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A evolução urbana da ilha de Santa Catarina e sua influência na hidroquímica e pressão de CO_2 de riachos subtropicais

.

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2020

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Tese submetida à banca do Programa de Pós-Graduação em Ecologia da Universidade Federal de Santa Catarina como pré-requisito para obtenção do grau de Doutora em Ecologia.

Orientador: Prof. Drº. Mauricio Mello Petrucio
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Michelle das Neves Lopes

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O presente trabalho em nível de doutorado foi avaliado e aprovado pela banca examinadora composta pelos seguintes membros:

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RESUMO

A presente tese de doutorado consiste em três capítulos, nos quais estudamos os efeitos do processo de urbanização em riachos subtropicais na Ilha de Santa Catarina. Utilizamos a associação entre a ferramenta de geoprocessamento (QGIS) e o índice de integridade do rio, com as características físico-químicas dos córregos subtropicais. Inicialmente, avaliamos o processo de evolução urbana nas bacias hidrográficas da ilha de Santa Catarina e o conhecimento científico gerado nas últimas três décadas. No primeiro capítulo, realizamos uma análise cientométrica dos trabalhos publicados de 1990 a 2010 para avaliar as tendências nas publicações de ecologia aquática relacionadas ao crescimento da urbanização. No segundo capítulo, usamos as bacias hidrográficas como uma unidade de estudo e exploramos as concentrações de carbono dissolvido (carbono orgânico e inorgânico) ao longo de um gradiente de urbanização para avaliar o aumento potencial da pressão de CO_2 nos riachos. Além disso, avaliamos os efeitos diretos e indiretos das mudanças locais devido ao aumento do processo de urbanização na qualidade da água. Por fim, no terceiro capítulo, investigamos os fatores locais (por exemplo, perda de mata ciliar e aumento do processo de erosão) que afetam a hidroquímica de dois tributários em uma bacia hidrográfica localizada dentro de uma área legalmente protegida na ilha de Santa Catarina. A bacia hidrográfica da lagoa Peri desempenha um papel importante no fornecimento de água potável aos habitantes locais e tem sofrido uma pressão urbana moderada nas últimas décadas. Nossas descobertas contribuem para preencher as lacunas de conhecimento sobre qualidade da água e mudanças ambientais associadas ao processo de urbanização, gerando dados científicos adequados para o planejamento e gerenciamento de bacias hidrográficas urbanas em sistemas subtropicais.

Palavras chave: Bacias hidrográficas, Rios urbanos, Uso e cobertura do solo, Integridade ambiental, Geoprocessamento.

ABSTRACT

The present doctoral thesis consists of 3 chapters, in which we studied the effects of urbanization process on subtropical streams in Santa Catarina Island. Here, we used the association between geoprocessing tool (QGIS) and river integrity index, with the physical-chemical characteristics of subtropical streams. Initially, we evaluated the urban evolution process on watersheds in Santa Catarina island and the scientific knowledge generated over the last three decades. In the first chapter, we carried out a scientometric analysis of the papers published from 1990 to 2010 to assess the trends on publications of aquatic ecology related to urbanization growth. In the second chapter, we used the watersheds as a study unit, and explored the dissolved carbon concentrations (organic and inorganic carbon) along a urbanization gradient to assess the potential increase in CO_2 pressure in the streams. In addition, we assessed the direct and indirect effects of local changes due to increased urbanization process on water quality. Finally, in the third chapter we investigate the local factors (e. g., loss of riparian forest and increased erosion process) that affecting the hydrochemistry of two tributaries in a watershed located within a legally protected area in Santa Catarina Island. Peri Lake watershed plays an important role in supplying drinking water to local inhabitants, and it has been under moderate urban pressure over the past decades. Our findings contribute to fill knowledge gaps regarding on water quality and environmental changes associated to urbanization process, generating scientific data suitable for planning and management of urban watersheds in subtropical systems.

Key words: Watersheds, Urban streams, Land use and Land Cover, Environmental integrity, Geoprocessing.

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1-INTRODUÇÃO GERAL

A ecologia urbana integra a teoria e os métodos das ciências naturais e sociais para estudar os padrões e processos dos ecossistemas urbanos (Grimm et al. 2000). A expansão conceitual para a ecologia urbana considera as cidades como paisagens heterogêneas, dinâmicas e complexas, adaptáveis e como sistemas socioecológicos, nos quais a prestação de serviços ecossistêmicos vincula a sociedade e os ecossistemas em várias escalas (Colins et al. 2007).

Os sistemas de água doce nas ilhas subtropicais estão sofrendo alterações substanciais à medida que a população humana aumenta, e as bacias hidrográficas tornam-se muito diferentes daquelas que outrora sustentavam comunidades nativas (Brasher, 2003). Dentro de duas décadas, 60% da população mundial viverá nas cidades, e gerenciar os problemas urbanos de água potável e saneamento é um dos maiores desafios deste século (Kaushal, 2010).

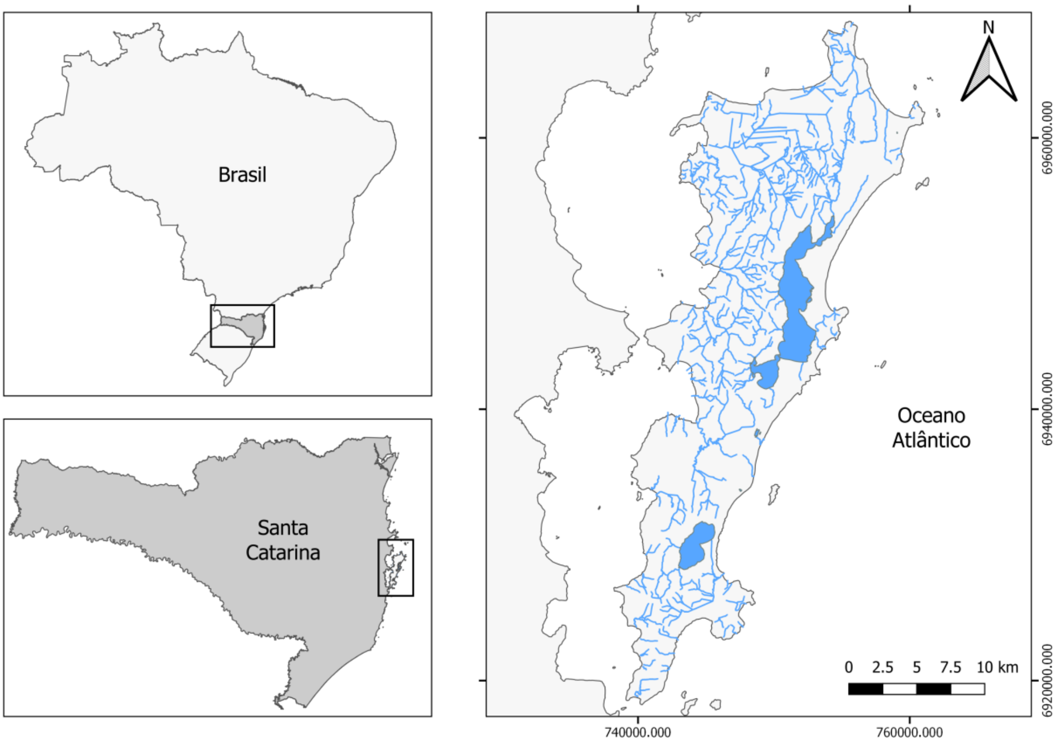
Áreas urbanas inseridas próximas ou dentro de bacias hidrográficas afetam direta e indiretamente os cursos de água, é a chamada "síndrome dos riachos urbanos" (Walsh et al. 2005). A urbanização altera o equilíbrio das funções do ecossistema nos riachos, alterando o regime hidrológico (por entrada de escoamento superficial), o habitat físico (remoção da cobertura ripária) e o ambiente físico-químico (entradas de nutrientes e poluentes) (Walsh et al. 2005; Parr et al. 2016) ameaçando a saúde do ecossistema aquático (Liao & Huang, 2013) e da biodiversidade (Cooper et al. 2013).

O desenvolvimento urbano aumenta a conectividade hidrológica através da instalação de redes de tubulações, calhas e valas (Roy et al. 2009). Além disso, o aumento da magnitude desses vínculos sugere que a elucidação da estrutura e função das bacias hidrográficas urbanas e mudanças associadas nos processos a jusante têm importantes implicações no ecossistema e na saúde pública (Kaushal et al. 2012).

Neste contexto, a teoria do "continuum de bacias hidrográficas urbanas" inclui um continuo de caminhos de fluxos hidrológicos que não são considerados pela síndrome do riachos urbanos, como interações verticais entre águas subterrâneas e rios e a evolução dos ciclos biogeoquímicos ao longo do tempo (Kaushal et al. 2012). Ele reconhece que a natureza da conectividade hidrológica influencia os fluxos a jusante e as transformações de carbono, contaminantes, energia e nutrientes em quatro dimensões de espaço e tempo (longitudinalmente, lateralmente, vertical e temporal).

A Ilha de Santa Catarina (27 ° 34 'S 48 ° 27' O) (Fig.1), está localizada na cidade de Florianópolis, em clima subtropical e tem sido um importante destino turístico no sul do Brasil (Wemple et al. 2017), o que resultou no aumento da urbanização com um aumento populacional subsequente na última década (Guerra et al. 2016). Os recursos hídricos presentes na ilha são caracterizados por bacias hidrográficas, lagoas, rios e riachos geralmente de pequena extensão (Pêgas Filho & Tirloni, 2009). A ilha possui ainda, um sistema lagunar que incorpora dois ambientes principais: Lagoa da Conceição (trata-se de uma laguna) e a Lagoa do Peri (Bastos, 2004).

Figura 1. Mapa da Ilha de Santa Catarina e sua rede hidrográfica, localizada na cidade de Florianópolis ao sul do Brasil.



Atualmente, a maioria dos riachos presentes nas áreas mais densamente ocupadas da ilha, está completamente alterada quanto a sua morfometria natural (Plano Municipal Integrado de Saneamento Básico-PMISB, 2009). Assim, com o contínuo desenvolvimento de ecossistemas urbanos na ilha, o potencial das bacias hidrográficas em alterar sua integridade ambiental permanece substancial, onde a compreensão do contexto mais amplo será importante para a gestão dos recursos hídricos. Neste estudo nós avaliamos as modificações ambientais geradas por atividades antrópicas resultantes do aumento de áreas urbanas na porção insular da ilha de Santa Catarina.

1.1-HIPÓTESE

O crescimento urbano das bacias hidrográficas ao longo das últimas três décadas gerou modificações no uso do solo, como por exemplo, a diminuição da mata ripária e o consequente aumento do processo de erosão, resultando no aumento das concentrações dos principais nutrientes e alterações da ciclagem de carbono em riachos subtropicais.

1.2-OBJETIVOS

Objetivo geral:

Contribuir para a compreensão do estado da arte do uso e ocupação do solo (áreas urbanas) das bacias hidrográficas da Ilha de Santa Catarina e a influência de diferentes níveis de urbanização na hidroquímica e pressão de CO_2 de riachos subtropicais.

Objetivos específicos:

- ✓ Estimar o crescimento urbano das bacias hidrográficas da Ilha de Santa Catarina nas últimas três décadas.
- ✓ Analisar como a evolução urbana nas bacias hidrográficas influenciou as pesquisas científicas nas últimas décadas.
- ✓ Avaliar os efeitos diretos e indiretos dos níveis de urbanização nas concentrações de carbono dissolvido (DOC e DIC) e pressão parcial de CO_2 em riachos subtropicais no sul do Brasil.
- ✓ Estimar a influência dos fatores locais sobre a hidroquímica de riachos de baixa ordem em bacias hidrográficas localizadas em área de preservação, com diferentes usos do solo e condições geomórficas.

2-CAPÍTULO I

Trends in aquatic ecology studies associated with increase of urbanization during three decades in Florianópolis /SC

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2.1-Abstract:

Aim: This paper systematically assessed trends of aquatic ecology publications related to the urbanization growth during three decades (1990-2010) in Santa Catarina Island. **Methods:** The study was carried out in fifteen watersheds of Santa Catarina Island, located in Florianópolis city, Southern Brazil. A combination of geoprocessing and scientometry tools was used to analyze the growth of urban areas and publications related to these watersheds during three decades. In order to delimitate the catchment area of each watershed, we have used the QGIS software and contrasted those areas with the built-up area for each decade, obtaining the percentage of area covered with buildings. A gradient was created allowing to classify the watersheds concerning urbanized area percent, resulting in 5 groups of urbanization (0-5%; 5-10%; 10-20%; 20-30%; >30% of urbanization). Aquatic ecology publications were obtained from several scientific and academic databases and were used in the scientometry analysis. The number of publications by decade, document type, knowledge area and watershed of the study was recorded. **Results:** Growth of urbanized areas mainly evidenced since the 2000s showed a moderate positive relationship with the increase of the number of publications in the ecology of aquatic systems in the Santa Catarina Island during the same period. However, differences between watersheds were observed, were the most urbanized watersheds were not necessarily the ones with the largest number of publications. **Conclusions:** Our results indicated that, in general, the greatest urbanization increase occurred between the 1990s and the 2000s. The positive relationships between increased urbanization and the number of publications suggest that anthropic pressure may have led to a slight increase in the studies in urban areas.

However, we observed differences in this expansion for each watershed, and the most urbanized watersheds were not necessarily the watersheds with the largest number of publications. The low number of studies might be contributing to the decline in biological integrity due to the lack of knowledge for evaluation and management in these environments.

2.2-Resumo

Objetivo: Este trabalho avaliou sistematicamente as tendências das publicações sobre ecologia aquática relacionadas ao crescimento da urbanização durante três décadas (1990-2010) na ilha de Santa Catarina. **Métodos**: O estudo foi realizado em quinze bacias hidrográficas da Ilha de Santa Catarina, localizadas na cidade de Florianópolis, no sul do Brasil. Uma combinação de ferramentas de geoprocessamento e cientometria foi utilizada para analisar o crescimento das áreas urbanas e publicações associadas a essas bacias hidrográficas durante três décadas. Para delimitar a área de abrangência de cada bacia hidrográfica, utilizamos o software QGIS e comparamos essas áreas com a área construída para cada década, obtendo a porcentagem de área coberta de edificações. Foi criado um gradiente que permite classificar as bacias hidrográficas em relação ao percentual da área urbanizada, resultando em 5 grupos de urbanização (0-5%; 5-10%; 10-20%; 20-30%;> 30% da urbanização). As publicações de ecologia aquática foram obtidas de diversas bases de dados científicas e acadêmicas e utilizadas na análise por cientometria. Foram registrados, o número de publicações por década, tipo de documento, área de conhecimento e bacia hidrográfica do estudo. **Resultados**: O crescimento das áreas urbanizadas evidenciado principalmente a partir da década de 2000 mostrou uma relação positiva moderada com o aumento do número de publicações em ecologia de sistemas aquáticos na ilha de Florianópolis no mesmo período. No entanto, foram observadas diferenças entre bacias hidrográficas onde as bacias hidrográficas mais urbanizadas não foram necessariamente as que apresentavam o maior número de publicações. **Conclusões**: Nossos resultados indicaram que, em geral, o maior aumento de urbanização ocorreu entre as décadas de 1990 e 2000. As relações positivas entre o aumento da urbanização e o número de publicações sugerem que a pressão antrópica pode ter levado a um ligeiro aumento da pesquisa em áreas urbanas. No entanto, observamos diferenças nessa expansão para cada bacia hidrográfica, onde as bacias mais urbanizadas não foram necessariamente as que apresentaram maior número de publicações. O baixo número de estudos pode estar contribuindo para o declínio da integridade biológica devido à falta de conhecimento para avaliação e gerenciamento nesses ambientes.

Keywords: Watersheds; Freshwater; Geoprocessing; Scientometry; Land use and Land cover

2.3-Introduction

Freshwater systems on subtropical islands are undergoing substantial alteration as the human population increases, and watersheds become much different from those that once sustained native stream communities (Brasher, 2003). Within two decades, 60% of the world's population will live in cities, and manage urban drinking water and sanitation issues is one of the greatest challenges of this century (Kaushal, 2010).

Changes in populations and associated socioeconomic factors drive the intensity, extent, and stage of urban development where it occurs, and also the rate at which it occurs, subsequently creating different mechanisms by which current and future watershed conditions may affect freshwater ecosystems (Parr et al., 2016). Urbanization changes the balance of ecosystem functions in streams by altering the hydrologic regime (by input of runoff), physical habitat (removal of riparian cover), and the physicochemical environment (inputs of nutrients and pollutants), (Walsh et al., 2005; Parr et al., 2016) threatening the health of aquatic ecosystem (Liao & Huang, 2013) and biodiversity (Cooper et al., 2013).

Effective water quality management of streams in urbanized watersheds requires identification of the elements of urbanization that contribute most to pollutant concentrations and loads (Hatt et al., 2004). Also, the expansion of urbanization across landscapes of the world has led to increased study on ecology in urban settings in the last decades (Smucker & Detenbeck, 2014; Walsh et al., 2005).

Recently, an increasing number of ecologists have collaborated with other scientists, planners and engineers to understand and even shape these ascendant ecosystems (Grimm, 2008). Urban ecological studies have investigated both impacts of urban development on native ecosystems and the dynamics of urban environments themselves as ecosystems (Grimm et al., 2000).

Santa Catarina Island shows a subtropical climate and has been a major tourist destination in Brazil (Wemple et al., 2017). This resulted in an increase of urbanization with a subsequent population increase in the last decade (Guerra et al., 2016). The water resources present on the island are characterized by watersheds, lagoons, rivers and streams usually of small extension (Pêgas Filho & Tirloni, 2009). Thus, with the continued development of urban ecosystems on the island, the potential for watersheds to change their environmental integrity remains substantial, where the understanding of the wider context will be important for water resources management.

Scientometrics methods have been used in many disciplines of science and engineering to measure scientific progress, and are a common research instrument for systematic analysis (Van Raan, 2005). The analysis results could provide a better understanding of local trends in aquatic ecosystem study and potentially give some guidance to researchers for developing future studies and assist policy-makers in public policies and management of environmental problems.

Hence, this paper aims to systematically assess trends and the correlations of the aquatic ecology publication with urbanization increase during three decades (1990, 2000 and 2010) in Santa Catarina Island, using a combination of geoprocessing and scientometry tools.

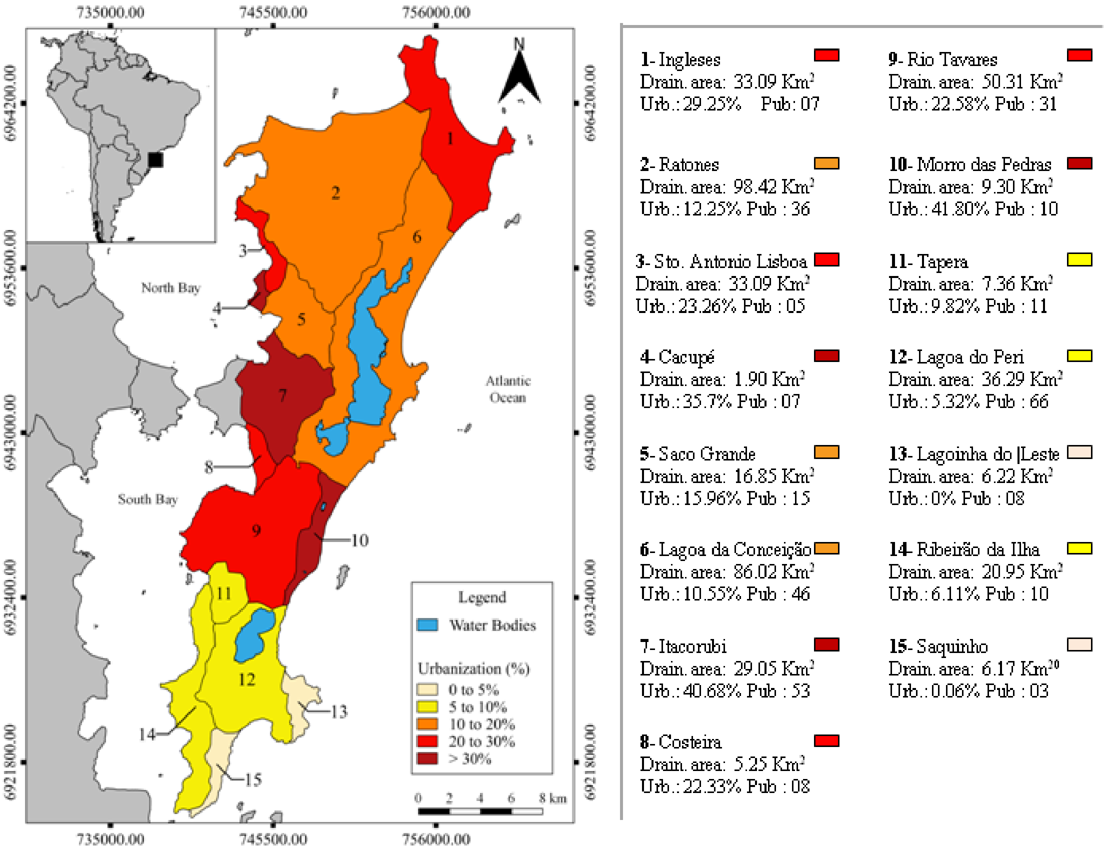
2.4-Methods

Study area

The study was carried out in Santa Catarina Island (27°34'S 48°27'O), located in Florianópolis city, Southern Brazil (Nascimento, 2002). Florianópolis has an approximate insular area of 423 km^2, with 42% of the city's land area established as a permanent preservation area (IPUF, 2004). However, since the 20th century, the process of modernization contributed to the development of the city and has been a major draw for tourism, resulting in an urbanization increase (Wemple et al., 2017).

In the 2010s, almost all the urbanizable portion of Santa Catarina island, this is, without physical limitations to its implantation, was occupied (IBAM, 2015). Such physical limitations are due to the presence of relief marked by a discontinuous mountain chain that forms a central dorsal, acting as a watershed for the local hydrography and coastal plains, where the occupation is concentrated (Santiago et al., 2014). Here we studied the fifteen major watersheds located along with the Florianópolis county (Fig.1).

Figure -1 Map of sampling locations in the Santa Catarina Island -SC, Brazil, with watersheds aggregated by urbanization gradient (beige: 0-5%; yellow: 5-10%; orange:10-20%; red: 20-30%; dark red: >30% of urbanization), drainage area and publications number.



Geoprocessing

An urbanization gradient design was used, which enabled to differentiate urbanization increase over three decades (1990-2010). Firstly, a Digital Elevation Model (DEM) with a 30m spatial resolution downloaded from the Santa Catarina State data repository (SIGSDS, 2017) was accessed. To delimitate the catchment area of each watershed, the algorithm r.watershed (GRASS GIS 7), implemented in QGIS software (QGIS, 2019), was used. After the delimitation of each watershed, their perimeter with the built-up areas for each decade (1993, 2003 and 2013) was clipped to obtain the percentage of area covered by buildings. The present built-up areas (scale: 1:50,000) were provided by the Institute of Urban Planning of Florianópolis – IPUF. Thus, a gradient was created, allowing to classify the watersheds concerning urbanized area percentage, resulting in 5 groups of urbanization (beige: 0-5%; yellow: 5-10%; orange: 10-20%; red: 20-30%;

dark red: >30% of urbanization) (Fig.1). The urbanized area refers only to buildings (not roads, parking lots, etc.).

Scientometrics

The data source used in this study was selected from the Institute for Scientific Information (ISI), Web of Science database, Science Citation Index (SCI), Google Scholar and Institutional Repository of Federal University of Santa Catarina (DSpace). The portuguese and english keywords used for retrieving valid data records were ("aquatic ecosystem*" or "water ecosystem*" or "hydrology*", or "ecology*", or "limnology*" and+ "watersheds*") with this last word expressing each of the 15 watershed's name of Santa Catarina Island. These terms yielded many non-relevant studies, being necessary an inspection to verify whether they addressed aspects related to aquatic ecology. Searches were restricted to the period from 1979 to 2018 and were finalized in May 2019.

The tabulation of the studies included information about the publication outputs, document type, number of publications for each decade, and studied watershed. The information contained in these documents was grouped by sub-areas within aquatic ecology and stored in a database of technical (congress summaries and technical reports) or scientific (articles, doctoral thesis, and master's dissertation, completion of course work) documents related to watersheds of Florianópolis. From the 212 publications registered, 181 was carried out in a single watershed, with the remaining merging two or more watersheds. Regarding the latter case, the publications were computed with repetition to know the exact number of studies for each watershed individually.

For this study, we've defined seven sub-areas of concentration within aquatic ecology publications registered during the three studied decades as follows: zoology, land use and land cover, hydrology, geology, water quality, socioenvironmental and botany.

Statistical analyses

To analyze the results, both urbanization area and outputs were classified in three decades, with the first decade (Dec1) comprising the period until 1999 (1979-1999), the second decade (Dec2) until 2009 (2000-2009) and the third decade (Dec3) until 2018 (2010-2018).

We used a non-parametric Kruskal-Wallis H test to compare variations of the urbanization and numbers of aquatic ecology studies among the three decades previously described. Statistical significance was calculated using Chi-square test ($\chi2$) and sets around p-value < 0.05. When a significant difference was detected, a pairwise test for multiple comparisons of ranked data (Conover's post-hoc test) with a Bonferroni correction was performed in order to explore these differences among decades using PMCMRplus package (Dinno, 2017).

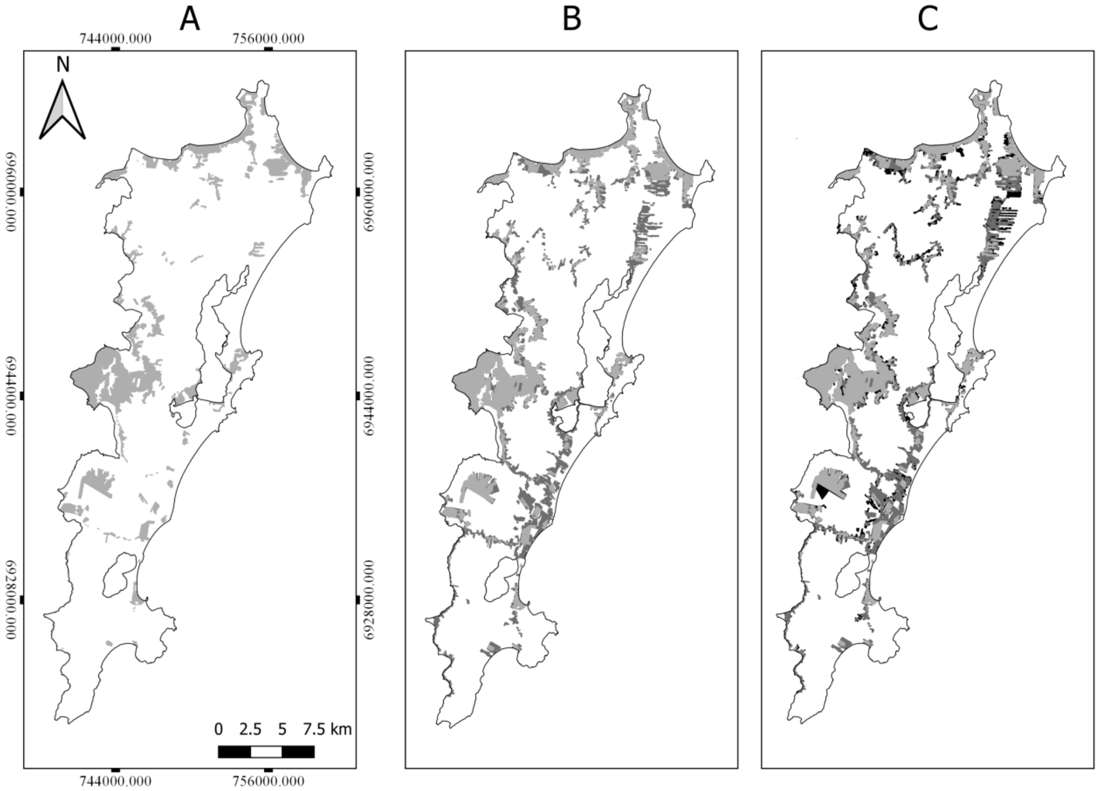
Spearman's Correlation Analysis was performed using all study watersheds, to evaluate the correlation of urbanization increase with aquatic ecology studies and watershed area. Statistical significance was calculated using the Chi-square test ($\chi2$) and sets around a p-value < 0.05. For this analysis, we used the package 'pspearman' (Savicky, 2015). We used nonparametric statistics since no normal distribution was found (p-value > 0.05; Shapiro Test). All statistical analyses were performed using the software R Studio version 1.1.383 (R Core Team 2015).

2.5-Results

Gradient of urbanization

The geoprocessing analyses indicate that, in general, the greatest urbanization boom occurred between the 1990s and the 2000s. The island of Florianópolis showed an urban area of 8% in 1993, increasing to 14% in 2003 and reaching 16% in 2013 of its total area (approx. 423 km^2) (Fig.2). Although total urbanization has increased twice in three decades, urban growth for each watershed has not shown the same growth pattern (Tab.1). In other words, there were no significant differences in the increase in urbanization of the watersheds between the three decades ($\chi2$, p-value > 0.05).

Figure -2 Maps of evolution urban in Santa Catarina Island, showing an urbanized area of 8% in 1993 (A = light grey) increasing to 14% in 2003 (B = medium grey) and reaching 16% in 2013 (C = dark grey) over total island area.



Lagoinha do Leste and Saquinho (with an averaged total area of 6 km^2) did not show the urbanization area over the three last decades. However, Saquinho showed a tiny urban area in the last decade, although below 1% of the total area.

In the 1990s, Tapera, Ribeirão da Ilha, Lagoa do Peri, Ratones and Lagoa da Conceição presented approximately 5% of urbanization in their total área (Tab.1). In the 2000s, these same watersheds showed a higher urbanization rate, between 5% and 10%, representing an increase of two or three times, being eight times higher in Ribeirão da Ilha. The 2010s also showed an increase in urbanization areas in these watersheds, although smaller. Considering the last three decades, Lagoa do Peri was the watershed which showed the smallest growth of its urban area.

Watersheds that showed in the 90s about 6 and 10% of the urbanized area, such as Saco Grande, Rio Tavares and Morro das Pedras, exhibit a strong increase in the following decades (Tab.1). Morro das Pedras watershed was considered the most urbanized among all watersheds in Santa Catarina Island in the 2010s, exceeding 41% of total area with urbanization. (Fig.1). However, it's important to emphasize that this is the smallest watershed in size (Tab.1). Indeed, Spearman's correlations showed that there no was significant association between urbanization and the watershed area (p-value > 0,05).

In the 1990s, Santo Antonio de Lisboa, Ingleses, Costeira and Cacupé have presented an urban area between 11 and 20%, which increased in the subsequent decades. Cacupé showed the most expressive growth, reaching 35% of the urbanization area in the 2010s. Itacorubi was the most urbanized watershed since the 1990s, and after the following decades, it was considered the second most urbanized watershed of Santa Catarina Island (Fig.1).

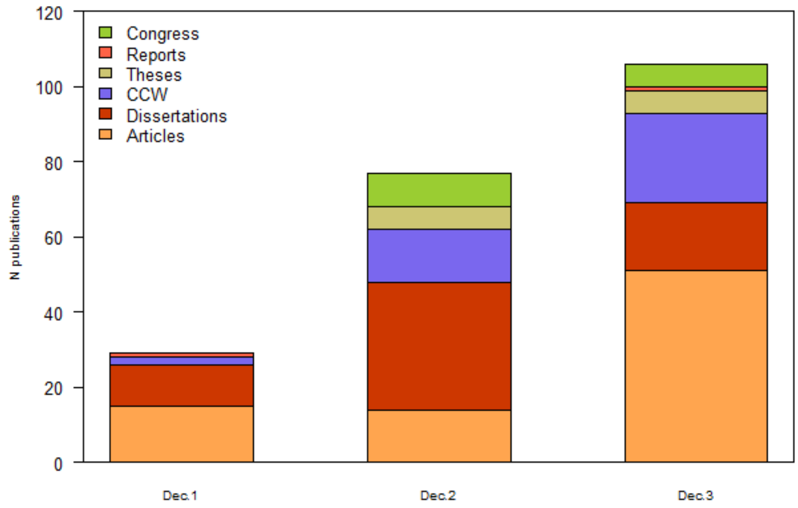
Table -1. Watersheds, their drainage areas, number of studies, and urbanization percentage the last three decades studied in Santa Catarina Island.

		Publications (Nº)			**Urbanization (%)**		
Watersheds	**Area**	**Dec.1**	**Dec.2**	**Dec.3**	**Dec.1**	**Dec.2**	**Dec.3**
	Km^2	**1980-90**	**2000**	**2010**	**1993**	**2003**	**2013**
Saquinho	6,17	0	2	1	0.0	0.06	0.06
Sto Ant. Lisboa	5,28	1	2	2	12.08	23.26	23.26
Cacupé	1,90	2	4	1	11.30	29.92	35.70
Ingleses	33,09	3	2	2	17.15	23.94	29.25
Costeira	5,25	2	3	3	11.31	20.90	22.33
Lagoinha do Leste	6,22	1	2	5	0.0	0.0	0.0
Morro das Pedras	9,30	1	5	4	6.05	36.43	41.80
Riberão da Ilha	20,95	1	4	5	0.65	5.73	6.11
Tapera	7,36	2	4	5	2.14	8.14	9.82
Saco grande	16,85	0	8	7	9.40	15.96	15.96
Rio Tavares	50,31	7	13	11	9.90	19.53	22.58
Ratones	98,42	3	17	16	5.64	9.90	12.25
Lagoa Conceição	86,02	10	20	16	3.54	8.62	10.55
Itacorubi	29,05	8	23	22	31.9	38.50	40.68
Lagoa do Peri	36,29	2	15	49	1.93	5.26	5.32

Scientometrics

Our study revealed that the publication of studies in Florianópolis watersheds began in 1979, with a technical report about the floristic survey in nine watersheds. Searches in the ISI, SCI, Google Scholar and Institutional Repository of UFSC platforms showed a total of 212 publications in the Florianópolis watersheds, demonstrating an increasing tendency in the last three decades (Fig. 3).

Figure- 3. Stacked bars represent the six document types registered for publication in watersheds in Santa Catarina Island in the last three decades (Orange = articles, Grey = doctoral theses, Dark-red = master's dissertation, Blue = completion of course work, Green = congress summaries and Red = technical reports).



The study development may be grouped into two stages. In the first, a restrained period from 1979 to 1999, with a total of 29 publications. The fast-growing period started in the second decade (the 2000s), when the publication sharply increased more than twice, reaching 77 publications. The same pace of growth was observed in the third decade analyzed, with 106 publications.

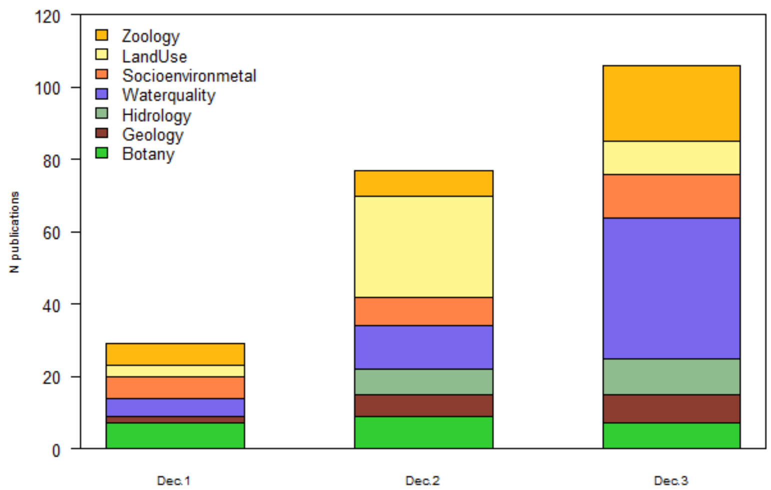
The growth in the number of publications showed significant differences between the three decades evaluated ($\chi 2$, p-value = 0.009). Where the first decade differs from the two subsequent decades ($\chi 2$, p-value = 0.015 and p-value = 0.022, respectively).

It was observed mainly six document types registered for publication outputs: articles, thesis, dissertations, completion of coursework (CCW), congress summaries and technical reports. Despite the number of publications that have increased in the second decade, the article's publication kept a similar number (Dec1 = 15, Dec2 = 14). In the same period, there was a substantial increase in academic studies, such as dissertations, CCW, congress summaries and thesis (Fig. 3). On the other hand, the publication of articles had increased in the third decade, reaching about three times more than the previous decades (Dec3 = 51).

Among studied watersheds, five watersheds have shown the largest number of publications: Lagoa do Peri (n = 66), Itacorubi (n = 53), Lagoa da Conceição (n = 46), Ratones (n = 36) and Rio Tavares (n = 31). Saco Grande and Tapera showed 15 and 11 publications, respectively, whereas Saquinho, Santo Antonio de Lisboa, Ingleses, Cacupé, Lagoinha do Leste, Ribeirão da Ilha, Morro das Pedras and Costeira showed less than ten publications over the selected three decades.

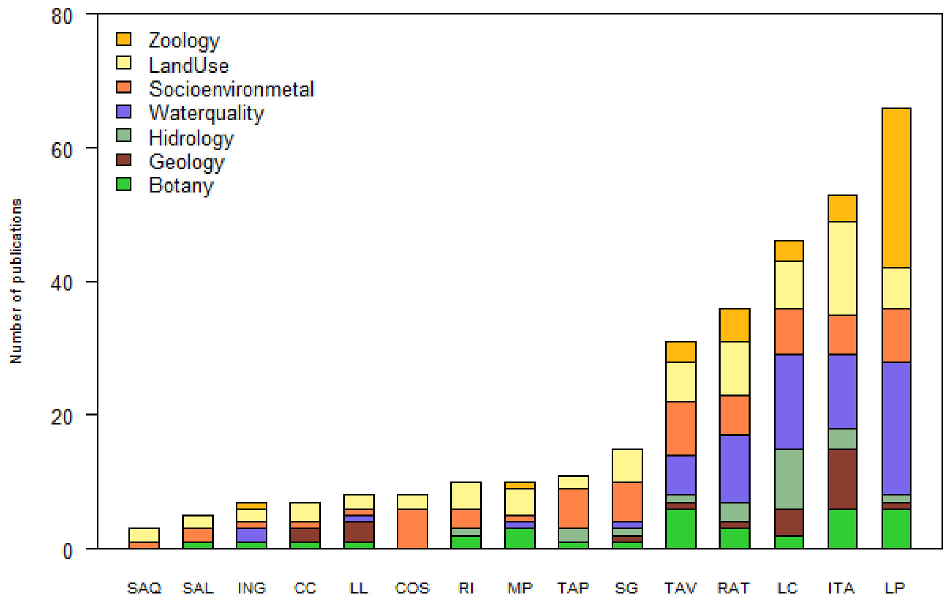
Seven sub-areas within aquatic ecology were defined (zoology, land use, socioenvironmental, water quality, hydrology, geology, and botany). Most of the themes were observed in all decades, except hydrology in the 1990s (Fig.4).

Figure -4. Stacked bars show the seven sub-areas more studied within aquatic ecology in Santa Catarina Island in the last three decades (Orange = zoology, Beige = land use and land cover, Grey = hydrology, Brown = geology, Blue = water quality, Red = socioenvironmental and Green = botany).



Land use and land cover, water quality and socio-environmental comprised about 21.8%, 20.9%, and 19.9% respectively (nearly 2/3 of the total). Studies on land use and socioenvironmental are present in all watersheds, but in those with more studies, there is a greater diversity of subjects being explored (Fig. 5). Furthermore, there was increase in studies in these knowledge areas in the last two decades, mainly in the 2000s. The third decade also showed an increase in zoology and hydrology studies.

Figure -5. Stacked bars represent the seven sub-areas more studied within aquatic ecology by watersheds in Santa Catarina Island (Orange = zoology, Beige = land use and land cover, Grey = hydrology, Brown = geology, Blue = water quality, Red = socioenvironmental and Green = botany), (SAQ = Saquinho, SAL = Santo Antonio de Lisboa, ING = Ingleses, CC = Cacupé, LL = Lagoinha do Leste, COS = Costeira, RI = Ribeira da Ilha, MP = Morro das Pedras, TAP = Tapera, SG = Saco Grande, TAV = Rio Tavares, RAT = Ratones, LC = Lagoa da Conceição, ITA = Itacorubi and LP = Lagoa do Peri).



Results of the Spearman's correlation indicated that there was a significant positive association between urbanization and number of publications in the study area, ($R = 0.56$, p-value = 0.0008), suggesting that anthropic pressure may have led to an increase of studies in urban areas, expanding the knowledge about the status of aquatic ecosystems under this pressure. More urbanized watersheds were not necessarily the ones showing the largest number of publications (p-value > 0,05). However, the size watersheds (drainage area) showed a positive correlation with the number of publications (R = 0.75, p-value = 0.0012).

2.6-Discussion

The growth of urbanized areas mainly after the 2000s showed a positive correlation with the number of publications on aquatic ecology in Santa Catarina Island. However, differences were observed in this expansion for each watershed, and the most urbanized watersheds were not necessarily the watersheds with the largest number of publications.

Urban expansion in Santa Catarina Island began in the late 1960s, undergoing processes of growth in the regional urban space (Campos, 2010) with the implementation of highways (BR 101) and the Federal University of Santa Catarina (IBAM, 2015). Besides, the 98 km of coast beaches were an important tourist attraction, boosting the development of new roads and resulting in subsequent urbanization (da Silva et al., 1996) and a population increase of 23% in the last decade (Guerra et al., 2016).

This population increase can be observed in the fast growth of urbanization between the 1990s and the 2000s, with almost twice as much built area, resulting in 14,2% of the urbanized area in the 2000s. Though in the 2010s the pace of growth of urban spot was slower, it reached index urbanization of 16.3% (Fig. 2) mainly in the coastal plains, where the occupation is concentrated.

Concomitant with the increase of urbanization, we observed in the same decades a strong increase in the number of publications on aquatic ecology in Santa Catarina island (from 29 to 77 publications in the 2000s and 77 to 106 publications in the 2010s) (Fig.3). Indeed, land use change to urban use has adversely affected aquatic ecosystems (Walsh et al., 2005; Grimm, 2008) and attracted more and more attention of the scientific community, becoming an important field of studies, mainly after the 21st century (Liao & Huang, 2013).

Results of Spearman's correlation suggest that the growth of urbanized areas can be a driver in the increase of publications on aquatic ecology. Urban streams are prevalent throughout the world, and the altered ecosystem structure with a subsequent reduction in ecosystem services provided by these systems has led to an exponential increase in the number of the studies in urban streams during recent years (Smucker & Detenbeck, 2014).

Aquatic ecosystems have gained more attention from scholars around the world and became one of the most dynamic fields in the study of ecology (Kong et al., 2002; Liao & Huang, 2013). There was a progressive increase in the number of publications during the three decades evaluated, with a greater diversity of document types observed mainly in the last two decades (the 2000s and 2010s), culminating mainly in 2010 decade with a strong increase in the number of articles (Fig.3).

The increase in the number of articles at the expense of the smaller number of theses and dissertations accompanies an international trend of consolidating regional knowledge (Almeida & Guimarães, 2013). Also, to speed up the writing and evaluation of the thesis, institutions and graduate programs in several countries, including Brazil, have chosen to replace the writing of the thesis chapters with articles.

Although the number of publications has increased in the last two decades, this number is still very low. Thus, it is necessary to consider two reasons for this result; first, lower investment in research in the emergent and developing countries (Andrade et al., 2010), leaving gaps in the current situation of the ecological systems. Second, most of the researchers have their fields of studies focusing on one aspect or another (Liao & Huang, 2013).

Urban ecology integrates natural and social sciences to study radically altered local environments and their regional and global effects (Grimm, 2008). Among ecological studies in Santa Catarina Island, it has been observed an increase in the number of publications on sub-areas as land use and land cover, water quality and socio-environmental in the last two decades. Besides, the third decade also showed an increase in zoology and hydrology (Fig. 4).

Urban development is a leading cause of stream degradation, resulting in a reduction of biodiversity and negatively affects ecosystem processes, habitat and services (Smucker & Detenbeck, 2014). The analyzed sub-areas have been explored in several studies of urban ecology (Karaer & Kucukball, 2006; Cooper et al., 2013) because they are directly affected by increased urbanization, which reinforces our findings. Indeed, studies have shown that the main causes of contamination in the coastal zone of Brazil are related to the population densification process (Braga et al., 2006; Pagliosa et al., 2005).

Studies have shown that, despite the variety of watershed characteristics and urban development, synthesis efforts in the last two decades has been focused primarily on describing and analyzing commonalities between urban streams (Paul & Meyer, 2001; Walsh et al., 2005; Wenger et al., 2009).

Although there is a positive relationship between urban growth and an increase in the number of aquatic ecology studies in the present study, the fifteen studied watersheds have not shown a proportional increase of publications in agreement with the urban gradient (Fig.1). In other words, the most urbanized watersheds were not the same watersheds that presented the largest number of publications. However, sub-areas more explored in these studies were present in watersheds that showed a higher number of publications, amongst them "*Land use and land cover* and *socioenvironmental*" was present in the publications of all watersheds (Fig. 5).

The watersheds with the largest number of publications were Lagoa do Peri, Itacorubi, Ratones, Lagoa da Conceição and Rio Tavares. In the exception of Itacorubi watershed (with 40.7% of the urban area, until the present date), these watersheds showed a low gradient of urbanization in their drainage areas. However, the positive correlation between the number of publications and drainage areas (watersheds size), shows that the largest watersheds are also the most studied.

A high level of the economic importance of these watersheds probably has contributed to the increase in the number of studies. It is known that water quality and good ecological status within watersheds are important for the economic activities developed, as supplying drinking water (Lagoa do Peri watershed), recreation (Lagoa do Peri, Lagoa da Conceição, Itacorubi watershed) and for the maintenance of the mangrove ecosystem (Itacorubi, Ratones, and Rio Tavares) (Silva, 2019; Barbosa & José, 1998; Torres et al., 2002).

Despite the importance of these watersheds, previous studies have focused only in the nutrient loading increase, as, Lagoa do Peri Watershed (Henneman and Petrucio 2010; Lemes-Silva et al. 2016; Tonetta et al. 2017) and Lagoa da Conceição watershed (Silva et al. 2017), but not evaluated relationships between land use and water quality of the main tributaries that supply watersheds.

Lagoa do Peri watershed plays an important role in supplying drinking water for about 25% of the Florianópolis Island population (Torres et al. 2002) and Lagoa da Conceição watershed is one of the main places for recreation and fishing in the Santa

Catarina Island (Silva, 2019). Thus, studies of these correlations can provide important results for the management of these natural resources.

On the other hand, watersheds which have show less than ten publications over the three decades, exhibited the highest gradient of urbanization (Fig.1), except Lagoinha do Leste, Saquinho and Ribeirão da Ilha, which showed their drainage areas free of urbanization or low-level of urban areas. It's possible that the low gradient of urbanization in the first two watersheds may be due to smaller drainage areas of these watersheds (Tab. 1), constituted in a mountain chain of the high slope, corroborating with Pegas-Filho & Tirloni (2009).

Studies have evidenced that urban growth in watersheds produces several disturbances that impair the functioning and maintenance of ecosystem services provided by these environments (Karaer & Kucukballi, 2006; Cooper et al., 2013). Even in relatively pristine watersheds, stream diversions can result in decreased flow velocity and water depth, reducing habitat availability (Brasher, 2003).

Studies on the biological health of lotic communities have a negative correlation with the amount of urban land use in the surrounding watershed. According to Miltner et al., (2004), the health of streams, declines significantly e.g., when the amount of urban land use measured as impervious cover exceeded 13.8% and fell below expectations when impervious cover exceeded 27.1%. Thus, the higher values of the urbanized area in Costeira, Santo Antonio and Ingleses watersheds (between 22 and 29%) and Cacupé and Morro das Pedras watersheds (more than 30%) suggest that these streams may have their water quality and integrity compromised. The few numbers of studies may be contributing to the lack of knowledge of the quantity and quality of water for human supply, economics, health and the conservation of water resources and subsequent management in these environments.

In recent years a large amount of studies focus on urban streams, but many questions about the mechanisms driving these changes remain unanswered (Wenger et al., 2009). Santa Catarina Island, with watersheds ranging from the relatively pristine to the highly degraded, may offer an opportunity to examine the impacts of human disturbance on water quality and native stream communities.

2.7-Conclusions

Our results indicated that, in general, the greatest urbanization increase occurred between the 1990s and the 2000s. The positive relationships between increased urbanization and a number of publications suggest that anthropic pressure may have led to a slight increase in the study in urban areas. However, we observed differences in this expansion for each watershed, and the most urbanized watersheds were not necessarily the watersheds with the largest number of publications.

The areas more explored in these studies were *Land use and land cover* and *socioenvironmental*" which were present in the publications of all watersheds. The low number of studies associated with the increase of urban areas in the last decades, in sensitive areas to the modifications, can lead to a decline in biological integrity due to the lack of knowledge for evaluation and management in these environments.

Understanding the relationship between habitat alteration and aquatic systems structure is critical for developing management strategies. Future studies must be developed to evaluate how specific management strategies can lessen the negative impacts mainly in sensitive environments of socio-environmental importance.

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Capítulo II

Urbanization increases carbon concentration and pCO$_2$ in subtropical streams

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3.1-Abstract

Urbanization growth may alter the hydrologic conditions and processes driving carbon concentrations in aquatic systems through local changes in land use. Here, we explore dissolved carbon concentrations (DIC and DOC) along urbanization gradient in Santa Catarina Island, to evaluate potential increase of CO_2 in streams. Additionally, we assessed chemical, physical and biotic variables to evaluate direct and indirect effects of urbanization in watersheds. We defined 3 specific urbanization levels: high (>15% urbanized area), medium (15-5% urbanized area), and low (<5% urbanized area) urbanization. The results showed that local changes due to growth of urban areas into watersheds altered the carbon concentrations in streams. DOC and DIC showed high concentrations in higher urbanization levels. The watersheds with an urban building area above 5% showed pCO$_2$ predominantly above the equilibrium with the atmosphere. These findings reveal that local modifications in land use may contribute to changes in global climate by altering the regional carbon balance in streams.

Key words: Watershed, Urban effects, Riparian degradation, Streams integrity, Dissolved carbon, Oversaturated pCO$_2$

3.2-Introduction

Urban ecosystems affect and are affected by environmental changes (Paul and Meyer 2001). The growth of urban areas has changed land use and land cover altering biogeochemical cycles (Wang et al. 2018), climate and hydrosystems at local and global scales (Grimm et al. 2008). Watersheds play an important role in biogeochemical cycles once the water chemistry and nutrient export in streams are determined by interactions between hydrological and biogeochemical processes that occur in the watershed scale and within the stream channels (Vink et al. 2007). These processes are also influenced by climatic conditions, in-stream processes, a set of watershed features and anthropogenic pressures (Andrade et al. 2011; Booth et al. 2016; Campeau and Del Giorgio 2014). Furthermore, given their position in landscape, watersheds of urban areas are particularly vulnerable to impacts associated with land use changes (Walsh et al. 2005).

Several studies have demonstrated that urbanization changes the functioning of streams by altering the hydrologic regime (e.g. input of runoff via stormwater), physical habitat, and physicochemical properties (e.g. input of nutrients and pollutants) (Walsh et al. 2005; Parr et al. 2015). The growth of urban areas into watersheds results in input of sewage and stormwater runoff in streams, impervious surface, increasing organic carbon and nutrients concentration (Han et al. 2017), microbial activity and reducing dissolved oxygen concentration and biodiversity (Karaer and Kucukballi 2006; Cooper et al. 2013). Land use and climate change may alter the hydrologic conditions and processes, which control carbon dynamics in rivers (Striegl et al. 2007; Barnes and Raymond 2009; Souza et al. 2011). Therefore, these systems can affect regional carbon balances by constraining other components of the global carbon cycle, most notably terrestrial net ecosystem production (Cole et al. 2007) and thus carbon emission via water–air interface (Wang et al.2017).

The major biogeochemical role of streams in the global carbon cycle is the fluvial export of organic carbon and dissolved inorganic carbon to the ocean (Degens et al. 1991; Aufdenkampe et al. 2011). However, carbon dioxide (CO_2) emission via water-air interface from fluvial networks plays an important role in the global carbon budget (Li et al. 2020). Watercourses can process carbon during downstream transport emitting significant amounts of carbon dioxide (CO2) to the atmosphere (Cole et al. 2007; Aufdenkampe et al. 2011; Sawakuchi et al. 2017; Ni and Li 2019). The accurate determination of dissolved inorganic carbon (DIC) and CO2 is a crucial part of the study of carbon in aquatic systems (Åberg and Wallin 2014), in which high partial pressures of CO2 translate into large gas evasion fluxes from water to atmosphere (Raymond et al. 2013; Abril et al. 2014).

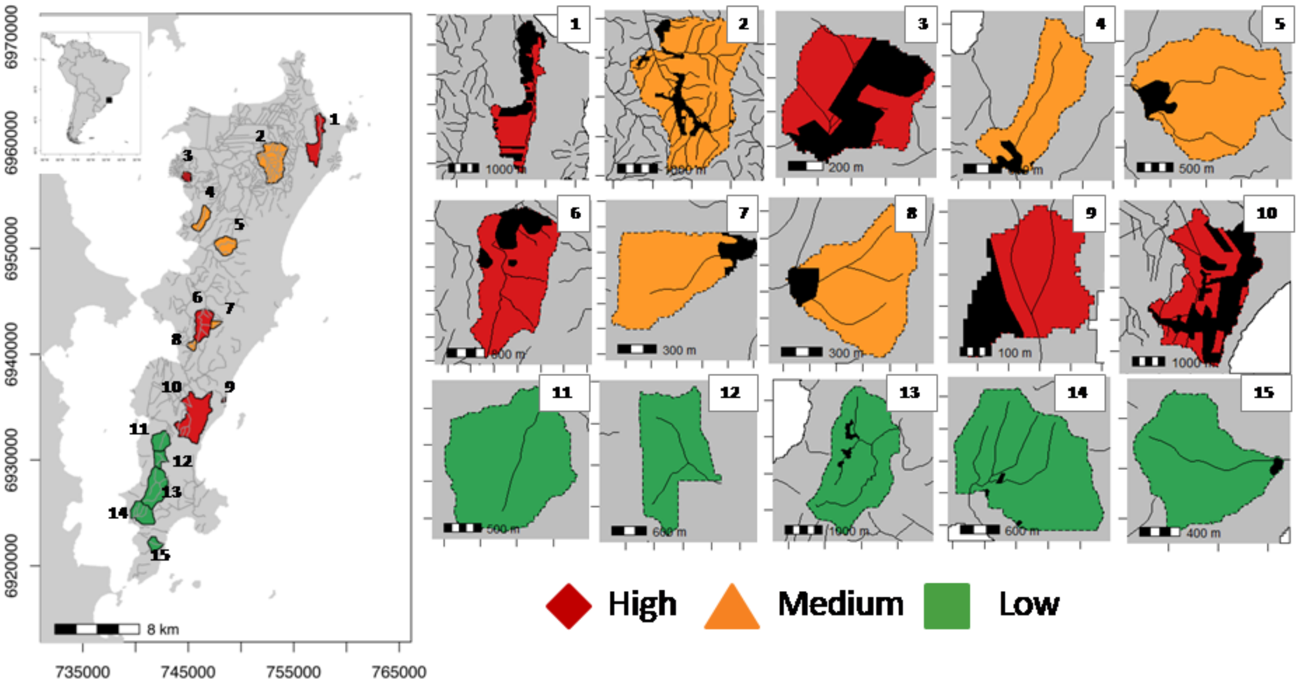
Streams can be either net sources of CO_2 to the atmosphere and ocean or sinks of organic carbon that go into the sediment in the active channel or riparian zone (Aufdenkampe et al. 2011; Wohl et al. 2017) within a watershed's carbon budget. Tropical streams are recognized as sources of CO_2 to the atmosphere which partial pressure of CO_2 (pCO_2) often exceed the atmospheric equilibrium (Rasera 2013; Abril et al. 2014). The above-mentioned studies have mainly focused on large tropical rivers. Nevertheless, there are few studies evaluating the effects of urbanization on carbon concentration of subtropical streams. Here, we evaluate the direct and indirect effects of urbanization gradient on the dissolved carbon concentrations (DOC and DIC) and CO2 partial pressure of subtropical streams in Southern Brazil. We tested the hypothesis that higher urbanization levels in small watersheds may promote an increase in dissolved carbon concentrations and *p*CO2 due to land use changes.

3.3-Methods

Study area

The study was carried out in Santa Catarina Island (27°34'S 48°27'O), located in Florianópolis city, Southern Brazil (Nascimento 2002). The climate in the region is humid subtropical Cfa (Peel et al. 2007), with rainfall well distributed throughout the year, although more intense events are observed during spring and summer months (Hennemann and Petrucio 2011; Lemes-Silva et al. 2014). Florianópolis has been a major draw for tourism, resulting in increase in urbanization (Wemple et al. 2017) with a subsequent population growth in the last decade (Guerra et al. 2016). The Santa Catarina Island has fifteen major watersheds, with differences in land uses and percentage of urbanized area. We evaluated a stream in each watershed, where all streams (15 streams) was classified as low order and represents the main watercourse of the studied watersheds. This sample design ensures a wide spatial distribution throughout the study area (Fig.1a). The sampling sites were chosen downstream of urban areas, comprising an extension of 30 meters for each stream. These sites represent an urbanization gradient, which was classified according to the land cover.

Figure 1a-b. Map of sampling locations in the Santa Catarina Island -SC, Brazil, with watersheds aggregated by urbanizations levels (High:>15%= red, Medium: 5-15%= orange and Low :<5%= green). Watershed map with hydrography and showing urbanization area (black) of sampling locations.



Land Cover and Basin Hydrology Analysis

We used an urbanization gradient design, which enabled to differentiate the local effects of urbanization across a range of land use and land cover (Gianuca et al. 2017). Firstly, we accessed a Digital Elevation Model (DEM) with 30m resolution (SIGSDS 2017). In order to delimitate the catchment area of each watershed we used the algorithm r.watershed (GRASS GIS 7) implemented in QGIS software. After the delimitation of each watershed, we contrasted those areas with the actual built-up areas to obtain the percentage of area covered by buildings.

The present urbanized areas (scale: 1:50000) were provided by the Institute of Urban Planning of Florianópolis – IPUF. Considering the urbanized area percentage, we defined 3 specific urbanization levels: high (>15% urbanized area), medium (15-5% urbanized area), and low (<5% urbanized area) (Fig.1a-b). The urbanized area refers only to buildings (not roads, parking lots, etc.), and 15% urbanized area translate into a very high level of urbanization (Gianuca et al. 2017). Also, we obtained the upstream distance from urban areas to each sampling site coordinate in GIS software. We evaluated 5 streams per each urbanization level. Additionally, to access the direct changes of urbanization process, the rapid assessment protocol (RAP) was applied for each sample campaign in each sample point by 3 different researchers. The RAP used was modified considering the protocol applied by Nessimian et al. 2008, in order to adapt the variables to the characteristics of the study field (Appendix A). The indicators compiled by RAP are qualifiers of the water body that show and evaluate the environmental conditions of the system (Kandziora et al. 2013), providing data about aquatic life and water quality, besides the presence of riparian vegetation, solid waste and pollution point sources along the river. Ten parameters were analyzed to describe the environmental local changes, concerning riparian deforestation, increase in sediment deposition/erosion and modifications in baseflow. Based on these characteristics, we produced an adapted Habitat Integrity Index (HII) to show the local changes in the physical structure of streams. This index varies from 0 to 20, and it is directly related to local changes in streams. Values close to 0 represent a more modified environment, whereas values closes to 1 represent a more pristine system.

Sampling methods

Samplings were conducted in two campaigns, the first one was in September 2016 and the second was in June 2017. The study sites was classified into 3 specific urbanization levels, and a total of 30 samplings were evaluated (ten samplings at each urbanization level). Water temperature (±0.2ºC accuracy and 0.1ºC resolution), electrical conductivity (±0.2 µs/cm accuracy and 0.1 µs/cm resolution), dissolved oxygen (±0.2 mg l^{-1} accuracy and 0.1 mg l^{-1} resolution) and pH (±0.004 accuracy and 0.001 resolution) were measured *in situ* in each stream with a multiparameter meter (YSI-85). One liter of water sample was collected to determine the dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), nitrate (NO_3^-), soluble reactive phosphorus concentrations (SRP) and Chlorophyll- a. The quality control of water chemicals (SRP, NO_3^- and Chlorophyll- a) were sampled through Standard Methods for the Examination of Water and Wastewater (APHA, 2012) with duplicates for each sample. For $NO_3^-$and SRP concentrations the water samples were filtered (glass fiber filter Whatman GF/F, nominal porosity of 0.7 µm) and preserved with thymol for subsequent analysis using a flow injection analysis (FIA).

DOC and DIC were determined separately in a Shimadzu total carbon analyzer (Model TOC-VCPH). For DOC samples, 30 ml of water was filtered through 0.7 µm pore size combusted GF/F filters (Whatman). DOC was measured on $HgCl_2$ preserved samples after the extraction of DIC by acidification and sparging. For DIC samples, 60 ml of water was filtered through 0.47 µm cellulose acetate membrane filters (Millipore). DIC was measured directly as DIC in the other sample preserved with thymol. DIC samples were analyzed for total organic carbon before acidification. Then, the samples were acidified using 6N HCl and sparged to remove gas and reanalyzed for total organic carbon.

Chlorophyll-*a* was measured spectrophotometrically after extraction from filters using 90% acetone, with correction for phaeopigment (Lorenzen 1967). Rainfall data were obtained from the Information Center for Environmental Resources and Hydrometeorology of Santa Catarina (EPAGRI/CIRAM) through the station number 02748024. For this study, the rainfall was calculated from accumulated precipitation for seven days before the sampling day. Stream discharge was calculated by the mechanical current-meter method (Model 2030 Series-General Oceanics) according to Santos et al. (2001).

Analytical methods

Dissolved organic and inorganic carbon concentrations were determined with a total organic carbon analyzer (Shimadzu TOC-5000 analyzer) whereas DOC was measured after acidification and sparing with N_2 to remove DIC. DIC was calculated as the difference between non-acidified and acidified/sparged samples. This method may slightly underestimate DIC concentrations due to degassing during filtration. However, this method has been compared to DIC calculations from CO_2 values and the variation is typically minimal, whereas alkalinity titrations result in high amounts of error in DOC-rich acidic waters (Neu et al. 2011).

DIC fractions (HCO_3^-, dissolved CO_2, CO_3^{-}) and pCO_2 (partial pressure of CO_2) were calculated based on DIC, pH and temperature, using thermodynamic equilibrium equations (Skirrow 1975), and ionic strength was estimated from EC (Snoeyink and Jenkins 1980). The majority of dissolved CO_2 values reported for natural waters have been, to date, through carbonate equilibrium calculations from measured pH and total alkalinity (Liu and Raymond, 2018). However, reported partial pressures of dissolved CO_2 and corresponding dissolved CO_2 concentrations in organic-rich and low pH inland freshwaters are likely overestimated (Abril et al. 2015).

These overestimations of CO_2 calculations in comparison with directly measured CO_2 are due to a more significant contribution of organic acids anions in waters with low carbonate alkalinity and high DOC concentrations besides of a lower buffering capacity of the carbonate system at low pH, which increases the sensitivity of calculated pCO_2 in acidic and organic-rich waters. In this study, we only used pH values between 6.0 and 8.0, in order to avoid CO_2 under- or overestimates as suggested by Abril et al. (2015). The pCO_2 was evaluated to determine if the streams present potential above or below the equilibrium with the atmosphere. Data from the Mauna Loa Observatory was used to access the current atmospheric CO_2 concentration (Dlugokencky and Tans 2016).

Statistical analyses

We used a non-parametric Kruskal-Wallis *H* test to compare variations of the chemical, physical and biotic variables among the urbanization levels (low, medium, high) previously described. Statistical significance was calculated using Chi-square test ($\chi2$) and sets around p-value < 0.05. When a significant difference was detected, a pairwise test for multiple comparisons of ranked data (Conover's post-hoc test) with a Bonferroni correction was performed in order to explore these differences among urbanization levels using PMCMRplus package (Dinno, 2017). Conover test (Conover, 1999) computes the stochastic dominance and reports the results among multiple pairwise comparisons after a Kruskal-Wallis test for stochastic dominance among k groups (Kruskal and Wallis, 1952).

Spearman's Correlation Analysis was performed using all sampled sites (n = 30), in order to evaluate direct and indirect effects of urbanization in pCO_2 for studied watersheds which has shown significant variables ($\chi2$, p-value < 0.05). For this analysis, we used the package 'pspearman' (Savicky, 2015). We used nonparametric statistics since no normal distribution was found (p-value > 0.05; Shapiro Test).

Generalized Linear Models (GLM) were performed to assess the relationship between environmental variables and pCO_2. Multicollinearity was verified by examining the Variance Inflation Factor (VIF) (Fox 2008) and only significant non-redundant variables were included in the model. The variables used as predictors in the models were: DIC, DOC, pH, dissolved oxygen, temperature, SRP, rainfall, discharge, urban area percentage, watershed area, upstream urban distance, HII (RAP) and Chlorophyll- *a*, with the addition of $pCO_{2.}$ We applied the Gamma probability distribution model with a link-log function, which relates the mean value of a variable to its linear predictor (Crawley 2005). The best model was selected based on the

Akaike's information criterion (AIC), and only models with ΔAIC < 4 were considered (Bolker 2008). A coefficient of pseudo-determination (pseudo-R^2) was calculated to examine the fraction of the explained variance by the selected model according to Zuur et al. (2009). All statistical analyses were performed using the software R Studio version 1.1.383 (R Core Team 2015).

3.4-Results

Over the 30 samplings, water temperature (WT) showed oscillations, reflecting a typical climate of subtropical region. The maximum recorded value was 20.8°C and the minimum was 13.9°C. WT did not show significant differences among urbanization levels ($\chi2$, p-value = 0.09). However, high temperature values were found in high urbanization level (mean WT = 19.01°C) (Tab.1).

Table-1. Mean and standard deviation, maximum and minimum of different stream environmental variables in the three different urbanization levels, Low, Medium, and High, with χ^2, and p-value presented for Kruskal-Wallis tests

		Urbanization level		
		Low <5%	**Medium 5-15%**	**Hight >15%**
pH	Mean-sd	6.15 - 0.75	6.65 - 0.47	6.50 - 0.36
	Min	5.38	6.06	5.8
	Max	7.83	7.71	7.03
	Kruskal-Wallis	χ^2= 5.077, p-value= 0.079		
DO (mg L^{-1})	Mean-sd	8.03 - 1.53	8.38 - 0.73	4.5 - 3.07
	Min	5.21	7.33	0.26
	Max	9.92	9.42	8.9
	Kruskal-Wallis	χ^2=9.12, p-value= 0.010		
Water temperature (C°)	Mean-sd	17.75 - 1.73	17.81 - 1.46	19.01 - 1.45
	Min	13.9	15.1	15.9
	Max	19.7	19.5	20.8
	Kruskal-Wallis	χ^2= 4.73, p-value= 0.094		
SRP (mg L^{-1})	Mean-sd	0.026 - 0.047	0.056 - 0.109	0.358 - 0.454
	Min	0.001	0.001	0.001
	Max	0.159	0.363	1.168
	Kruskal-Wallis	χ^2= 9.40, p-value= 0.009		
DOC (mg L^{-1})	Mean-sd	2.19 - 0.93	2.92 - 1.32	6.18 - 3.21
	Min	0.84	1.16	2.21
	Max	3.40	4.94	11.01
	Kruskal-Wallis	χ^2= 10.23, p-value= 0.006		
DIC (mg L^{-1})	Mean-sd	1.77 - 0.63	3.17 - 0.30	9.04 - 8.75
	Min	0.91	2.63	2.87
	Max	2.57	3.65	25.82
	Kruskal-Wallis	χ^2= 22.35, p-value= 0.014		
Dissolved CO_2 (µM)	Mean-sd	25.99 - 17.47	27.84 - 13.18	84.87 - 78.08
	Min	1.36	3.46	18.25
	Max	53.15	48.94	258.72
	Kruskal-Wallis	χ^2=8.0206, p-value= 0.018		

HCO_3^- (μM)	Mean-sd	14.30 - 12.21	44.25 - 16.13	120.69 - 128.06
	Min	2.35	22.81	19.56
	Max	36.88	71.83	382.38
	Kruskal-Wallis	χ^2=16.815, p-value= 0.0002		
pCO_2 (μatm)	Mean-sd	377.305 - 274.67	665.519 - 327.59	2145.196 - 2029.52
	Min	32.555	84.035	410.147
	Max	825.064	1226.948	6736.886
	Kruskal-Wallis	χ^2=8.2297, p-value= 0.016		
HII (RAP)	Mean-sd	12.33 - 4.46	7.22 - 3.04	5.33 - 2.10
	Min	7.17	3.1	3.7
	Max	16.93	11.17	9.1
	Kruskal-Wallis	χ^2= 12.47, p-value= 0.002		
Discharge (cm^3 s^{-1})	Mean-sd	0.13 - 0.32	0.05 - 0.11	0.08 - 0.25
	Min	0.004	0.01	0.0
	Max	1.03	0.36	0.78
	Kruskal-Wallis	χ^2= 7.26, p-value= 0.027		

Differences among urbanization levels

Differences were found for chemical, physical and biotic variables among (Tab. 1). Groups with low and medium urbanization levels were characterized by higher values of DO and HII. The high urbanization level differs from low and medium urbanization levels ($\chi2$, p-value < 0.05) for all variables, except for HII, with significant variance between them ($\chi2$, p-value = 0.002).

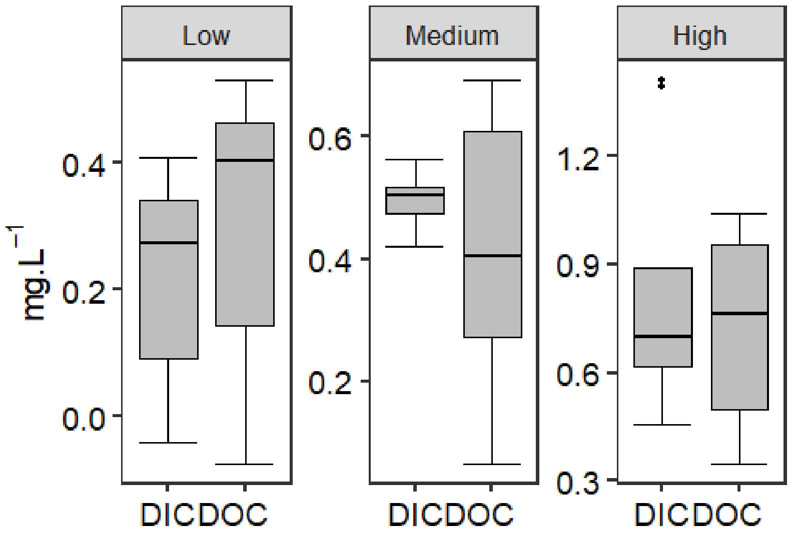
Statistical differences on watershed scores were detected for discharge ($\chi2$, p-value = 0.02). Yet, low urbanization level was larger across upstream distance from urbanization. Statistical differences were also detected for SRP concentrations between low and high urbanization levels ($\chi2$, p-value = 0.004, Tab. 1). Watershed area showed a large range among sampling sites (1,298.24 and 97,388.99 Km^2) and have not shown significant differences among urbanization levels ($\chi2$, p-value = 0.96). The mean Chlorophyll-a concentration did not show significant differences among urbanization levels ($\chi2$, p-value = 0.14), although the highest concentration (10.15 μg L^{-1}) was recorded within high urbanization level.

Distribution patterns of DOC and DIC

Distribution of organic and inorganic carbon in the streams are shown in Fig. 2. An increase in DOC concentration along the urbanization levels was observed. Through pairwise comparison test among the urbanization levels, we observed that only the high level of urbanization presented significant differences in relation to the medium and low levels ($\chi2$, p-value = 0.006). The concentrations varied from 0.84 mg L^{-1} to 11.01 mg L^-

[1]. The mean concentration of DOC in high urbanization level was 6.18 ± 3.21 mg L^{-1} (mean ± SD), whereas in medium urbanization level was 2.92 ± 1.32 mg L^{-1} (mean ± SD), and in low urbanization level was 2.19 ± 0.93 mg L^{-1} (mean ± SD). As indicated in Fig. 2, DOC concentrations increase three times more with urbanization growth.

Figure 2. Boxplots grouped by urbanization level for dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) concentrations (log 10). Boxes indicate 25th and 75th percentiles, with the solid black line within the box indicating the mean value. Whiskers extend from the box to observations with values within 1.5 times the inner-quartile range of the box, with other observations appearing as outliers. It is important to note that the y-axis of the scale are different.



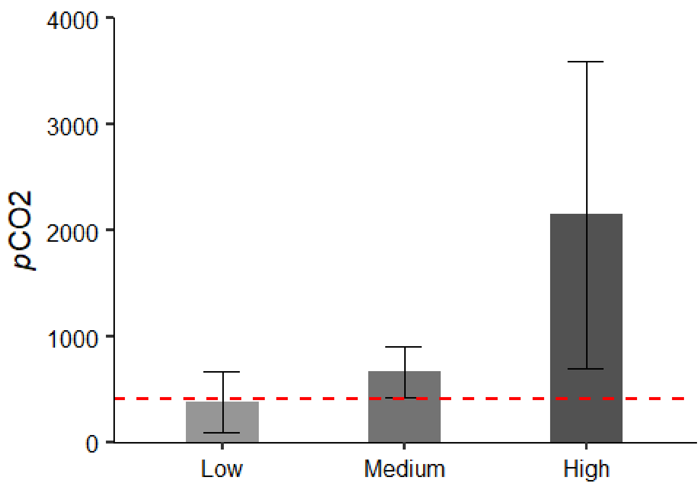
All urbanization levels (low, medium, high) showed significant differences in DIC concentrations (χ2, p-value = 0.014). We observed a gradual increase in DIC concentration in all urbanization levels, where it was possible to observe almost twice as much increase in streams with medium urbanization and five times higher for those within high urbanization level. The lowest concentration was observed in low urbanization level (mean = 1.77 ± 0.63 mg L^{-1}; minimum = 0.91 mg L^{-1}; maximum= 2.57 mg L^{-1}). In the medium urbanization, the mean concentration of DIC was 3.17 ± 0.30 mg L^{-1} (minimum = 2.63 mg L^{-1}; maximum= 3.65 mg L^{-1}) and in high urbanization, the mean concentration of DIC was 9.04 ± 8.75 mg L^{-1} (minimum = 2.87 mg L^{-1}; maximum = 25.82 mg L^{-1}) (Fig.2).

DIC fractioning and CO_2 partial pressure (pCO_2)

Regardless of the gradual increase of DIC concentration, the proportional contribution of each DIC fraction was similar among low and high urbanization levels, with 46% and 44% of dissolved CO_2, respectively. Bicarbonate (HCO_3^-) contribution was 53% and 55% for low and high urbanization levels, respectively. In medium urbanization level a decrease in dissolved CO_2 contribution (39%) and an increase in HCO_3^- (60%) were observed. The dissolved CO_2 concentration showed significant differences between high and medium urbanization levels ($\chi 2$, p-value = 0.02), and between high and low urbanization levels ($\chi 2$, p-value = 0.045). The mean concentrations of dissolved CO_2 across urbanization levels were 25.99 ± 17.47; 27.84 ± 13.18; 84.87 ± 78.09 from low to high urbanization levels, respectively. We observed a gradual increase in HCO_3^- concentration among low (14.29 ± 12.21 µM), medium (44.25 ± 16.13 µM) and high (120.7 ± 128.06 µM) urbanization levels ($\chi 2$, p-value = 0.0002). A significant difference was observed between low and high urbanization levels ($\chi 2$, p-value < 0.001; Tab.1). Carbonate (CO_3^{-}) showed a minor contribution to the total DIC (<1%).

The pCO_2 was highly variable among urbanization levels. In general, high pCO_2 values were recorded in medium (665.519 ± 327.59 µatm) and in high urbanization levels (2,145.196 ± 2,029.52 µatm). The pCO_2 was predominantly above the equilibrium with the atmosphere (410 µatm). However, in low urbanization level, pCO_2 values were slightly below the average (377.305 ± 274.67 µatm; Fig.3).

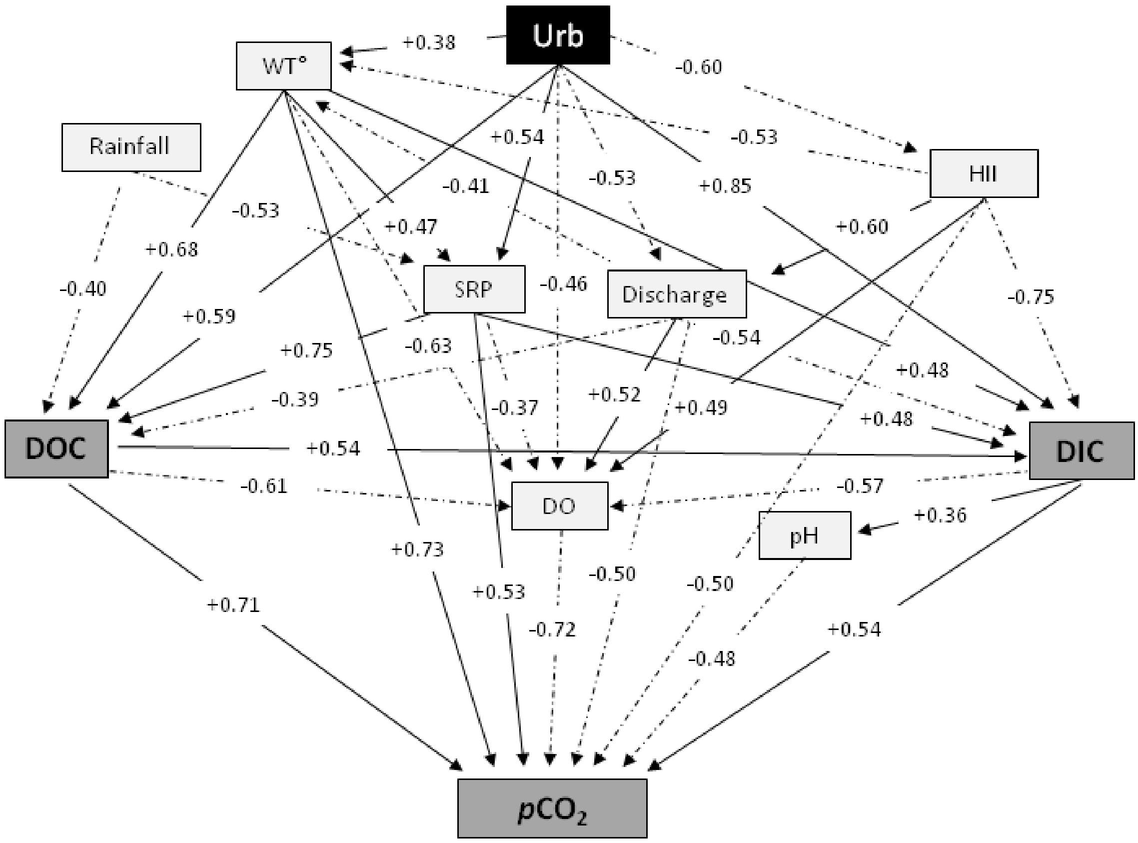
Figure 3. Vertical bars grouped by urbanization level represent the mean of partial pressure of carbon dioxide (µatm). The outside lines 75 and 25% confidence intervals. The dotted red line shows atmospheric CO_2 concentration (410 µatm).



Direct and indirect effects of the urbanization process in dissolved carbon concentrations and pCO_2

Rainfall has not shown a significant correlation with urbanization and WT, even though these variables showed direct and indirect correlation with DOC, DIC and pCO_2 (Fig. 4). Rainfall showed a negative correlation with DOC (r = -0.40, p-value = 0.03) and SRP (r = -0.53, p-value = 0.002). Both variables (DOC and SRP) were strongly correlated with pCO_2 (r = 0.71, p-value < 0.001, and r = 0.53, p-value = 0.002, respectively). WT increase was positively correlated with urbanization level (r = 0.38, p-value = 0.03), DOC (r = 0.68, p-value < 0.001), DIC (r = 0.48, p-value = 0.006) and SRP (r = 0.47, p-value = 0.008) and was negatively correlated with dissolved oxygen (r = -0.63, p-value = 0.0001, Fig. 4).

Figure 4. Diagram from Spearman's Correlation coefficients to parameters direct and indirectly related to dissolved carbon (DOC and DIC) and pCO_2 in Florianópolis streams. Solid lines represent positive correlations and dashed lines represent negative correlations. Urb=Urban area percent; DIC= Dissolved inorganic carbon; DOC= Dissolved organic carbon; pCO_2= partial pressure of carbon dioxide; DO= Dissolved oxygen; WT= Water temperature; SRP=PO_4; Rainfall= Precipitation (mm.7d); Discharge= Discharge (cm^3 s^{-1}); pH= Potential hydrogen; HII=RAP. All correlations were significant at P\0.05.



We observed that urbanization growth into the watersheds contributes to an increase of DIC and pH as can be evidenced by positive correlation demonstrated in Fig. 4. The increased concentrations of DIC along the urbanization gradient were contrasting with a decrease in habitat integrity (HII), reflecting the relevance of local changes in these streams (negative correlation). Dissolved oxygen was also a key environmental variable related to changes in the water chemistry, and to local changes of the watershed caused by a growth of urbanization process. DO was positively correlated with HII (r = 0.49, p-value = 0.005) and discharge (r = 0.52, p-value = 0.002), and both were negatively correlated with pCO_2 (HII: r = -0.50, p-value = 0.004, and discharge: r = -0.50, p-value = 0.005). Furthermore, DO was directly correlated with pCO_2 (r = -0.72, p-value < 0.001). In a spatial scale, urbanization levels showed a strong correlation with DOC (r = 0.59, p-value = 0.0006) and DIC concentration (r = 0.85, p-value < 0.001), and these two variables showed a positive correlation with pCO_2 (DOC: r = 0.71, p-value < 0.001; and DIC: r = 0.54, p-value = 0.002). Significant correlations results are shown in Fig. 4.

The relationships between all variables and pCO_2 were investigated using GLMs. The best model included DIC, Urban percentage (Urb), pH, HII and discharge (ΔAIC = 1.69). This model explained 89.6% of the pCO_2 variation (pseudo R^2 = 0.89) with four significant variables: pH, DIC, Urb and HII. Both variables DIC and Urb had a positive effect on pCO_2. The growth of urban percentage reflected an increase in DIC concentration and pCO_2 values. On the other hand, pH and HII showed an inverse relationship, with low values (characteristics of changes at local scale) associated to high values of pCO_2.

3.5-Discussion

Land use changes in urban watersheds may lead to loss of habitat integrity which is associated to the reduction of riparian forest, erosion/sediment increase and baseflow modification. These local modifications in streams alter the dissolved carbon concentrations (DOC and DIC) and elevate the pCO_2 to above the equilibrium with the atmosphere.

The urbanization growth can reduce the baseflow due to the low infiltration rates caused by increasing of impervious surfaces in urban areas. In the other hand, this effect may be counteracted by water runoff to the watershed (Walsh et al.2005; Parr et al.

2015), which in turn increases the baseflow. This could explain the increased discharge found in high urbanization level, which was probably a result of sewerage supply (Tab.1). Additionally, the integrity indexes reveal that the increased land use change and riparian degradation are usually covariates (Morley and Karr 2002; Booth 2005), that modify stream channels and reduce its natural flow (Brasher et al. 2003).

The inorganic carbon inputs from urban areas can be much higher than those from a naturally vegetated landscape, enhancing CO_2 production (Barnes and Raymond 2009, Ji and Chen 2017). It is plausible, therefore, that the loss of riparian forest, usually observed in more urbanized streams (as in the medium and high urban levels for the present study), may severely shift carbon balance in the watersheds due to reduction of lateral connectivity between the channel and riparian zone (Wohl et al. 2017).

Changes in land use primarily through increased soil erosion result in high sediment yield and make the mobilized carbon flux into streams become greater than the ability of most streams to stabilize carbon (Aufdenkampe et al. 2011; Wohl et al. 2017). Therefore, it’s likely that increasing urbanization is a primary driver behind the correlations between discharge and stream integrity (HII), and between these variables and the carbon dynamic (DOC, DIC and $p\mathrm{CO_2}$; Fig.4). The larger urbanized area in watersheds, the lower the natural baseflow and habitat integrity values and greater the carbon loads in streams. This carbon excess can contribute for both carbon load increase which is transported into the sea as to increase in CO_2 concentrations to atmosphere (Cole et al. 2007; Ni and Li 2019). These results show a significant decline in habitat integrity when the percentage of urbanized areas exceeds 5% (Tab 1).

Reduced baseflow due to urbanization usually results in water chemistry problems by increasing temperature (Walsh et al. 2005). This variation can be related to urban heat island effects in response to storms draining heated paved surfaces (Nelson and Palmer 2007, Grimm 2008). In tropical urban streams the growth of urbanization can lead to higher temperatures (Brasher et al. 2003). The positive correlations about WT and urbanization (Fig.4) were evidenced by increases of temperature in high urbanization level, followed by a significant increase in carbon concentrations (DOC, DIC) and $p\mathrm{CO_2}$ (Tab 1). This result may suggest that temperature and trophic status regulate biodegradability of DOC as showed in Southwest China rivers (Ni and Li 2019). Similar results were found in small subtropical streams where the temperature and concentrations of DOC increased with changes in land use (Hatt et al. 2004).

The causes of variation in water chemistry are primarily associated with features determining the supply of pollutants (e.g., sewage runoff by the growing level of urbanization) (Walsh et al. 2005). The significant increase in SRP and Chlorophyll-*a* concentrations can probably be related to an increased nutrient load, since there was also a slight increase in baseflow over streams with higher urbanization levels. The correlation between SRP with DIC and pCO_2 along the urbanization gradient corroborates that increased levels of nutrients can alter the fixation of DIC and the mineralization of organic carbon, which in turn have varied effects on carbon fluxes and can potentially stimulate the production of algae (Wohl et al. 2017).

Human-induced changes, such as the removal of riparian vegetation, can increase levels of light and temperature facilitating algal growth and causing reduction in dissolved Oxigen (DO) concentrations in streams (Carpenter et al. 1998; Cooper et al. 2013). Thus, the growth of urbanization leads to a decrease in DO level, suggesting that in-streams processes can contribute to increase DOC, DIC and pCO_2 concentrations. The strong correlations between DO and pCO_2 among streams demonstrated the importance of these processes in the control of pCO_2 concentrations (Fig.4).

It is known that urban runoff increases DOC concentration/export and changes organic carbon quality in streams (Westerhoff and Anning 2000; Kaushal et al. 2014). The higher DOC concentrations found in the high urbanization level may be influenced by sewage runoff and dumping, since the urban area covers more than 15% of these watershed areas (Fig.2). Several studies evaluating the influence of urbanization in streams over different regions and climates (Westerhoff and Anning 2000; Daniel et al. 2002; Liu and Sheu 2003; Vidon et al. 2008; Petrone 2010; Li et al. 2020) have shown similar values of organic carbon concentration as reported by the present study.

In inland waters, some fractions of DOC are typically mineralized to CO_2 and outgassed to the atmosphere, from a combination of background and anthropogenically altered sources (Aufdenkampe et al. 2011; Cole et al. 2013; Wallin et al. 2013; Cardoso et al. 2014). According to these authors, most of this carbon returns to the atmosphere as carbon dioxide (CO_2), explaining the strong positive correlation found here between DOC and pCO_2.

Furthermore, the positive correlation between DOC and DIC concentrations suggests that the load input in higher urbanization levels can be influenced by organic carbon mineralization, increasing DIC concentration and potentially increasing pCO_2 (Ni and Li 2019). The strong correlation observed between DOC and pCO_2 corroborates with Campeau et al. (2017), which showed that DOC mineralization, as well as in-stream processes, contributed to DIC fluxes.

Although DIC dynamics are known to be controlled by geology and soil types, several researchs has shown that DIC concentration increases in urban watersheds, mainly those that show a combination of human-accelerated weathering with sewage dumping (Leite 2004; Barnes and Raymond 2009; Kaushal et al. 2017). The increase in carbon flux caused by human activities is usually dominated by dissolved inorganic carbon from weathering and anthropogenic inputs (Cole et al. 2007; Kaushal et al. 2013). In the present study, we registered DIC predominance only in watersheds with more than 5% of urbanization area, suggesting that in low levels of urbanization, DIC concentration probably comes from natural sources (e.g. weathering).

Our results also suggest that the growth of urbanization areas and human-accelerated weathering have contributed to higher DIC concentrations in urban streams. Similar patterns were observed in small watersheds in temperate systems (Dawson et al. 2001; Campeau et al. 2017), while high values were observed in large watersheds (i.e., in temperate and subtropical regions) at sites close to urban areas (Souza et al. 2011; Kaushal et al. 2017). Although watershed size may influence carbon loading in streams, our results suggest that increasing land use may act as a more important driver of changes in carbon concentrations than the watershed size. This result corroborates with values found by Silva et al. (2007), which observed higher values of DIC in small subtropical basins under anthropic influence.

The growing watershed urbanization leads to accelerated weathering and has the potential to increase DIC and pH of urban waters (Kaushal et al. 2017). Carbon and mineral cycles are coupled mainly by chemical weathering, producing DIC and carbonate, buffering capacity that strongly modulate downstream pH, and CO_2 outgassing in rivers (Barth et al. 2003; Aufdenkampe et al. 2011). The small pH variability along the urbanization gradient most likely due to the carbonate ability to buffer the aquatic environment, may have contributed in the similar proportion in our study. On the other hand, there can be accumulation of weathering products and elevated pH, resulting in a slightly increase of HCO_3^- and less dissolved CO_2 in the medium urbanization level. The negative correlation between pH and pCO_2 (Fig.4) suggests that decrease pH values lead to increase in dissolved CO_2, driving the increase in pCO_2.

Increases in the export of DIC due to urban activities are related mainly to land disturbance activities and domestic effluent inputs, releasing more CO_2 to the watersheds and making the water more acidic (Barnes and Raymond 2009; Souza et al. 2011). Nevertheless, there may also be anthropogenic sources of carbonates in urban watersheds that can interact with climate variability and warming, and further influence pCO_2 in streams (Kaushal et al. 2014). The pCO_2 negatively correlated with pH and positively correlated with DOC (Fig. 4) observed in the present study is consistent with the observations of Abril et al. (2015) in 12 contrasting tropical and temperate systems in Europe, Amazonia, and Africa.

CO_2 emissions and DOC export are particularly high in the tropics, likely associated to high rates of terrestrial productivity and rapid erosion (Hilton et al. 2012). Additionally, when carbon budgets via runoff are include, stream evasion of CO_2 to the atmosphere can be larger than downstream DIC export (Wallin et al. 2010). We found that larger pCO_2 values occurred in high urbanization level, which was about 5 times higher than the equilibrium with the atmosphere. The watersheds in medium urbanization level showed pCO_2 mean values about 2 times higher than the equilibrium with the atmosphere, suggesting that the net effect of human activities could, therefore, to effectively convert streams from carbon sinks to carbon sources to atmosphere and ocean (Wohl et al. 2017).

Our values of pCO_2 were lower than those found in many streams without urbanization influence (Richey et al. 2002; Souza et al. 2011; Wallin et al. 2013; Bodmer et al. 2016). However, all streams in watersheds with more than 5% of urbanized area, presented oversaturated pCO_2 in relation to the atmosphere (Fig.3). Observed variation in pCO_2 values of streams studied showed that watersheds with more than 5% of urban building areas may act as carbon sources to the atmosphere. However, for an accurate result, we fully recommend a continuous sampling with direct measurements of pCO_2 for each stream studied.

3.6-Conclusions

In this study, there was a marked pCO_2 increase in subtropical streams in urbanization gradient, primarily due to enhanced local change in streams integrity. The growth of urbanization was the primary determinant of streams water quality degradation and increase of dissolved carbon concentration. Watersheds with more than 5% of urbanized area had direct and indirect effects on the dissolved carbon concentrations, mainly by the modification of land use and increase in runoff and sewage input into the streams. The lack of urban planning leads to loss of subtropical streams integrity, decrease in water quality, and a possible oversaturated pCO_2 in relation to the atmosphere.

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Capítulo III

Local determinants influencing water quality in low-order streams in Southern Brazil

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4.1-Abstract

The conversion of forest into urban and agricultural areas has increased the transport of the major ions into streams due to human-accelerated local changes. In this study, the abiotic and environmental influences of hydrochemical composition on urban streams (RG and CG) located in a protected area that plays an important role as water source for Santa Catarina Island's population were characterized. In addition, the relative importance of these metrics were quantified using variation partitioning analysis. Environmental metrics were described integrating remote sensing and *GIS tool* with habitat integrity index (i.e., local changes). RG showed clear signs of degradation (e.g., increases in Ca^{2+}, NO_3^- and Al^{3+} concentrations) and low habitat integrity index associated with nonpoint source of pollution and watershed size. Variation partitioning revealed that abiotic (e.g., dissolved oxygen, temperature and pH) and environmental metrics explained a great proportion of the variation in ion composition, with a relatively larger effect of the latter. In summary, anthropic activities increasing derived mainly from nonpoint sources of pollution may lead to local modifications, such as intensification of erosive processes and loss of riparian forest, and consequent decrease in water quality, compromising the integrity of streams.

Keywords: Subtropical, Urban watersheds, Land use and land cover, Local modifications, Ion concentrations

4.2-Introduction

Land use activities has generally been considered a local environmental issue, but it is becoming a force of global importance (Foley et al. 2005) that induces changes at different spatial and temporal scales (Kok and Veldkamp 2001). The growth of urban areas has changed many ecosystems by altering biogeochemical cycles, climate and ecosystem functioning at local, regional and global scales (Walsh et al. 2005; Grimm et al. 2008; Parr et al. 2016).

Environmental changes associated with urban development are especially evident in urban streams (Coles et al. 2012). Conversion of natural habitats into anthropogenic landscapes to cater to the increasing human demand for resources is one of the main factors behind the degradation of water quality (Giri and Qiu 2016; Su et al. 2016).

Meanwhile, watershed dynamics are fundamental to biogeochemical cycles since water chemistry and nutrient export in streams are determined by the interaction between hydrological and biogeochemical processes (Vink et al. 2007). Distinct geomorphic settings of low-order streams influence the spatial patterns of land use, which in turn may affect the water quality by altering sediments, chemical loads and watershed hydrology (Basnyat et al. 1999; Strayer et al. 2003; Kaushal et al. 2013).

In the past decade, several studies have demonstrated that changes in land use and land cover by a combination of human-accelerated ecosystem disturbances (i.e., deforestation, soil erosion, water pollution by chemical inputs and waste disposal) can increase the transport of the major ions into streams (Carey and Fulweiler 2012; Castillo et al. 2012; Kaushal et al. 2017).

However, the effect of land use on a stream ecosystem can vary depending on many factors, including riparian forest integrity, watershed size, location of pollution sources, the presence of other pressures, and the scale on which land use is measured (Roy et al. 2003; Dodds and Oakes 2008). Due to their close association with the landscape, low-order streams are highly vulnerable to land-use disturbances, such as deforestation, agriculture, the introduction of livestock and urbanization (Freeman et al. 2007).

Peri Lake watershed plays an important role in supplying drinking water for about 25% of the Florianópolis Island population (Torres et al. 2002) and is drained by low-order streams, that flows into Peri Lake. In the past three decades the watershed has been under pressure, mainly due to urban growth that drives changes in land use and cover (Cardozo et al. 2008). In recent years there has been an increasing concern regarding the deterioration of water quality and the nutrient loading increase into the downstream portion of those streams and the lake (Henneman and Petrucio 2010; Lemes-Silva et al. 2016; Tonetta et al. 2017).

Despite the importance of this watershed, previous studies have not evaluated relationships between land use and water quality of the main tributaries that supply Peri Lake, and at some extent are carrying all anthropogenic influences into this system. Such information is essential for regional land use planning and the sustainable use of water resources in this watershed, which is currently a Municipal Natural Monument and a Conservation Unit (Dechoum and Arellano 2016).

In this study were evaluate the main factors influencing water quality in two main streams of Peri Lake watershed (RG and CG), using an integrity index to evidence the local modifications (i.e. environmental metrics). The aims were to address the following questions.1) There are differences in the major ion concentrations and environmental metrics between the two streams? 2) Which environmental factors are more important for hydrochemical composition in low-order streams?

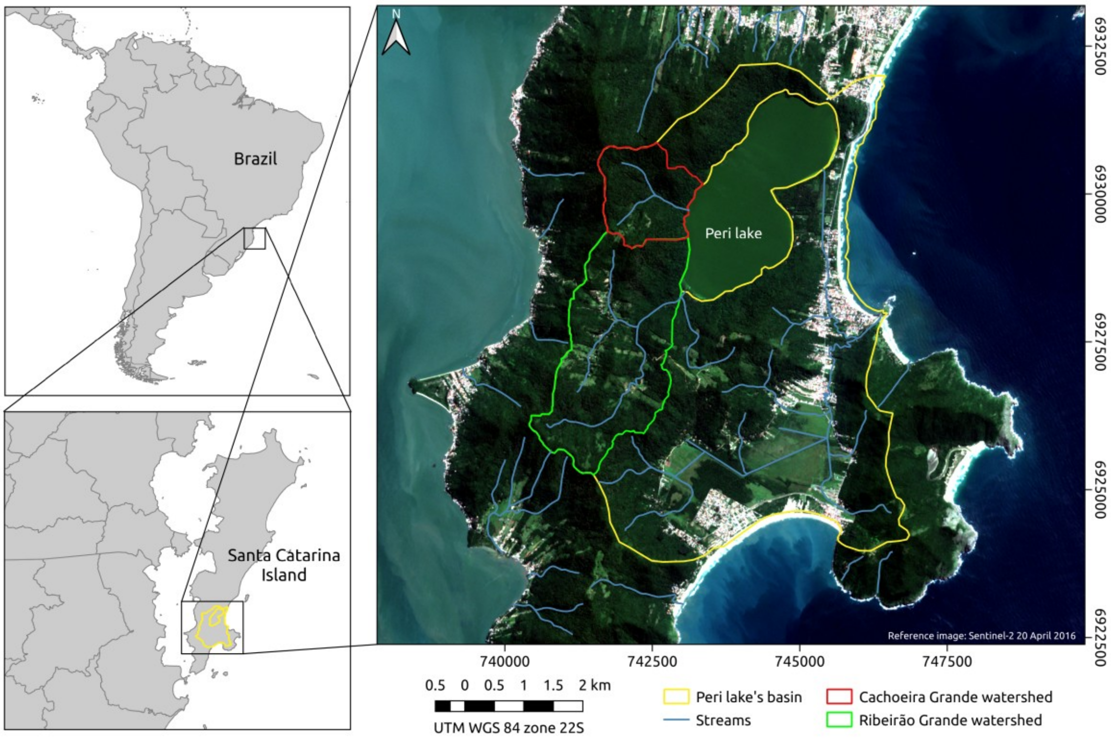
4.3-Methods

Study area

This study was conducted at the Peri Lake Municipal Natural Monument (PLMNM), a protected area located in Florianópolis city, Santa Catarina, Brazil (Pereira 2001). The PLMNM (27°44'S; 48°31'W) has a drainage area of 31.66 Km^2, which is surrounded by mountains with primary forest, namely Atlantic Forest, and a typical vegetation of coastal plain at lower altitudes (Cecca 1997). Its geology comprises a Precambrian crystalline complex and Quaternary sedimentary deposits (Santos et al. 1989; Neto and Madureira 2000). The climate in the region is humid subtropical (Cfa) according to the Köppen-Geiger climate classification (Peel et al. 2007), with rainfall well distributed throughout the year, but more intense events observed during the spring and summer months (Hennemann and Petrucio 2011; Lemes-Silva et al. 2014).

Sampling was conducted in Cachoeira Grande and Ribeirão Grande low-order streams, located in the western part of Peri Lake (Fig. 1). These sites show differences in land use patterns and percentage of built-up area, which was classified according to land cover.

Figure 1. Map of sampling locations in the Peri Lake Municipal Natural Monument (PLMNM), located in Santa Catarina Island, Santa Catarina, Brazil, with Cachoeira Grande and Ribeirão Grande, located in watersheds at the western part of Peri Lake. Hydrography map showing Cachoeira Grande watershed (red), Ribeirão Grande watershed (green), belonging to Peri Lake basin (yellow).



Land use and land cover patterns (LULC) and environmental metrics

In order to delineate the drainage area of each watershed, a Digital Elevation Model (DEM) with 30m spatial resolution was processed downloaded from the Santa Catarina State data repository (SIGSC 2017). The algorithm *r.watershed* of GRASS GIS software version 7.2 (GRASS Development Team 2017) was implemented using Quantum GIS software, version 2.74 (QGIS Development Team 2017). The algorithm was used to delineate the watershed boundaries. Quantum GIS processing tools were used to calculate the area of each land-use type within each watershed, which was subsequently divided by the watershed area to derive the relative cover percentage. In addition, two images from the Sentinel 2 satellite (Copernicus Sentinel data 2017, processed by ESA) were used for mapping the natural and anthropic areas. Scenes from the period April 20 2016 and November 11 2017 were used to vectorize land use classes, i.e. natural and anthropic. The images were selected based on the absence of cloud coverage and because their acquisition dates were either before or after the period of stream sampling. Other spatial information related to the physical environment available in the Santa Catarina State data repository, such as soil type and vegetation maps, were also used to improve the understanding of spatial patterns in the study area.

Based on QGIS analysis, land use was categorized into three groups: 1) forest; 2) urban + agriculture areas, including built-up areas and croplands; and 3) pastures. The anthropic areas were classified as point or nonpoint source of degradation, according to the QGIS generated image tools.

The environmental metrics were described based on rapid river assessment protocol (RRAP), and was applied by 3 different researchers. The RRAP used was modified considering the protocol applied by Nessimian et al. 2008, in order to adapt the variables to the characteristics of the study field (Appendix A). The indicators compiled by RRAP are qualifiers of the water body that show and evaluate the environmental conditions of the system (Kandziora et al. 2013), providing data about aquatic life and water quality, besides the presence of riparian vegetation, solid waste and pollution point sources along the river. Ten parameters were analyzed to describe the environmental local changes, concerning riparian deforestation (rip), increase in sediment deposition/erosion (eros) and modifications in baseflow (flow). Based on these characteristics, was produced a Habitat Integrity Index (HII) for each local change (HIIrip, HIIeros, and HIIflow). This index varies from 0 to 20, and it is directly related to local changes in streams. Values close to 0 represent a more modified environment, whereas values closes to 1 represent a more pristine system.

Sampling methods

Monthly sampling was conducted from April 2016 to March 2017, yielding a total of 12 sample sets each stream during all stages of streamflow comprising a hydrologic year. The sampling sites were close to the stream mouth (50 m). Water temperature (±0.2ºC accuracy and 0.1ºC resolution), electrical conductivity (±0.2 µs/cm accuracy and 0.1 µs/cm resolution), dissolved oxygen (±0.2 mg l-1 accuracy and 0.1 mg l-1 resolution) and pH (±0.004 accuracy and 0.001 resolution) were measured in situ in each stream with a multiparameter meter (YSI-85) and will be considered in this study as abiotic metrics.

One litter of water sample was collected to determine the ions concentration. The quality control of water chemicals were sampled through Standard Methods for the Examination of Water and Wastewater (APHA, 2012) with duplicates for each sample. The samples used for dissolved ion analysis were filtered (glass fibre filter Whatman GF/F, nominal porosity of 0.7 mm), then kept in high-density polyethylene bottles (60 mL) and preserved with thymol prior to subsequent analysis. The dissolved ions were measured using inductively coupled plasma optical emission spectrometry (ICP-OES) and flow injection analysis (FIA). The chemical parameters analysed were the cations calcium (Ca2+), magnesium (Mg2+), sodium (Na+), potassium (K+), iron (Fe2+), aluminum (Al3+), phosphate (PO43-) and ammonium (NH4+), and the anions chloride (Cl-), sulphate (SO42-), nitrate (NO3-), nitrite (NO2-), and silica (Si). Rainfall data were obtained from the Santa Catarina Information Centre for Environmental Resources and Hydrometeorology (EPAGRI/CIRAM), measured using the station number 02748024. Rainfall was calculated from accumulated precipitation for seven days before each sampling day.

Statistical analysis

To evaluate the differences in ions concentration, abiotic and environmental metrics between two streams, was used a non-parametric Wilcoxon-Mann-Whitney test (for variables with non-normal distribution) and a parametric t-test (for variables with normal distribution).

To characterize the hydrochemical composition and its relationship with environmental metrics, was applied the standardized principal component analysis (PCA). Multicollinearity among variables was verified by examining the variance inflation factor (VIF) (Fox 2008), and only significant non-redundant variables were included in the PCA. The following variables were used in the analysis: ions (Ca2+ , K+, Al3+, NO3-, NO2-), WT, pH, DO, HIIrip, HIIeros, HIIflow, soil type and watershed area. All variables were centred by their average and scaled to unit standard deviations (z-scores) and then, PCA was performed based on the correlation matrix (Gotelli and Ellison 2011).

In order to assess the relative importance of abiotic and environmental metrics in determining the hydrochemical composition was applied variation partitioning based on partial regressions (Whittaker 1984; Bocard et al. 1992; Legendre and Legendre 2012). In the model, the hydrochemical concentrations was used as dependent variable (the same used in PCA), while a matrix of abiotic factors (i.e., WT, pH, DO) and environmental metrics (i.e., watershed area, HIIrip, HIIeros, HIIflow) were used as independent variables. The proportion of explained variation for each independent variable was given by the partial adjusted R^2. Statistical significance was calculated using Monte Carlo permutation tests and sets around p-value > 0.05. For all statistical analyses, we used R ver. 3.5.1 (R Core Team, 2013), using the package 'HH' (Heiberger 2018) and 'vegan' (Oksanen et al. 2019).

4.4-Results

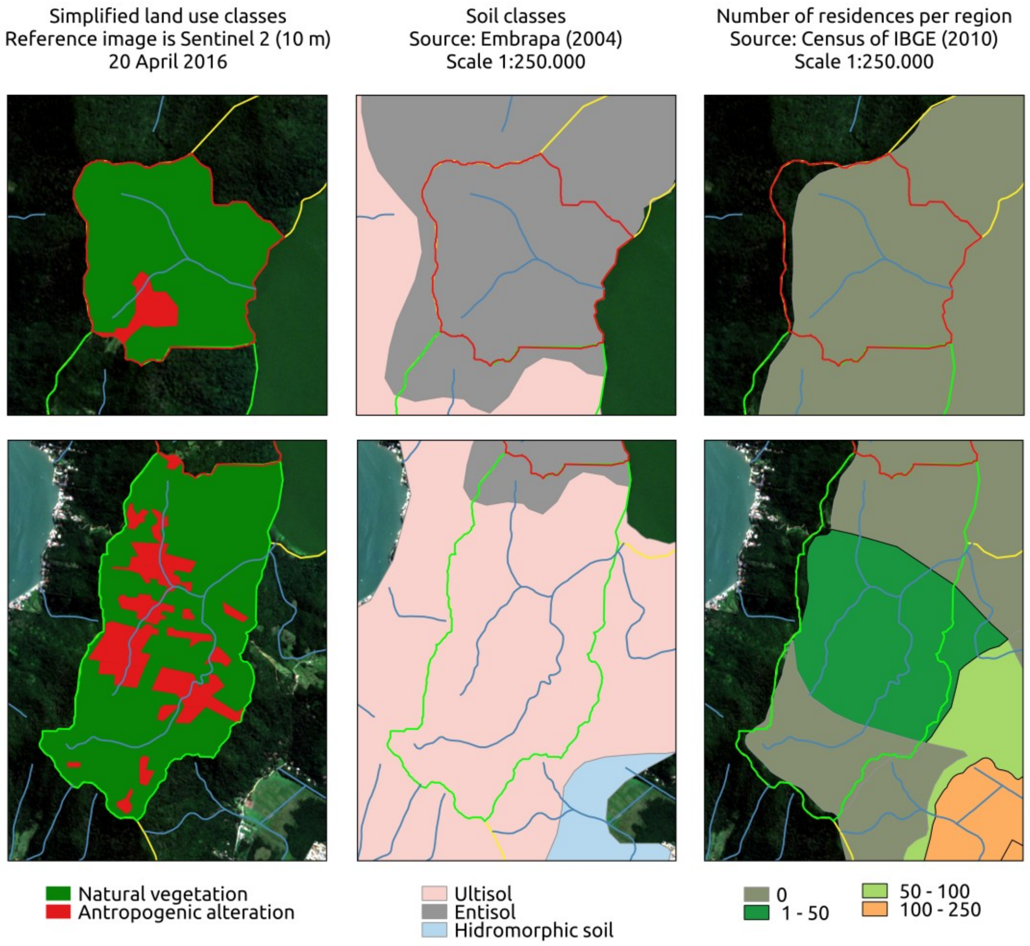
The varied set anthropic activities (urban area + agriculture area) along watersheds evidenced a combination of local modifications as riparian deforestation, erosion process increase and base flow changes (Table 1). These environmental metrics (HIIrip, HIIeros, and HIIflow) showed statistical differences (p-value < 0.05) between the watersheds. Precipitation showed no significant influence on hydrochemistry across the watersheds.

T**able 1** Environmental metrics (QGIS tool and HII) for Cachoeira Grande (CG) and Ribeirão Grande (RG) watershed, showing: Drainage area of watershed (km^2), Land use and cover percent (categorized in Forest; Urban + agriculture areas; Pasture), Source of degradation (point or nonpoint), Habitat Integrity index (HIIrip -Riparian deforestation index; HIIeros-Sediment deposition/erosion index; HIIflow-Baseflow index) and type soil (Entisols or Utilsols).

Site	**Drainage area (Km^2)**	**Land use and cover %**			**Source degradation**	**Habitat Integrity Index HII**			**Soil classes**
		Forest	Urb+Agri	Pasture		Riparian	Erosion	Base Flow	
CG Watershed	2.76	72	0	28	point	19.67	17.00	15.5	Entisols
RG Watershed	6.76	71	29	0	nonpoint	19.00	13.17	14.17	Ultisols

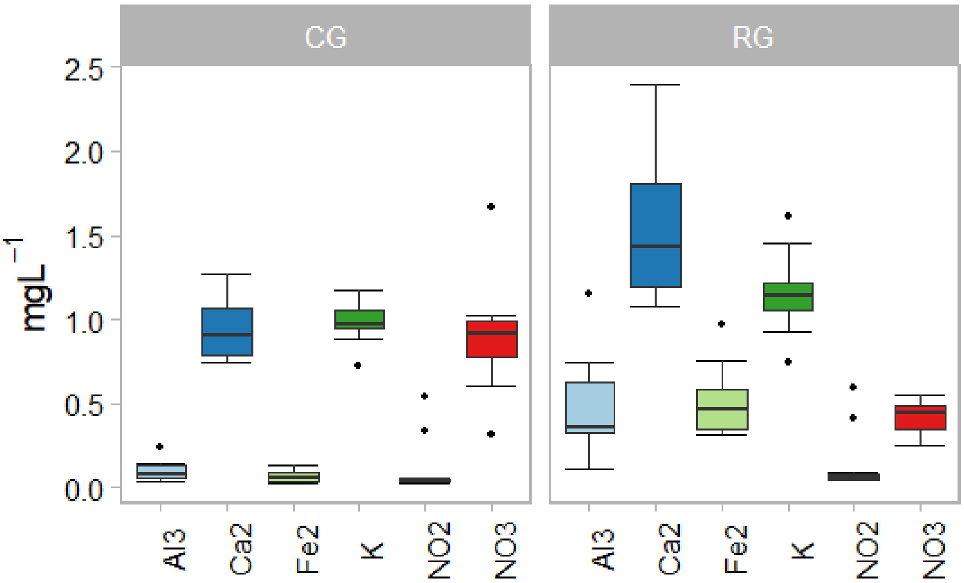
The LULC maps indicate that Cachoeira Grande watershed (CG) has a drainage area of 2.76 km^2 with an Entisol soil class and no human present (Fig.2). CG watershed has yet 29% of its area is covered with pasture and point source of pollution. In contrast, the Ribeirão Grande watershed (RG) has a drainage area almost three times larger (6.76 km^2) than CG, an Ultisol soil class, and land use including 28% urban and agricultural, with nonpoint sources of degradation along the watershed. Forested areas composed 72% and 71% of the total drainage areas, respectively (Table 1).

Figure 2. LULC (Land Cover and Land Use) maps of watersheds boundaries (Quantum GIS software): A- Cachoeira Grande Watershed; B- Ribeirão Grande Watershed, showing the natural (green) and anthropic area (red) (classified as point or nonpoint) and vegetation cover, geology (soil classes- ultisol and entisol) and number of residences per region evidencing low human impact.



Differences between the hydrochemistry and abiotic parameters among watershed studied are showed in Table 2. Higher ion concentrations were found in the RG watershed (except for PO_4^{3-} and NO_3^-), which was also characterized by displaying a larger drainage area, elevated percentage of urban use and lower habitat integrity index (Table 2). However, only Al^{3+}, Ca^{2+}, Fe^{2+}, K^{+}, NO_3^-, and NO_2^- showed significant statistical differences between the watersheds (p-value < 0.05, Figure 3).

Figure. 3 Box plots depict ion concentrations (Aluminum= Al^{3+}, Calcium= Ca^{2+}, Iron= Fe^{2+}, Potassium= K^{+}, Nitrate= NO_3^-,and Nitrite= NO_2^- mg/L^{-1}) with significant statistical differences between the watersheds (p-value < 0.05) . CG= Cachoeira Grande watershed, RG= Ribeirão Grande watershed.



These differences in the hydrochemistry, abiotic and environmental metrics among the watersheds (RG and CG) were confirmed through PCA. PCA produced two significant principal components explaining 74.1% of the parameters' variation (Fig. 4). The first component of the PCA accounted for 57.6% of the total variation, being mainly associated with higher values of the drainage area, Al^{3+} and Ca^{2+}, ions concentration. The hydrochemistry of the CG watershed was related to higher values of HII (i.e., HIIrip, HIIeros, and HIIflow), NO_3^- and DO. The second principal component (PC2) explained 16.5% of the total variation and it was mainly related to WT and pH. However, statistical differences between the watersheds for these variables were not significant (p-value > 0.05) (Table 2).

Figure 4. Principal component analysis (PCA) showing the ordination of the measured environmental variables. explaining 74.1% of the variation in hydrochemical composition (Ca^{2+} , K^{+}, Fe^{2+}, Al^{3+}, NO_3^-, NO_2^-), abiotic metrics, such as WT (Water temperature), pH (Potential hydrogen), DO (Dissolved oxygen), and environmental metrics, such as HIIrip (Riparian deforestation index) , HIIeros (Sediment deposition/erosion index), HIIflow (Baseflow index) and Watershed area (Km^2), where Groups represent the Sites (CG= Cachoeira Grande watershed, RG= Ribeirão Grande watershed).

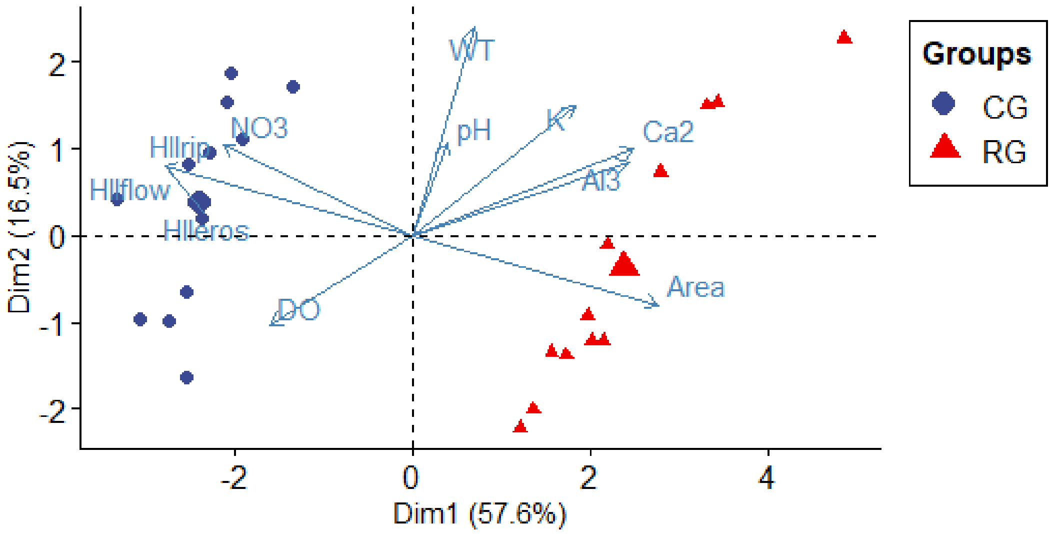


Table 2 Mean and standard deviation, maximum and minimum of abiotic parameters and ion concentrations in both CG and RG watersheds, with non-parametric Wilcoxon-Mann-Whitney test (non-normal distribution) and a parametric t-test (normal distribution). All tests and analyses were considered significant (*) at p-values<0.05.

	CG			RG			p-value
	Minimum	Maximum	Mean ± SD	Minimum	Maximum	Mean ± SD	
WT (C°)	12.90	23.80	18.97 ± 3.55	13.10	24.80	19.04 ± 4.06	0.965
DO (mg L^{-1})	6.64	9.75	7.97 ± 0.91	3.37	9.12	6.74 ± 1.75	0.046
pH	6.23	7.78	6.86 ± 0.50	6.04	7.70	6.94 ± 0.50	0.685
Al^{3+} (mg L^{-1})	0.03	0.24	0.10 ± 0.06	0.11	1.16	0.48 ± 0.29	0.000
Ca^{2+} (mg L^{-1})	0.748	1.274	0.95 ± 0.19	1.080	2.39	1.52 ± 0.40	0.000
Fe^{2+} (mg L^{-1})	0.03	0.14	0.07 ± 0.04	0.32	0.97	0.51 ± 0.20	0.000
K^{+} (mg L^{-1})	0.73	1.17	0.99 ± 0.11	0.75	1.61	1.54 ± 0.23	0.029
Mg^{2+} (mg L^{-1})	0.77	2.61	1.25 ± 0.52	0.93	3.76	1.62 ± 0.83	0.160
Na^{+} (mg L^{-1})	3.63	5.46	4.89 ± 0.47	3.92	5.90	5.20 ± 0.57	0.052
SO_4^{2-} (mg L^{-1})	1.51	3.63	2.84 ± 0.67	1.52	3.94	2.78 ± 0.75	0.590
Si (mg L^{-1})	4.72	8.88	6.06 ± 1.18	5.92	9.06	6.94 ± 0.98	0.060
NH_4^{+} (mg L^{-1})	0.01	0.07	0.03 ± 0.03	0.01	0.011	0.05 ± 0.03	0.116
PO_4^{3-} (mg L^{-1})	0.01	0.22	0.04 ± 0.06	0.01	0.03	0.02 ± 0.00	0.523
NO_3^{-} (mg L^{-1})	0.31	1.67	0.90 ± 0.32	0.25	0.55	0.42 ± 0.10	0.000
NO_2^{-} (mg L^{-1})	0.03	0.54	0.11 ± 0.16	0.05	0.60	0.13 ± 0.18	0.028
Cl^{-} (mg L^{-1})	7.84	11.09	9.34 ± 1.31	7.70	11.82	9.62 ± 1.57	0.409

Variation partitioning revealed that both abiotic and environmental metrics explained 52% of the observed variation in hydrochemical composition (F =7.26; p =0.001; Table 3) and overlapped 6% in explaining this variation (Fig. 5). Environmental metrics uniquely explained 33% (F =14.9; p =0.001; Table 3) of the variation, while abiotic metrics accounted for 13% of the explained variance of hydrochemical composition (F =2.98; p =0.012; Table 3).

Figure 5. Variation partition analysis explaining the percentage of variation explained by abiotic (pH, WT, DO) and environmental metrics (Watershed area, HII rip, HII eros, HII flow) on the hydrochemical concentrations of RG and CG watersheds.

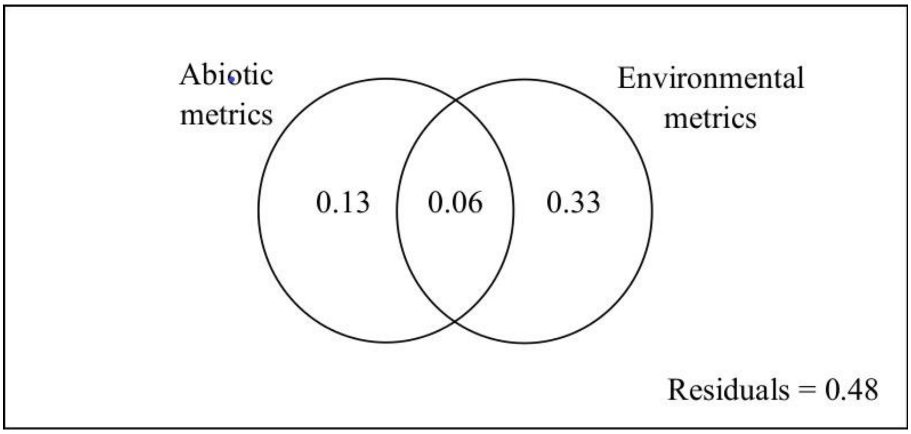


Table 3. Proportion of explained variation obtained through variation partitioning analysis based on partial regressions on hydrochemical concentrations given by each predictor and their shared effects. Predictors are as follows: abiotic metrics (pH, WT, DO) and environmental metrics (Watershed area, HII rip, HII eros, HII flow). P-values were calculated for pure-effects, since it is not possible to calculate for intersections. Three asterisks represent $p < 0.001$ and one asterisk represent $p < 0.05$.

Components	$_{adj.}R^2$	
Pure effect of abiotic metrics	0.129	*
Pure effect of environmental metrics	0.334	***
Shared effects between abiotic and environmental metrics	0.060	
Total explained variance	0.521	***

4.5-Discussion

This study of main tributaries that supply Peri Lake watershed, improved the understanding about how local modifications due land use and cover may affect low-order streams. The LULC maps indicate that RG watersheds are predominantly covered by agriculture and urbanization lands due to the urban growth that occurred in this region (Cardozo et al. 2008).

Higher ion concentrations were found in the RG watershed (except for PO_4^{3} and NO_3^-), which was also characterized by display a larger drainage area, higher percentage of urban and agriculture use with nonpoint sources of pollution. Nonpoint source pollution is mainly linked to agricultural and urban activities and represents a serious problem that degrades surface water quality and aquatic ecosystems (Carpenter et al. 1998; Dodds and Oakes 2008). Indeed, non-point sources pollution is difficult to assess due to the complex and diffuse nature of interactions between hydrologic and landscape patterns (Chiwa et al., 2012).

However, considering the geomorphological differences between the watersheds, these results may still be related multiple influences on the hydrochemical composition of the studied streams as, riparian deforestation and increased erosion process.

According Castillo et al. (2012), the conversion of forest into agricultural and urban areas increased the ion concentrations in streams, although the magnitude of the impact is largely influenced by the type of agricultural practice and alteration of the riparian zone. This study, the RG watershed showed higher concentrations of the majority of the chemical species (Fig.3). Additionally, 29% of its drainage area is covered by agriculture and urban areas showing the lowest riparian index values.

On the other hand, the highest values in NO_3^- concentrations in the CG watershed, may be correlated to both land use (i.e., pasture) and higher values for HII (Fig.4). Excessive inputs of phosphorus and nitrogen have been associated with human activities such as fertilization from livestock farming and other forms of agriculture, potentially causing changes in the trophic state of aquatic systems (Dodds 2006). Farther, the high local riparian cover in CG watershed (HIIrip), associated with turbulent mixing in this stream, may explain high DO concentrations, which, in turn, may also contribute to the increase in NO_3^- concentration through the nitrification process (Berner and Berner 2012).

Conversely, were observed larger local changes in the RG watershed (minors HII values). These modifications, possibly may have contributed to an increase in soil erosion rates, reduction of riparian vegetation and base flux (Table 1). Changes in riparian forests may affect energy input from organic matter and sunlight where the structure of the channel itself can be disrupted by direct modification (Booth 2005).

Human-induced changes, such as the removal of riparian vegetation, can also increase the levels of light and temperature causing a DO reduction in streams

(Carpenter et al. 1998; Cooper et al. 2013). Further, Nimick et al. (2011) state that WT has a great influence on the kinetic reactions and equilibrium of a river, since cycles of temperature are the basis of many biogeochemical cycles observed within these environments. These studies corroborate with the found results here, and could explain the influence of 13% of abiotic metrics on hydrochemical composition on streams (Fig.5).

So far, the increase in nutrient concentrations in disturbed sites in comparison with those which are more pristine usually indicates the influence of intensive agriculture, fertilizer use, and untreated domestic sewage (Walsh et al. 2005; Castillo et al. 2012).

Other studies carried out in forest, urban, and rural watersheds showed that deforestation alters the structure and functioning of streams and contributes to the increased export of nutrients from the continent to coastal waters (Syvitski et al. 2005; Andrade et al. 2011). Overall, were observed that relationship between environmental metrics (e.g., HIIeros, HIIrip) with watershed area, could explain the influence of 33% on hydrochemical composition (Fig.5), and may have negatively affected the hydrochemical dynamic of the streams, resulting in signs of degradation (e.g., increases in Ca^{2+}, NO_3^- and Al^{3+} concentrations). Indeed, the influence of land use on streams hydrochemistry have shown evidence of increase in some of these ions in water bodies around the world (Walsh et al. 2005; Leite et al. 2011; Kaushal et al. 2015).

High concentrations of Ca^{2+} and Al^{3+} may be associated with different types of land use (i.e., urban and agriculture), which suggest the presence of anthropogenic sources in the system (Moreira et al. 2014; Petersen et al. 2017) and with soil type. More recently, studies that have attempted to evaluate the effects of land use on tropical streams have found larger concentrations of Ca^{2+} (Jesus Crespo and Ramirez 2011). The same pattern was found by Bhatt et al. (2013) who observed higher concentrations of aluminum compared to previous studies, leading to changes in water quality in urban streams. However, in the same way that high concentrations of Al^{3+} are usually found in the clays of the Ultisols, we might expect high concentrations of this ion for RG watershed that showed dominance by this soil type. (Da Silva et al. 2019).

There is a clear association between urban and agriculture land use and red Ultisol, which is a fertile soil class. Yet, the vulnerability of Ultisols to erosion when there is no vegetation cover (FLORIANÓPOLIS-IPUF) may have contributed to the high concentrations of Al^{3+} in RG. Erosion processes in nonpoint source of pollution, increase the loss of riparian vegetation (low-HII) in RG watershed, suggesting that the concentrations of these ions are probably influenced by groundwater in association with anthropic weathering as previously reported by other studies (Syvitski et al. 2005; Markewitz et al. 2011).

Water quality in low-order streams of both the CG and RG watersheds showed acceptable water quality in relation to some ion concentrations, based on the CONAMA (357/2005) which establish the Brazilian water quality standards. However, it is important to emphasize that Al^{3+} concentrations were close to the limits established by this standard.

Our results suggest that the increase in urban activities lead to local changes in the structure of low-order streams, mainly due to the loss of riparian vegetation and increased erosion process. These modifications alter the hydrochemical balance and decrease the water quality. However, it is possible that other factors, such as soil type, also could influence the observed variation in hydrochemical composition, since the importance of this factor was not evaluated as unique effect in the present study. In addition, repeated observations of environmental variables related to geology over long period of time may provide more accurate results about human impact (e.g., land use) in hydrochemical dynamics on urban streams. While we recognize that it is a limitation of this study, we fully recommend future studies to take this into account to assess the generality of our findings in other watersheds and beyond.

4.6-Conclusions

Although both watersheds still have a high proportion of forest cover, the conversion to conventional agriculture, urban areas and pasture, have promoted changes in low-order streams integrity. These changes were influenced by local modifications, such as degradation of protected riparian areas and increased erosion process, which was more evident in the most disturbed stream (RG watershed).

Indeed, the increase of anthropized areas may lead to modifications to the integrity of streams that associated with soil type and larger watersheds area can promote consequent increase ion concentrations, resulting in deteriorating the water quality.

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5-CONCLUSÕES E PERSPECTIVAS FUTURAS

Na ilha de Santa Catarina, nossos estudos evidenciaram que a evolução da urbanização nas últimas três décadas tem gerado modificações na estrutura local dos rios, como reportado na Síndrome dos Riachos Urbanos. Este crescimento urbano no entorno das bacias hidrográficas, tem causado impactos negativos na integridade destes ambientes principalmente pela diminuição da mata ripária.

Em geral, o maior crescimento de urbanização de Florianópolis ocorreu entre as décadas de 1990 e 2000. Em 1993, a ilha de Florianópolis apresentava uma área urbana de 8% da sua área total, aumentando para 14% em 2003 e atingindo 16% de área urbana em 2013. O aumento progressivo de população e o crescimento de áreas urbanas que ascende sobre a rede hidrográfica, ameaçam diretamente estes ecossistemas aquáticos.

Dentre as 15 principais bacias hidrográficas presentes na ilha, 10 bacias localizadas entre as regiões centro e norte, apresentam acima de 10% de suas áreas urbanizadas. Entre as bacias estudadas neste grupo (>10% área urbanizada), nossos resultados evidenciam em sua maioria, modificações locais no uso do solo, provenientes da ocupação e desenvolvimento urbano.

Os efeitos da substituição da mata ripária por construções (perda de vegetação), modificações na cobertura vegetal (facilitandor do processo de erosão) e lançamentos de efluentes de esgoto (aumento de nutrientes) são refletidos na diminuição da qualidade de água e integridade ambiental nestas bacias hidrográficas. Estas modificações locais atuam como elementos chave para a diminuição da integridade ambiental de rios e qualidade da água (por exemplo, o aumento da temperatura da água), que comprometem direta e indiretamente as funções ecossistêmicas providos por estes ambientes em dimensões espaço-temporais como defendido na teoria ecológica do Contínuum de Bacias Urbanas.

Além disso, nossos estudos sobre a qualidade de água realizados em bacias com alto nível de urbanização (>10%), evidenciaram um aumento da concentração de nutrientes (ions, carbono orgânico e carbono inorgânico dissolvidos) além de aumento de pressão de CO_2 acima do limite da atmosfera. Tais evidências sugerem ainda, que as modificações originadas de atividades antrópicas tem efeitos negativos tanto locais quanto regional e global nos ecossistemas aquáticos por transformar os rios urbanizados de sumidouros em fontes de CO_2 para a atmosfera.

Por outro lado, as bacias localizadas ao sul da ilha, apresentaram os menores índices de urbanização, entre elas a bacia hidrográfica da Lagoa do Peri, que desempenha um papel importante no fornecimento de água potável para a população da ilha de Florianópolis. Embora localizada em uma área de preservação, nas últimas três décadas tem estado sob pressão, principalmente devido ao crescimento urbano causando pelas mudanças no uso e cobertura do solo.

Nossos estudos realizados com duas microbacias constituintes da bacia hidrográfica da Lagoa do Peri, com diferentes usos e ocupação do solo, evidenciaram que mesmo com uma baixa pressão antrópica, as modificações na integridade ambiental causadas pela urbanização e agricultura podem comprometer a qualidade da água dos rios (aumento da concentração de nutrientes).

É fato que, o crescimento da população e pressões para o desenvolvimento industrial têm se tornado os principais fatores de ameaça de perda das funções ecológicas das bacias hidrográficas. E, levando em consideração que dados recentes do IBGE (2019), indicam que o crescimento populacional alcançou 500 973 pessoas residentes na cidade Florianópolis (região insular+ continental), uma contextualização mais ampla sobre modelos de integridade ambiental que diminuam tais modificações, torna-se vital para a gestão e planejamento dos recursos hídricos de bacias hidrográficas urbanas.

Trabalhos futuros devem ainda, avaliar e quantificar estas modificações geradas, em perdas e alterações dos serviços ecossistêmicos prestados por estes ambientes. Uma vez que, os efeitos das atividades antrópicas devido à urbanização têm sido estudados ao longo do mundo e tem revelado diminuição da qualidade e prestação de serviços ambientais que estes ambientes fornecem à sociedade.

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7-Apêndice A- Protocolo de Avaliação Rápida de Rios (PARR).

Nome do rio	Local
Estação de coleta #	
Lat Long	Bacia hidrográfica
Investigadores	
Formulário preenchido por: Observações:	Data ___________ Hora ___________

Parâmetros ambientais	Categorias			
	ÓTIMO	**BOM**	**REGULAR**	**RUIM**
1. Substrato para animais que vivem no fundo dos rios / Cobertura disponível	Mais de 70% do ambiente favorável para colonização de animais bentônicos e abrigos para peixes; presença de gravetos e troncos; margem do rio sem quebras na vegetação, substratos estáveis.	40- 70% mistura de ambientes estáveis, potencialmente preparados para colonização; hábitat adequado para sustentar as populações; grande presença de folhas recém caídas ainda despreparadas para colonização.	20- 40% mistura de ambientes estáveis com disponibilidade de hábitats menor do que o desejado, substrato freqüentemente removido ou perturbado.	Menos de 20% de ambientes estáveis; ausência de hábitats adequados para colonização; substrato instável ou deficiente.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Características do fundo do rio	Cascalho, seixos e pedras grandes são de 0-25% cobertos por sedimentos finos. Espaço entre as pedras proporciona diversidade de habitats.	Cascalho, seixos e pedras grandes são de 25-50% cobertos por sedimentos finos.	Cascalho, seixos e pedras grandes são de 50-75% cobertos por sedimentos finos.	Cascalho, seixos e pedras grandes são mais de 75% cobertos por sedimentos finos.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocidade / Regime do Fundo	Todas as 4 velocidades / regimes de fundo estão presentes: fundo lento, fundo rápido, raso lento, raso rápido (lento é < 0,3m/s e fundo é > 0,5m).	Somente 3 dos 4 regimes estão presentes (se o raso rápido está faltando pontue menos do que se estivesse faltando outro regime).	Só 2 dos 4 regimes estão presentes (se o raso rápido ou o raso lento estiverem faltando pontue menos).	Dominado por um regime (geralmente fundo lento).
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Deposição de Sedimentos	Pequena ou sem ampliação de ilhas ou de barreiras de areia; menos de 5% do fundo afetado por deposição de sedimentos.	Alguns novos pontos com aumento na formação de barreiras; a maior parte formado por areia e sedimento fino; 5-30% do fundo afetado, com pequenas deposições nos poços.	Moderada deposição de areia ou sedimento fino nas barreiras; 30-50% do fundo afetado, depósito de sedimentos em obstrução, constrição e inclinação; moderada deposição nos poços.	Grande deposição de sedimento fino, aumento do desenvolvimento de barreiras; mais de 50% do fundo instável; quase todas os poços ausentes devido ao grande depósito de sedimentos.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Status do canal de água corrente	Alcance da água no limite do seu leito normal e mínimos aglomerados de substrato expostos.	A água preenche >75% do canal disponível ou <25% do substrato está exposto.	A água preenche 25-75% do canal disponível, e/ou quase todo substrato de corredeira está exposto.	Pouca água nos canais e a maioria desta presente como poços permanentes.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Parâmetros ambientais	***Categorias***			
	Ótimo	**Bom**	**Regular**	**Ruim**
6.Alterações do canal	Ausência de canalizações ou drenagens, rio com padrões normais.	Algumas canalizações presentes, geralmente em áreas próximas a pontes; podem existir evidências de canalizações passadas, mas sem sinais de canalização recente.	Grande trecho canalizado, formação de barreiras de areia nas duas margens; de 40-80% do trecho do rio canalizado ou modificado.	Margens cimentadas; mais de 80% do rio canalizado e modificado. Grande parte dos hábitats aquáticos alterados ou removidos.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Freqüência de corredeiras	Corredeiras freqüentes; em rios onde as corredeiras são contínuas, verificar a presença de pedras grandes ou outros mecanismos de obstrução natural.	Ocorrência de corredeiras infreqüentes; diversidade de hábitats para a fauna; apresenta corredeiras separadas por remansos de diversos tamanhos.	Corredeiras ou curvas ocasionais; longos remansos separados por corredeiras curtas; fundo do rio em curvas propicia alguns hábitats para a fauna aquática.	Geralmente águas calmas ou corredeiras rasas; hábitats pobres.
Pontuação	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Estabilidade das margens Nota: determinar as margens esquerda e direita olhando em direção a foz.	Margens estáveis; ausência de erosão ou falhas nas margens; chances remotas para futuros problemas. < 5% da margem afetada.	Estabilidade moderada; pequenas áreas de erosão, com sinais de recuperação. 5-30% da margem com áreas de erosão.	Instabilidade moderada 30-60% do banco no trecho tem áreas de erosão, grande potencial de erosão durante enchentes.	Instável; muitas áreas erodidas, áreas nuas freqüentes ao longo do trecho. 60-100% da margem com marcas de erosão.
Pontuação (MD)	Dir 10 9	8 7 6	5 4 3	2 1 0
Pontuação__ (ME)	Esq 10 9	8 7 6	5 4 3	2 1 0
9. Cobertura Vegetal	Mais de 90% da margem e da mata ciliar composta por vegetação nativa, incluindo árvores de grande porte, arbustos e macrófitas; ausência de pastos e campos no trecho.	70-90% da margem e da mata ciliar composta por vegetação nativa; modificação da vegetação evidente.	50-70% da margem coberta por vegetação; modificação da vegetação óbvia; manchas de solos nus ou com vegetação roçada.	Menos de 50% da superfície da margem coberta por vegetação; vegetação muito alterada; ausência de vegetação nativa.
Pontuação__ (MD)	Dir 10 9	8 7 6	5 4 3	2 1 0
Pontuação__ (ME)	Esq 10 9	8 7 6	5 4 3	2 1 0
10. Extensão da mata ciliar	Largura da mata ciliar maior do que 18m; atividades humanas não causam impactos à área.	Largura da mata ciliar de 12-18m; atividades humanas causam impactos mínimos à área.	Largura da mata ciliar de 6-12m; atividades humanas causam grandes impactos à área.	Largura da mata ciliar menor do que 6m; atividades humanas eliminaram a mata ou reduziram-na drasticamente.
Pontuação__ (MD)	Dir 10 9	8 7 6	5 4 3	2 1 0
Pontuação__ (ME)	Esq 10 9	8 7 6	5 4 3	2 1 0

Some todos os valores e marque a **Pontuação Total** :_________

RESULTADO
Pontuação Média entre **20 e 16,** condição ambiental **Ótima** .
Pontuação Média entre **15 e 11**, condição ambiental **Boa**.
Pontuação Média entre **10 e 6**, condição ambiental **Regular**.
Pontuação Média entre **5 e 0**, condição ambiental **Ruim**.

Divida este número por 10 e marque a **Pontuação Média**:______

Obs: Aumentar o nível de zoom para 150% para melhor visualização do appendix A.