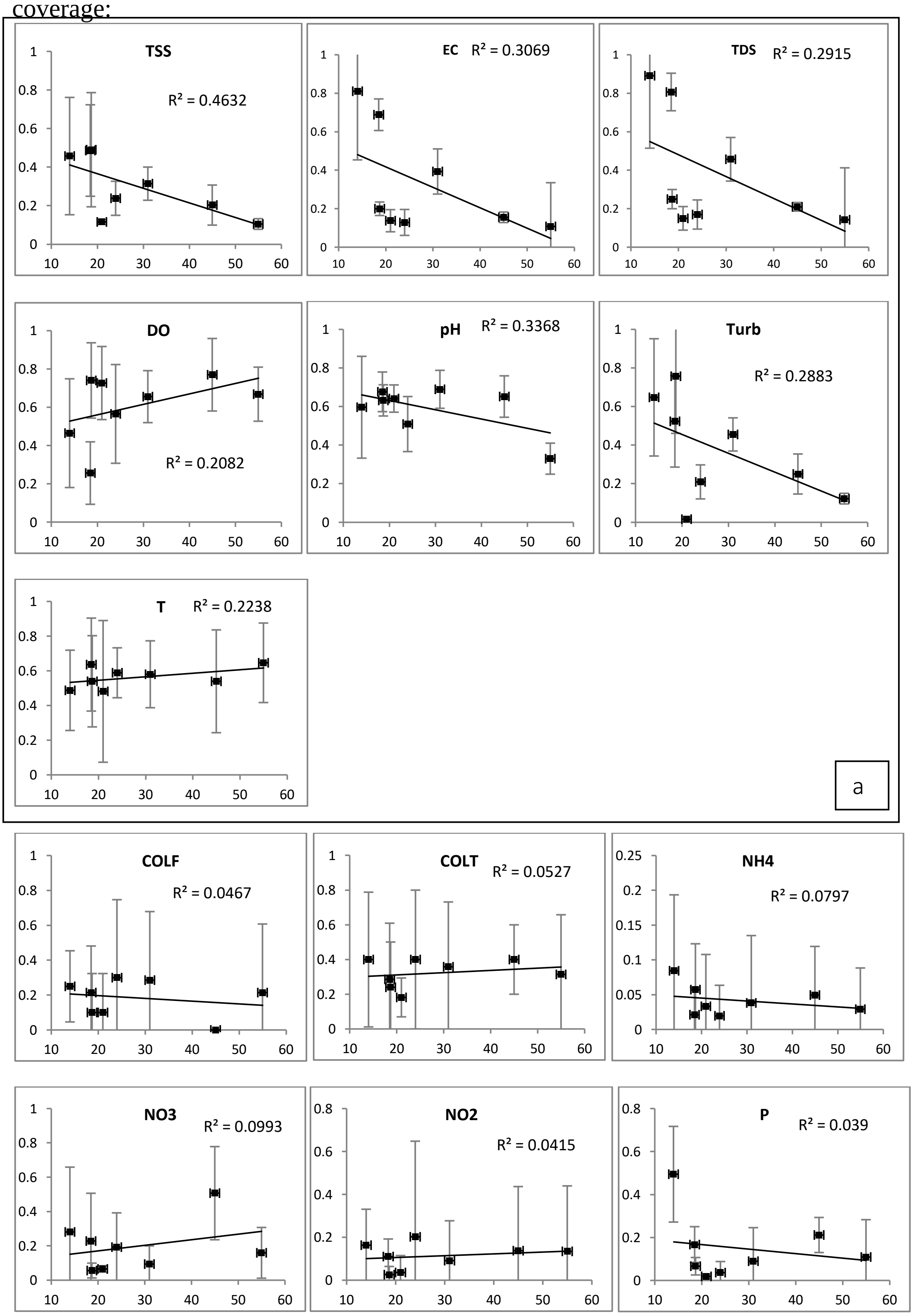


Figure SM-6. 2. Trendlines for the coefficient of variation of each parameter.

SM - 7: WQp in landscapes up to 55% natural forest coverage: As technologies enable the expansion of eucalyptus plantations, natural forest land coverage tends to diminish in the future. By applying simple linear regression to our samples up to 55% natural forest coverage, we can observe that (a) responded quickly to the increase in forest coverage:



SM - 8: Results from Equation 1

Table SM-8. 1. Indexes we acquired from Equation 1, of ESw for each landscape.

%	Water for human use	Drink water	Disease control	Fishing	Agriculture	Erosion control	Recreational
14	14.84	18.86	13.83	15.42	12.31	18.22	10.92
18.5	16.77	19.47	16.48	18.00	13.53	18.64	12.58
18.7	9.44	10.35	9.91	10.35	7.35	9.31	7.21
21	5.47	5.20	5.06	5.58	2.75	5.03	2.32
24	7.24	6.65	6.46	7.38	4.83	6.64	4.56
31	13.15	14.62	12.90	13.78	7.63	13.67	8.86
45	8.78	7.65	6.55	8.73	3.69	8.76	3.87
55	7.63	6.77	6.47	7.53	3.07	6.96	4.81
97.7	6.38	4.92	5.63	6.72	3.45	5.22	5.34
97.8	9.49	10.26	9.05	10.46	5.84	9.97	6.33
99	14.50	16.28	12.00	14.77	7.55	16.85	8.16

SM - 9: Trendlines for the provision of ESw with all samples and compaired R^2.

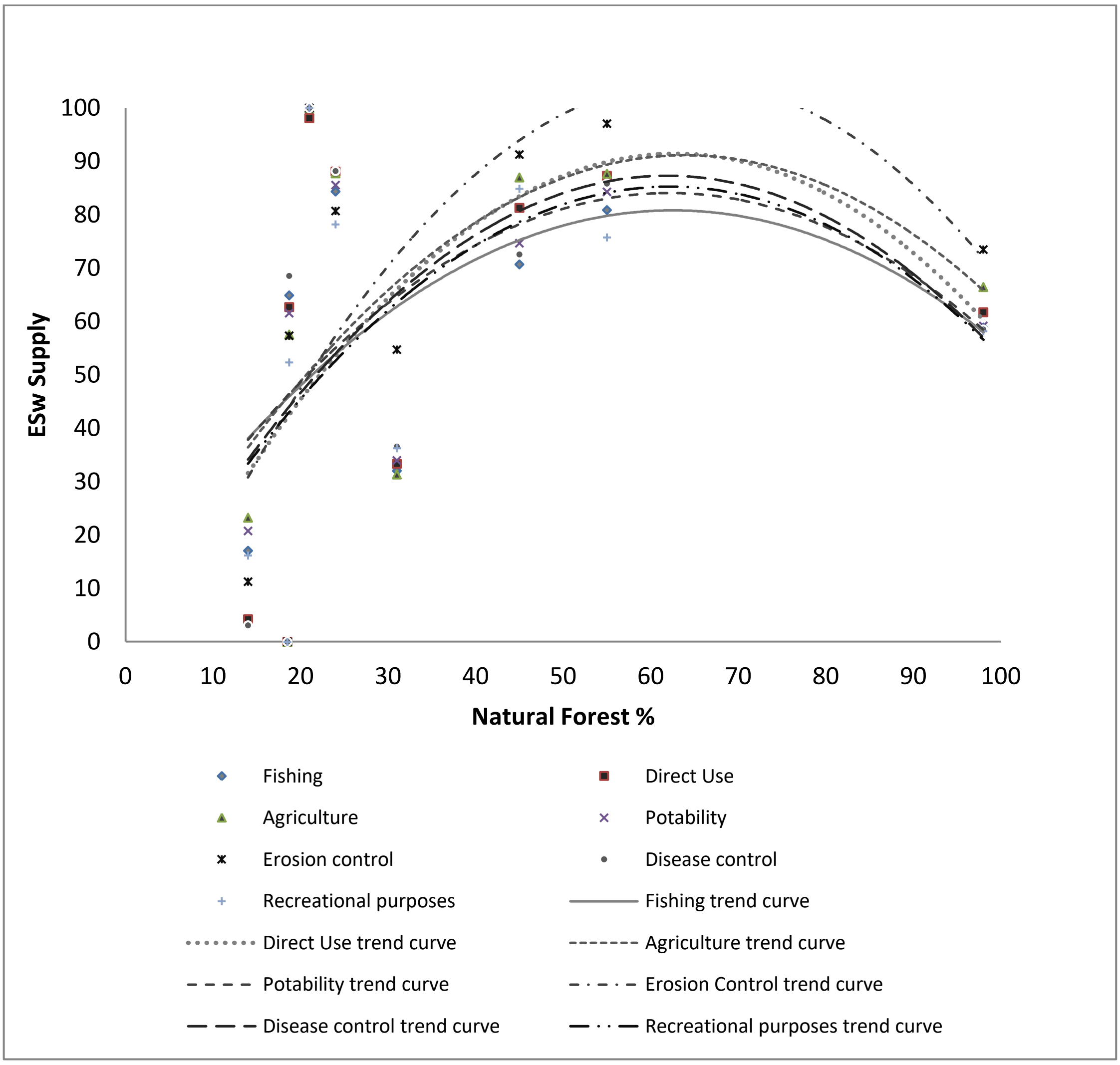


Figure SM-9. 1 – Each ESw, total sample

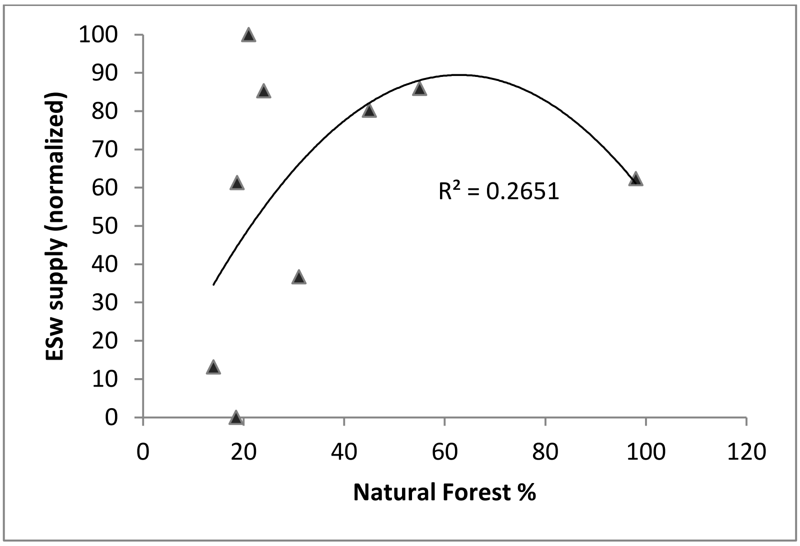


Figure SM-9. 2– Summed ESw, total sample

Table SM-9 1: R^2 of the ESw supply trendlines above, for the total sample and the reduced sample.

ESw	R^2 Total sample	R^2 Reduced sample
Fishing	0.17	**0.27**
Direct Use	0.28	**0.31**
Agriculture	0.26	**0.28**
Potability	0.21	**0.23**
Erosion Control	0.44	**0.45**
Disease Control	0.23	**0.26**
Recreational Purposes	0.26	**0.27**
Summed ESw	0.26	**0.29**

SM - 10: Raw data. Blank spaces are due to lack of information, for reasons beyond our control (p. ex. equipment fail on field).

%	Hydro-period	Q (L/s)	pH	EC µg/cm²	TDS ppm	T°C	DO ppm	COLT (CFU/ 10ml)	COLF (CFU/ 10ml)	Turb (NTU)	TSS (mg/L)	Organic TSS (mg/L)	NH_4 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	P (µg/L)
B14	<75mm	7.09	6.37	52	21	18.1	6.00	2	0	7.34	6.35		13.63	0.83	0.00	49.40
B14	<75mm	6.78	6.84	44	21	19.1	4.53	3	0	7.95	5.08	2.11	<DL	2.29	10.36	47.07
B14	<75mm	3.36	6.68	43	22	16.6	4.79	0	0	5.13	0.83		4.05	15.38	55.62	34.24
B14	>75mm	2.19	6.91	35	18	14.2	4.64	1	1	10.04	9.49	3.16	<DL	2.33	8.83	21.86
B14	>75mm	3.03	6.57	46	23	16.7	7.43	5	0	6.78	1.90	1.90	<DL	<DL	10.09	39.53
B14	>75mm	4.69	6.55	41	20	20.7	7.03	1	2	8.00	6.16	2.59	53.11	1.80	11.51	58.69
B18.5	>75mm	5.75	6.90	41	21	20.6	4.61	3	1	3.73	3.79		<DL	1.15	4.53	29.17
B18.5	<75mm	6.77	6.51	36	18	21.0	3.48	0	1	6.59	6.85		2.55	1.61	<DL	24.61
B18.5	<75mm	8.56	6.91	37	19	19.4	4.12	1	0	9.41	7.37	3.64	<DL	2.48	25.94	12.91
B18.5	<75mm	8.83	7.11	41	21	14.9	4.77	0	0	6.26	9.15	5.80	<DL	5.83	50.42	32.61
B18.5	>75mm	5.09	7.00	33	16	15.7	5.00	4	0	4.26	3.43	1.70	<DL	1.02	11.64	17.04
B18.5	>75mm	8.07	6.63	35	18	19.6	5.99	0	0	4.17	0.56		<DL	<DL	10.09	7.06
B18.5	>75mm	3.00	6.69	43	21	23.2	5.11	2	1	9.49	5.77	2.43	27.99	0.83	39.99	16.11
B18.7	<75mm	27.57	6.71	18	9	19.3	6.81	1	0	11.13	6.60		6.00	<DL	<DL	35.37
B18.7	<75mm	24.28	6.70	14	7	18.5	7.54	3	0	10.03	4.33	1.67	9.45	0.49	45.21	21.80
B18.7	>75mm	19.37	7.01	15	7	14.1	5.67	0	1	7.16	3.30	1.15	5.54	4.32	17.92	52.86
B18.7	>75mm	41.12	6.67	17	9	16.9	8.25	2	0	16.12	6.85	2.33	<DL	2.38	21.48	26.75
B18.7	>75mm	30.27	6.55	16	8	21.9	7.09	0	0	10.92	5.51	2.32	39.65	0.24	39.99	33.14
B21	<75mm	33.12	6.93	17	8	20.2	5.47	0	0	1.03	0.43		<DL	<DL	36.98	4.49
B21	<75mm	28.18	6.81	14	6	13.4	7.89	1	0	1.15			<DL	12.09	40.89	4.93
B21	>75mm	21.92	6.58	12	5	12.2	6.95	1	0	0.92	0.67	0.53	<DL	0.05	14.02	12.23
B21	>75mm	12.54	6.81	13	6	19.1	7.49	1	1	1.26	0.92	0.64	<DL	<DL	15.78	7.06
B21	>75mm	20.23	6.61	10	5	22.6	7.23	10	0	1.07	0.92	0.66	25.89	<DL	18.63	9.72

B24	<75mm	6.03	5.97	12	6	20.3	5.00	3	0	3.85	3.83		<DL	<DL	4.10	15.25
B24	<75mm	8.44	6.55	12	6	20.4	5.59	1	2	4.04	1.84	0.96	<DL	<DL	22.04	<DL
B24	<75mm	6.55	6.67	18	9	17.5	5.94	1	0	2.31			4.94	15.87	57.78	3.33
B24	>75mm	6.30	6.72	10	5	17.0	6.30	0	0	2.01	1.41	0.54	<DL	<DL	18.56	3.68
B24	>75mm	16.27	6.44	12	6	18.2	8.29	5	1	3.11	2.32	1.13	<DL	0.39	14.36	0.67
B31	>75mm	3.52	6.85	30	14	19.9	6.14	18	2	5.25	4.52		<DL	1.13	1.93	31.19
B31	<75mm	36.93	6.90	23	12	20.3	6.04	0	0	5.76	4.49		<DL	<DL	<DL	19.00
B31	<75mm	29.86	6.88	32	15	19.1	5.84	4	0	7.28	4.50	2.23	2.25	0.29	21.16	5.43
B31	<75mm	14.01	7.12	28	14	16.7	6.96	3	0	4.52	2.41	1.00	<DL	16.89	74.25	3.46
B31	>75mm	13.31	7.02	18	9	14.9	6.82	0	0	5.50	1.51	1.23	<DL	<DL	17.06	17.04
B31	>75mm	24.76	6.51	21	11	18.4	7.50	4	1	5.81	3.04	1.43	<DL	0.15	44.26	11.32
B31	>75mm	11.72	6.66	21	10	20.8	7.33	0	1	4.92	3.75	1.75	23.20	<DL	14.36	12.38
B45	<75mm	5.51	6.81	16	8	19.0	6.77	1	0	4.28	2.26	1.03	<DL	<DL	41.11	14.32
B45	<75mm	3.40	6.74	13	7	13.9	8.33	3	0	2.96			<DL	5.54	52.82	17.70
B45	>75mm	5.72	7.06	14	7	15.8	6.11	2	0	2.28	0.14		<DL	<DL	19.44	27.74
B45	>75mm	5.67	6.43	14	7	20.0	7.99	3	0	4.87	2.90	1.15	6.44	0.20	51.38	13.98
B45	>75mm	5.05	6.81	13	7	22.0	6.88	1	0	3.02	2.25	1.20	40.55	<DL	32.87	31.01
B55	>75mm	2.79	5.99	9	4	20.7	5.66	4	1	1.76	1.32		<DL	0.76	<DL	27.65
B55	<75mm	5.76	5.93	9	5	21.9	6.47	1	2	1.82	1.35		<DL	<DL	<DL	14.79
B55	<75mm	7.13	6.08	8	4	19.7	6.66	3	0	2.30	0.49	0.45	2.55	<DL	25.75	4.49
B55	<75mm	7.06	6.24	7	3	16.4	7.80	3	0	2.36			<DL	14.03	49.55	3.33
B55	>75mm	9.84	6.11	35	18	15.2	6.45	0	0	2.52	0.61	0.61	<DL	<DL	23.99	12.23
B55	>75mm	13.25	6.38	8	4	20.2	6.69	0	0	2.27	0.46		<DL	0.20	48.54	0.67
B55	>75mm	10.01	5.92	7	3	21.1	7.34	0	0	2.19	0.64	0.53	12.14	<DL	17.21	4.93
B97.7	>75mm	21.11	5.80	8	4	20.8	4.33	1	1	1.29	1.04		<DL	0.76	6.80	18.05
B97.7	<75mm	14.66	5.50	7	4	19.6	4.31	0	0	1.50	1.36		<DL	<DL	6.26	14.79
B97.7	<75mm	12.55	5.61	9	5	19.2	4.81	0	0	1.67	1.59	1.03	<DL	<DL	29.19	20.87

B97.7	<75mm	9.56	5.81	10	5	17.3	4.27	0	0	1.28			<DL	11.41	37.86	0.14
B97.7	>75mm	5.15	5.83	12	6	16.8	4.14	1	0	1.49	1.15	0.61	<DL	<DL	9.26	5.82
B97.7	>75mm	17.37	5.43	9	5	19.0	6.09	1	0	1.47	0.68	0.68	12.74	<DL	32.87	4.40
B97.7	>75mm	4.18	5.40	7	3	21.9	4.81	1	0	1.39	1.96	1.96	23.80	<DL	34.30	4.93
B97.8	>75mm	2.36	6.57	18	9	22.2	5.41	1	0	4.62	6.00		2.95	0.94	30.92	47.36
B97.8	<75mm	11.96	6.55	17	8	21.0	5.98	0	0	5.84	10.69		<DL	<DL	1.06	37.24
B97.8	<75mm	8.90	6.67	20	9	17.7	7.02	0	0	4.90	3.35	1.30	3.15	<DL	35.36	26.48
B97.8	<75mm	14.24	6.48	16	8	14.4	7.70	1	0	3.51			3.45	8.11	23.13	21.75
B97.8	>75mm	15.89	6.41	14	6	16.8	6.82	0	0	3.40	1.75	0.84	<DL	<DL	32.87	32.55
B97.8	>75mm	10.54	6.64	17	9	20.1	7.55	1	0	4.24	3.82	2.24	<DL	0.68	54.23	37.93
B99	>75mm	1.54	7.50	37	19	20.3	4.63	1	0	3.66	5.65		<DL	1.03	45.21	51.91
B99	<75mm	6.64	6.54	36	18	19.5	6.52	1	0	4.09	4.35		6.90	0.05	<DL	38.64
B99	<75mm	4.49	6.75	34	17	18.7	7.32	0	0	3.30	2.45	0.89	<DL	<DL	32.16	16.19
B99	<75mm	2.88	6.68	33	16	15.6	8.03	2	0	2.92			<DL	5.88	13.17	32.07
B99	>75mm	3.10	6.67	25	13	15.0	5.86	0	0	2.33	1.46	0.81	8.23	<DL	43.48	26.13
B99	>75mm	3.44	6.59	39	19	20.5	6.76	5	0	3.08	2.26	1.13	2.85	0.15	38.57	48.05
B99	>75mm	6.13	6.88	32	16	20.9	7.59	3	0	5.53	5.51	2.23	47.13	<DL	35.72	33.14