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**DESENVOLVIMENTO E AVALIAÇÃO DE UM *WETLAND*
CONSTRUÍDO FLUTUANTE COMO SOLUÇÃO INSPIRADA NA
NATUREZA PARA REVITALIZAR RIOS URBANOS**

PORTO ALEGRE

2020

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REVITALIZAR RIOS URBANOS

Tese apresentada ao Programa de Pós-graduação em
Recursos Hídricos e Saneamento Ambiental da
Universidade Federal do Rio Grande do Sul, como
requisito parcial à obtenção do grau de doutora.

Orientadora: Dr^a Lúcia Helena Ribeiro Rodrigues

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Para minha Mãe.

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RESUMO

A revitalização de rios é uma abordagem alternativa para enfrentar os crescentes desafios de gestão da água e o atual estado de degradação dos rios urbanos. Compreender os processos da bacia hidrográfica, que mantém o funcionamento do ecossistema fluvial, torna-se necessário para que ações de revitalização sejam implementadas com sucesso, bem como é essencial avaliar métodos que podem ser empregados para reestabelecer a integridade dos rios. As soluções inovadoras e inspiradas na natureza (*Nature-based solutions* - NBS) apresentam princípios amplos e representam um conceito chave que engloba vários conceitos de gestão da água no meio urbano, como as técnicas compensatórias. Este trabalho visa avaliar o potencial de aplicação de sistemas de *wetlands* construídos flutuantes, como parte das NBS, para revitalizar rios urbanos. A avaliação foi efetuada, primeiro, de forma teórica, através da revisão e discussão de como as NBS vêm sendo implementadas no contexto dos projetos de revitalização, considerando por um lado a necessidade de esforços baseados na recuperação dos processos da bacia hidrográfica e por outro lado, as limitações que existem para a aplicação de ações de restauração de rios em área urbana. Segundo, através do desenvolvimento de um sistema flutuante de *wetlands* construídos (*Constructed Floating Wetlands* – CFW), uma técnica de tratamento de água relativamente recente que consiste em macrófitas emergentes plantadas em estruturas flutuantes. Esse tipo de sistema vem sendo testado para o tratamento de águas residuárias e de escoamento superficial urbano. Contudo, poucos estudos fornecem resultados detalhados da adaptação das espécies e há poucos dados sobre o desempenho dos sistemas durante curtos períodos de tempo de retenção hidráulica. A análise dos estudos de caso de revitalização mostra a dificuldade que existe na tentativa de reestabelecimento da integridade dos rios urbanos. Mesmo quando são aplicadas técnicas distribuídas na bacia hidrográfica, há reestabelecimento de processos físicos, relacionados ao ciclo hidrológico e melhora da qualidade da água, mas os resultados ecológicos ainda são questionáveis. Nesse sentido, os experimentos realizados na tese mostram que as técnicas compensatórias, especificamente o sistema de CFW, como instrumentos de aplicação da abordagem promovida pelas NBS, tem alto potencial para a melhoria da qualidade da água dos rios, através do tratamento do escoamento superficial urbano. Houve diferença na eficiência de remoção entre as espécies, sendo que *T. domingensis* obteve melhor desempenho, com remoção de nutrientes para os tempos de retenção de 24h e 4h, enquanto que não houve remoção significativa para o *S. californicus* nos tempos de retenção inferiores a sete dias. O sistema alcançou eficiências de remoção da ordem de 78% de nitrogênio total (NT) e de 47% de fósforo total (PT), para a espécie que melhor se adaptou (*T. domingensis*), para o período de 7 dias. A comparação com os padrões estabelecidos pela Resolução 357/2005 do CONAMA para rios de Classe 1 e 2, considerando 24h como de tempo de retenção e a eficiência correspondente a esse período de tempo, mostra que o efluente de entrada poderia ter a concentração máxima de 20 mg/L de NT, para que o sistema tenha capacidade de fornecer um tratamento adequado à legislação ambiental. Assim, a aplicação potencial dos CFW se mostrou viável, contudo, são necessárias adaptações na estrutura flutuante para melhorar o desempenho do sistema como um todo e permitir a sua validação em escala real.

Palavras-chave: Ecotecnologia. Macrófitas emergentes. Revitalização de rios. Soluções inspiradas na natureza. Técnicas compensatórias. *Wetlands* construídos flutuantes.

ABSTRACT

River revitalization is an alternative approach to face the challenges of water management and the current condition of degradation of the urban rivers. To understand the catchment process that sustain the fluvial ecosystem functioning is necessary to implement successful restoration measures and, in addition, it is important to assess the methods which can be applied to reestablish the river integrity. The innovative and nature-based solutions (NBS) present broad values and represent a key concept that comprises a range of previous concepts of urban water management, such as compensatory techniques. This work aims to assess the potential of application of constructed floating wetlands systems, as a part of NBS, to urban river revitalization. The assessment were conducted first theoretically, through the review and discussion of how NBS have been implemented in the context of revitalization projects. This discussion has taken into account, on the one hand, the efforts to recover catchment process; on the other hand, the limitations that exist to apply river restoration measures in urban rivers. Second, through the development of a constructed floating wetland (CFW), which is a water treatment technique relatively recent that consists of emergent macrophytes planted in floating structures. This kind of system has been tested to effluent and stormwater runoff treatment. However, few studies provide detailed results of species adaptation and there are limited knowledge about the performance of these systems during short periods of hydraulic retention time. The analysis of river revitalization case studies presents the difficulty inherent to the attempt of integrity reestablishment of urban rivers. A recovery of physical processes, related to hydrological cycle and water quality improvement, occurs even when distributed techniques are applied inside catchment. But ecological results are still questionable. In this regard, the experiments showed that compensatory techniques, specially the CFW system as an instrument to NBS approach application, had a great potential to river water quality improvement, through the treatment of the urban surface runoff. Removal efficiency was different between the species, with best performance of *T. domingensis* which removed nutrients on retention times of 24 and 4 hours, while there was no significant nutrient removal to *S. californicus* on retention times less than seven days. The system reach efficiency removal rates of 78% of total nitrogen (TN) and 47% of total phosphorus (TP), to specie that had the best adaptation (*T. domingensis*) and to the period of seven days. The comparison with standards established by Resolução 357/2005 CONAMA to 1 and 2 rivers class, considering 24 hours of retention time and the correspondent efficiency, shows that the input effluent should have the maximum concentration of 20 mg/L of TN to the system provide treatment according to environmental regulation. Thus, the potential application of CFW is feasible, however, adaptations on floating structure are required to improve the performance of the system as a whole and to allow its validation in field.

Keywords: Compensatory techniques. Constructed floating wetlands. Ecotechnology. Emergent macrophytes. Nature-based Solutions. River revitalization.

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LISTA DE ABREVIATURAS E SIGLAS

ANOVA - *Analysis of variance*
ANOSIM - *Analysis of similarities*
BMPs - *Best Management Practices*
CAP - *Canonical analysis of principal coordinates*
CFW - *Constructed floating wetlands* - wetlands construídos flutuantes
CONAMA - Conselho Nacional do Meio Ambiente
COT - Carbono Orgânico Total
CW - *Constructed wetlands* - wetlands construídos
DO - *Dissolved oxygen*
DBO - Demanda Bioquímica de Oxigênio
DQO - Demanda Química de Oxigênio
EC - *European Commission*
ECRR - *European Centre for River Restoration*
FPC - *Flood pulse concept* - conceito do pulso de inundação
FTW - *Floating treatment wetlands* - tratamento de wetlands flutuantes
GBN - *Green and blue networks* - redes verdes e azuis
GBI - *Green and blue infrastructure*
HPD - *Hierarchical patch dynamics* - dinâmica hierárquica dos fragmentos
HRT - *Hydraulic retention time*
INMET - Instituto Nacional de Meteorologia
IUCN - *International Union for Conservation of Nature*
LID - *Low-impact development* - desenvolvimento urbano de baixo impacto
NBS - *Nature-based Solutions* - soluções inspiradas na natureza
nMDS - *Non-metric multidimensional scaling*
NO₃ - nitrato
NT - nitrogênio total
NRC - *National Research Council*
PERMANOVA - *Permutational multivariate ANOVA based on distances*
PHT - *Physical habitat template* - teoria do padrão físico do habitat
PO₄ - Ortofosfato
PT - Fósforo total
RCC - *River continuum concept* - conceito do *continuum* fluvial
SER - Sociedade Internacional para a Restauração Ecológica
SUDS - *Sustainable urban drainage systems* - sistemas sustentáveis de drenagem urbana
TP - *Total phosphorus*
TN - *Total nitrogen*
TOC - *Total organic carbon*
WSUD - *Water sensitive urban design* - cidades sensíveis a água

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1. INTRODUÇÃO

O processo de urbanização causa alterações severas no regime hidrológico e no balanço de sedimentos das bacias hidrográficas. O escoamento superficial, gerado nas extensas áreas impermeáveis das cidades, a ocupação das áreas de inundação natural e o desencadeamento de processos erosivos e de sedimentação nos leitos dos rios geraram a necessidade de intervenções estruturais nos cursos d'água, com o objetivo de estabilização de margens ou proteção contra as inundações. Essas extensas modificações morfológicas associadas à degradação da qualidade da água trouxeram sérias consequências ecológicas para os rios. Adicionalmente, há o efeito da degradação do ambiente, como um todo, nos próprios habitantes dos centros urbanos que supostamente se beneficiam da urbanização e da forma como ocorre a gestão das águas.

A revitalização de rios é caracterizada pelo movimento no sentido inverso à degradação, ou seja, busca o reestabelecimento da integridade dos rios. O processo de revitalização em áreas urbanas envolve também a regeneração de espaços públicos e o aumento de áreas de recreação que promovam o contato com a natureza. Nesse sentido, as soluções inspiradas na natureza (*nature-based solutions* – NBS) representam uma abordagem conceitual integradora de várias técnicas que promovem o bem-estar das pessoas e a recuperação dos ecossistemas. As NBS correlacionam-se com as abordagens promovidas pelos serviços ecossistêmicos e pela engenharia ecológica. Além disso, englobam termos como infraestrutura verde, redes verdes e azuis (*Green and Blue Networks* – GBN), além de outros termos relativos ao controle do escoamento superficial urbano, como: cidades sensíveis à água (*Water Sensitive Urban Design* – WSUD), desenvolvimento urbano de baixo impacto (*Low-Impact Development* – LID), técnicas compensatórias, entre outros.

Os *wetlands* construídos são uma tecnologia de tratamento de água que representa a multifuncionalidade das NBS, pois são sistemas que mimetizam os processos que ocorrem nas áreas úmidas naturais, fornecem serviços ecossistêmicos e promovem a biodiversidade através da melhoria de habitats e despoluição das águas. Uma variante dos *wetlands* construídos são os *wetlands* construídos flutuantes (*Constructed Floating Wetlands* – CFW). Esta ecotecnologia pode ser empregada tanto no contexto de medidas de revitalização distribuídas na bacia hidrográfica, como em medidas estruturais de revitalização, visando a aplicação direta em rios poluídos. A primeira forma de aplicação dos CFW, para o tratamento do escoamento superficial urbano, será defendida nesta tese como uma forma mais efetiva de recuperar a saúde dos rios urbanos. Assim, a tese apresenta e discute a aplicação das NBS

nos projetos de revitalização, além de mostrar os resultados experimentais da implantação e remoção de nutrientes de um sistema de CFW em escala piloto.

1.1. Justificativa

As soluções de drenagem urbana que usualmente canalizam cursos d'água sofrem de certa unilateralidade, a qual não lhes permite enfrentar adequadamente os múltiplos aspectos da gestão da água nas áreas urbanas e o atual estado de degradação dos rios. Nesse sentido, faz-se necessário entender os processos hidrológicos, geomorfológicos e biológicos que mantêm o funcionamento dos sistemas fluviais, assim como avaliar métodos para reestabelecer a integridade dos rios ou, pelo menos, minimizar a condição de degradação. As soluções inspiradas na natureza fornecem uma base conceitual abrangente e multidisciplinar, sendo que suas técnicas vêm sendo aplicadas para lidar com os desafios da problemática ambiental urbana. Contudo, o caráter inovador de algumas ecotecnologias exige avaliar a efetividade e limitações, bem como esclarecer as implicações para a revitalização de rios urbanos.

1.2. Hipótese central

Esta tese se fundamenta na proposição de que o tratamento do escoamento superficial urbano, através da aplicação de ecotecnologias distribuídas nos sistemas de drenagem, contribui para a revitalização de rios.

1.3. Objetivos

Objetivo geral

Avaliar o potencial de aplicação de sistemas de *wetlands* construídos flutuantes, como parte de soluções inspiradas na natureza, para revitalizar rios urbanos.

Objetivo específico - 1

Discutir a efetividade de métodos de intervenção empregados em projetos de revitalização de rios urbanos, com a abordagem de soluções inspiradas na natureza.

Objetivo específico – 2

Analisar a adaptação e eficiência de duas espécies de macrófitas emergentes, em um sistema de *wetland* construído flutuante, e discutir a aplicabilidade do sistema para o tratamento do escoamento superficial urbano.

1.4. Estrutura da tese

Além desta parte introdutória, a tese apresenta um breve referencial teórico seguido de três artigos científicos. O primeiro artigo corresponde ao primeiro objetivo específico da tese. Para a composição deste artigo foi realizada uma extensa revisão bibliográfica sobre os métodos de intervenção para revitalizar rios urbanos. O trabalho, intitulado “*Understanding the relationship between river restoration and nature-based solutions: from instream measures to catchment approaches*”, tem como objetivo analisar estudos de caso de revitalização que implementaram medidas de restauração na bacia hidrográfica de acordo com a abordagem das soluções inspiradas na natureza (*Nature-based Solutions - NBS*) e conceitos relacionados ao controle do escoamento superficial urbano.

Os artigos seguintes abordam a parte experimental da tese e correspondem ao segundo objetivo específico do trabalho. O segundo artigo expõe os resultados do período de adaptação das diferentes espécies de macrófitas emergentes utilizadas nos experimentos. Neste artigo, intitulado “*Establishment of a constructed floating wetland: perspectives to urban drainage application*”, foi detalhado o desenvolvimento do sistema de *wetland* flutuante e a metodologia experimental. Além disso, destacamos as dificuldades e lições aprendidas com objetivo de facilitar a realização de outros trabalhos experimentais na mesma temática. Este artigo foi submetido à Revista Brasileira de Recursos Hídricos e encontra-se em análise.

O terceiro artigo, intitulado “*Nature-based solutions for managing the urban surface runoff: an application of a constructed floating wetland*”, traz os resultados dos experimentos realizados, após a etapa de adaptação das espécies. A ênfase está voltada para a avaliação das eficiências de remoção de nutrientes (nitrogênio e fósforo) das duas espécies de macrófitas emergentes empregadas. Este trabalho foi publicado na revista *Limnetica* (DOI: 10.23818/limn.39.28).

Por fim, os principais resultados são discutidos de forma integrada, retomando a hipótese central do trabalho e as conclusões e recomendações da tese são apresentadas.

2. REVISÃO BIBLIOGRÁFICA

2.1. Integridade dos sistemas fluviais

Os sistemas fluviais são complexos e dinâmicos. Para a compreensão desses sistemas é necessário contemplar os aspectos geomorfológicos, hidráulico-hidrológicos e biológicos dos rios (POOLE, 2002). Schwarzbald (2010) expõe algumas teorias ecológicas sobre os rios que auxiliam na sua compreensão sistêmica, entre elas, destaca-se conceito do rio contínuo – *River Continuum Concept* – RCC (VANNOTE *et al.*, 1980). Essa teoria mostra que as variáveis físicas dentro do sistema do rio apresentam um gradiente contínuo de condições físicas da cabeceira à foz, e esse gradiente deve obter uma série de respostas dentro das populações, resultando num contínuo de adaptações bióticas e padrões consistentes de carga, transporte, utilização e armazenamento da matéria orgânica ao longo do comprimento do rio (VANNOTE *et al.*, 1980). Outros modelos também foram propostos baseados em estudos experimentais: teoria da espiral de nutrientes - *Spiraling Concept* (WEBSTER, 1975); conceito do pulso de inundação – *Flood Pulse Concept* - FPC – (JUNK *et al.*, 1984); as quatro dimensões do sistema lótico (WARD, 1989); e a dinâmica hierárquica dos fragmentos - *Hierarchical Patch Dynamics* – HPD (THORP *et al.*, 2008). Além das teorias discutidas por Schwarzbald (2010), destacamos também a teoria do padrão físico do habitat - *Physical Habitat Template* - PHT (SOUTHWOOD, 1977) e do corredor hiporréico (BULTON *et al.*, 1998).

Segundo Allan (2004), a integridade ecológica, a condição dos cursos d'água e a saúde dos cursos d'água são termos que descrevem o estado dos ecossistemas fluviais e suas respostas às perturbações. A integridade ecológica pode ser definida como a manutenção de atributos estruturais e funcionais característicos de um determinado local, considerando a existência de uma variabilidade normal (NRC, 1992). De acordo com Karr *et al.* (1986), a integridade física, química e biológica, em conjunto podem ser equiparadas à integridade ecológica. A integridade biótica depende de cinco fatores: fontes de energia, qualidade da água, qualidade do habitat, regime do fluxo e interações biológicas (KARR *et al.*, 1986). A alteração em qualquer um desses fatores comprometeria a integridade biológica e por extensão, a integridade ecológica dos rios. Deste modo, indicadores bióticos multimétricos, por exemplo, os índices de integridade biótica para macroinvertebrados ou peixes, são usualmente empregados para medir a saúde dos cursos d'água (WOZNICKI *et al.*, 2015; LEE; AN, 2014; EINHEUSER *et al.*, 2012).

Além destes indicadores bióticos, protocolos que avaliam a condição hidromorfológica são utilizados como instrumentos de avaliação da integridade dos rios e

seu potencial de recuperação (FERNÁNDEZ *et al.*, 2011; SHUKER *et al.*, 2015). Índices qualitativos também são empregados para a avaliação das características físicas do habitat, os quais em conjunto com parâmetros químicos e bióticos podem ser empregados para avaliar a condição ecológica antes e depois da restauração (LEE; AN, 2014). As condições do fluxo, conectividade fluvial e heterogeneidade são características físicas que afetam diretamente a qualidade e diversidade do habitat fluvial (WARD, 1998; MADDOCK, 1999). Portanto, são elementos fundamentais para avaliar a integridade do sistema como um todo.

De acordo com Meyer (1997), o conceito de saúde dos cursos d'água incorpora integridade ecológica (mantendo estrutura e função) e valores humanos (o que a sociedade valoriza no ecossistema). Todavia, o que a sociedade tem como valores não necessariamente está associado aos ecossistemas construídos, ou aqueles restritos à produtividade. Ou seja, além dos valores instrumentais, como os serviços ecossistêmicos, os ecossistemas são dotados de valores intrínsecos. Apesar de haver uma tendência de reconhecimento dos valores instrumentais pela sociedade, a educação ambiental pode ajudar na incorporação dos valores primários. Além de avaliar a saúde do ecossistema é preciso manter a saúde do curso d'água, para a isso as instituições sociais e econômicas precisam estar envolvidas (MEYER, 1997).

2.2. Cidades e rios: caminhos da degradação

As múltiplas atividades humanas têm produzido mudanças complexas e provavelmente permanentes, tanto na estrutura física como nos processos hidrológicos dos sistemas fluviais (ALLAN, 2004). Nesse sentido, os efeitos da urbanização das bacias hidrográficas sobre o ciclo hidrológico e as alterações provocadas pelo aumento da superfície impermeável na hidrologia e geomorfologia dos rios urbanos são amplamente discutidas (ARNOLD; GIBBONS, 1996; TUCCI; CLARKE, 1997; PAUL; MEYER, 2001).

Segundo Gorski (2008), no Brasil, a relação harmoniosa de encontro da população com o rio ocorreu até metade do século XX; quando se ampliaram os conflitos entre desenvolvimento, sociedade e meio físico. O crescimento rápido da população urbana, desacompanhado da infraestrutura de saneamento e de políticas habitacionais inclusivas, trouxe sérias consequências para os rios e para a qualidade ambiental das cidades brasileiras como um todo. Além do adensamento urbano das bacias hidrográficas, as Áreas de Preservação Permanente dos cursos d'água foram pouco consideradas na construção das cidades (CARVALHO, 2011). Essa ruptura das cidades com os rios levou a grandes alterações nesses ecossistemas (GORSKI, 2008).

As consequências ecológicas da degradação das bacias hidrográficas urbanas foram caracterizadas como “a síndrome dos rios urbanos” (WALSH *et al.*, 2005a), devido aos sintomas similares descritos em vários estudos dos rios em área urbana. Os sintomas incluem hidrogramas com elevadas vazões de pico em curtos períodos de tempo, elevadas concentrações de nutrientes e contaminantes, alterações na morfologia do canal (canalização), redução da riqueza de espécies e aumento da dominância de espécies tolerantes (WALSH *et al.*, 2005a). Não é incomum os rios urbanos se encontrarem confinados e reduzidos a canais de escoamento de efluentes.

O escoamento originado nas superfícies impermeáveis contribui de forma significativa para a degradação dos ecossistemas fluviais em áreas urbanas (PAUL; MEYER, 2001). Isso ocorre, tanto em relação ao aumento da frequência dos eventos que causam perturbação nos cursos d’água (aumento da vazão de pico e velocidade do escoamento) – devido aos índices de impermeabilização; como em relação à composição do efluente resultante, cuja presença de elevadas concentrações de metais traço é uma forte característica (SANSALONE; BUCHBERGER, 1997).

A avaliação da presença de metais, como Cobre, Chumbo e Cadmio, em águas de drenagem urbana mostra que tais poluentes são encontrados em quantidades elevadas e são fontes de poluição dos corpos d’água (PRESTES *et al.*, 2006). Esses poluentes encontrados nas superfícies urbanas, junto com aqueles que estavam na atmosfera e precipitam junto com a chuva, formam uma mistura de compostos orgânicos e inorgânicos, nutrientes, óleos, graxas e metais que são transportadas para corpos de água mais próximos através do escoamento superficial (DRAPPER *et al.*, 2000).

A quantificação dos poluentes do escoamento superficial é difícil, considerando que os valores das concentrações de nutrientes são bastante amplas, dependendo do uso do solo, dos eventos de precipitação, condições climáticas anteriores e do método de amostragem, pois a concentração se altera com o tempo. Lee e Bang (2000) encontraram em área residencial a variação de 0,01 a 4,31 mg.L⁻¹ para nitrato (N-NO₃⁻), 0,89 a 21,05 mg.L⁻¹ para ortofosfato (P-PO₄⁻³) e 2,4 a 22,4 mg.L⁻¹ para fósforo total (PT). Liu *et al.* (2013) encontraram os maiores valores de nutrientes associados a eventos chuvosos de alta intensidade (maiores de 20mm/h) e baixa duração (menores de 2h), com valores médios por evento de 6,85 mg.L⁻¹ de NT, 1,16mg.L⁻¹ de PT e 14,63 mg.L⁻¹ de carbono orgânico total (COT).

2.3. Rios e cidades: caminhos da revitalização

A partir de vários trabalhos científicos de diagnóstico da condição dos cursos d'água e dos impactos da urbanização emerge o movimento de revitalização de rios para tentar reestabelecer a integridade ecológica dos cursos d'água degradados. Contudo, apesar de ser global o progresso desse movimento, contrário à degradação dos rios, ele não acontece da mesma forma e com a mesma intensidade em todos os países. Ademais, mesmo entre os pesquisadores não há consenso entre os métodos empregados e tampouco conhecimento da restauração de forma completa. Pode-se dizer que este campo está em um período de revolução científica, na qual ocorre a mudança de paradigma, no sentido epistemológico explicado por Kuhn (1962). Durante essa fase, há uma variedade de conceitos sendo propostos e várias disciplinas são utilizadas para formar uma base conceitual comum, a qual ainda não está sujeita a convenções bem estabelecidas (ARENAS-IBARRA; SOUZA FILHO, 2010). Entre as disciplinas que dão suporte para a ciência da restauração estão a geografia, a hidrologia e a ecologia, sendo que a restauração ecológica se realiza na interseção entre esses campos científicos. Ademais, a restauração ecológica proporciona uma oportunidade de ligação entre as ciências sociais e naturais, dado que sua aplicação exige abordagens integradas entre ecologia, ciências ambientais, economia, sociologia e política (CAIRNS; HECKMAN, 1996).

Deste modo, não se estabeleceu um consenso para as definições que são aplicadas conforme os termos utilizados, o que pode representar aparentemente falta de clareza. Há vários termos na literatura, como *restauração* (PALMER; BERNHARDT, 2006), *reabilitação* (RUTHERFURD *et al.*, 2000; McCORMICK *et al.*, 2015), *revitalização* (DALLA COSTA; POMPÊO, 2008; GROLL *et al.*, 2016) e *naturalização* (SAMMONDS; VIETZ, 2015). Apesar de ser possível a compreensão dos termos, em um sentido amplo, como sinônimos; também se pode diferenciá-los através de descrições, justificativas e interpretações. Descrições estas que não são estanques, pois os mesmos termos são aplicados em diferentes contextos, com objetivos, ações e implicações bastante diversas. Nesta tese, não iremos empreender a tarefa que já foi realizada por Contreras (2018) de reunir os termos e suas descrições, apenas vamos discutir brevemente a origem do termo *restauração ecológica* e outros conceitos que emergiram da definição inicial e são correlacionados a ela (*reabilitação*, *renaturalização* e *remediação*), além de trazer a contextualização do uso do termo *revitalização* que é adotado nesta pesquisa.

A definição de restauração dada pelo *National Research Council*, como “o retorno de um ecossistema a uma condição próxima ao estado anterior à degradação” (p.18, NRC,

1992), pressupõe um estado de referência anterior ao estado de degradação. Porém, esta definição, apesar de ser amplamente conhecida e ter inspirado um grande número de iniciativas de restauração a partir da década de 1990, levantou vários questionamentos teóricos e práticos sobre o ecossistema de referência (CAIRNS; HECKMAN, 1996). Além disso, houve uma proliferação de outros termos, pela dificuldade ou impossibilidade de restaurar a condição original do ecossistema (CAIRNS; HECKMAN, 1996).

Baseado na definição do NRC, Bradshaw (1996) propôs um esquema que mostra duas componentes do ecossistema, estrutura e função, que seriam recuperadas no processo de restauração de rios. Essa figura foi bastante utilizada e adaptada para auxiliar na compreensão da terminologia da restauração. Rutherford *et al.* (2000) e posteriormente Findlay e Taylor (2006) adaptaram a figura para mostrar a diferença adotada entre restauração, reabilitação ou naturalização e remediação (Figura 1).

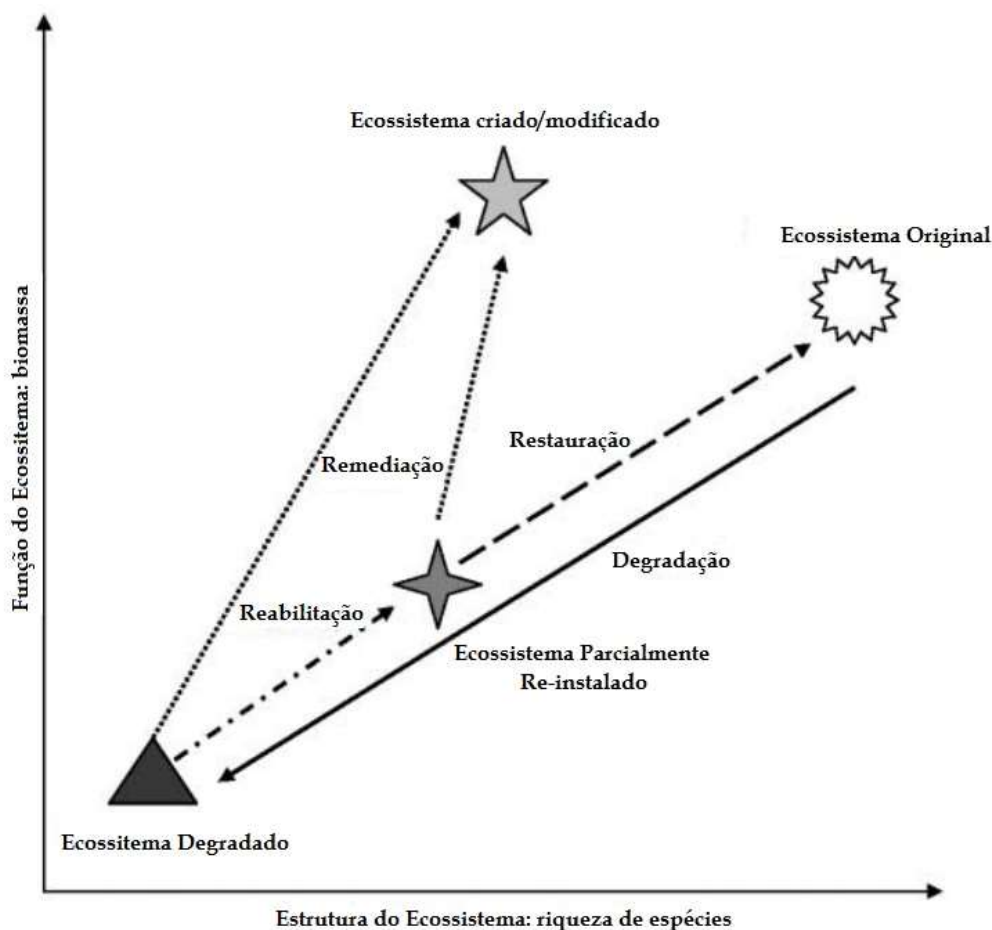


Figura 1. Desenho esquemático para explicação dos termos restauração (retorno ao ecossistema próximo à condição original), reabilitação ou naturalização (melhoria parcial do ecossistema, como o objetivo final de restauração) e remediação (desenvolver um ecossistema melhorado sem a busca pelas características originais). Fonte: traduzido de Findlay; Taylor (2006).

De acordo com essa interpretação a restauração pode ser entendida como a trajetória a ser percorrida no sentido inverso da degradação. Contudo, os autores notam a necessidade de outros termos, pelas dificuldades em se obter resultados ecológicos similares ao estado de referência ou pela impossibilidade da “restauração completa”. Sammonds e Vietz (2015) argumentam que as medidas de restauração são frequentemente consideradas impossíveis no contexto das alterações biofísicas na bacia hidrográfica e das limitações físicas impostas pela urbanização nos cursos d’água, assim são necessárias abordagens alternativas para melhorar a condição do ecossistema aquático. O termo *renaturalização* é sugerido por Sammonds e Vietz (2015) baseado na inclusão da dimensão social no processo. Roni e Beechie (2013) definem a *reabilitação* como a ação de restaurar ou melhorar alguns aspectos ou um ecossistema, sem restaurar completamente todos os componentes. A reabilitação seria uma “restauração parcial”, e pode também ser utilizado como um termo geral para uma variedade de atividades de restauração e de melhorias (RONI; BEECHIE, 2013).

A definição de restauração da Sociedade Internacional para a Restauração Ecológica (SER) reduz os questionamentos que geraram a diferenciação entre os termos, pois a ênfase passa a ser orientada pelos processos ecológicos e não no objetivo de retorno ao ecossistema original (CAIRNS; HECKMAN, 1996). Assim, a *restauração* seria: “o processo de auxílio ao restabelecimento de um ecossistema que foi degradado, danificado ou destruído” (SER, 2004). De fato, se deslocarmos a ênfase da restauração no ecossistema original ou ecossistema de referência, para a ênfase na restauração de processos ecológicos, poderia haver uma unificação das abordagens, convergindo para o termo restauração. Porém, a restauração do aspecto ecológico seria a única motivação das intervenções que vêm sendo realizadas nos cursos d’água?

No contexto de áreas densamente urbanizadas, os resultados alcançados pelas intervenções nos cursos d’água não são exclusivamente para obter melhoria de aspectos ecológicos, embora a motivação geralmente o é (PALMER *et al.*, 2007). Nesse sentido, pode-se justificar o uso de outros termos, como a revitalização que pode ser entendida como o processo de recuperação “da saúde” dos cursos d’água e a reinserção dos rios à paisagem urbana. O uso do termo revitalização é bastante significativo por remeter ao radical latino *vita*, que traz outra perspectiva aos rios urbanos, ou seja, uma alternativa ao simples canal de transporte de águas de chuva e esgotos (POMPÊO *et al.*, 2013). Desta forma, adotamos ao longo da tese o termo revitalização quando nos referimos às intervenções em área urbana que contemplam aspectos estéticos, sociais e econômicos. Outros termos são utilizados no contexto das citações, nas quais os termos foram traduzidos de acordo com as referências.

Além disso, o termo restauração também foi utilizado ao longo do trabalho para se referir à restauração ecológica e quando o texto está escrito em Inglês, por ser o termo mais recorrente que se encontra na literatura científica disponível em língua inglesa sobre o assunto.

Apesar das incertezas no meio técnico-científico, as práticas de restauração se tornam cada vez mais difundidas, e essa popularização da restauração mostra uma mudança nas atitudes públicas em relação aos cursos d'água (KONDOLF; YANG, 2008). Mesmo em situações de baixa integridade ecológica, há potencial de reabilitação, dado que os cursos d'água são dotados de elevado valor de qualificação da paisagem em virtude de suas características naturais e culturais (SARAIVA, 1999). Segundo Cairns e Heckman (1996), a restauração ecológica não precisa ser excluída dos centros urbanos mais densamente povoados, uma vez que o reestabelecimento das interações da sociedade com os sistemas naturais, através da restauração, talvez seja um dos melhores argumentos para essas atividades.

Nas últimas décadas a abordagem de restauração de rios está se estabelecendo como uma componente importante da gestão ambiental (WHEATON *et al.*, 2008; MUHAR *et al.*, 2016). O tema é bastante complexo, pois além do reconhecimento das dimensões morfológicas, hidráulicas e ecológicas dos cursos d'água, há o aspecto sociocultural, o qual acrescenta valores estéticos e paisagísticos nos projetos de reabilitação de rios (McCORMICK *et al.*, 2015; JOHNSON *et al.*, 2018). A identificação dos significados e valores estéticos e ecológicos das paisagens fluviais é um fator de compreensão da percepção e da utilização do rio pela população e do potencial de recuperação desses sistemas (GORSKI, 2008).

De acordo com Everard e Moggridge (2012), os benefícios ambientais dos rios são reconhecidos também como serviços ecossistêmicos, os quais podem ser uma abordagem útil para o planejamento tanto da restauração como para evitar ou minimizar a degradação no desenvolvimento urbano futuro. Adicionalmente, uma gama variada de técnicas estão disponíveis, no âmbito da infraestrutura verde, sistemas sustentáveis de drenagem urbana, corredores ecológicos e NBS. Tais técnicas levam em consideração a abordagem ecossistêmica e empregam aspectos dos serviços ecossistêmicos (EVERARD; MOGGRIDGE, 2012).

2.4. Soluções inspiradas na natureza (*Nature-based solutions* – NBS)

As soluções inspiradas na natureza (*Nature-based solutions* - NBS) foram definidas pela Comissão Europeia (*European Commission* – EC, 2015) como soluções inspiradas,

continuamente sustentadas e beneficiadas pela natureza, as quais são designadas para gerenciar vários desafios sociais de forma eficiente e adaptável, fornecendo ao mesmo tempo benefícios econômicos, sociais e ambientais. Já a União Internacional para a Conservação da Natureza e dos Recursos Naturais (*International Union for Conservation of Nature - IUCN*) define NBS como ações para proteger, gerenciar sustentavelmente e restaurar ecossistemas naturais ou modificados que se dirigem aos desafios sociais de forma efetiva e adaptável, fornecendo simultaneamente bem-estar humano e benefícios para a biodiversidade (COHEN-SHACHAM *et al.*, 2016).

As soluções inspiradas na natureza são consideradas um conceito chave que engloba outras abordagens bem estabelecidas baseadas na conservação dos ecossistemas como: serviços ecossistêmicos, infraestrutura verde e azul (*Green-Blue Infrastructure – GBI*), engenharia ecológica, gestão baseada no ecossistema e capital natural (RAYMOND *et al.*, 2017). De acordo com Kabisch *et al.* (2016), essas abordagens são complementares e possuem considerável sobreposição de significados. Krauze e Wagner (2019) compreendem que as infraestruturas verdes são um instrumentos de implementação das NBS, com o objetivo de melhorar o fornecimento de serviços ecossistêmicos. Além disso, nos casos de sistemas fortemente degradados as NBS são importantes para a remediação ou compensação dos impactos, por exemplo, elas podem ser aplicadas para compensar a falta de capacidade do solo de armazenar água, falta de recarga de aquíferos ou falta de mecanismos de regulação climática em áreas urbanas (KRAUZE; WAGNER, 2019). Nesse sentido, Krauze e Wagner (2019) acrescentam que as NBS se aproximam da abordagem das técnicas compensatórias (ou *Best Management Practices - BMPs*).

A aplicação das NBS na escala urbana enfatiza a multifuncionalidade em termos de serviços e funções que incluem gestão da drenagem, fornecimento de habitat, conectividade ecológica, saúde e bem-estar, espaço para recreação, redução do consumo de energia e mitigação e adaptação em relação às mudanças climáticas (SCOTT; LENNON, 2016). Nas áreas urbanas, a implementação das NBS também envolve oportunidades de pesquisa e inovação relacionadas a novos projetos urbanísticos e procedimentos de gestão que utilizam os componentes naturais como ferramentas importantes para sustentar os processos de regeneração urbana (MUSSINELLI *et al.*, 2018).

Raymond *et al.* (2017) desenvolveram um procedimento sistemático para identificar como as NBS podem fornecer ao mesmo tempo serviços ecossistêmicos e co-benefícios (ou custos) em outros diferentes elementos (socioculturais, socioeconômicos, ambientais, biodiversidade, ecossistemas e clima), especialmente em áreas urbanas. Nesse sentido,

Albert *et al.* (2019) posicionam o planejamento da paisagem e a pesquisa em governança dentro de uma compreensão sistêmica das NBS e outras intervenções no sistema social e no ecossistema, esclarecendo desta forma as interações entre os processos naturais e humanos (Figura 1). Os ecossistemas ilustrados no lado direito do esquema podem ser protegidos, utilizados de forma sustentável ou restaurados através das NBS para garantir ou melhorar a biodiversidade e o provimento de serviços ecossistêmicos (ALBERT *et al.*, 2019).



Figura 2. Esquema conceitual mostrando a interligação entre os sistemas sociais e ecológicos através das soluções inspiradas na natureza e dos serviços ecossistêmicos. Fonte: Adaptado e traduzido de Albert *et al.* (2019).

O uso do termo paisagem é aplicado no contexto do planejamento do território, como uma forma de abordar uma problemática generalizada, dispersa em uma determinada superfície urbana (Alves, 2006). Através do estudo de caso do rio Emscher (Alemanha), Alves (2003) descreve de forma detalhada o uso do conceito de paisagem na revitalização de cursos d'água urbanos e aborda a temática de reinserção dos rios na paisagem urbana.

Para a aplicação no planejamento da paisagem e pesquisa em governança, Albert *et al.* (2019) definem NBS como ações que reduzem desafios sociais bem definidos, utilizam processos ecológicos de um local (redes de infraestrutura verdes e azuis – *green-blue networks*) e se integram com gestão viável ou modelo de negócio para serem implementados (viabilidade prática). Albert *et al.* (2019) apresentam três exemplos relativos as paisagens fluviais, a saber: revitalização de planícies de inundação, proteção e estabelecimento de *wetlands* e adaptação de usos da terra às condições locais dentro da bacia hidrográfica, nos quais as NBS podem ter muitas vantagens em relação as soluções técnicas convencionais.

2.5. Drenagem urbana e gestão de sistemas fluviais

Drenagem urbana

A drenagem urbana como disciplina clássica é usualmente dividida em microdrenagem e macrodrenagem. Resumidamente, em termos de projeto, a microdrenagem seria composta pelos elementos básicos: sarjetas, bocas de lobo, galerias e poços de visita (PORTO *et al.*, 1993). A macrodrenagem foi definida como: “intervenções de fundos de vale que coletam águas pluviais de áreas providas de sistemas de microdrenagem ou não” (PORTO *et al.*, 1993). Ainda, segundo esses autores, as obras de macrodrenagem buscam evitar enchentes através das construções de canais, revestidos ou não, com maior capacidade de transporte que o canal natural e bacias de retenção.

Contudo, o conceito de drenagem se modificou e essas definições ainda estão em grande parte enquadradas na visão tradicional da drenagem urbana, sob o paradigma higienista, no qual a água é vista como vetor de doenças e deve ser escoada o mais rápido possível do meio urbano. Segundo Canholi (2005), essa abordagem pode ser denominada de convencional, de acordo com as diretrizes da canalização; em contraposição, há as medidas não-convencionais, que levam em conta o conceito de reservação. Pompêo (2000) aponta que após o paradigma higienista, a drenagem passou para a fase de novas abordagens (incluindo as medidas compensatórias e de controle difuso de fluxo) e, em seguida, para a fase do manejo sustentável das águas urbanas.

Sob o conceito de *Águas Urbanas* está o manejo da água no meio urbano como um todo, incluindo as águas pluviais, os esgotos e as redes de abastecimento de água para o consumo. Segundo Walsh *et al.* (2012), a natureza do escoamento superficial como um problema ambiental pode ser resolvido pelo uso das águas pluviais como recurso hídrico. Ou seja, o excesso de escoamento superficial gerado pela impermeabilização das superfícies urbanas poderia ser utilizado para o abastecimento de água, através do aproveitamento das águas de chuva.

A suposta melhoria do problema das enchentes urbanas através dos projetos de macrodrenagem, que propõem a canalização dos cursos d'água, vem sendo aos poucos contestada e substituída pela abordagem da restauração de rios e da gestão dos sistemas fluviais. Por exemplo, Miguez *et al.* (2015), fizeram a comparação entre técnicas de drenagem urbana que utilizam a canalização ou técnicas compensatórias, para três cenários de urbanização (cenário 1 – urbanização de acordo com o plano diretor, cenário 2 – urbanização com controle da impermeabilização, cenário 3 – condição de saturação, com uma urbanização densa), em uma bacia hidrográfica do Rio de Janeiro. Miguez *et al.* (2015)

mostraram que as soluções convencionais (canalização) produziram uma vazão de pico mais de duas vezes superior às vazões encontradas com as medidas distribuídas na bacia hidrográfica, para as mesmas condições de uso da terra. Tal resultado mostra a eficiência das técnicas compensatórias em relação a abordagem de canalização para o controle de enchentes.

Além disso, a drenagem urbana deixou de ser uma área restrita ao controle de enchentes, ela precisa ocorrer junto ao desenho urbanístico e suas relações com o ambiente natural, considerando as funções naturais dos espaços, como os alagados e cursos d'água (SOUZA, 2013). Souza (2013) identifica que houve uma evolução, nesse sentido, na pesquisa em drenagem urbana no país, porém destaca a necessidade de fortalecimento técnico-institucional. Esse fortalecimento é essencial para a aplicação das técnicas compensatórias, pois, se por um lado a mudança de abordagem, que passa a incluir os aspectos naturais e urbanísticos antes desconsiderados pelos projetistas, aumentou as possibilidades de técnicas de drenagem urbana; por outro lado, essa evolução conceitual exige capacitação dos profissionais e fortalecimento das instituições para sustentar resoluções e projetos de longo prazo.

Gestão de sistemas fluviais

Di Silvio (2015) expõe três fases da engenharia fluvial. A primeira voltada ao controle dos rios, principalmente visando a prevenção de inundações, necessidades de navegação, preocupação com o abastecimento e produção de energia. Essas obras envolviam projetos específicos, em extensões limitadas do rio (por exemplo, diques, barragens e hidrovias). A segunda fase se caracteriza pelo aumento da preocupação com os eventos extremos, tanto inundações como secas. Os trabalhos foram incorporados em planos, como os planos de gestão de bacia hidrográfica. A terceira fase de atividades relacionadas aos rios se caracteriza pelo aumento da preocupação ambiental e a demanda pela restauração de rios. As disciplinas envolvidas nos projetos de restauração incluem, entre outras, a geomorfologia e a biologia.

Além da ampliação das disciplinas e profissionais envolvidos nas atividades relacionadas aos cursos d'água, no arcabouço do paradigma da sustentabilidade há a necessidade de monitoramento dos ecossistemas restaurados e de gestão adaptativa. De acordo com Convertino *et al.* (2013), inúmeras métricas potenciais para o monitoramento dos ecossistemas emergem da complexidade dos sistemas ecológicos e dos objetivos da restauração; contudo, métricas apropriadas e claramente definidas podem reduzir as

incertezas associadas a restauração, aumentar o conhecimento do sistema e avaliar a utilidade de alternativas.

Gestão adaptativa significa gerenciar os recursos para desenvolver a resiliência ecológica do sistema, envolvendo uma visão de gestão baseada nos processos ecológicos (CLARK, 2002). Ela é descrita como um método de aprender com e, em última instância, superar as incertezas na gestão dos recursos (FARAG *et al.*, 2017). Desta forma, a gestão adaptativa é uma forma de enfrentar as dificuldades que existem entre as ações de restauração e as respostas dadas pelos processos que ocorrem no ecossistema fluvial. Segundo Downs e Kondolf (2002), devido à incerteza em prever respostas às intervenções, a gestão adaptativa é considerada mais adequada para planejar os programas de restauração. A revisão constante dos dados de monitoramento é essencial durante todo o processo de restauração, pois as decisões fornecidas durante a gestão adaptativa não são “tentativa e erro” e sim modelos definidos que podem ser utilizados nas ações de restauração (FARAG *et al.*, 2017). Assim, as ações que foram implementadas são monitoradas e o resultado do monitoramento é utilizado para guiar ações futuras, em um processo iterativo.

Técnicas compensatórias em drenagem urbana

A degradação do habitat que impacta as comunidades bióticas dos rios já ocorre mesmo com índices bastante baixos de impermeabilização da superfície urbana, quando a rede de drenagem está diretamente conectada no curso d'água (WALSH *et al.*, 2005b). Assim, a proteção da integridade ecológica dos ecossistemas fluviais provavelmente requer interceptação e tratamento do escoamento superficial de quase toda a superfície impermeável da bacia hidrográfica, incluindo a prevenção do excesso de escoamento dos córregos atingidos (WALSH *et al.*, 2012). Nesse sentido, as técnicas compensatórias de drenagem urbana têm grande potencial de utilização para mitigar os efeitos da urbanização no balanço hídrico das bacias urbanas e modificar a abordagem tradicional dos projetos de drenagem urbana.

O termo técnicas compensatórias é empregado ao longo da tese para caracterizar medidas nos sistemas de drenagem urbana que possuem tanto o objetivo de reestabelecer o balanço hídrico da bacia hidrográfica, que são alterados pela urbanização, como reduzir a carga poluidora das águas de drenagem. Há na literatura outros termos que podem ser empregados de acordo com os objetivos de cada trabalho. De acordo com Fletcher *et al.*, 2015, os sistemas sustentáveis de drenagem urbana (SUDS), as *Best Management Practices* (BMPs) e as técnicas compensatórias são termos aplicados para caracterizar soluções de

caráter pontual, voltadas ao aspecto hidrológico. Já outros termos como *Water Sensitive Urban Design* (WSUD) ou *Low Impact Development* (LID) são mais abrangentes e envolvem também a preocupação com a melhoria da qualidade da água e remoção de poluentes (FLETCHER *et al.*, 2015). No Brasil, não há uma diferenciação rígida em relação aos significados dos termos, porém, observando a classificação sugerida por Fletcher *et al.* (2015), nota-se que os trabalhos brasileiros (por exemplo: BAPTISTA *et al.*, 2005; SOUZA *et al.*, 2012; CAPUTO, 2012) se referem muito mais a aplicações técnicas específicas do que a princípios amplos.

Entre as técnicas compensatórias, o uso de sistemas de *wetlands* construídos possui reconhecido potencial de remoção de poluentes e nutrientes (SCHOLES *et al.*, 2008; MEYER *et al.*, 2013; LI *et al.*, 2016). Entre outros benefícios, os *wetlands* construídos possuem a capacidade de regularizar vazões, diminuindo os picos de vazão de acordo com seu dimensionamento, também podem atuar no controle e retenção dos sedimentos (POLETO; TASSI, 2012). As aplicações podem ser em sistemas compostos, em conjunto com filtros (JIA *et al.*, 2014; LIN *et al.*, 2015), sistemas convencionais (VYMAZAL, 2013; QUAN *et al.*, 2016), ou em sistemas flutuantes (STEFANI *et al.*, 2011; TANNER; HEADLEY, 2011; BORNE *et al.*, 2015; LYNCH *et al.*, 2015).

Wetlands ou banhados naturais

A vegetação encontrada nos banhados naturais é caracterizada por populações de diversos tipos de plantas adaptadas para crescimento na água ou em ambientes saturados (GUNTENSPERGEN *et al.*, 1988). Por isso, sua classificação em grupos específicos é complexa, conseqüentemente há vários termos que se referem às plantas que crescem ao longo do gradiente entre o ambiente terrestre e aquático: macrófitas aquáticas, hidrófitas, hidrófitas vasculares, plantas aquáticas e plantas aquáticas vasculares (GUNTENSPERGEN *et al.*, 1988). Neste trabalho usaremos a denominação macrófitas aquáticas para designar estas plantas.

A figura 3 ilustra a classificação das macrófitas aquáticas de acordo com Esteves (1998). Em concordância com essa classificação, Bianchini Jr. (2003) descreve que em geral são distinguidos três tipos principais de plantas aquáticas quanto à posição na superfície da água: a) Submersas: podem estar fixas aos sedimentos por meio de raízes, como *Egeria* e *Hydrilla*; ou livres, acumulando-se nos estratos próximos à superfície, como a *Utricularia* e *Ceratophyllum*; b) Emergentes: plantas enraizadas, cujas folhas e flores podem ser flutuantes (*Nymphaea*, *Vitoria amazonica*) ou emergem eretas (*Typha*, *Juncus*); c) Flutuantes: flutuam

livremente na superfície da água, entre os gêneros mais comuns destacam-se *Salvinia*, *Lemna*, *Eichhornia* e *Pistia*.

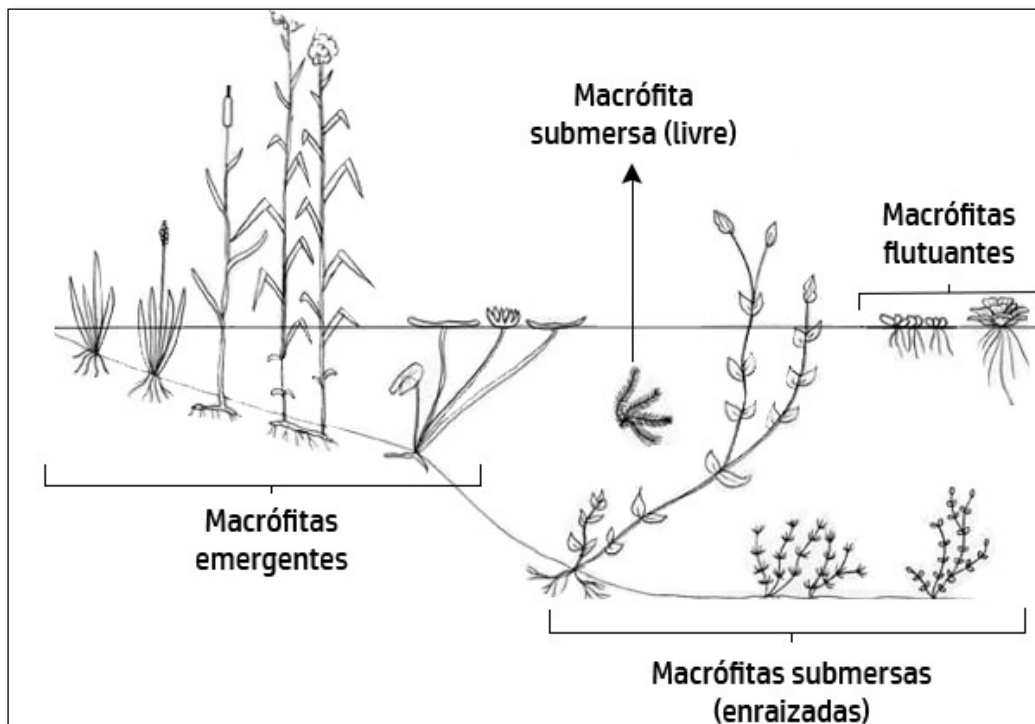


Figura 3. Classificação das macrófitas de acordo com seu modo de vida na água. Fonte: Adaptado de Esteves (1998).

Filtros plantados com macrófitas, banhados artificiais ou wetlands construídos (Constructed Wetlands – CW)

Os filtros plantados com macrófitas, banhados artificiais, *Constructed Wetlands* (CW) ou simplesmente *wetlands* podem ser definidos como um complexo de substratos saturados, vegetação emergente e submersa, fauna e água, simulando os banhados naturais, que são projetados e feitos artificialmente para beneficiar ou serem usados para alguma atividade humana (HAMMER; BASTIAN, 1988).

Os CW podem ser classificados de acordo com: as formas de crescimento das macrófitas (plantas flutuantes, submersas ou emergentes), o nível de água (saturado ou insaturado), a forma de escoamento (superficial ou subsuperficial) e a direção preferencial do fluxo (horizontal, vertical ou híbrido) (SEZERINO *et al.*, 2015; CHEN *et al.*, 2016). Chen *et al.* (2016) propõem uma classificação incluindo a variante dos CW que, apesar de ser constituída de macrófitas emergentes, funciona como se fosse um sistema com plantas flutuantes. Tal sistema, ilustrado na figura 4-a, será avaliado nesta tese. A figura 4 também

ilustra as diferenças de funcionamento de outros sistemas, conforme a classificação proposta por Chen *et al.* (2016).

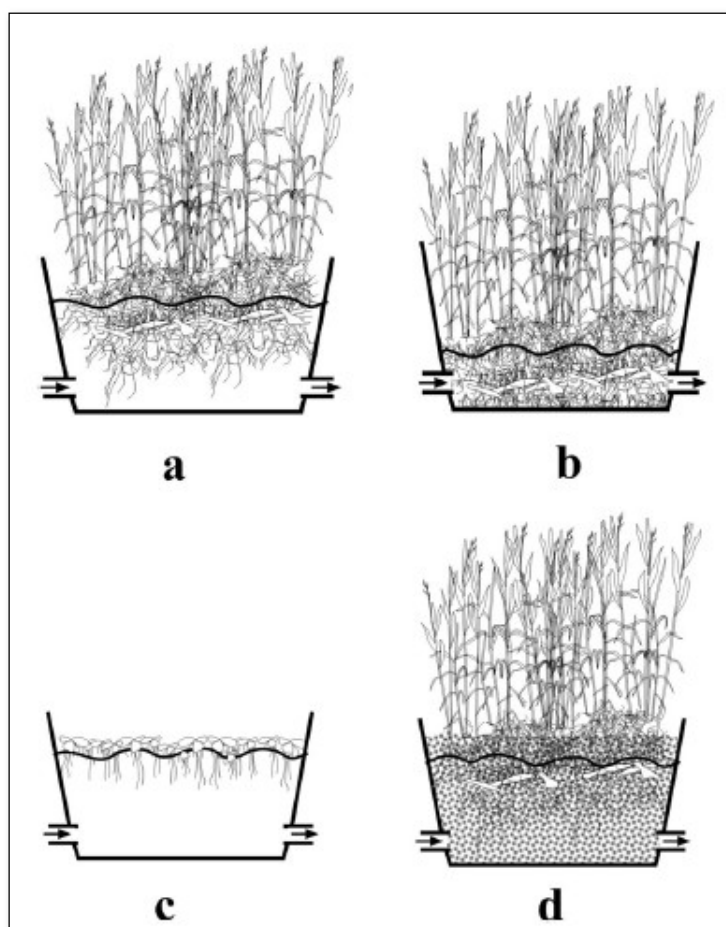


Figura 4. Ilustração dos tipos de sistemas de tratamento com macrófitas. a) tratamento de wetlands flutuantes (FTW) ou zona hidropônica de raízes (hydroponic root mats). b) filtro hidropônico de raízes (hydroponic root mat filters). c) plantas flutuantes de superfície livre (free-floating plants). d) wetland construído horizontal de fluxo subsuperficial (horizontal subsurface flow constructed wetland). Fonte: traduzido de Chen *et al.* (2016).

Entre as espécies de macrófitas emergentes que são comumente utilizadas nos CW podemos citar: *Typha domingensis*, *Schoenoplectus californicus*, *Pontederia cordata*, *Phragmites australis*, *Sagittaria montevidensis*, *Juncus effusus*, *Zizaniopsis bonariensis* e *Pontederia parviflora*. A descrição das características destas espécies encontra-se em apêndice (APÊNDICE 1). Além das espécies citadas acima, há uma série de macrófitas emergentes que foram utilizadas em sistemas de tratamento de efluentes domésticos como: *Zantedeschia aethiopica* (SCHIRMER *et al.*, 2009) e *Heliconia psittacorum* (DECEZARO *et al.*, 2018), entre outras, que possuem boas características para o tratamento de efluentes e alto potencial paisagístico. As macrófitas desempenham um papel extremamente importante

nos sistemas de flutuantes de *wetlands*, sendo que as espécies nativas geralmente apresentam melhor desempenho e não têm o risco de se tornarem invasoras (BI *et al.*, 2019).

Wetlands construídos flutuantes (Constructed Floating Wetlands – CFW)

Tratamento de *wetlands* flutuantes (*Floating Treatment Wetlands – FTW*) ou *wetlands* construídos flutuantes (*Constructed Floating Wetlands – CFW*) são sistemas de tratamento formados por uma estrutura flutuante (matriz) que fica na superfície da coluna d'água, na qual são plantadas as macrófitas emergentes (Figura 5). O sistema é relativamente recente e possui outras denominações como zona hidropônica de raízes (CHEN *et al.*, 2016) e ilhas flutuantes artificiais (CHANG *et al.*, 2017), sendo FTW e CFW as denominações mais comuns. A inovação do sistema consiste na utilização de macrófitas do tipo enraizadas (macrófitas emergentes), porém ao invés de crescerem aderidas ao sedimento do fundo – como ocorreria em um sistema convencional de *wetlands* construídos – elas crescem na estrutura flutuante (TANNER; HEADLEY, 2011). A estrutura flutuante permite que suas raízes fiquem em contato direto com a coluna d'água ou efluente a ser tratado, além disso, os CFW possuem a vantagem de poderem ser aplicados em maiores profundidades do que os sistemas de CW convencionais, pois o sistema acompanha a variação do nível (TANNER; HEADLEY, 2011).

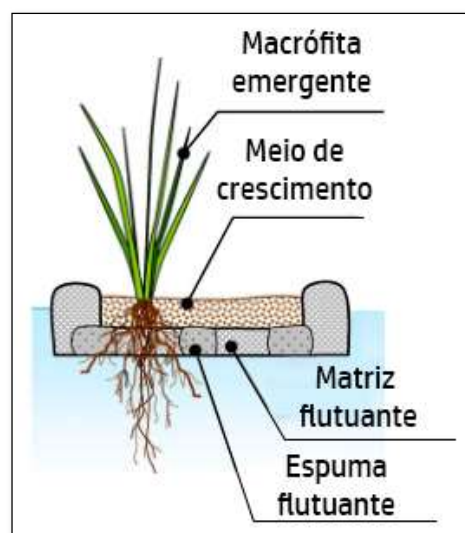


Figura 5. Ilustração dos componentes do sistema de tratamento de *wetlands* flutuantes. Fonte: Adaptado e traduzido de Tanner e Headley (2011).

Os estudos em escala piloto, com experimento de mesocosmos, que avaliam os CFW possuem os mais variados delineamentos amostrais (resumo dos delineamentos em

APÊNDICE 2) e constituem a maioria dos estudos sobre esse tipo de sistema (LUCKE *et al.*, 2019).

Os principais componentes que atuam na remoção de poluentes nos CFW são as macrófitas e o biofilme que fica aderido às raízes (Bi *et al.*, 2019). Segundo Borne *et al.* (2015), os processos que envolvem a remoção dos poluentes ocorrem através da densa rede de raízes e biofilmes que se forma associada às raízes. Devido à relevância do biofilme, há a introdução de suportes artificiais nos CFW para a adesão e crescimento dessa comunidade microbiana (Zhang *et al.*, 2014; Zhang *et al.*, 2018). Na zona de raízes há liberação de compostos orgânicos e detritos pelas raízes das plantas; além de ser uma zona de baixo potencial redox, o que aumenta o sequestro de metais e fósforo para os sedimentos e favorece também o processo de desnitrificação (BORNE *et al.*, 2015).

De acordo com Lynch *et al.* (2015), as bacias de retenção atenuam o pico da inundação e fornecem um tratamento limitado da água através da sedimentação, a aplicação dos CFW nessas estruturas de contenção, portanto, oferecem a oportunidade de melhorar o tratamento do escoamento superficial. Deste modo, seria possível a combinação do controle de inundações e do tratamento do escoamento superficial urbano de modo mais efetivo. A instalação dos CFW em estruturas de contenção existentes não requerer movimentação de terra ou aquisição de área adicional para dedicar ao tratamento e não diminui a capacidade de armazenamento da estrutura (WINSTON *et al.*, 2013). Segundo Zhao *et al.* (2012) a utilização dos CFW é crescente principalmente em países emergentes, como China (LI *et al.*, 2010; Bi *et al.*, 2019) e Índia (KAMBLE; PATIL, 2012), onde a população urbana possui alta densidade e os sistemas de tratamento de efluentes convencionais são deficientes na remoção de nutrientes (principalmente, nitrogênio e fósforo).

Contudo, há muitos desafios para a aplicação dessa ecotecnologia, como o vandalismo que acontece com frequência em área urbana; a necessidade de estudos hidráulicos e hidrológicos detalhados para a definição do local correto para a instalação e o monitoramento do sistema que é necessário, apesar de ser simples. Além do mais, a aplicação direta em cursos d'água, apesar de ser defendida em alguns estudos experimentais (como: ZHAO *et al.*, 2012; NING *et al.*, 2014), pode não atingir a eficiência prevista. Isso ocorre devido aos curtos períodos de retenção hidráulica característicos de rios urbanos, também devido aos poluentes se encontrarem na forma particulada ao invés da dissolvida, sendo que os nutrientes na forma particulada não são prontamente absorvidos pelas plantas (BI *et al.*, 2019).

3. UNDERSTANDING THE RELATIONSHIP BETWEEN RIVER RESTORATION AND NATURE-BASED SOLUTIONS: FROM INSTREAM MEASURES TO CATCHMENT APPROACHES

Este manuscrito é a primeira versão do artigo que será submetido para publicação em periódico de livre acesso. Nesta versão, optou-se pela manutenção do maior número de detalhes sobre os estudos de caso, esse detalhamento será suprimido na versão para submissão em periódico.

3.1. Introduction

Over the last few decades, especially since the 1990s, several river restoration projects were documented worldwide. The European Centre for River Restoration (ECRR, 2019) collects 1284 river restoration cases in 31 countries. Between 1990 and 2004, more than 23,000 river works projects were initiated throughout Japan (NAKAMURA *et al.*, 2006). Bernhardt *et al.* (2005) report information about 37,099 river restoration projects in the United States from National River Restoration Science Synthesis (NRRSS) database until 2004. However, most projects are small scale (implemented on less than 1 km of stream length) and have few information about implementation and outcomes (BERNHARDT *et al.* 2005). According to Bernhardt *et al.* 2005, the most common goals of stream and river restoration projects in the United States are to enhance water quality, to manage riparian zones and to improve instream habitat. Morandi *et al.* (2017) reported that the most measures implemented on both 181 restoration projects in Germany and 99 projects in France are related to river morphology, especially instream habitat enhancement.

The ecological degradation typically motivated restoration projects (PALMER *et al.*, 2007), but there is a gap between restoration goals and the restoration techniques. Doll *et al.* (2015) reported that many projects have not yet developed specific habitat and bedform conditions that support diverse aquatic ecosystems. Long-term hydraulic and geomorphic effects of site-specific restoration approaches are also controversial (KONDOLF; YANG, 2008). The monitoring works have been documented positive results to biological parameters on restoration projects that are associated with the use of catchment-scale controlling factors on restoration framework (LÜDERITZ *et al.*, 2011). While the biological negative results are associated with projects that involved high earth moving activities related to morphological reconfiguration efforts (BERNHARDT; PALMER, 2011). In addition, the enhancement on section-scale macrohabitat conditions have limited effects on

microhabitats resulting in poor results to macroinvertebrates communities, since substrate composition and diversity are particularly important to these aquatic organisms (POPPE *et al.*, 2016; VERDONSCHOT *et al.*, 2016).

Restoration efforts tend to focus on small-scale specific sites without considering broader land use patterns, while the major disturbances that lead to stream degradation typically are catchment-scale disturbances (WALSH *et al.*, 2005; BERNHARDT; PALMER, 2011; COCKERILL; ANDERSON, 2014). Reports from adaptative river restoration provided conditions to theoretical transition for catchment-based approaches, since restoration practices had moved from a focus on geomorphic structure and form to a focus on restoration of the hydrologic, geomorphic and biological process that maintain healthy stream ecosystems (BEECHIE *et al.*, 2010; BERNHARDT; PALMER, 2011; RONI; BEECHIE, 2013). Sediment transport, hydrological balance, nutrient cycling in the aquatic food web and biological diversity dynamics are examples of processes that should be restored (BEECHIE *et al.*, 2010).

This scope alteration can be identified also on restoration definition, which has been altered from goal-oriented definitions to process-oriented definitions (CAIRNS; HECKMANN, 1996). The goal-oriented definition from National Research Council – NRC at 1992 provided a starting point to research on ecological restoration, but lead to various questions about reference state (CAIRNS; HECKMANN, 1996), additionally, terminological difficulties arose from attempts to restore a condition prior to disturbance of very degraded sites (BRADSHAW, 1996). Thus, process-based approach helped to enlighten misleading interpretation about the different terms applied on restoration efforts as well as make space to catchment-based efforts, since the processes that must be restored are related to catchment scale.

In this regard, nature-based solutions (NBS) have been indicated as critical for the watershed management, ecosystem restoration as well as improvement of human well-being in urban areas (KRAUZE; WAGNER, 2019). Nature-based solutions is an umbrella concept that are closely related to other concepts as ecosystem services and green and blue infrastructure with focus on multiple benefits in urban landscapes (LAFORTEZZA *et al.*, 2018). Krauze; Wagner (2019) argue that green and blue infrastructures are an implementation instrument for NBS, with the aim of improving the delivery of ecosystem services and serving as the structural framework for NBS functionality. The water cycle plays a role on NBS approach (KRAUZE; WAGNER, 2019), in this sense, previous concepts – that focus on reestablishment of hydrological processes through distributed

measures in catchment area – as water sensitive urban design (WSUD), low impact design (LID), best management practices (BMPs), green and blue infrastructure (GBI), among others urban drainage terminologies (FLETCHER *et al.*, 2015a) are concepts correlated to NBS.

This paper review the current literature about how NBS have been implemented in the context of river restoration projects. The objective is to analyze case studies of urban rivers restoration that implemented broad restoration measures into the catchment area, according to NBS framework and correlated concepts. The discussion of case studies takes into account the need for process-based restoration efforts to reestablish hydrologic, geomorphic and biological functionality of urban catchments, and, on the other hand, the restoration constraints related to urban rivers.

3.2. Restoration case studies

The case studies were selected according to reports of catchment approaches in the context of landscape planning, with focus on urban areas. Instream measures and cases with site-specific results that are not associated with additional catchment measures were not included on the scope of this review.

The studies were described according to objectives, catchment historical land uses and the characteristics of intervention. Table 1 summarized the general data of the restoration projects. Catchment areas of studies vary from 8.5 km² of a small experimental catchment to 2160 km² of a complex hydrographic basin.

Tabela 1. General data of the restoration projects.

River	Local	Drainage area (km ²)	Instream intervention length (km)	Land use (% urbanization)	References
Nine Mile Run	Pittsburgh, USA	19.4	3.54	85	Bain <i>et al.</i> (2014); NMRWA (2019)
Emscher	Northrhine-Westphalia, Germany	865.0	120.00	>40	Gerner <i>et al.</i> (2018); Alves (2006); Perini; Sabbion (2017)
Bronx	New York City, USA	99.0	37.00	>60	Perini; Sabbion (2017)
Los Angeles	Los Angeles, USA	2160.0	51.00	32	Perini; Sabbion (2017); City of Los Angeles (2019)
Manzanares	Madrid, Spain	710.0	6.00	>13	Perini; Sabbion (2017); Magdaleno (2017); Ballesta <i>et al.</i> (1994)
Sokolowka	Lódz, Poland	45.4	13.40	47	Wagner; Zalewski (2009); Ratajczyk <i>et al.</i> (2017); Zalewski; Wagner (2005)
Little Stringybark Creek	Melbourne, Australia	8.5	0.00	13	Walsh <i>et al.</i> (2005); Walsh <i>et al.</i> (2015); Fletcher <i>et al.</i> (2015b); Prosser <i>et al.</i> (2015)

A description of restoration techniques are presented according to instream and catchment measures, while project results and monitoring were organized into the following topics river flow, river morphology, water quality, biological indicators, social and cultural services, and economic benefits (Table 2).

Tabela 2. Restoration measures, results and monitoring data of case studies.

River	Instream measures	Catchment measures	Results and monitoring
Nine Mile Run	(1) Installation of hydraulic structures, (2) stream channel moved from the valley wall to the center of the valley, (3) large amounts of overbank sediment removed from system, (4) establishment of wetlands in floodplain areas, (5) moderation of physical barriers to fish passage.	(1) Extensive repairs and upgrades of the basin's sewer system infrastructure, (2) capture and diversion of slag leachates, (3) an ambitious rain barrel and rain garden projects.	River flow: Hydraulic structures were compromised during extreme events of flow. River morphology: The powerful dynamics that continue to shape the channel, despite substantial effort to prevent these processes. Water quality: Sampling campaigns pre- and post-restoration reveal limited changes in nitrate concentrations. Biological indicators: Monitoring efforts demonstrate a continual and substantial improvement in the fish community. These improvements likely result from the reconnection of the stream with the Monongahela River following removal of fish barriers. Benthic macroinvertebrate communities recover relatively slowly, %EPT increased significantly and substantially after the restoration. Social and cultural services: Analysis shows a clear increase in rain barrel installations, number of urban "Eco-Stewards" and their volunteer person hours in the watershed. Economic benefits: The region was redeveloped to a mix of housing and green areas.
Emscher	(1) Removal of concrete shells and reverse channelization, (2) stream profiles widened, (3) secondary floodplains created, (4) flood retention basins, pumping stations and dykes.	(1) Construction of a network of underground wastewater channels and the accompanying grey infrastructures, followed by the ecological restoration of the streams, (2) construction of 423 km length of sewer network to separate waste and river water, (3) stormwater runoff management to reduce runoff (volume and peak flow) by 15%.	River flow: The level of flood protection after restoration complies with the regulatory thresholds. River morphology: Mitigating morphological alteration improves the hydromorphological condition of the streams. Water quality: The physicochemical conditions of recipient water bodies are enhanced by reducing the point and diffuse pressures. The restoration of the streams enhanced their self-purification potential by 38% (nitrogen), 266% (phosphorus), 77% (carbon retention), and 39% (carbon stock). Biological indicators: All response capabilities positively affect the aquatic communities of benthic invertebrates and fish. Social and cultural services: The appearance of the riparian environment is enhanced. Economic benefits: The restoration measures influence the placement of new infrastructure and the value of existing infrastructure, such as commercial places with a view on restored stream sections and flats/houses with a view on restored stream sections.

River	Instream measures	Catchment measures	Results and monitoring
Bronx	(1) Installation of canoe and kayak launch site serving for public canoe tours and river wide events.	(1) The green infrastructure program converts unused spaces within the right-of-way, such as vacant traffic islands and medians, into rain gardens, (2) new green spaces in the neighborhood have been inaugurated and existing parks have been enlarged, connecting some areas which were separated by highways, railroads, and other barriers, (3) native trees, plants, and shrubs, as well as green infrastructure elements, were also added along the parks, (4) remediation of contaminated areas.	River flow: Installation of an USGS station in 2006, operated in cooperation with Bronx River Alliance and municipal institution. River morphology: Where the channel has been artificially widened or confined, it was added in-stream structures. Water quality: The improvement in water quality and the actions implemented have led to important results. The Bronx river stewards program engages individuals and groups in monitoring water quality. Biological indicators: There was a significant and measurable biodiversity increase. Social and cultural services: Most of the green areas have been built or renovated along with the greenway construction to exploit ecological, environmental as well as social and recreational positive effects. The education program involves teachers, community-based educators, and scientists in a common effort to use the Bronx river as a classroom setting for ecological initiatives. Economic benefits: Enhancement of neighborhood conditions and land value in the watershed areas due to the opening of the greenway.
Los Angeles	(1) River channel modifications include flow velocity reduction, measures to increase flood protection and to allow the growth of vegetation in and along the river channel.	(1) Variety of public space development measures as the creation of small pocket parks, natural areas, urban plazas and civic spaces in reclaimed channel areas, (2) spaces available for active sports and associated support facilities on appropriate locations along the river corridor, (3) a network of trails, paths, and bikeways along the river corridor	River morphology: The river is still channelized, but the revitalization master plan included alternatives to reconfigure the channel dimensions which may include the removal of concrete in portions of the river. Water quality: Sites in the upper watershed are in better condition than lower watershed sites across various metrics of stream health. Temporal trends in water chemistry after eight years of monitoring the Los Angeles river watershed are weak or absent. Water quality is suitable for recreational activities, but swimming in the river is still prohibited. Biological indicators: There were no significant temporal trends in biological condition and riparian habitat condition across confluence sites during the eight years of monitoring (from 2009 to 2017). Social and cultural services: Waterfront re-invigoration work is connecting communities to the river's water and providing social, environmental, and recreational benefits. Economic benefits: There was an increased value of both properties and businesses.

River	Instream measures	Catchment measures	Results and monitoring
Manzanares	(1) Actions for recovery and improvement of fluvial habitat, (2) silviculture work and elimination of exotic vegetation, (3) plantation of irregular forest of native species in bands parallel to the channel and protection of singular trees, (4) removal of sediments in La Trofa stream, lowering of gauging station slab, installation of fish ramp in the El Pardo dam, (5) improve accessibility to the river and pedestrian footbridge installation.	(1) The highway that run along the river was relocated underground through several tunnels and a renovation plan for this area was started, (2) 13 new km of pipes and storm tanks funnel clean water through the river (with a capability nine times higher compared to the older system), (3) 110 ha of new green areas, (4) adaptation of different types of paths and trails.	River morphology: Rehabilitation of relevant hydromorphologic processes, allowance of natural river forms to develop inside the riverbed, re-connection of the urban reach with upstream and downstream semi-natural and protected river reaches, improvement of riparian stands, and rehabilitation of the river corridor. Water quality: The new underground and safe infrastructure, improved water quality and a safer hydrological system within the Manzanares basin. Biological indicators: Biodiversity increases by new plant species, which were chosen according to riverbanks characteristics. Improvement of fauna corridor, especially birds and nocturnal animals. The strategies to favor the movement of aquatic fauna increases biologic vitality and, in some specific areas, facilitate game fishing. Social and cultural services: The linear park created a friendly and inclusive urban environment, connecting the city neighborhoods and providing green areas. It has improved the citizens' quality of life and the ecological, landscape and recreational connectivity. Economic benefits: The urban renovation has increased private real estate value.
Sokolowka	(1) Installation of Sedimentary-Biofiltration System in 2010 for efficient stormwater purification at stormwater outflows, (2) design of two reservoirs, constructed in 2006 and 2011, (3) design of two detention ponds, constructed in 2009 and 2012.	(1) Installation of the online hydrological monitoring stations, (2) adoption of the blue-green network concept become a part of the development strategy of city, since 2013, the Łódź office has implemented a comprehensive strategic management system, comprising separate sectoral policies, (3) thirty-one areas were earmarked for protection as protected landscape areas, natural and scenic complexes or ecological sites.	River morphology: There is a plan to reconfigure a part of river to construction of the Sokolowka river park. Water quality: The measures resulted in the elimination of toxic cyanobacterial blooms and improvements in the ecological quality of the system. Social and cultural services: Increased amount of water and green space in the city. Improvement of quality of life and promote human health, as well as value of the area for its inhabitants. The variety of activities conducted using the Learning Alliance methodology allowed the research and demonstration projects to be widely extended with the aspects addressing the priority issues in the city. Economic benefits: The initial demonstration projects have become models for up-scaling in other areas of the city, by both the city management and private investors.
Little Stringybark Creek	No instream intervention.	(1) Installation of catchment distributed measures: 63 rainwater tanks; 6 tanks with rain gardens; 49 tanks with infiltration systems; 81 tanks with passive irrigation to garden; 47 tanks with baseflow trickle to stormwater; 41 rain gardens; 6 infiltration systems; and, 2 low-flow water quality filtration system.	River flow: Flows are measured continuously. Water quality: Temperature, salinity, dissolved oxygen, pH, nitrogen, phosphorus and suspended sediment are measured on a monthly basis as well as during at least 12 storm events per year. Clear decreasing trends in the concentrations of TSS, TN and TP. For example, concentrations of TP are now typical of those observed in the forested reference streams in the region. Biological indicators: A range of ecological indicators (macroinvertebrates, fish, algal and diatom assemblages, algal biomass and leaf breakdown rates) are measured. No ecological responses as yet. Social and cultural services: The public and private stormwater control measures have saved potable water and returned stormwater into the ground, helping to recharge natural groundwater and stream baseflows.

Nine Mile Run (Pittsburgh, USA)

The watershed of Nine Mile Run was urbanized in the first half of the 20th Century, predominantly as residential suburbs to the city of Pittsburgh (BAIN *et al.*, 2014). It drains substantial portions of City of Pittsburgh, Swissvale, Edgewood, and Wilkinsburg, and relatively small portions of three others municipalities Braddock Hills, Forest Hills, and Penn Hills. The major part of the streams of Nine Mile Run catchment are culvert, but in the late of 1990s begin an effort to restore than culvert and bury the Nine Mile Run (BAIN *et al.*, 2014). The stream restoration project was completed in 2006, with reparation work on 2007 and 2009 (BAIN *et al.*, 2014). The restoration project was done on the open portion of the stream flowing through Frick Park (NMRWA, 2019). The restoration was supervised by the Army Corps of Engineers in partnership with the City of Pittsburgh and the maintenance for the restored stream is the responsibility of the City of Pittsburgh's Department of Public Works (NMRWA, 2019). The initial objectives of the restoration were improve stream stability and water quality, diminish peak discharges resulting from urbanization, improve the aesthetic quality of the valley, and to enhance recreational opportunities (BAIN *et al.*, 2014).

Emscher (Northrhine-Westphalia, Germany)

The Emscher River flows in an old German industrial region, the Ruhr area. This region was profoundly altered by industrialization, since the beginning of the 19th Century it also had a high population density (PERINI; SABBION, 2017). The coal mining generated the major impact on river as well as industrial wastewater that contaminated the river, destroying its ecosystem and increasing the risk of epidemics (PERINI; SABBION, 2017). From 1906 to 1920 a concrete structure was built reducing river course from 109 km to 80 km (PERINI; SABBION, 2017). However, after the end of mining activities, in the 1980s, the region sliding into economic depression (PERINI; SABBION, 2017). In this context, the river restoration project is a part of a major landscape restoration planning (ALVES, 2006). The project started in 1990, restoration works have been implemented in the catchment area of the river and its tributaries along 120 km, with removal of concrete channels to restore natural vegetation (PERINI; SABBION, 2017). The project objectives are (1) construction of decentralized wastewater treatment plants and pumping stations to treat wastewater locally, (2) renaturation of rivers and creeks, (3) rainwater and wastewater separation to reduce the amount of water processed by treatment plants and to recharge groundwater and water bodies (PERINI; SABBION, 2017).

Bronx (New York City, EUA)

The Bronx River flows on New York City landscape, through southern Westchester and the Bronx. The river valley remained forested well up into the 1800s, but the construction of the New York Central Railroad in the 1840s turned the valley into an industrial corridor, and by the end of the 19th Century the Bronx River had degenerated into “an open sewer” (BRONX RIVER ALLIANCE, 2019). The ecological restoration of the Bronx River started in the mid-1970s. In 1974, local residents formed the Bronx River Restoration Project, Inc (PERINI; SABBION, 2017). The interest of local communities drew attention to the ecological restoration of the Bronx River conditions to improve the neighborhood degraded characteristics (PERINI; SABBION, 2017). The public and private initiatives allowed the construction of the Bronx River Greenway which was devised for recreational use and environmental preservation and it clearly improves the ecological conditions of the region (PERINI; SABBION, 2017). The main ecological goals are (1) protect and improve water quality, (2) protect and improve aquatic and riparian plant and animal biological diversity and habitat, and (3) reduce environmental stresses on the river ecosystem (CRIMMENS; LARSON, 2006). In addition, the New York Department of Environmental Protection has made stormwater management via green infrastructure one of their primary goals, with Bronx catchment as a priority area (BRONX RIVER ALLIANCE, 2019).

Los Angeles (Los Angeles, EUA)

Los Angeles River originates in the San Fernando Valley and flow to its mouth in Long Beach, on the Pacific Coast of the United States. Following urban development in the 1880s the city’s relationship with the river changed due to the rapid urbanization (PERINI; SABBION, 2017). After floodings that occurred in 1886, 1914 and 1934 an 83 km concrete channel was built, from the 1940s to the 1960s, additionally, most of the Los Angeles tributaries were channelized (PERINI; SABBION, 2017). However, since the 1980s, the Los Angeles River drew increasing attention from artists and activists to focus on the rehabilitation of the river, watersheds and ocean (PERINI; SABBION, 2017). Over the past two decades the City of Los Angeles and the US Army Corps of Engineers of the Los Angeles District through various partnerships, agencies and activist groups have been actively pursuing the revitalization of the Los Angeles River. In 1991, the County of Los Angeles developed the Los Angeles River Master Plan, which was approved in 1996. Since

the adoption of the Master Plan, dozens of projects along the River have been completed (PERINI; SABBION, 2017). The Los Angeles River Revitalization Master Plan was devised in 2007. The river revitalization goals are (1) enhance flood storage, (2) enhance water quality, (3) enable safe public access, and (4) restore a functional riparian ecosystem (LARRMP, 2007). In addition, Los Angeles River Greenway goals are (1) create a continuous River greenway, (2) connect neighborhoods to the River, (3) extend open space, recreation, and water quality features into neighborhoods, (4) enhance River identity, and (5) incorporate public art along the River (LARRMP, 2007). Complementary goals include re-purposing schoolyards, underused property, and other public and private open spaces for multipurpose shared use; cleaning stormwater through the use of best management practices (BMPs) in public landscapes (LARRMP, 2007).

Manzanares (Madrid, Spain)

The Manzanares River is one of the main river systems of the Madrid region, in Central Spain; it connects the Guadarrama hill at the north of the region with the lowland areas and the Countryside at the south (MAGDALENO, 2017). The river has suffered for centuries many human pressures, which have gradually changed its flow pattern, geomorphic features, ecologic processes, and environmental services. Those pressures transformed the landscapes of the Manzanares River in a heterogeneous way, depending on the original conditions and the dynamics of each river reach (MAGDALENO, 2017). Manzanares River is one of the three rivers that supply the Madrid Metropolitan Area, while the headwaters of these three rivers have been used and regulated for supply purposes, the middle and lower parts of the rivers are used as natural reception water bodies of the wastewaters of Madrid (PAREDES *et al.*, 2010). In addition, urban development has negatively affected the environment of the Manzanares basin due to land use changes around the River to provide urban services, in particular, the M-30 highway was built in the 1970s and this had a major impact on the river ecology and the River became inaccessible to citizens (PERINI; SABBION, 2017). The Plan de Rehabilitación del Entorno del Río Manzanares was published in 2003, and Madrid Río is the name of the redevelopment project which has interested an important area of Madrid (PERINI; SABBION, 2017). The project encompasses the M-30 highway that ran next to the river for a total 6 km. This highway was relocated underground from 2005 to 2007 through several tunnels, a total of 43 km, and an extensive urban renovation plan was implemented reusing the space left available (PERINI; SABBION, 2017). The Madrid Río Project is based upon five key elements: the river restoration, Salón de Pinos (a green

corridor on top of the highway tunnel), green and blue areas, sports and recreation facilities, and urban regeneration (PERINI; SABBION, 2017). The project is concentrated specifically on environmental quality management, functional aspects, creation of new green areas and connections within the city (PERINI; SABBION, 2017). The objectives of restoration of Manzanares River were (1) recover the hydrological, morphological and ecological naturalness of the river, (2) restore longitudinal and transversal connection of the river, (3) recover accessibility to the river, encouraging public use, (4) bring the river closer to the people, with the creation of paths and tracks, (5) decrease flood risks in the area and downstream, all the way to the city of Madrid, (6) extend Manzanares River environmental corridor (RFRM, 2019).

Sokolowka (Łódź, Poland)

Łódź area is the source to 18 streams, most of them were channelized and converted into a combined sewerage and stormwater system in the early years of the Twentieth Century (WAGNER; ZALEWSKI, 2009). The water management challenges in Łódź are being addressed by two demonstration projects which Sokolowka River one is related to restoration of a municipal river for stormwater management, increase of water retentiveness, purification, and improvement of quality of life (WAGNER; ZALEWSKI, 2009). The Sokołówka River is situated in the north-western part of the city of Łódź, Central Poland and represents a highly urbanized and industrialized catchment area (URBANIAK *et al.*, 2013). River degradation during the industrial era reduced their capacity for water retention and self-purification (ZALEWSKI; WAGNER, 2005). The good opportunity to bring ecohydrology concepts to reality has been provided by the European Project SWITCH “Sustainable Water management Improves Tomorrow’s Cities’ Health” (WAGNER; ZALEWSKI, 2009). The idea of demonstration projects has received great interest and support from the Łódź Learning Alliance (LA) members. Learning Alliance is a group of interconnected players that was formed in the first phase of the development of the SWITCH project. According to Zalewski and Wagner (2005) the project objectives are (1) increase water retentiveness in the landscape for mitigation of extreme flows, increasing groundwater levels and supporting city vegetation by shaping the vegetation and landscape development in the catchment, (2) reduce storm water sewage flow peaks in streams by the construction of series of ponds and reservoirs, creation and restoration of river floodplains and wetlands, (3) develop permanent monitoring systems for hydrology, pollution and climate control, education and rising environmental awareness, (4) increase in the quality of life and aesthetic

values in the city by restoration of river corridors, ecotone zones and the landscape, (5) increase human health by reducing the number of allergies and asthma cases due to improved microclimate (increased green spaces and amount of standing water in the city).

Little Stringybark Creek (Melbourne, Australia)

Little Stringybark Creek (LSC) is a small stream located on Melbourne metropolitan area (WALSH *et al.*, 2005). A significant portion of the upper catchment has been developed for urban housing, while the most part remained with agricultural use (EARTHTECH, 2006). A catchment-scale experiment have been conducted on LSC catchment to test whether new stormwater control measures technologies applied across an urban area could adequately alter flow- and water-quality regimes to elicit change in in-stream ecological condition (WALSH *et al.*, 2015). Monitoring in LSC and the three control and three reference catchments commenced in 2001, and since 2008, a total of 300 interventions has been constructed (FLETCHER *et al.*, 2015b). In Melbourne, responsibilities for stormwater management are partitioned among regional catchment authorities, municipalities, and private land holders (PROSSER *et al.*, 2015). Despite the fact that catchment responsibilities are well defined in Melbourne, strong leadership, collaboration, and unilateral commitment will be required to progress stormwater management at every scale across catchments (PROSSER *et al.*, 2015). According to LSC project (2019), the objectives of the actions are (1) increase the adoption and effectiveness of new approaches to stormwater, urban water and stream management, (2) trial alternative community engagement and market-based instruments, (3) evaluate costs and benefits of stormwater harvesting, treatment and retention at different scales, (4) develop new stormwater control measures (simple, cheap, robust), (5) develop new stormwater management performance targets (for incorporation into state and national policies).

3.3. Discussion

River flow and morphology: looking for process-based approaches

Improve river morphology is one of the most common river restoration goals (BERNHARDT *et al.*, 2005; MORANDI *et al.*, 2017). This general tendency was observed on all case studies, with exception of Little Stringybark Creek which had no instream measures. In case of Nine Mile Run the instream measures of bank stabilization and channel reconfiguration, could not avoided erosion and sedimentation processes, since the hydraulic structures were compromised during extreme events of flow (BAIN *et al.*, 2014). According

to Bain *et al.* (2014), channel incision raises some doubt about the sustainability of urban floodplain reconnection without concentrated effort to ameliorate the impacts of high-flow events associated with densely urban watersheds. In this regard, Kondolf and Yang (2008) argue that it is difficult to maintain the channel dimensions face to catchment alterations of superficial runoff and sediments load. According to Kondolf and Yang (2008), if the restoration projects were designed to maintain superficial runoff without flood adjacent areas or cause no erosion, the restoration will be a kind of gardening in which the elements are chosen to maintain the human input. This criticism about the sustainability of river restoration instream measures was also pointed out by Gregory and Downs (2008), since the restoration of the process of fluvial system should focus on catchment scale.

On the other hand, remain difficult to know to what extent it is possible to reestablish physical catchment processes that have been disrupted during decades by urban and industrial activities. Indeed, even in relatively low urbanized areas, with extensive efforts to urban runoff control, as Little Stringybark Creek, the runoff coefficient for individual stormwater events has reduced subsequent to the implementation of the catchment retrofit works, but the untreated areas remain a problem (FLETCHER *et al.*, 2015b), additionally, the ecological recovery responses probably will span multiple years (WALSH *et al.*, 2015).

Schwartz *et al.* (2015) sustain that some hydraulic and geomorphic processes can be achieved in urban streams over time even while confining lateral adjustment. According to Magdaleno (2017), occurred a rehabilitation of relevant hydromorphologic processes in Manzanares River, with development of natural river forms inside the riverbed, in spite of bank stabilization that remain in Madrid region. The measures allowed the re-connection of the urban reach with upstream and downstream semi-natural and protected river reaches (MAGDALENO, 2017). Gerner *et al.* (2018) reported also that mitigating morphological alteration improves the streams hydromorphology of the Emscher's basin.

NBS effectiveness on improvement of water quality and biological indicators

Scott and Lennon (2016) summarized multifunctionality of services and functions of NBS as drainage management, habitat provision, ecological connectivity, health and well-being, recreational space, energy reduction and climate change, mitigation and adaptation. The application of techniques to stormwater runoff management according to the NBS framework have been resulted in the reducing of point and diffuse pressures in Emscher's streams (GERNER *et al.*, 2018). In the Little Stringybark Creek, Fletcher *et al.* (2015b) reported decreasing trends in the concentrations of total suspended solids, total nitrogen and

total phosphorus; the total phosphorus concentrations are now typical of those observed in the forested reference streams in the region. There is a tendency to increase the application of NBS techniques in the restoration projects that have not documented good results to water quality such as Nine Mile Run and Los Angeles river. According to Nine Mile Run Water Association (NMRWA, 2019) there are a broad effort to inform the residents the benefits of green stormwater infrastructure through Rosedale Runoff Reduction Project. In addition, the regional plan of water management predict a performance targets range from a 50% to a 90% storm runoff reduction or reuse in developed areas of Los Angeles (PERINI; SABBION, 2017).

The restoration projects that reported clear positive biological results to aquatic communities of fish and macroinvertebrates are Nine Mile Run and Emscher (BAIN *et al.*, 2014; GERNER *et al.*, 2018). Bronx river achieved positive results in vague terms, and Manzanares report improvement to plants, birds and nocturnal animals (PERINI; SABBION, 2017). While Los Angeles river have not documented significant trends of biological condition (SANCHEZ *et al.*, 2018), Sokolowka river mention just a control of cyanobacterial blooms (RATAJCZYK *et al.*, 2017) and Little Stringybark Creek did not have significant ecological responses that is due perhaps a lag or simply that further intervention is required to achieve an ecological response (FLETCHER *et al.*, 2015b). In this way, the biological responses are not as good as to water quality.

In this regard, Cockerill and Anderson (2014) argue that the optimism about the feasibility of ecologically restoring an urban or any degraded stream should be avoided, since the major of restoration results have not been achieved positive ecological responses (PALMER *et al.*, 2010). The reasons of the lack of positive ecological results go beyond the scope of this work, but these findings revealed that restoration efforts should give priority first to conservation of well-preserved areas and second to sites with high recovery potential (BRIERLEY; FRYIRS, 2005; FRYIRS *et al.*, 2018). In addition, urban stream restoration can provide valuable services that are not purely ecological (COCKERILL; ANDERSON, 2014).

Are social and cultural services the best results of urban river restoration?

All the restoration case studies reported social and cultural services due both enhancement of riverine landscape and community involvement on catchment measures to stormwater control (Table 2). When the restoration initiatives have top-down approaches as in the Emscher and Manzanares case studies, the population may take time to understand

and recognize the project benefits, especially when the project have to reconfigure constructed urban infrastructures (PERINI; SABBION, 2017). While bottom-up approaches as Bronx and Los Angeles rivers had more social engagement on educational activities and water quality monitoring, since restoration efforts arose from community desire of green areas and recreational opportunities (PERINI; SABBION, 2017). The universities also played a role in restoration initiatives of Nine Mile Run, Sokolowka and Little Stringybark Creek. However, the university's initiatives have not be only a scientific experiment, the researchers should to educate the public about the river's processes and train volunteers to monitor its condition, since community involvement is a crucial component in sustaining urban stream restoration (BAIN *et al.*, 2014).

Human well-being is one of the benefits addressed by NBS that by definition apply ecosystem processes to deal with societal challenges and provide co-benefits for nature and people (ALBERT *et al.*, 2019). Both the International Union for the Conservation of Nature and the European Commission have suggested priority areas encompassed by NBS, among them are included regeneration and well-being in urban areas, watershed management and ecosystem restoration (ALBERT *et al.*, 2019). According to Kabisch *et al.* (2017), the provision of ecosystem services through urban green and blue spaces can be seen as NBS, since these spaces provide various health benefits that can be categorized as cultural and regulating ecosystem services. Cultural services often act to promote health by, for example, increasing physical activity, while regulating services rather prevent disease by reducing risk factors (KABISCH *et al.*, 2017). In this regard, Vujcic *et al.* (2017) showed that recuperation of people health was much more complete when participants were involved in horticulture therapy for improving mental health, since the isolation of citizen from contact with natural environment are related with mental disorders including depression, stress and psychosomatic disorders. Thus, river restoration initiatives have the potential of recover the citizen relation with nature, and this result are achieved even when the restoration measures occurs on small scale and in heavy urbanized areas.

Economic benefits exceed the restoration costs

Restoration costs are relatively high, especially when they encompass river morphology modifications, however the economic perspective provide convincing arguments for justifying the restoration efforts (GERNER *et al.*, 2018). All of case studies with instream measures reported economic benefits related to increase of land value of neighborhood. In addition, the assessment of the economic value provided by green and blue

infrastructures tends to increase these benefits, in spite of the remaining methodological, ethical and practical difficulties to evaluate and attribute a value to natural environments (WILD *et al.*, 2017). Especially, the restoration ecology is a bridge between the social and natural sciences, its application requires integrative approaches of ecology, environmental sciences, economics, sociology and politics (CAIRNS; HECKMAN, 1996).

3.4. Conclusions

This work synthetize and discuss the results of seven case studies of river restoration that employ NBS as restoration measures. However, the NBS-based measures are still at an early stage of implementation. The instream measures had more positive results to provide social and cultural services than to enhance ecological or morphological condition. In spite of ecological goals being the common motivation to restoration efforts, the best results are related to human well-being as recreation benefits, educational activities and aesthetics improvement. In addition, economic benefits are also achieved by land use valorization and urban landscape regeneration. These results highlight that restoration efforts have more benefits beyond the ecological improvement, moreover, to reestablish ecological and hydromorphological process in urban areas are uncertain and may require long period of time as well as a wide effort to implement catchment-based approaches grounded in NBS.

4. ESTABLISHMENT OF A CONSTRUCTED FLOATING WETLAND: PERSPECTIVES TO URBAN DRAINAGE APPLICATION

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Resumo

Wetlands Construídos Flutuantes (CFW) são uma tecnologia de tratamento de água relativamente recente que vem sendo empregada mundialmente para melhorar a qualidade da água de reservatórios de retenção e para restaurar rios urbanos. Este artigo descreve o desempenho de *Typha domingensis* e *Schoenoplectus californicus* em um sistema de CFW. O experimento foi conduzido em mesocosmos (120 L) com duas réplicas para cada espécie de macrófita emergente. Foram aplicadas bateladas semanais com três concentrações diferentes de solução sintética. O crescimento das raízes foi medido para avaliar a adaptação das macrófitas à estrutura flutuante. Os valores de entrada e saída dos tanques foram monitorados para temperatura, condutividade, oxigênio dissolvido, potencial redox, turbidez, pH e cor. Além disso, nutrientes foram quantificados para avaliar a eficiência de remoção. A análise de variância foi aplicada para avaliar as diferenças entre os tratamentos e as condições. A análise canônica de coordenadas principais foi realizada para avaliar o desempenho das espécies. A estrutura flutuante não impediu o crescimento das raízes, apesar de ser rígida e desprovida de substrato. Ambas as espécies se adaptaram ao funcionamento do sistema, mas *T. domingensis* mostrou melhor eficiência de remoção de nitrogênio e fósforo. A manutenção da verticalidade das plantas e a ancoragem da estrutura foram algumas das dificuldades enfrentadas, assim, a estrutura flutuante necessita de algumas adaptações para melhorar esses aspectos e viabilizar a aplicação do sistema para o tratamento do escoamento superficial urbano em escala real.

Palavras-chave: Tratamento Flutuante de wetlands; Ecotecnologia; Gerenciamento de águas pluviais; Macrófitas emergentes; Remoção de nutrientes.

4.1. Introduction

Urban drainage solutions that consider the ecological and landscape aspects, as well as the purely hydraulic-hydrological aspect, are increasingly defended in the scientific environment and desired by society. This is due to three factors: a) limitations of

conventional solutions and the need for sustainability in urban drainage management (Pompêo, 2000; Burns et al., 2012), b) recognition of the social value of urban watercourses (McCormick et al., 2015), c) need for maintenance and recovery of ecosystem services provided by rivers (Everard; Moggridge, 2012; Vermaat et al., 2016).

In order to implement new approaches, however, it is necessary to design and to evaluate new alternatives. The approaches should be multidisciplinary, since the issues are very complex. In this sense, emerging scientific fields such as ecological engineering have much to contribute on stormwater management. Water treatment with constructed wetlands is considered a good example of ecological engineering because the fusion between engineering and ecology is almost uniform (Kangas, 2004). This means that constructed wetlands systems of treatment encompass sophisticated flow regulation and carefully design, while they mimics the natural ecosystem. Filters planted with macrophytes or constructed wetlands by definition are a complex formed by saturated substrates, emergent and submerse vegetation, fauna and water; they imitates natural wetlands and are designed artificially to benefit some human activity (Hammer; Bastian, 1988).

Floating treatment wetlands or constructed floating wetlands (CFWs) are a variant of constructed wetlands that employ emergent macrophytes planted in a floating structure (Tanner; Headley, 2011; Pavlineri et al., 2017). These systems are also named as floating emergent macrophyte treatment wetlands (Fonder; Headley, 2013), hydroponic root mats (Chen et al., 2016), artificial floating islands (Chang et al., 2017), among others denominations. The macrophytes used in these systems are the rooted type, however, instead of growing in the solid substrate (as it would be usual on conventional constructed wetlands) they develop in the floating structure (Tanner; Headley, 2011; Weragoda et al., 2012). The floating structure allows the roots to be into direct contact with the water column.

According to Borne et al. (2015), the processes that involve the removal of the pollutants in the CFWs occur through the dense network of roots and biofilms that are associated with the roots. In this region, the release of organic compounds and debris by the roots of the plants are common; as well as being a zone of low redox potential, which increases the sequestration of metals and phosphorus to the sediments and favors the denitrification process (Borne et al., 2015). Thus, the combination of the biofilm and the root system satisfies the plant growth needs and provides ecosystem services through water treatment and habitat supply to a diverse range of plants and animals (Vymazal, 2013; Lin et al., 2015).

Conventional constructed wetland systems tolerate relatively low water depths (less than 0.5m for long periods) and short periods of total submersion (Tanner; Headley, 2011). The CFWs have in turn the advantage that they can be applied at greater depths, since the system is on the surface of the water and follow the variation of its level. This characteristic allows its application in stormwater detention or retention systems (Lucke et al., 2019). According to Lynch et al. (2015), retention basins attenuate peak floods and provide limited water treatment through sedimentation. The CFWs provide the opportunity to improve the treatment of surface runoff. In this way, through this application, it would be possible to combine flood control and urban surface runoff treatment more effectively.

Another positive aspect of the system is the reduced cost of installation. Since CFWs do not require solid substrate, the cost of floating systems become more competitive over conventional constructed wetlands (Chen et al., 2016). In addition, if the CFWs will be applied in an existing detention pond the cost will be cheaper than the acquisition of new areas for the construction of another compensatory techniques to improve water quality (Wang et al., 2014).

According to Zhao et al. (2012) the use of CFWs is expanded mainly at emerging countries where the urban population has high density and the locations presents a conventional wastewater treatment systems which are deficient in the removal of nutrients (nitrogen and phosphorus). These nutrients, together with other pollutants from urban drainage, end up reaching the natural waterways decreasing their water quality. The use of CFW in river restoration projects is another form of application of this ecological technology (Zhao et al., 2012, Ning et al., 2014, Chang et al., 2014). However, rivers are very dynamic and complex environments, thus the application would require a greater effort of maintenance and monitoring, especially in relation to the control of the proliferation of the used species.

The use of CFWs is recent in Brazil, and the application in the treatment of domestic wastewater is reported successfully (Quevedo et al., 2015). However, the direct application of technology in river systems without experiments that consider the use of different species and hydraulic operating conditions may lead to misleading conclusions about its applicability. Experimental studies provide critical data for the application in urban drainage compensatory techniques and in river restoration projects, since there is a lack of detailed information about system establishment period and macrophytes adaptation to the floating system.

This study aims to evaluate the performance of two native species of emergent macrophytes (*Typha domingensis* and *Schoenoplectus californicus*) under a CFW system. This work reports detailed results of the macrophytes establishment period into the floating structure, additionally, the nutrient removal efficiency was assessed for three different concentrations of synthetic solution.

4.2. Material and methods

4.2.1. Selection of species

Typha domingensis Pers. and *Schoenoplectus californicus* (C.A.Mey.) Sojak were selected among the emergent macrophytes. The criteria of species selection were: origin of the species, proliferation potential, application in phytoremediation and potential commercialization of pruning residue. The two species are well described by botany. They are considered native, non-endemic and have a confirmed occurrence in southern Brazil (Bove, 2015; Alves et al., 2015), where the experiment was installed.

The native species selection is justified by the risk of introducing exotic species of plants which could be invasive and compete or eliminate native species. Although invasive species may have high nutrient uptake rates, their negative impacts would be more significant than other benefits (Pavlineri et al., 2017). In addition, it must be taken into account that despite the ecological importance of macrophytes, they can also cause problems, such as excessive distribution in reservoirs (Thomaz; Bini, 2003); even though these reservoir problems are not associated with emergent species.

Typha domingensis Pers.

In general terms *T. domingensis* is perennial, reaches up to 3 m in height, the leaves pass, equal or not reach the inflorescence, with sheaths gradually continued on the blade, blades 45 to 120 cm long by 0.6 to 2 cm (Hurrell et al., 2004). In plants of the genus *Typha*, the development of the primary roots usually occurs for a short period of time, the root system being formed by the adventitious roots that originate in the stem, forming the fasciculate root system (Silva, 2014). Due to its high plasticity and adaptability to stressful environments, *T. domingensis* can be used as remediation specie of water and sediment contaminated by heavy metals and water with high pH and salinity (Silva, 2014).

Schoenoplectus californicus (C.A.Mey.) Soják

Schoenoplectus californicus is a perennial plant, with horizontal rhizomes and aerial stems in triangular shape, dark green color, from 1 to 3 m in height (Hurrell et al., 2004). The leaves are reduced to the sheaths or they develop only at the base of the stem. The verticality of *S. californicus* is due both to the triangular pyramidal shape of the scape that gives greater support at the base, being five times larger in the transverse area than at the apex; as to the lacunar system of parenchyma cells (Corsino et al., 2013). In addition, the subterranean caulinar system is well developed and the root system is extensive, which gives greater stability to the scapes, forming a dense mesh with the rhizomes (Corsino et al., 2013).

4.2.2. Experiment installation

The experiment was installed during the month of May, 2017 at the Hydraulic Research Institute (IPH) - Federal University of Rio Grande do Sul (UFRGS), in Porto Alegre, Southern Brazil. The experiment consists of four tanks with a volume of 120 L each (dimensions of 62 x 43 x 45 cm), two for each plant species, in addition to an 800 L reservoir in which the incoming effluent was prepared. The 800 L reservoir is at the upper level and supplies the tanks with gravity (Figure 6A).



Figura 6. A. Structure of the experiment set up at IPH – UFRGS. B. Seedling of *S. californicus* collected on the shore of Lake Guaíba. C. Seedling of *T. domingensis* collected on a humid area at the university campus. D. Seedlings of both species after pruning.

The species were collected on 18 May 2017 during the morning. Specimens of *S. californicus* were collected on the shore of Lake Guaíba (-30.042992, -51.237557), while *T. domingensis* specimens were collected on a humid area at the university campus (-30.076620, -51.117571), both areas are placed in Porto Alegre, RS (Figure 6B, C). About 30 seedlings with similar size were collected. On the same day, the seedlings were transported to the experiment site, where they were installed in the floating structure. The roots of the seedlings were immersed in the water to remove soil residues from the collection sites. Seedlings were pruned to provide the same initial conditions of developing to both species, and also to minimize the effect of leaves breakdown due to the beginning of senescence period (Figure 6D).

The floating structure was conceded by Ecotelhado company from Porto Alegre, RS. The structure consists of plug-in modules with dimensions of 40 cm x 40 cm, consisting of rigid plastic material of recycled polypropylene and polyethylene floats. Thus, the structure has no growth medium and the source of nutrients comes exclusively from the effluent. Therefore, the operation of the system is similar to hydroponic systems.

For the experiment, a module and a half was used in order to completely cover the tanks' surface area. The structures' final dimensions were 40 cm x 60 cm. In the floating structure of each tank, 12 seedlings were planted in an intercalated way.

4.2.3. Synthetic effluent

The input effluent is a synthetic nutrient solution composed of: $\text{Ca}(\text{NO}_3)_2$, KNO_3 , $\text{NH}_4\text{H}_2\text{PO}_4$, MgSO_4 , CuSO_4 , ZnSO_4 , MnSO_4 , H_3BO_3 , $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$, FeDTPA . The proportion of the reagents used was adapted from the solution of hydroponic cultures of Furlani et al. (1999), whose proportion of the essential nutrients is based, in turn, on the formulation of Hoagland & Arnon (1938) according to Resh (1996). This formulation, and its variations, is the basis of the commercial fertilizers available for hydroponics, which were applied to elaborate the synthetic effluents used in CFWs trials (Tanner; Headley, 2011; Zhang et al., 2014; Geng et al., 2017).

The water used for the preparation of solutions was drinking water. The drinking water presented the following initial average characteristics: fluoride 0.551 mg.L^{-1} ; chloride 8.269 mg.L^{-1} ; sulfate 9.483 mg.L^{-1} ; nitrate 0.902 mg.L^{-1} ; total nitrogen $1,331 \text{ mg.L}^{-1}$; total phosphorus 0.004 mg.L^{-1} ; orthophosphate of less than 0.004 mg.L^{-1} ; total organic carbon 3.172 mg.L^{-1} . The use of the synthetic solution aims for a greater control of the incoming

conditions, minimizing the influence of the variability that would occur with the use of drainage or domestic effluents.

Three different proportions were used for the preparation of the synthetic solutions, during the establishment period. In solution 1 the same amount used in hydroponic crops were maintained (Furlani et al., 1999). In solution 2 a ten-fold dilution was applied and in solution 3 a three-fold dilution was applied over the amounts of previous solution (Table 3). Before weekly batches pH of each solution was adjusted after dilution of all reagents to values close to neutrality using Sodium Hydroxide.

Table 3: Proportions of the reagents for the preparation of the synthetic nutrient solution (FURLANI et al., 1999).

Reagents	Quantities to prepare 1000 L of solution		
	Solution 1 (g)	Solution 2 (g)	Solution 3 (g)
1 $\text{Ca}(\text{NO}_3)_2$	750,00	75,000	25,000
2 KNO_3	500,00	50,000	16,667
3 $\text{NH}_4\text{H}_2\text{PO}_4$	150,00	15,000	5,000
4 MgSO_4^*	395,00	39,500	13,167
5 CuSO_4	0,15	0,015	0,005
6 ZnSO_4	0,50	0,050	0,017
7 MnSO_4	1,50	0,150	0,050
8 H_3BO_3	1,50	0,150	0,050
9 $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$	0,15	0,015	0,005
10 FeDTPA^{**} (mL)	23,00	2,300	0,767

* Quantity recalculated because in fertilizer KNO_3 there were Mg and S, both at 1%.

** Amount of Iron recalculated to adjust the same concentration used by Furlani et al. (1999). Amount in volume (mL).

Among the synthetic solutions, solution 3 has nitrogen and phosphorus concentrations more similar of urban surface runoff characteristics, since the drainage effluent commonly has irregular contribution of domestic sewage in drainage network (BRASIL, 2018). However, the pollutants concentration of stormwater runoff have high variability, according to density and class of land use (Lee; Bang, 2000), rainfall parameters (Alias et al., 2014) and catchment characteristics (Liu et al., 2013).

4.2.4. Experimental procedures

The tanks were operated in batch system, with weekly filling frequency. The establishment period predicted for the experiment was from 4 to 12 weeks. During this stage, each tank operated with 20 cm water depth and 50 L volume. The evaluation of the system

occurred by the measurement of in situ parameters of the input and output effluent values. Temperature, conductivity, dissolved oxygen and redox potential (YSI-Pro Plus) were measured. In addition, input and output effluent samples were collected for nutrient analysis. The samples were conditioned in a thermal box, transported to the laboratory and kept under refrigeration until the analyzes were carried out.

The weekly procedure started at the day before of each collection, with the cleaning and filling of the reservoir with drinking water up to 80% of the required volume. The next day, a sample of water was collected per tank, the parameters were measured with the multiparameter probe and the tanks were cleaned for the next batch. The nutrients were diluted in the reservoir and the final volume was filled with water. The tanks were then filled with the fresh solution, one sample was collected per tank and the parameters measured with the probe.

Four seedlings per tank were selected and identified at the beginning of the experiment to root growth assessment. Root growth was evaluated four times during the establishment period (70 days) and two times until the end of the experimental trials (130 days). Measurement of the total length of the roots was performed with a vertical and horizontal line, without removing the seedlings from the structure.

4.2.5. Laboratory procedures

In the laboratory, pH (Digimed), turbidity (Hach-2100N) and color (Digimed-DM-COR) were measured immediately after collection. An aliquot of the samples was filtered using a glass fiber filter (0.45 μm porosity) and analyzed by the ion chromatography method (IHA chromatography with chemical suppression of eluent conductivity 4110-B (APHA, 2005). The chromatogram presented the results of: fluoride, chloride, nitrite, nitrate and sulphate. Total phosphorus and orthophosphate (P-PO_4^-) were evaluated by the Stannous Chloride Method 4500P-D (APHA, 2005) and the values were determined with a spectrophotometer (UV / vis Pro-Analysis 190-1100nm), at the wavelength of 690nm. Total nitrogen and total organic carbon analyses were performed in a TOC analyser (SHIMADZU-TOC- VCPN), with wet oxidation method.

4.2.6. Data analysis

Six weeks of data were selected for analysis among the 11 weeks of the establishment period. They correspond to the application of two weeks for each synthetic solution. The

selected weeks were to solution 1 from 01 to 14 June, to solution 2 from June 22 to July 6 and, to solution 3 from July 20 to August 2.

Data were analyzed using descriptive statistics and analysis of variance (two-way ANOVA) to evaluate the differences in the adaptation between the treatments (*Typha domingensis* and *Schoenoplectus californicus*) and the conditions (input and output), under a significance level of 0.05. The test was performed with the parameters: total phosphorus, orthophosphate, nitrite, nitrate and total nitrogen, for each synthetic solution separately. In addition, canonical analysis of principal coordinates (CAP) was performed to assess the species behavior to the different synthetic solutions. For this multivariate analysis, a normalization was applied to all parameters measured in situ and in laboratory and the Euclidean distance was used to construct the dissimilarity matrix. Statistical program PRIMER (version 6.1.15) was used to run the CAP.

Removal efficiency was calculated to evaluate the applicability of macrophytes to treatment of effluent on CFW, it was determined by:

$$E(\%) = \left(\frac{C_{in} - C_{out}}{C_{in}} \right) \cdot 100$$

where E is the removal efficiency in %, C_{in} is the input concentration and C_{out} is the output concentration.

4.3. Results and discussion

4.3.1. Floating structure and macrophytes growth

The floating structure presented any limitation to root growth although it was made of rigid plastic and have no growth substrates. However, the floating structure did not benefit the maintenance of plants verticality, that was a difficulty observed after the plants growth. The plants presented a tipping over tendency according to the wind direction because some seedlings grew more than others, specially to *T. domingensis*. We used counterweights to maintain the same level of the structure and to provide the plants verticality. In addition, the counterweights were used to increase the structure submersion in the case of *S. californicus*. The challenge of verticality can be mitigated through plant species diversification. This diversification was used by Saeed et al. (2016) that employed specie with high vertical growth in the core and specie with low vertical growth in the borders of the floating structure layout. Additionally, the anchoring of the system on the field application was reported as an important factor of verticality maintenance (Borne et al., 2015).

The density of seedlings was 42 seedlings/m², since 12 seedlings were used by 0.28 m² of superficial area. The floating capacity of the structure applied allowed this high density. Similar studies presented densities of: 42-47 seedlings/m² (Tanner; Headley, 2011), 59 seedlings/m² (Zhang et al., 2014), 27 seedlings/m² (Lynch et al., 2015), 30 seedlings/m² (McAndrew et al., 2016), 20 seedlings/m² (Zhang et al., 2018). The interleaved planting aimed to the propagation of sprouts and rhizomes on the empty spaces. This was registered over time to both species, but *T. domingensis* propagation was faster than *S. californicus*. Šantrůčková et al. (2016) reported that *T. domingensis* developed robust rhizomes for expansion and accumulation of assimilates, according to specie strategy of growth. In addition, *Typha spp.* are recognized as strong competitor, resistant and proliferative species (Vymazal, 2013; Šantrůčková et al., 2016).

Establishment periods applied on CFWs varied from four weeks (Zhang et al., 2014) to two years (Borne et al., 2015). The establishment period of eleven weeks, applied on this study, were enough to observe the differences between the macrophytes strategies of root growth as well as the adaptation of each specie to floating structure. *Typha domingensis* presented superior vertical root growth in relation to *S. californicus* at the end of establishment period, that correspond to 77 days (Figure 7-A). This result might be related to the *T. domingensis* adaptability and tolerance to a diverse range of environmental conditions (Cabo et al., 2015). On the other hand, besides *S. californicus* presented low vertical root growth, it recorded more quantity of seedlings that should be replaced than *T. domingensis*. A week after the procedure of pruning, 19 of the 24 seedlings of *T. domingensis* had sprouts while just 8 of 24 seedlings of *S. californicus* had sprouts. On 23 July, three seedlings of *T. domingensis* were replaced and five seedlings of *S. californicus* were replaced from substitute seedlings.

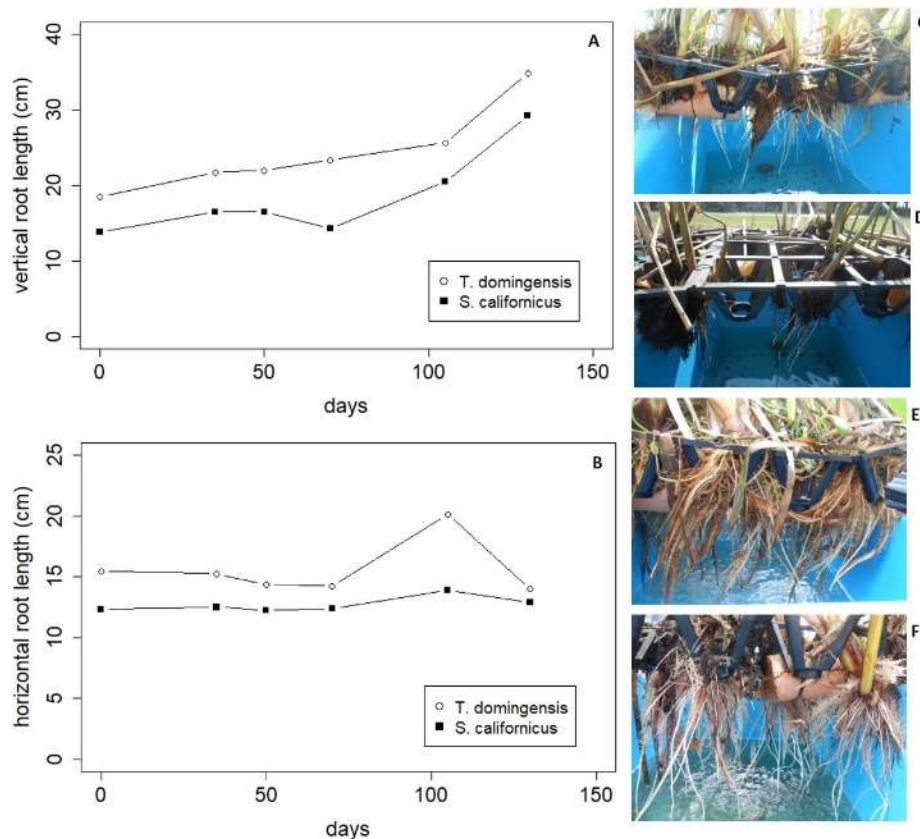


Figure 7: Mean root growth values of *T. domingensis* and *S. californicus*. A. Vertical root length. B. Horizontal root length. C. Root growth of *T. domingensis* at 70 days. D. Root growth of *S. californicus* at 70 days. E. Root growth of *T. domingensis* at 130 days. F. Root growth of *S. californicus* at 130 days.

Tanner and Headley (2011) reported a mean growth of 62 cm to a species with the same genera of *S. californicus* (*S. tabernaemontani*), over a period of one year of experiment, using a floating structure with growth substrates. Borne et al. (2015) registered a root growth of 40cm to the period of 3 months on New Zealand pond planted with *Carex virgata*. In this way, a long time of monitoring seems to result in higher root growth. Horizontal root growth showed a stabilization trend around 15 cm (Figure 7-B). After 130 days the vertical root growth were similar to both species (Figure 7-A, E, F).

The insolation was another factor that contributed to macrophytes growth. According to INMET (2017), the mean daily insolation was about 5 h during the establishment period (May to August) and 6 h until the end of experimental trials (August to October). The values of insolation was slightly higher on summer, since climatological normal from 1981 to 2010 indicates an approximated value of 7 h of mean daily insolation from December to February (INMET, 2017). In addition, the experiment protection did not control the effects of variation in air temperature. Mean air temperature ranged from a minimum of 12.7°C to a maximum

of 22.8°C during the establishment period and from a minimum of 14.3°C to a maximum of 25.4°C until the end of the experiment (INMET, 2017).

The establishment period thus did not match with the higher daily insolation. Instead, the experiment installation period was chosen according to the begin of senescence time. In this regard, macrophytes pruning was an important aspect. The pruning allowed the simultaneous growth of seedlings and was important to overall functioning of the system, since both species would come in senescence on winter period, when decomposition rates increase. Periodic wetlands maintenance, in this sense, is crucial to the performance of the treatment system. Constructed wetlands plants need nutrients to growth and reproduction, the nutrients are absorbed mainly by radicular system on rooted macrophytes (Brix, 1997). However, if plants are not appropriately managed the major part of nutrients that have been incorporated on plant biomass will return to water by decomposition processes (Brix, 1997).

Macrophytes selection should taking account the need of annual pruning, that have to occur before the period of senescence. Hence, aerial part of the macrophytes should have a desirable application. This aspect was considered on macrophyte selection, since the leaves of both species are used as craft material (Hurrell et al., 2004). Furthermore, the commercial use of *S. californicus* fiber to paper production has been showed feasible (Wille et al., 2017; Hidalgo-Cordero & García-Navarro, 2018).

4.3.2. *Macrophytes performance*

Conductivity was the main physicochemical parameter that expressed the difference between the synthetic solutions (Table 4). The mean effluent temperature was similar to the synthetic solutions. The input solution had pH values adjusted to values close to neutrality. The reduction of the pH values that was observed on output results might indicated the occurrence of the nitrification process, since nitrification acidifies the environment (Šantrůčková et al., 2016). Dissolved oxygen values reduced from the input to the output effluent to all synthetic solutions and to the both species of macrophytes. Redox potential values were positive on input effluent and negative on output effluents. The negative values indicated favorable conditions to occurrence of nitrogen and phosphorus transformations (Borne et al., 2015; Saad et al., 2016).

Table 4: Mean values of physicochemical parameters to each specie and effluent condition (input and output) according to the tree synthetic solutions (n=4, for each specie). The period of time to application of each synthetic solution are: Solution 1 – from June, 01 to June, 14; Solution 2 – from June, 22 to July, 6, Solution 3 – July, 20 to August, 02.

Parameters	Specie	Input/output	Synthetic solution		
			S1	S2	S3
Temperature (°C)	<i>T. domingensis</i>	in	16.95	15.93	14.55
		out	15.75	16.00	17.78
	<i>S. californicus</i>	in	16.95	16.00	14.65
		out	15.68	15.93	17.90
pH	<i>T. domingensis</i>	in	6.01	5.91	7.11
		out	5.77	5.85	6.00
	<i>S. californicus</i>	in	5.98	5.78	6.64
		out	5.79	5.88	6.07
Conductivity (μS/cm)	<i>T. domingensis</i>	in	1661.00	264.23	145.68
		out	1623.75	271.90	135.03
	<i>S. californicus</i>	in	1665.50	259.45	146.30
		out	1629.50	266.23	161.60
DO (mg/L)	<i>T. domingensis</i>	in	8.50	9.16	9.66
		out	7.98	7.76	7.14
	<i>S. californicus</i>	in	8.22	9.06	9.38
		out	8.54	8.25	7.41
ORP (mV)	<i>T. domingensis</i>	in	135.75	176.40	36.43
		out	-21.33	-30.00	-56.03
	<i>S. californicus</i>	in	123.85	173.60	24.50
		out	-16.08	-4.03	-61.73

The separation among the synthetic solutions was emphasized on CAP (Figure 8), the axis 1 of CAP showed the solutions differences and explain data variation on 53%, while axis 2 explain more 20% of variation. The synthetic solution 1, the most concentrated, kept separated from others but did not show differences between input and output results. The synthetic solutions 2 and 3 presented more similarities to each other and they showed differences between input and output results.

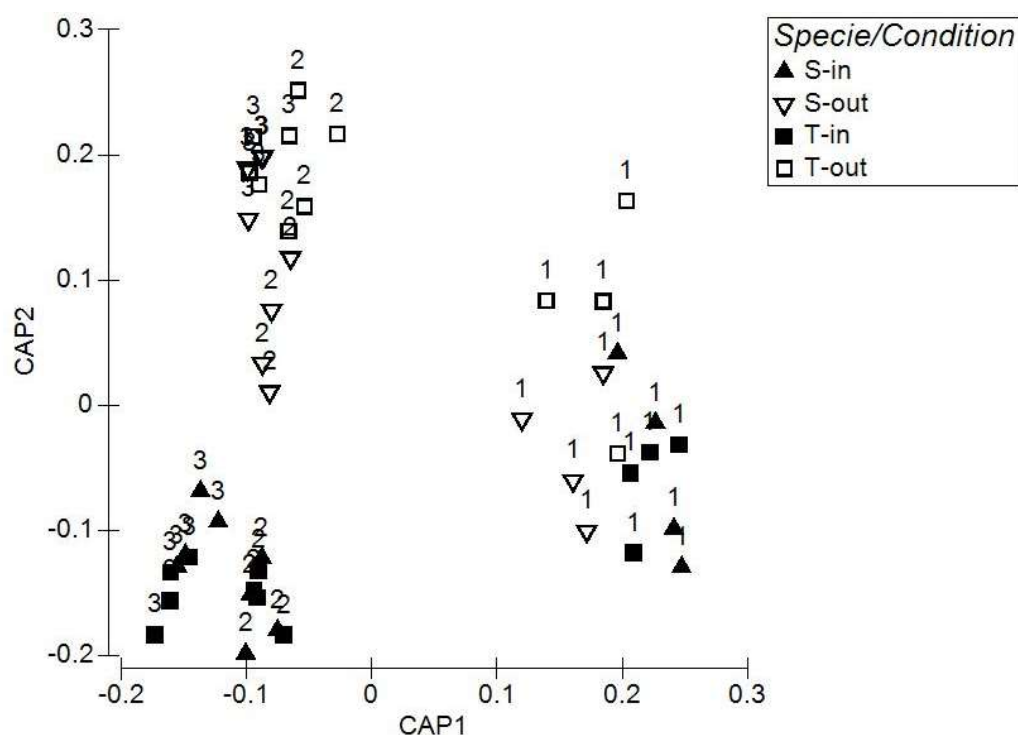


Figure 8: Result of canonical analysis of principal coordinates (CAP). Synthetic solutions: 1 – solution 1, 2 – solution 2 and 3 – solution 3. Specie: S - *Schoenoplectus californicus* and T- *Typha domingensis*. Condition: in – input and out - output.

The application of the three synthetic solutions showed that the system is robust and can operate under a wide range of nutrient concentrations. The results of total phosphorus indicated a possible reduction to both species under the period of the application of synthetic solution 1 (Figure 9A). The same pattern was observed to orthophosphate, but only to *T. domingensis* (Figure 9B). Total nitrogen results did not present a reduction from initial values (Figure 9C), in addition, nitrate showed a increase of values from input to output (Figure 9D). The system performance during the application of solution 1, thus, was generally not good. ANOVA confirm this result, since no significant difference was observed between input and output condition and neither between the species.

System performance become better just during the application of synthetic solution 3. Total phosphorus, orthophosphate and total nitrogen showed reduction from input to output to both species (Figure 9I, J, K). Nitrate results, however, showed a reduction just to *T. domingensis* (Figure 9L). ANOVA results confirmed the significant difference between input and output values to total phosphorus ($F=9.948$, d.f.=1, $p=0.008$), nitrate ($F=5.990$, d.f.=1, $p=0.031$) and total nitrogen ($F=40.212$, d.f.=1, $p=0.00004$). Total nitrogen also presented significant difference between *S. californicus* and *T. domingensis* ($F=20.833$, d.f.=1, $p=0.0006$), which confirmed the best adaptation of *T. domingensis*.

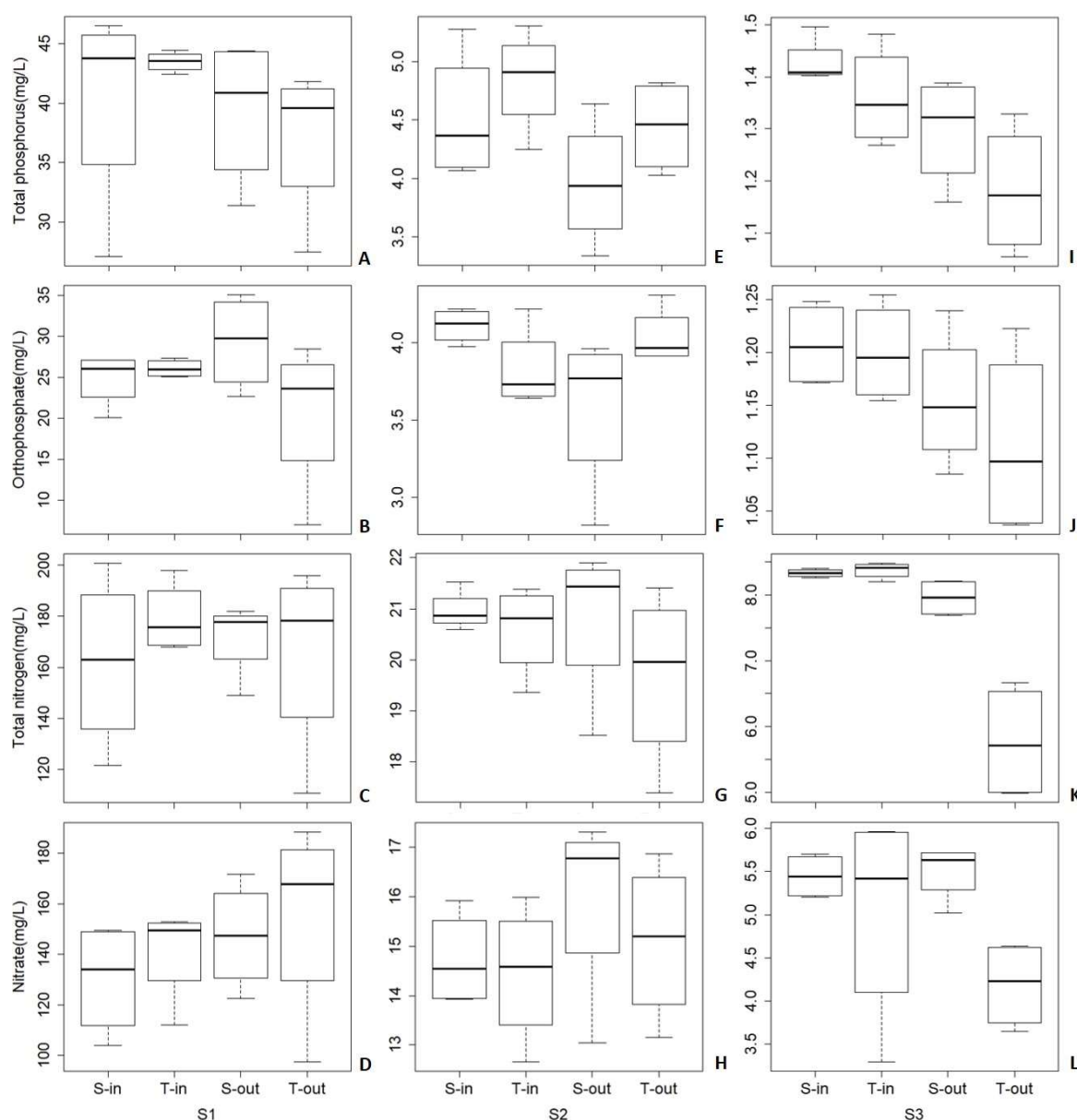


Figure 9: Box-plot graphics of nutrients according to synthetic solutions and species (n=4, for each specie). Synthetic solutions: S1 – solution 1, S2 – solution 2 and S3 – solution 3. Specie: S - *Schoenoplectus californicus* and T- *Typha domingensis*. Condition: in – input and out – output.

Nitrite values were not represented on graphics, because they were found on very small concentrations just on output values, which can indicate an incomplete process of nitrification. On the first step of nitrification occurs the conversion of ammonia to nitrite, a process mediated by *Nitrosomonas* bacteria, while on second step the nitrite is converted to nitrate, through *Nitrobacter*. The values of pH and temperature were bellow of optimal values to complete process of nitrification, that vary from 7.5 to 8.6 for pH and from 25 to 35 °C for temperature (Sezerino, 2006). Sezerino (2006) explained that bellow to 15 °C there are a reduction of conversion rates and the minimum temperature to occurrence of

nitrification process is around 4 or 5 °C. In addition, the decrease of temperature affect more bacteria that produce nitrate than those that produce nitrite (Sezerino, 2006).

The removal efficiency values were low, sometimes negatives, on macrophytes establishment period (Table 5). However, the best removal efficiency (31 %), observed to total nitrogen to *T. domingensis*, was similar of results obtained by Lynch et al. (2015). Lynch et al. (2015) found different removal efficiencies according to the two commercial CFW technologies. The removal rates were 25.1 – 39.6 % of total nitrogen and 4.07 – 47.6 % of total phosphorus (Lynch et al., 2015). According to Pavlineri et al. (2017), a review of 63 cases that investigated efficiencies of total nitrogen removal and 53 cases that reported results of total phosphorus removal indicated removal averaged at 58 % for total nitrogen and 48.75 % for total phosphorus.

Table 5: Removal efficiency according to the tree synthetic solutions and macrophyte specie (n=4, for each specie). S1 – Solution 1; S2 – Solution 2; S3 – Solution 3.

Parameters	Specie	Removal efficiency (%)		
		S1	S2	S3
Total phosphorus	<i>S. californicus</i>	2	12	9
	<i>T. domingensis</i>	15	8	13
Orthophosphate	<i>S. californicus</i>	-18	13	4
	<i>T. domingensis</i>	21	-5	7
Total nitrogen	<i>S. californicus</i>	-6	1	5
	<i>T. domingensis</i>	8	4	31
Nitrate	<i>S. californicus</i>	-13	-8	-1
	<i>T. domingensis</i>	-10	-4	17

There are few results of CFWs in full-scale field applications (Pavlineri et al., 2017). Winston et al. (2013) that report the application of CFW in detention pond showed an increase in removal efficiency of total nitrogen from 36 – 59 % in pre-installation of CFW to 48 – 88 % in post-installation of CFW, and removal of total phosphorus from 36 – 57 % in pre-CFW to 39 – 88 % in post-CFW. A larger number of pollutant removal mechanisms were provided by the CFW (increase of hydraulic resistance, plant uptake of nutrients and microbial biofilm development), additionally, statistical comparisons between pre and post-CFW effluent concentrations showed that the improvement seems to be related to CFW surface area coverage (Winston et al., 2013). However, Lucke et al. (2019) report that surface area coverage may not be as effective as improving the design efficiency. The hydraulic flow on pond is a critical factor, because the flow can form a preferential way around the islands, without contact with the network of roots (Lucke et al., 2019). Moreover, plant roots grow

into the water column and help to reduce runoff flow velocities (Lucke et al., 2019). This hydraulic aspect should be considered since appropriate design of CFWs can have minimal impact on the flood storage capacity of the stormwater ponds where the system will be installed (Lucke et al., 2019).

4.4. Final Remarks

Both species have adapted to the floating system functioning, in spite of initial difficulties to establishment of *S. californicus*. However, *T. domingensis* showed the best performance of both nitrogen and phosphorus removal. The removal results are below of the average values found on similar studies, but the results are satisfactory, since they are related to the macrophytes establishment period. The main found difficulties were associated to verticality maintenance of seedling on floating structure, because the structure was rigid and without growth substrate. Field application would have to consider the structure adjustment to provide verticality and maintain the same structure level. These challenge can be improved by system anchoring in field installation, additionally, plant design on floating structure can contribute to overall stability, since different plant species can be arranged according to specie traits of size and growth.

The installation facility and low cost should be emphasized, among system advantages. Furthermore, the esthetic aspect is a rather favorable and the habitat created by the experiment attracted aquatic insects and amphibians. These good environmental results tend to be better on field application. However, the system would require a continuous monitoring, especially during species adaptation phase and the monitoring is a challenge in general to the ecotechnologies application. In spite of the ecological engineering principle of mimics the natural process, the environmental conditions where the techniques will be implemented are often so artificial that the system sustainability as a whole depends of human input.

5. NATURE-BASED SOLUTIONS FOR MANAGING THE URBAN SURFACE RUNOFF: AN APPLICATION OF A CONSTRUCTED FLOATING WETLAND

Este trabalho foi apresentado, na forma de pôster, no XIX Congresso da Associação Ibérica de Limnologia e o trabalho completo foi submetido posteriormente e aceito para publicação na edição especial da revista *Limnetica* (DOI: 10.23818/limn.39.28).

Resumo

O escoamento superficial urbano contribui de maneira significativa para a degradação dos ecossistemas fluviais. As soluções inovadoras e inspiradas na natureza vêm sendo aplicadas para enfrentar esses problemas ambientais. Nesse sentido, os wetlands construídos – uma tecnologia de tratamento verde e de baixo custo – representam um exemplo bem-sucedido de uma solução com benefícios sociais e ambientais. O sistema Flutuante de Wetlands Construídos é uma técnica de tratamento de água relativamente recente que consiste em macrófitas emergentes plantadas em estruturas flutuantes. O sistema tem sido testado para o tratamento de águas residuárias e de escoamento superficial urbano. Contudo, poucos estudos avaliam a capacidade dos sistemas durante curtos períodos de tempo de retenção e seu desempenho sob cargas de choque. Essa pesquisa relata o desempenho de um sistema flutuante de wetlands construídos aplicado ao tratamento de escoamento superficial urbano sintético. A eficiência de remoção de nitrogênio total (NT) e fósforo total (PT) foi investigada para duas espécies de macrófitas: *Typha domingensis* e *Schoenoplectus californicus*. Carbono orgânico total, biomassa úmida, clorofila-a, oxigênio dissolvido (OD), pH, potencial redox (ORP), condutividade, temperatura e turbidez também foram analisados. No trabalho foi empregada uma estrutura flutuante comercial, sem meio de crescimento. O experimento se deu através de bateladas, em mesocosmos, inicialmente com 7 dias de tempo de retenção e em seguida sob cargas hidráulicas de choque com 24, 2 e 4h de tempo de retenção. As diferenças entre os tratamentos e os controles foram analisadas pelo teste estatístico PERMANOVA e ANOSIM. Os resultados para a batelada de sete dias indicaram que a *T. domingensis* obteve melhor eficiência de remoção em relação ao *S. californicus* (eficiência de PT=47% e NT=78%; PT=11% e NT=30%, respectivamente). Houve diferença significativa para a remoção de nutrientes para os tempos de retenção de 24h e 4h para a *T. domingensis*. Não houve remoção significativa para o *S. californicus* nos tempos de retenção inferiores a sete dias.

Palavras-chave: Tratamento do escoamento superficial, Macrófitas emergentes, Wetlands construídos flutuantes.

5.1. Introduction

Urban surface runoff strongly contributes to the degradation of river ecosystems, either due to alterations on water quality (Paul & Meyer, 2001) or hydrogeomorphic modifications (Navratil et al., 2013). The water drained from pavement, sidewalks and drainage pipes has high pollution loads, high nutrient concentrations (Lee & Bang, 2000; Liu et al., 2013) and heavy metals (Wijesiri et al., 2016). Furthermore, the volume of stormwater runoff and flooding, amplified by climate changes, require urban adaptation strategies to mitigate those impacts (Zölch et al., 2017).

Innovative and nature-based solutions have been applied to address such environmental problems. Kabisch et al. (2017) showed that green and blue spaces help reduce urbanisation-related risk factors to human health. Permeable and porous pavements can be effective nature-based solutions to mitigate the impact of paving upon the water and carbon cycle, besides promoting sustainable urbanisation (Fini et al., 2017). Wetlands are known as provisioners of ecosystem services and thereby have great potential as nature-based solutions to address a variety of environmental, social and economic challenges (Thorslund et al., 2017).

Constructed Floating Wetlands (CFW) are a relatively new water treatment technique that consists of emergent macrophytes planted on floating structures (Tanner & Headley, 2011; Lynch et al., 2015). The system has other designations such as floating hydroponic root mats, constructed floating islands, artificial floating islands, etc. (Chen et al., 2016). CFW have been tested for the treatment of wastewater (Weragoda et al., 2012), stormwater runoff (Borne et al., 2013; Winston et al., 2013; Ladislav et al., 2015), synthetic stormwater (Tanner & Headley, 2011; White & Cousins, 2013) and polluted rivers (Zhao et al., 2012; Saeed et al., 2016). However, few studies assess the system's capability during short periods of retention time and its performance under hydraulic shock-loading. Moreover, less work has been done in CFW systems without substrates (Geng et al., 2017).

Nature-based solutions are directly relevant to several policy areas and, because of their systemic nature, they also interact with many other areas, such as land use and spatial planning (Raymond et al., 2017). The amount of land that sustainable drainage systems may demand is a major issue in the redevelopment of existing built-up areas (Jones & McDonald, 2007). In that sense, CFW are profitable solutions, since their installation does not require additional land to be dedicated to treatment or diminish the space of the required storage volume for wet ponds

(Winston et al., 2013). Moreover, application of conventional constructed wetlands might be difficult because, the erratic nature of storm events affects establishment of vegetated littoral zones, algal growth and survival of sediment-rooted plants (Chang et al., 2012). On the other hand, CFW may be applied on draining detention structures, combining flood control and surface runoff treatment (Lynch et al., 2015). System implementation depends both on the presence of solar radiation and a minimal permanent water level of detention structures. Borne et al. (2013) and Ladislav et al. (2015), both report good results for CFW on existing water runoff ponds.

Within the context of surface runoff treatment, it is important to evaluate the efficiency of the systems for short retention periods and high loads. The variability (intensity, duration and frequency) of rainfall events is quite large, but it is in the first-flush phase that pollutants are concentrated (Alias et al., 2014). Nitrogen and phosphorus are nutrient constituents of stormwater that influence the overgrowth of algae and other aquatic weeds in stormwater detention ponds (Chang et al., 2012). Borne et al. (2015) suggest that the main factors contributing to the overall performance of retention ponds in the presence of a CFW are: dense root networks and attached biofilms, release of root organics and detritus, neutral pH and low redox potential.

CFW vegetated with different plant species may show a significant difference in removal performance of pollutants (Zhang et al., 2014). *Typha* and *Schoenoplectus* are the most common genera applicable on constructed wetlands (Vymazal, 2013). Others genera commonly employed on CFW are: *Canna* (Saeed et al., 2016), *Juncus* (Lynch et al., 2015), *Cyperus* (Zhang et al., 2014) and *Carex* (McAndrew & Ahn, 2017). Given that biological invasion has been identified as one of the major causes of loss of biodiversity in aquatic ecosystems (Allan & Castillo, 2007), the importance of native species during macrophyte selection should be considered. In spite of the fact that macrophytes represent an essential component of aquatic communities, invasive macrophytes negatively alter ecosystem properties (Fleming & Dibble, 2015).

This research reports the results of CFW applied to the treatment of simulated urban surface runoff. Two plant species were tested, using a floating structure without growth medium (substrates). This configuration of floating structure is innovative, and the structure was tested for the first time. The goals of this research were: a) to assess the nutrient removal efficiency of *Typha domingensis* and *Schoenoplectus californicus* during a seven-day batch period and b) to investigate the system removal performance of total nitrogen (TN) and total phosphorus (TP) under short retention times and hydraulic shock-loading.

5.2. Material and Methods

5.2.1. Construction of CFW

A mesocosm experiment was set up at the Hydraulic Research Institute of the Federal University of Rio Grande do Sul, Porto Alegre, Brazil, to evaluate the performance of native macrophytes in FCW. Each mesocosm consisted of 120 L tanks (43 x 62 x 45 cm). Six tanks were installed with two replicas for each treatment and two controls with no plants. The tanks, which housed the aquatic macrophytes, were protected from direct rain by the installation of a transparent plastic cover. The mesocosms were supplied with synthetic effluent prepared in a reservoir of 800 L. The synthetic effluent was composed of a dilute Hoagland nutrient solution: $\text{Ca}(\text{NO}_3)_2$, KNO_3 , $\text{NH}_4\text{H}_2\text{PO}_4$, MgSO_4 , CuSO_4 , ZnSO_4 , MnSO_4 , H_3BO_3 , $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$ and FeDTPA. After dilution of the solution components, pH was controlled in the range of 6.5 and 7.0 with addition of H_2SO_4 or KOH.

The structure was comprised of plug-in modules with dimensions of 40 cm x 40 cm consisting of rigid recycled polypropylene plastic material and polyethylene floats. Therefore, the structure did not have a growth medium and the source of nutrients came exclusively from the synthetic effluent. For each mesocosm, a module and a half was used to completely cover the surface area of the tanks. The final structure dimension was 40 cm x 60 cm. In the floating structure of each tank, 12 seedlings were planted in an intercalated way (Fig. 10A).

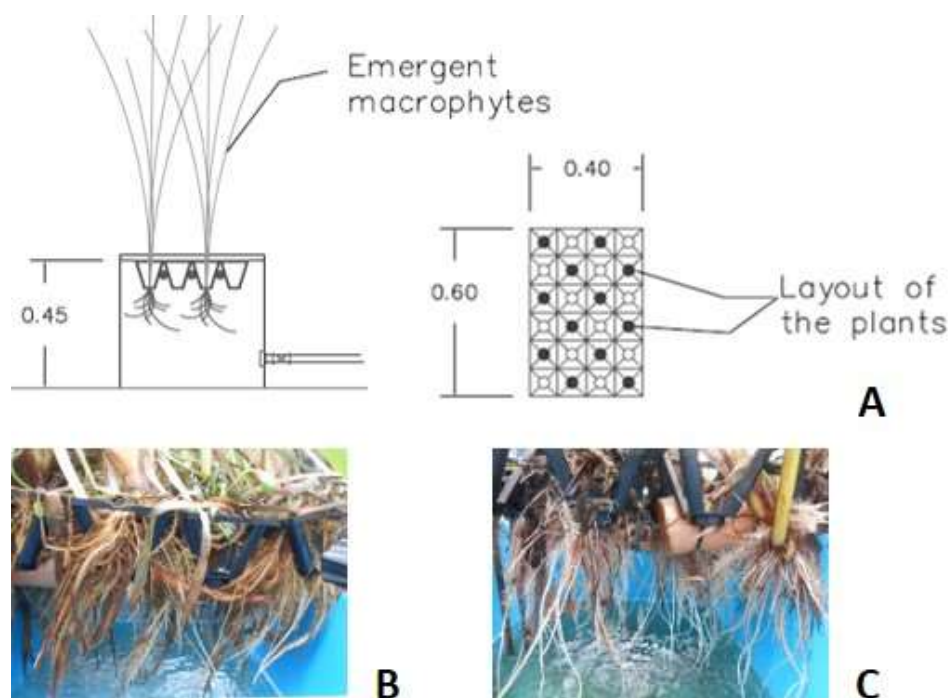


Figura 10. A. Floating structure details. The dimensions are in centimeters. B. Root growth of *Typha domingensis*. C. Root growth of *Schoenoplectus californicus*.

5.2.2. Macrophytes

Two species were selected among the native emerging macrophytes: *Typha domingensis* Pers. and *Schoenoplectus californicus* (CA Mey.) Soják. These macrophytes are considered non-endemic and have a regular occurrence in Southern Brazil. The selection of both species was based on their origin, their reproduction potential and growth, in addition to the applicability in phytoremediation and possible commercial application (Wille et al., 2017; Hidalgo-Cordero & García-Navarro, 2018). The species were collected on May 18, 2017. About 30 seedlings were collected for each species. The seedlings were selected according to size and vitality. *S. californicus* was collected from the littoral zone of Guaíba Lake, whereas *T. domingensis* was collected from a wetland area on the university campus. Both species were collected in Porto Alegre, RS in Southern Brazil. On the day of collection, the plants were transported to the experiment site where they were installed in the floating structure: 12 seedlings were planted in each tank. Some seedlings of each species were set aside in case of difficulties with plant adaptation. The system was supplied with synthetic effluent for 11 weeks to provide macrophyte establishment and root growth (Fig. 10. B, C).

5.2.3. System operation

7-days batch

After the macrophytes were established, the batch was started with the application of the synthetic effluent. The initial sampling was then conducted, and the system was exposed to 0.5 mg/h of TP and 2.8 mg/h of TN loads at the 20 cm level for four weeks, corresponding to a seven-day hydraulic retention time (HRT).

Hydraulic shock-loading

Following the seven-day batch, we conducted the hydraulic shock-loading stage. The system was exposed to 24 h of HRT at the 20 cm level with 3.2 mg/h of TP and 19.4 mg/h of TN loads. After sampling, the tanks were filled with an additional 20 cm of water, for a total of 40 cm. From this stage on, samples were collected within 2 and 4 h of HRT to quantify the effluent concentrations under hydraulic shock-loading. The loading applied was 77.4 mg/h of TP and 465.4 mg/h of TN load for 2h of HRT, and, 38.7 mg/h of TP and 232.7 mg/h of TN load for 4h of HRT. At the end of the 4 hours, the level was reduced to 20 cm, followed by exposure for the remaining 6 days of the batch before final collection.

5.2.4. Sampling and water quality analyses

In the field, pH, redox potential, conductivity and temperature were measured with the use of a multiparameter probe (YSI-Pro Plus). One sample of water was collected for the analysis of phosphorus, nitrogen, total organic carbon (TOC), chlorophyll-a, turbidity and colour.

In the laboratory, turbidity (Hach-2100N) and colour (Digimed-DM-COR) were measured and 500 mL of sample was immediately filtered and frozen. Total phosphorus (TP) and orthophosphate (PO_4^{3-}) analyses were performed with the Stannous Chloride Method 4500P-D (APHA, 2005). Nitrate (NO_3^-) was analysed by ion chromatography with chemical suppression of eluent conductivity 4110-B (APHA, 2005). TN and TOC analyses were made in a TOC analyser (SHIMADZU- TOC- VCPN) using the wet oxidation method. Chlorophyll-a was extracted using the Nusch (1980) method and the absorbance was read by a spectrophotometer (CARY-UV/VIS) and determined by Lorenzen's equations (1967). Wet biomass was obtained through the selection of four plants from each mesocosm which were weighed before and after pruning. The same plants were identified and weighed at the end of the experiment.

5.2.5. Statistical analyses

Non-Metric Multidimensional Scaling (nMDS) was performed using Euclidian distance to represent the distribution of samples according to nutrient and physicochemical data (software Primer 6 version 6.1.15). In addition, analysis of similarities (ANOSIM) was performed to evaluate the differences between controls, inflows and outflows of nMDS groups. Besides indicating *p-value*, ANOSIM indicated R values that varied from 0 to 1. Box-plot graphics were used to illustrate the differences between treatments and controls (R Core Team, 2018) and ANOSIM was performed to evaluate the contribution of both species to carbon elimination and to the increase in the biomass of *T. domingensis* in relation to *S. californicus*. The nutrient removal differences were also analysed by permutational multivariate ANOVA based on distances (PERMANOVA) using software Primer 6. The distance matrix (Euclidian distance) was created with normalized data of nutrients (TP, PO_4^{3-} , TN and NO_3^-). The statistic used (t-statistic) is analogous to Fisher's F-ratio and is constructed from sums of squared distances or dissimilarities within and among groups (Anderson, 2001).

5.3. Results

5.3.1. Removal Efficiency from 7-days batch

Physical, Chemical and biological parameters

Table 6 presents the summary statistics of experimental physicochemical parameters which were monitored weekly. The mean daily insolation was 6h during the total experimental period (August and September). The experiment protection did not control the effects of variation in air temperature. Mean air temperature ranged from a minimum of 14.3°C to a maximum of 25.4°C (INMET, 2017). The mean values of water temperature ranged from a minimum of 14.0°C to a maximum of 20.0°C during the period assessed. pH values decreased for both *T. domingensis* and *S. californicus* after the seven-day batch. Conductivity results pointed to the efficacy of the removal process, showing lowest values for *T. domingensis*. During the seven-day, DO values decreased for both species. Redox potential values became negative in outflows, a reduced condition is favorable to nitrogen and phosphorus uptake (Saad et al., 2016; Borne et al., 2015). Turbidity had little variation, and colour values showed that the dissolved substances increased for both species.

Tabela 6. Statistics of input and output of experimental physicochemical parameters to 7-days batch (n=8). T- *Typha domingensis*; S- *Schoenoplectus californicus*; C- Control.

		T input	T output	S input	S output	C input	C output
Temperature (°C)	X min	14.9	13.4	14.9	13.1	14.8	12.9
	X mean	16.2	15.9	16.2	15.7	16.2	15.5
	X max	18.4	21.7	18.5	21.5	18.4	21.2
pH	X min	6.57	5.46	6.56	6.29	6.47	6.54
	X mean	6.75	6.21	6.76	6.46	6.80	6.82
	X max	6.96	6.67	7.09	6.60	7.15	7.06
Conductivity (µS/cm)	X min	134.3	61.5	138.8	135.6	138.9	145.5
	X mean	153.9	89.2	154.1	147.0	154.3	158.6
	X max	163.0	110.8	162.8	159.7	163.2	182.3
DO (mg/l)	X min	7.74	4.78	7.89	5.84	7.69	7.64
	X mean	8.63	7.20	8.53	7.73	8.49	9.19
	X max	9.09	8.91	8.90	9.09	9.51	10.15
Redox potential (mV)	X min	-125.1	-145.0	-34.5	-168.0	-176.5	-185.9
	X mean	15.2	-108.2	24.4	-135.2	12.0	-140.5
	X max	76.2	-55.9	78.5	-105.7	106.0	-77.6
Turbidity (NTU)	X min	0.35	0.70	0.61	0.51	0.56	0.47
	X mean	0.67	0.91	0.80	0.71	0.70	0.77
	X max	0.86	1.22	0.97	1.02	0.86	1.25
Colour	X min	0.0	2.6	0.0	3.6	0.0	0.0
	X mean	1.3	8.2	1.6	7.7	1.6	1.4
	X max	3.1	13.1	3.9	13.3	3.4	4.2

Chlorophyll-a concentrations increased in output effluent (Fig. 11A). Interestingly, concentrations in macrophytes treatment were higher than in control tanks. Wet biomass increased from initial to final data (Fig. 11B). The ANOSIM showed the increase of wet biomass of *T. domingensis* to *S. californicus* (3.S to 3.T, $R=0.583$ and $p=0.001$). Additionally, there was no significant difference between the species after pruning (2.S to 2.T, $R=0.12$ and $p=0.115$).

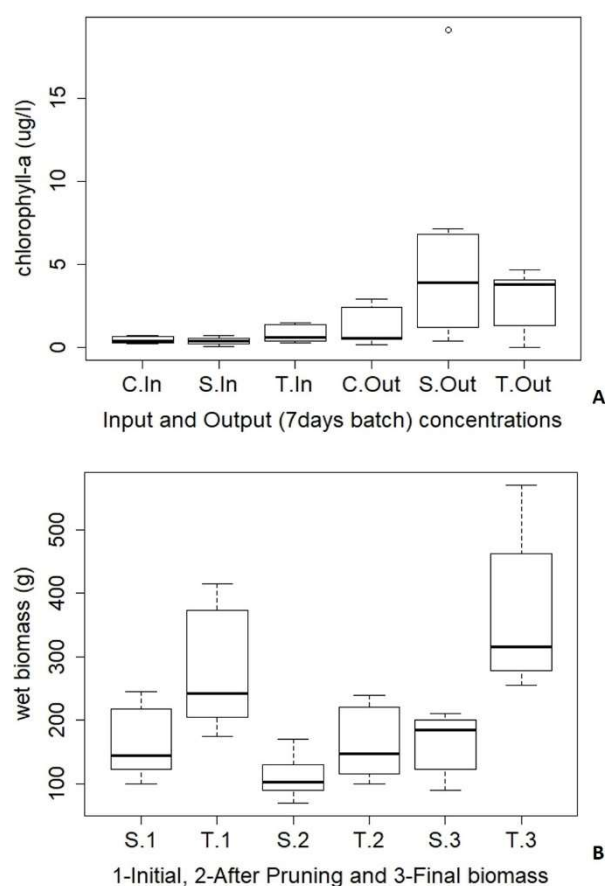


Figure 11. A. Results from input and output of chlorophyll-a concentrations to 7-days batch. C- Control; S- *Schoenoplectus californicus*; T- *Typha domingensis*. B. Results of wet biomass. 1- Initial biomass; 2- After Pruning biomass; and 3- Final biomass. S- *Schoenoplectus californicus*; T- *Typha domingensis*.

Nutrient removal

The separation among the samples according to removal efficiency is illustrated on the nMDS graph in Figure 12, where it was observed that control and input samples presented a greater similarity to each other than to *T. domingensis* outputs and *S. californicus* outputs. Pearson correlation values of parameters explained the distribution of samples related to nMDS

axes. The statistical test among nMDS groups presented a large difference between *T. domingensis* outputs and control outputs ($R=0.73$ and $p=0.001$). A difference between *T. domingensis* outputs and *S. californicus* outputs was also observed, but it was less expressive ($R=0.403$ and $p=0.001$). Furthermore, there was no significant difference between inputs of species ($R=0.024$ and $p=0.579$) and controls (T.In to C.In, $R=0.047$ and $p=0.769$; S.In to C.In, $R=0.047$ and $p=0.659$).

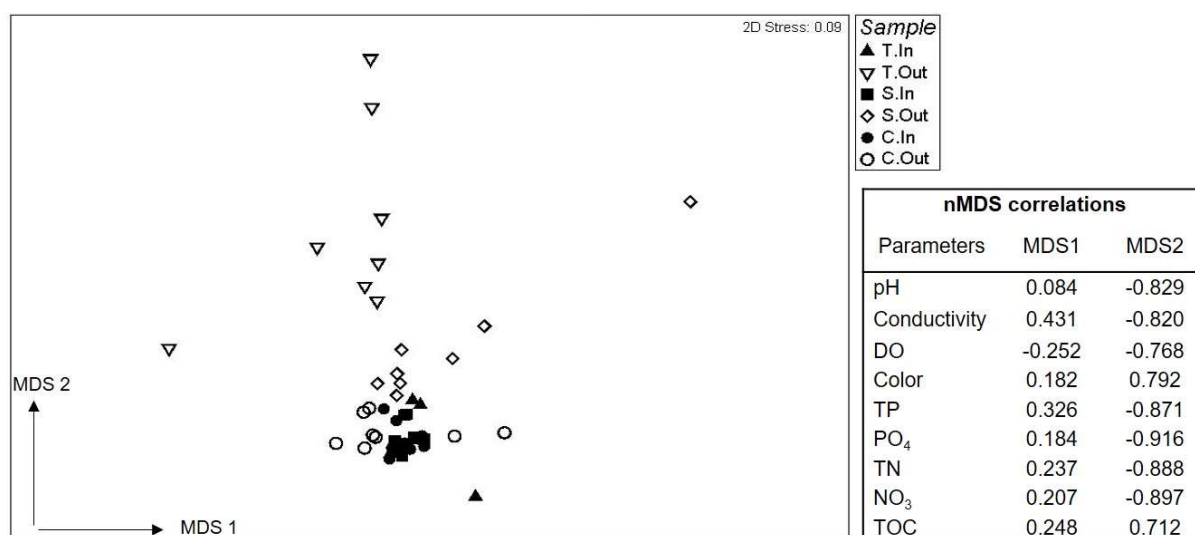


Figure 12. nMDS diagram and Pearson correlation values related to nMDS axis to 7-days batch. T- *Typha domingensis*; S- *Schoenoplectus californicus*; C- Control.

The removal efficiency of *T. domingensis* was superior to the one of *S. californicus*. *T. domingensis* presented 78% TN removal efficiency and 47% TP removal, while *S. californicus* removed 30% and 11% TN and TP, respectively (Fig. 13A, B). Controls showed 5% TN increase and 2% TP removal efficiency. Both species presented carbon concentration increases in output samples (Fig. 13C). ANOSIM confirmed the graphic results. *T. domingensis* outputs did not present differences in relation to *S. californicus* outputs ($R=0.073$ and $p=0.166$). There was no difference between input and controls (T.In to C.In, $R=0.048$ and $p=0.662$; S.In to T.In, $R=0.161$ and $p=0.069$; C.In to C.Out, $R=0.055$ and $p=0.192$). In addition, there was difference between *T. domingensis* outputs and control ($R=0.539$ and $p=0.002$) and *S. californicus* outputs and control ($R=0.603$ and $p=0.001$). The patterns of nutrient removal were also confirmed through PERMANOVA tests. There was a significant difference ($p<0.05$) between input and output samples for both *T. domingensis* and *S. californicus*. Differences in species and controls were also identified. Furthermore, pairwise tests confirmed that output results differed between the two species assessed (Table 7).

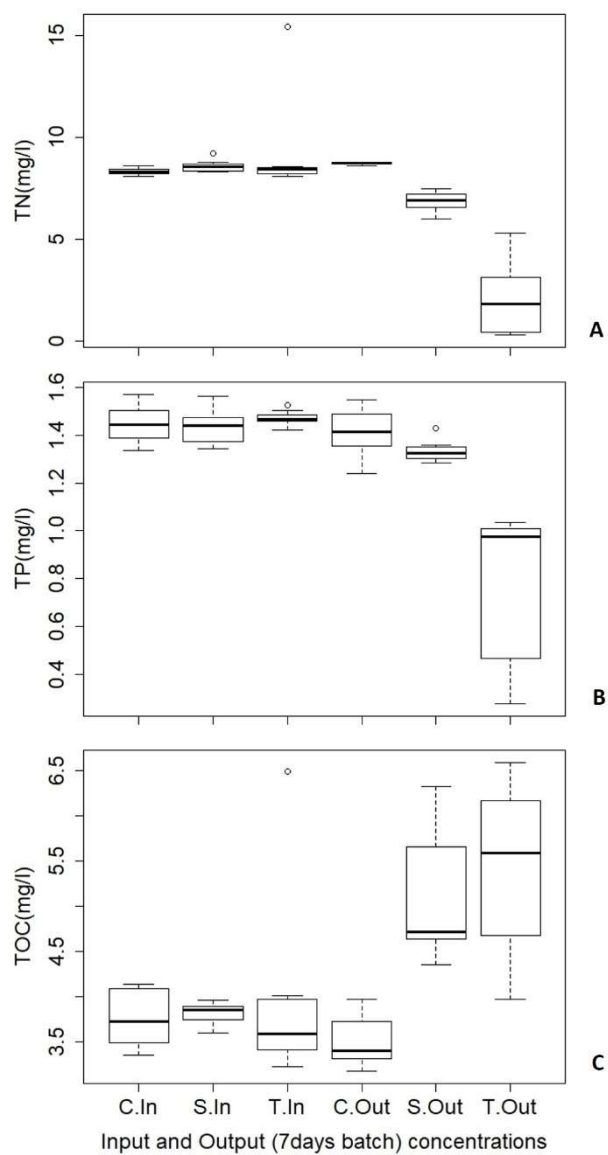


Figura 13. 7-days batch nutrients concentration results. C- Control; S- *Schoenoplectus californicus*; T- *Typha domingensis*. A. Total Nitrogen (mg/l). B. Total Phosphorus (mg/l). C. Total Organic Carbon (mg/l).

Tabela 7. 7-days batch results of PERMANOVA test between the treatments. Where: T- *Typha domingensis*; S- *Schoenoplectus californicus*; C- Control; A and B- represent the treatment replicas; I- Input; O- Output. The bold values indicate significant difference.

Source	df	SS	MS	Pseudo-F	P(perm)
Treatment	11	399.78	36.344	3.7147	0.001
Residual	36	352.22	9.7838		
Total	47	752			
Pairwise test between treatments					
Treatment	t	P	Treatment	t	P
TAI, TAO	3.65	0.02	SAI, SAO	2.41	0.03
TAI, TBO	4.84	0.02	SAI, SBO	2.35	0.04
TBI, TAO	3.94	0.03	SBI, SAO	2.48	0.03
TBI, TBO	5.47	0.02	SBI, SBO	2.46	0.04
TAO, TBO	0.91	0.31	SAO, SBO	0.61	0.76
TAO, CAO	3.70	0.03	SAO, CAO	2.02	0.03
TAO, CBO	3.84	0.03	SAO, CBO	2.45	0.03
TBO, CAO	5.17	0.02	SBO, CAO	1.94	0.03
TBO, CBO	5.36	0.02	SBO, CBO	2.36	0.03
TAO, SAO	3.10	0.03	TBI, CBI	0.30	0.91
TAO, SBO	3.05	0.03	SAI, SBI	0.40	0.76
TBO, SAO	4.57	0.03	SAI, CAI	0.43	0.95
TBO, SBO	4.51	0.02	SAI, CBI	0.66	0.61
TAI, TBI	0.85	0.97	SBI, CAI	0.50	0.92
TAI, SAI	0.70	1.00	SBI, CBI	0.61	0.64
TAI, SBI	0.85	0.94	CAI, CBI	0.55	0.67
TAI, CAI	0.89	0.75	CAI, CAO	0.62	0.78
TAI, CBI	0.87	0.84	CAI, CBO	0.48	0.87
TBI, SAI	0.54	0.77	CBI, CAO	0.82	0.63
TBI, SBI	0.42	0.80	CBI, CBO	0.73	0.64
TBI, CAI	0.56	0.76	CAO, CBO	0.32	0.94

5.3.2. Performance under hydraulic shock-loading

Physical and Chemical parameters

Physical and chemical parameters over short periods of time presented less variability than seventh-day values (Table 8). Mean temperature increased from 24h to 2h and 4h of retention time, showing a daily variation. DO did not present the same tendency in both species, i.e., there was an increase in DO after hydraulic shock-loading in *T. domingensis*. The conductivity indicated the best performance in *T. domingensis*. The reduction of 16% in 2h for *T. domingensis* was similar to *S. californicus*' reduction at day seven. Turbidity values presented variation only in tanks with plant species; control tanks had little variation.

Tabela 8. Mean values of physicochemical parameters to hydraulic shock-loading phase (n=4). T- *Typha domingensis*; S- *Schoenoplectus californicus*; C- Control.

		Temperature (°C)	pH	Conductivity (μS/cm)	DO (mg/l)	Redox potential (mV)	Turbidity (NTU)	Colour
T	0	21.7	7.00	169.7	8.21	-161.1	0.73	3.2
	24h	17.5	5.82	122.8	6.18	-210.3	1.26	7.3
	2h	18.6	6.16	142.6	7.02	-180.7	1.31	6.5
	4h	20.1	6.16	144.5	6.84	-191.3	1.77	6.5
	7d	17.8	5.47	64.6	6.20	-201.8	2.48	13.2
S	0	21.7	7.05	169.7	8.44	-141.8	0.68	4.4
	24h	17.6	6.44	153.6	7.82	-212.7	1.43	5.7
	2h	18.7	6.61	158.9	7.90	-180.0	1.29	4.7
	4h	20.6	6.61	165.1	7.80	-200.0	1.18	4.5
	7d	17.8	6.30	144.8	7.52	-205.8	2.15	11.5
C	0	21.7	7.07	169.6	8.41	-129.2	0.83	3.7
	24h	17.3	6.70	153.6	8.91	-213.7	0.98	1.2
	2h	18.7	6.87	159.4	8.19	-170.3	0.76	1.9
	4h	21.2	6.93	167.4	8.46	-191.4	0.81	1.4
	7d	17.4	6.94	158.6	9.20	-211.6	0.90	2.9

Nutrients removal

Typha domingensis revealed a better nutrient removal than *S. californicus*, considering all retention times assessed (Fig. 14). Only *T. domingensis* did not present any removal in retention time of 2h for TP (Fig. 14B). However, the best efficiencies were observed for the retention time of 24h and seven days.

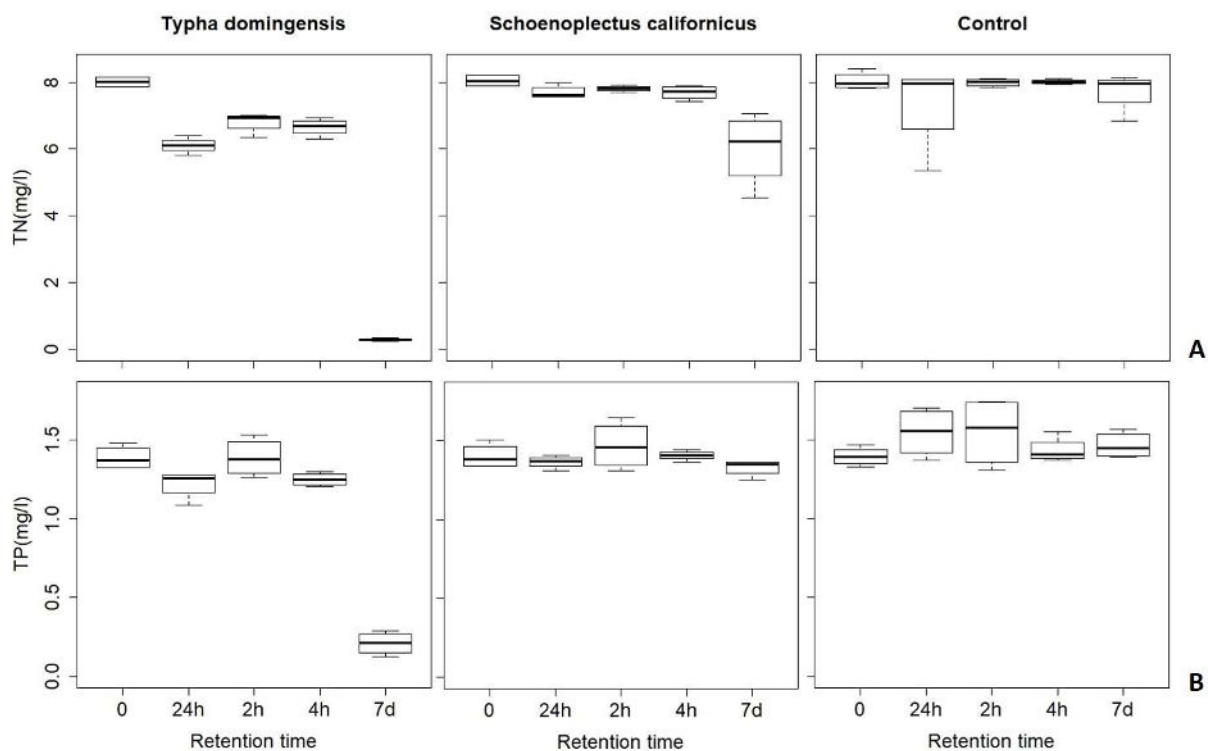


Figure 14. Results of nutrient removal under hydraulic shock-loading. A. Total Nitrogen concentrations (mg/l). B. Total Phosphorus concentrations (mg/l).

PERMANOVA tests highlighted a significant difference in the retention times of 24h and 4h for *T. domingensis*, besides the efficiency reported for the seven-day batch. In contrast, no significant reduction was found for *S. californicus* when retention time was less than seven-day. Moreover, there was no significant difference between controls and initial values of input solution (Table 9).

Tabela 9. Hydraulic shock-loading results of PERMANOVA test between the treatments: T- *Typha domingensis*; S- *Schoenoplectus californicus*; C- Control. The bold values indicate significant difference.

Source	df	SS	MS	Pseudo-F	P(perm)
Treatment	14	209.98	14.999	25.94	0.001
Residual	45	26.019	0.5782		
Total	59	236			
Pairwise test between treatments					
Treatment	t	P	Treatment	t	P
TI, T24h	3.04	0.03	SI, S24h	1.67	0.20
TI, T2h	1.43	0.15	SI, S2h	0.97	0.47
TI, T4h	2.26	0.03	SI, S4h	0.90	0.54
TI, T7d	17.87	0.03	SI, S7d	2.49	0.03
T24h, T2h	2.30	0.06	S24h, S2h	1.95	0.16
T24h, T4h	1.30	0.15	S24h, S4h	0.94	0.24
T24h, T7d	17.25	0.04	S24h, S7d	1.70	0.06
T24h, C24h	2.04	0.02	S24h, C24h	1.19	0.21
T2h, T4h	1.45	0.26	S2h, S4h	1.14	0.25
T2h, T7d	17.03	0.03	S2h, S7d	2.30	0.04
T2h, C2h	1.59	0.16	S2h, C2h	0.56	0.56
T4h, T7d	20.38	0.04	S4h, S7d	1.87	0.11
T4h, C4h	4.14	0.04	S4h, C4h	1.26	0.24
T7d, C7d	18.08	0.02	S7d, C7d	2.14	0.03
TI, CI	1.05	0.28	SI, CI	1.71	0.18
CI, C24h	0.75	0.62	C24h, C4h	2.28	0.03
CI, C2h	1.72	0.14	C24h, C7d	1.73	0.06
CI, C4h	2.04	0.08	C2h, C4h	0.74	0.60
CI, C7d	1.58	0.17	C2h, C7d	0.62	0.77
C24h, C2h	1.82	0.08	C4h, C7d	0.73	0.76

5.4. Discussion

Plant species used in CFW have different removal capacities of pollutants due to their specific biological properties such as uptake efficiencies for nutrients, growth rate and root types (Chang et al., 2017). Wetland may be built with fibrous and thick root plants; however, most CFW are composed of fibrous root plants (Chen et al., 2016) since fibrous root plants have significantly higher TN removal rates (Li et al., 2013). Both *T. domingensis* and *S. californicus* have fibrous roots, but the removal efficiency presented by *T. domingensis* was more expressive in all retention times tested. This result could be explained by the different species growth rates. In addition, the adaptation of *T. domingensis* was superior to *S. californicus* considering that the employed floating structure had no growth medium.

As well as in our results, studies evaluating the removal of pollutants showed that differences in the plant species affected the removal of pollutants in the CFW, and the above-ground biomass significantly affected the removals of pollutants, showing the importance of

macrophytes in mediating the pollutant removals in the floating islands (Zhang et al., 2014). The absence of growth substrate in the floating structures employed did not present a limiting factor to the removal process of nitrogen by *T. domingensis* (78% TN removal efficiency). The removal efficiency of TP of both species tested was inferior compared to previous studies. Geng et al. (2017) found high rates of P removal (74–98%) using hydroponic microcosms without growth substrate. Such results could be related both to HRT (of 10 days) applied by Geng et al. (2017), which enhanced the biotic processing and the retention of phosphorus and to the different design that used polyculture on treatments.

The reduced condition increases the solubility of nutrients (Jones et al., 2004), phosphorus sequestration and denitrification (Borne et al., 2015). In the present study, the negative redox potential was registered especially to output values. In addition, our results did not show different patterns between the two species. Saad et al. (2016) found differences in redox potential along the flow path to species *J. effusus* and *P. australis*.

Another factor that determines the CFW functioning is the percentage of coverage of the floating structure. This factor is very important for real scale applications. According to Chang et al. (2017), around 20% cover seems optimal if the basin is to be maintained as an aerobic system without artificial aeration and still achieve good removal efficiency. Chang et al. (2017) argue that the total coverage of the water surface by the system can lead to low levels of DO due to the loss of air contact area for oxygenation of water by diffusion. In our work, a coverage of 100% of the surface area was used; however, the contents of DO remained acceptable within the period evaluated and under mesocosm conditions. The lowest values of DO occurred for the *T. domingensis* at the end of the seven-day batch. These results can be explained by the greater coverage of this specie in the structure. The multiplication by lateral rhizomes and adaptation of the *T. domingensis* in the structure was superior in comparison to the *S. californicus*, whose structure had more empty spaces between seedlings.

The empty space allowed greater penetration of light, which provided better conditions for the growth of photosynthetic microorganisms, as evidenced by the high values of chlorophyll-a for the *S. californicus* treatment. Furthermore, higher concentrations of chlorophyll-a were found in the macrophyte tanks as compared to the control tanks. A possible explanation for this is that algae benefited from the floating structure and the roots, and during sampling procedure, the biofilm possibly detached from them and remained suspended in the water column. CFW remove nutrient-pollution through biosynthesis and also benefit the biofilm of fungi, bacteria and beneficial algae that form along the roots and the floating structure (Chang et al., 2012).

In addition to nutrient removal, wetlands are a potential carbon sink (Schultz & Pett, 2018). Carbon sequestration is a wetland ecosystem service that has received attention in the current climate scenario (Villa & Bernal, 2018). According to Means et al. (2016), the carbon storage potential is affected by the characteristics of each species. In this sense, we observed significant increase in carbon concentration in the final effluent of both species that could be attributed to carbon release which occurs in the rhizosphere (Dunn et al., 2016). Carbon storage was also observed through wet biomass data. *T. domingensis* showed the best potential to produce and store carbon (though biomass increase) in relation to *S. californicus*.

The feasibility of implementing the CFW in the treatment of urban drainage depends on the area required by the system, which may be greater for conventional wetland systems. Also, plant assimilation of nutrients may be higher in a CFW compared with a sediment-rooted wetland since the roots hanging beneath the floating structure are in direct contact with the effluent to be treated (Tanner & Headley, 2011). Furthermore, considering our results, there is the possibility of applying the floating system in existing detention basins to improve nutrient removal. Whereas stormwater detention ponds are frequently designed to maintain a volume of water and to discharge surplus levels within 24 to 72h (Chang et al., 2012), the present study showed that *T. domingensis* had a removal efficiency for similar retention times. On the other hand, *S. californicus* presented no removal efficiency for retention times less than seven days under the conditions tested. Although nutrient removal efficiency could be enhanced through the application of biofilm carriers that increase surface area (Zhang et al., 2018), this configuration was not employed in the present study. The short duration of the experiment, although it is in line with another experimental studies (Chang et al., 2012; Lynch et al., 2015; Geng et al., 2017), did not allow us to assess the influence of seasonal patterns. Therefore, long term field studies are necessary to check the possible influence of environmental factors on CFW.

5.5. Conclusion

Typha domingensis achieved the best nutrient removal efficiency rates during the seven-day batch. The study also indicated that under hydraulic shock-loading, *T. domingensis* presented nutrient removal at 4 and 24 hours, whereas *S. californicus* showed nutrient removal just for seven-day batch. These results suggest that *T. domingensis* is best adapted to the floating structure applied, as well as its specific biological properties. The results of this research support the idea that the selection of macrophytes species is an important factor for the success of floating wetland systems. The scope of this study was however, limited to mesocosm design

and short period of assessment time. Therefore, more research is needed to assess field application of the system and long term evaluation. But CFW could be applied to stormwater treatment under the framework of nature-based solutions with ecosystem service benefits and enhanced conservation of aquatic ecosystems.

6. CONSIDERAÇÕES FINAIS DA TESE

A análise e discussão dos estudos de caso de revitalização comprovam a dificuldade que existe na tentativa de reestabelecimento da integridade dos rios urbanos. Isso ocorre, primeiro, porque as alterações promovidas nas áreas urbanas causaram efeitos muito severos na morfologia e ecologia dos rios. Segundo, porque a maioria dos projetos aplica, além das medidas na bacia hidrográfica, medidas estruturais no leito dos rios que reconfiguram o seu traçado. Essas novas intervenções dificultam, em muitos casos, o reestabelecimento das comunidades biológicas, principalmente a de macroinvertebrados bentônicos, que tem baixa mobilidade e vive intimamente ligada ao sedimento dos rios. Terceiro, porque o emprego de técnicas sob a abordagem das soluções inspiradas na natureza possuem pouco tempo de implementação. Assim, mesmo o projeto que emprega exclusivamente medidas no contexto da bacia hidrográfica, com o objetivo de reestabelecer os processos hidrológicos e melhorar o estado ecológico dos rios, apresenta bons resultados no reestabelecimento de processo do ciclo hidrológico, mas os resultados ecológicos ainda são pouco mensuráveis.

As medidas na área contígua aos cursos d'água – como instalação de parques lineares, reservatórios de amortecimento, trilhas e áreas verdes para a prática de esportes – resultam em benefícios sociais e econômicos bastante relevantes que devem ser enfatizados. No contexto da implementação das NBS, essas medidas comprovam os benefícios fornecidos para a saúde da população urbana, além de trazer os rios de volta para a paisagem. Desta forma, os projetos de revitalização em áreas densamente urbanizadas, apesar de nem sempre fornecerem resultados ecológicos relevantes, minimizam a perda de conectividade fluvial durante a passagem do rio na malha urbana; de resto, trazem outros benefícios que podem despertar nas pessoas o interesse na conservação dos rios. Por outro lado, esses resultados reforçam a necessidade de investimentos em ações de conservação de locais pouco impactados, pois a imagem de rios urbanos restaurados são esteticamente agradáveis, mas não garantem a recuperação da integridade dos rios. Assim, deve-se evitar o falso otimismo de que se pode continuar com as mesmas soluções para canalizar e regularizar os rios, e depois basta fazer a revitalização para atingir bons resultados ecológicos.

Os experimentos realizados na tese mostraram que as técnicas compensatórias, como instrumentos de aplicação da abordagem promovida pelas NBS, têm alto potencial para melhorar a qualidade da água através do tratamento do escoamento superficial urbano. Especificamente, a nova tecnologia de *wetlands* construídos flutuantes (*constructed floating wetland* – CFW) – composta por macrófitas emergentes, porém com funcionamento flutuante – alcançou eficiências de remoção da ordem de 78% de nitrogênio total (NT) e de 47% de

fósforo total (PT), para a espécie *T. domingensis* e para o período de 7 dias. Para o mesmo período de tempo, *S. californicus* obteve 30% de remoção de NT e 11% de PT. Contudo, os sistemas de retenção do escoamento não são dimensionados para tempos de retenção hidráulicos tão elevados. As eficiências alcançadas para o período de 24h, que seria um período de tempo mais razoável, foram de 24% de NT e 12% de PT para a *T. domingensis*, espécie que apresentou eficiência significativa para períodos inferiores a 7 dias. Para efeitos de verificação da efetividade do tratamento, a comparação com os padrões estabelecidos pela Resolução 357/2005 do CONAMA para rios de Classe 1 e 2, considerando 24h como de tempo de retenção, mostra que o efluente de entrada poderia ter a concentração máxima de 20mg/L de NT. Esse seria o valor limite, dentro das condições testadas, para haver eficiência que corresponda aos padrões da legislação (sendo NT a soma dos parâmetros nitrato, nitrito e nitrogênio amoniacal total, constantes na resolução). Já para o PT, o sistema não apresentou eficiência significativa para corresponder aos padrões da legislação ambiental.

Embora as duas espécies tenham se adaptado ao funcionamento do sistema, a espécie *T. domingensis*, além de se adaptar mais rapidamente, mostrou resultados de eficiência de remoção maiores. Talvez *S. californicus* apresentasse melhores resultados se houvesse substrato para seu crescimento na estrutura flutuante, até mesmo para que *T. domingensis* pudesse alcançar melhores eficiências, através da adaptação da estrutura, uma vez que o desenvolvimento do biofilme na zona de raízes é favorecido pela presença do material de preenchimento. Adicionalmente, a eficiência de remoção de fósforo poderia aumentar, pois o fósforo possui a tendência de se ligar aos compostos orgânicos e sedimentar para a região do fundo. Outra adaptação necessária na estrutura, para garantir sua aplicabilidade, seria favorecer a manutenção da verticalidade das plantas. Esse aspecto também poderia ser melhorado com a adição de um meio suporte (substrato), pelo ancoramento da estrutura no local de aplicação (nas margens ou no fundo), ou através do uso de mais de uma espécie de planta com diferentes características de crescimento, de modo que as plantas com maior crescimento vertical fiquem no centro da estrutura e plantas mais baixas (em forma de arbusto) fiquem nas laterais da estrutura.

Do ponto de vista hidráulico, a aplicação dos CFW em bacias de retenção do escoamento é viável se o sistema for dimensionado para manter uma lâmina de água permanente que seja suficiente para manter a estrutura em flutuação. A forma de disposição das estruturas flutuantes no reservatório é essencial para obter maior eficiência no tratamento. O *layout* deve favorecer o contato do efluente com a zona de raízes, reduzindo a possibilidade de caminhos preferenciais do efluente no sistema de tratamento. A modelagem hidráulica é uma ferramenta que pode

auxiliar nesse dimensionamento, considerando que a zona de raízes irá fornecer resistência ao escoamento que pode ser estimada via modelagem. Uma disposição adequada das estruturas irá favorecer o tratamento e irá minimizar a interferência das estruturas na capacidade de armazenamento do reservatório de detenção.

A discussão dos estudos de caso de revitalização e a execução dos experimentos fornecem fortes indícios para a comprovação da proposição de que o tratamento do escoamento superficial urbano, através da aplicação de ecotecnologias distribuídas nos sistemas de drenagem, contribui para a revitalização de rios. As técnicas compensatórias se mostraram efetivas, quando aplicadas em projetos de revitalização, para a recuperação dos processos hidrológicos e para melhorar parâmetros de qualidade da água. Contudo, até o momento, os resultados desses projetos não apresentam unanimidade em relação aos indicadores biológicos; até mesmo há dúvidas sobre a possibilidade de recuperação dos processos ecológicos dos rios em áreas urbanas. Em relação às medidas estruturais nas calhas dos rios, embora haja relato de melhorias, os resultados não mostraram uma recuperação efetiva dos indicadores biológicos, morfológicos e hidráulicos. Por outro lado, medidas na área contígua aos cursos d'água possuem um apelo estético e urbanístico que favorece valores sociais, culturais e econômicos – e tais valores não podem ser desconsiderados no contexto de áreas densamente ocupadas. Entretanto, os valores podem ser trabalhados, através da educação ambiental, para corresponder tanto às expectativas da comunidade, como favorecer a recuperação da integridade ecológica.

Os desafios inerentes à aplicação das NBS precisam de estudos inter e transdisciplinares devido à complexidade envolvida no manejo dos cursos d'água. Nesse sentido, enfatiza-se a importância da gestão adaptativa na implementação e monitoramento de medidas de revitalização, principalmente àquelas referentes aos processos ecológicos e hidromorfológicos. A recuperação desses processos possuem muitas incertezas associadas que interferem na quantificação de indicadores, dificultando a previsão dos resultados das medidas implementadas. Ademais, os resultados da implementação são diferentes para cada situação, pois cada sistema fluvial é único.

6.1. Recomendações

Com base na parte experimental que foi realizada neste trabalho, foram levantadas algumas sugestões para novos estudos experimentais e recomendações práticas para auxiliar a aplicação desse tipo de sistema em campo:

- Avaliar o desempenho de outras espécies de macrófitas, que são utilizadas em CW convencionais, no sistema de CFW;

- Investigar se o sistema apresenta diferença de remoção de nutrientes na forma particulada e dissolvida;
- Investigar de modo detalhado a fixação de carbono e a remoção de nutrientes em um maior período de monitoramento;
- Utilizar espécies diferentes de macrófitas na mesma estrutura flutuante para auxiliar na manutenção da verticalidade das plantas;
- Estudar e desenvolver formas de ancoragem do sistema para aplicação em lagos e reservatórios de retenção do escoamento, considerando a influência do vento, movimento da água, interação com a biota local, vandalismo e outras variáveis que podem dificultar a instalação dos CFW;
- Adaptar a estrutura flutuante, através da adição de um meio suporte, para diminuir o tempo de adaptação das plantas e aumentar a eficiência de remoção;
- Estudar detalhadamente os aspectos hidráulicos da implantação do sistema e sua influência no escoamento, se o sistema for implementado em cursos d'água, bem como a influência na capacidade de armazenamento das estruturas de retenção;
- Considerar o favorecimento da sedimentação que irá ocorrer pelo contato com a zona de raízes e utilizar essa característica durante o dimensionamento para aumentar a capacidade de tratamento do sistema, através da divisão da bacia de retenção em compartimentos;
- Considerar a porcentagem de cobertura da superfície da água no local onde os CFW serão implantados e investigar essa relação com a eficiência do sistema;
- Investigar a influência da aplicação dos CFW na biota local.

7. APÊNDICES

7.1. Material complementar 1 – descrição das características das espécies

Nome científico	Nomes comuns	Descrição física	Reprodução	Características
<i>Typha domingensis</i>	Taboa	Planta de 1,10 a 2,50 m de altura, com folhas que sobrepassam, igualam ou não alcançam a inflorescência (SILVA, 2014).	Propaga-se por sementes e vegetativamente por meio de rizomas (SILVA, 2014).	É uma espécie rizomatosa que forma densos estandes, frequentemente é uma espécie dominante em comunidades de macrófitas (SILVEIRA <i>et al.</i> , 2007). Tolerante à água salobra. Não raramente observam-se várias espécies desse gênero ocorrendo juntas, o que provoca a hibridização. Possui importância comercial para artesanato (HURRELL <i>et al.</i> , 2004).
<i>Schoenoplectus californicus</i>	Junco; piri	Se caracteriza por ter um escapo ereto, de forma piramidal triangular, fotossintetizante, muito longo e fino, podendo atingir até 3 m de comprimento. Os rizomas são bem desenvolvidos, as raízes são numerosas (CORSINO <i>et al.</i> , 2013).	Sementes (sexuada) que servem de alimento para aves aquáticas e pequenos pássaros (TRINDADE <i>et al.</i> , 2010) ou clones (assexuada).	Planta com ciclo anual, as folhas tendem a apodrecer após esse período (WILLE <i>et al.</i> , 2016). O gênero <i>Schoenoplectus</i> é constituído por três espécies no Brasil, <i>Schoenoplectus americanus</i> (Pers.) Volkart, <i>Schoenoplectus californicus</i> (C.A.Mey.) Soják e <i>Schoenoplectus tabernaemontani</i> (C.C.Gmel.) Palla (ALVES <i>et al.</i> , 2014), todas com ocorrência no estado do Rio Grande do Sul e sempre associadas a ambientes alagados (WILLE <i>et al.</i> , 2016). <i>Schoenoplectus californicus</i> é a espécie mais comum do gênero (WILLE <i>et al.</i> , 2016). Nativa da região sudoeste dos EUA, se estendendo até o Chile e Argentina (CORSINO <i>et al.</i> , 2013). Possui importância comercial (móveis e artesanato; indústria de papel). Coloração verde brilhante propicia sua utilização como folhagem ornamental (WILLE <i>et al.</i> , 2016).
<i>Pontederia cordata</i>	Rainha dos lagos; aguapé	Plantas fixas emergentes, cespitosas, presentes em praticamente todos os ambientes aquáticos e paludosos, com caule vegetativo contraído e caule florífero ereto de tamanho variado. Raízes curtas, filetosas com grande quantidade de radículas absorventes. Suas folhas são pecioladas emergentes, basais (GASTAL Jr., 1999).	Propagação vegetativa e reprodução sexuada: floração e frutificação - predominantemente no verão, mas pode haver floração desde a primavera (GASTAL, 1999).	Originária da região tropical e subtropical da América do Sul (GASTAL Jr., 1999). No Brasil ocorre em todas as regiões. No Rio Grande do Sul, encontramos esta planta em todas as regiões fisiográficas. A família Pontederiaceae apresenta uma grande proximidade entre seus gêneros, acarretando muitos problemas quanto a uma determinação precisa entre várias de suas espécies (GASTAL Jr., 1999). No Rio Grande do Sul, estabeleceu-se para a família quatro gêneros (<i>Eichhornia</i> , <i>Pontederia</i> , <i>Heteranthera</i> e <i>Reussia</i>) com oito espécies (GASTAL Jr., 1999).

Nome científico	Nomes comuns	Descrição física	Reprodução	Características
<i>Phragmites australis</i>	Caníço	Planta robusta, com colmos eretos, com folhas em forma de lâminas. Pode atingir 6,0m de altura (ABRANTES, 2009).	Pode ocorrer por sementes ou assexuadamente por rizomas (ABRANTES, 2009).	As folhas secam no inverno. Extensa distribuição geográfica (ocorrência no mundo todo). Pode ter importância comercial (ABRANTES, 2009).
<i>Sagittaria montevidensis</i>	Chapéu-de-couro; Agupé-de-flexa	De 0,5 a 1,0 m de altura. Folhas glabras (desprovida de pêlos), limbo linear quando submersa e espatulado ou sagitado quando emersa (BARBOSA, 2012). Aerênquima bem desenvolvido, o que favorece o transporte de oxigênio da atmosfera às raízes e sua disponibilidade na rizosfera (BREGUNCE et al., 2011).	Sexuada (rosetas) que possuem dormência e germinam em condições adequadas. E por reprodução vegetativa por rizomas (BARBOSA, 2012)	Reprodução por clones em períodos de cheia e reprodução sexuada em período de seca (BARBOSA, 2012). Aloca os recursos disponíveis para o crescimento em detrimento de estruturas reprodutivas sexuadas (BARBOSA, 2012). Alta plasticidade, garantindo alto potencial de infestação. Não houve diferença significativa de remoção no verão e no inverno (BREGUNCE et al., 2011).
<i>Juncus effusus L.</i>	Junco solto	É uma espécie rizomatosa, apresenta crescimento horizontal longelíneo, com ramos segmentados composto de nós e entrenós, e folhas envolvidas em bainhas encontradas em cada nó. A altura varia de 60 cm a 130 cm, possuindo haste cilíndrica e flexível. As inflorescências aparecem lateralmente à haste, com grande número de pequenas flores (ROESSING, 2007).	Se multiplica, sobretudo, através de rizomas, com possibilidade de propagação sexuada em habitat natural (ROESSING, 2007).	Emite hastes continuamente durante o ano, podendo aumentar em até quatro vezes a quantidade do verão até o inverno. O máximo crescimento de uma haste nova ocorre no verão (ROESSING, 2007). Não há certeza sobre a origem da planta, devido a sua ampla distribuição no mundo (ROESSING, 2007).

Nome científico	Nomes comuns	Descrição física	Reprodução	Características
<i>Zizaniopsis bonariensis</i>	Palha; espadana	Planta perene, robusta, rizomatosa (que contém rizoma, tipo de caule longo). Colmos de 1 a 3m de altura, herbáceos, não ramificados e folhas não agregadas na base, com lâminas foliares lineares largas e esponjosas no interior. (FERREIRA, 2005).	Reprodução sexuada e por clones vegetativos (FERREIRA, 2005).	Emergência contínua de indivíduos durante todo o ano. Durante os meses de agosto, setembro e outubro de 2004 ocorreu a estação reprodutiva da população de <i>Z. bonariensis</i> , observando-se a presença de estruturas reprodutivas (FERREIRA, 2005). Apenas 13,5% da população realizou reprodução sexuada. Dispersão das sementes observado por um período de 60 dias (FERREIRA, 2005). Associou a taxa de mortalidade com o evento reprodutivo, já que a biomassa dos indivíduos que apresentaram inflorescências sofreu um decaimento brusco após o período de dispersão de sementes. Senescência total entre 2 e 4 meses após a dispersão das sementes. Produção de biomassa clorofilada: maiores valores de janeiro a maio e de setembro a dezembro, separados temporalmente pelos meses que compreendem o inverno: junho, julho e agosto (FERREIRA, 2005). Ocorre no Sul da América do Sul (Brasil, Paraguai e Argentina).
<i>Pontederia parviflora</i>	Aguapé; camalote; lanceiro; orelha-de-veado	Planta aquática emergente, perene, com folhas estreitas ou largas que podem variar de 15 a 120 cm de comprimento e raízes em forma de cabeleira (IWAKURA, 2013).	Floresce praticamente o ano todo e produz muitas sementes, sendo seus frutos dispersos pela água e animais (IWAKURA, 2013).	Não tem registro de ocorrência no Sul. É bastante resistente no tratamento de diferentes tipos de efluentes, além de possuir boa eficiência quanto a remoção de matéria orgânica, pode ser classificada como espécie hiperacumuladora (IWAKURA, 2013).

7.2. Material complementar 2 – resumo dos delineamentos amostrais de experimentos de CFW

Referência	Local	Número de espécies	Nome das espécies de macrófitas	O que foi avaliado?	Tamanho dos mesocosmos	Número de réplicas	Tempo de estudo (dias)	Frequência da amostragem	Tipo do efluente utilizado	Comentários adicionais
Saeed <i>et al.</i> (2016)	Bangladesh	2	<i>Phragmites australis</i> ; <i>Canna indica</i> .	Nutrientes; DBO; DQO; E. coli.	A - 4.176 m ² Prof. - 1.14m	1	147	Uma vez por semana.	Rio poluído.	Tempo de estabelecimento de 8 semanas. Adição do efluente durante 24 semanas. Monitoramento da qualidade da água na estrada e saída do tanque. Cargas hidráulicas variáveis.
Lynch <i>et al.</i> (2015)	Estados Unidos	1	<i>Juncus effusus</i> L.	Diferença entre duas estruturas flutuantes. Remoção de nutrientes e parâmetros físico-químicos.	A - 0.6105 m ² Prof. - 0.46 m	4	63	Duas vezes por semana, no 3º e 7º dia.	Efluente de um reservatório de retenção.	Tempo total do experimento 18 semanas, semana 1 a 8 - estabelecimento das plantas. Densidade de 27 plantas por m ² e as estruturas cobriram 65% da superfície. Reabastecimento dos tanques no dia 3 de cada semana - estilo reator batelada. A área drenada possui uso misto de cultivo e residências.

Referência	Local	Número de espécies	Nome das espécies de macrófitas	O que foi avaliado?	Tamanho dos mesocosmos	Número de réplicas	Tempo de estudo (dias)	Frequência da amostragem	Tipo do efluente utilizado	Comentários adicionais
Tanner; Headley (2011)	Nova Zelândia	4	<i>Carex virgata</i> ; <i>Cyperus ustulatus</i> ; <i>Juncus edgariae</i> ; <i>Schoenoplectus tabernaemontani</i>	Remoção de N, P, K, S, Ca, Mg, Na, Fe, Mn, Zn, Cu, B. E parâmetros físico-químicos. Crescimento de raízes.	A - 1 m ² Prof. - 1 m	3	14	Amostragem de 4 vezes durante 2 bateladas de 7 dias.	Escoamento superficial sintético.	Além das espécies trabalhou com a comparação com raízes artificiais, em comparação com os outros tratamentos, inclusive com controle (sem plantas nem matriz). Efluente sintético (simulando água de drenagem), segunda batelada com avaliação de sedimentos (argila). Parâmetros físico-químicos medidos com maior frequência. Experimento com curto período de tempo, mas maior número de amostragens. Deixou todas as estruturas montadas em um tanque grande, depois conduziu o experimento com cada espécie separadamente.
Zhang <i>et al.</i> (2014)	China	5	<i>Canna generalis</i> ; <i>Scirpus validus</i> ; <i>Alternanthera philoxeroides</i> ; <i>Cyperus alternifolius</i> ; <i>Thalia geniculata</i>	Diferença de eficiência de remoção entre espécies e entre os microorganismos do biofilme. DBO, DQO, nitrogênio, fósforo.	A - 0.25 m ² Prof. - 0.60 m	3	150	Amostragem após 120 dias e no final dos 5 meses.	Solução sintética de cultivos hidropônicos (Hoagland).	120 dias de estabelecimento das plantas. Fluxo intermitente: 5 dias com efluente e 5 dias sem.
Weragoda <i>et al.</i> (2012)	Sri Lanka	2	<i>Typha angustifolia</i> ; <i>Canna iridiflora</i>	Diferença de remoção de DBO, N e P entre as espécies. Influência de operação em batelada ou fluxo contínuo.	A - 3.0 m ² Prof. - 0.50 m	1	32	Uma amostra em 7 dias e outra depois de 14 dias. Em seguida: 4 dias de avaliação diária.	Esgoto doméstico.	Dois tanques e um controle. Não foi coberto e não foi compensado, pois não houve chuva significativa.

Referência	Local	Número de espécies	Nome das espécies de macrófitas	O que foi avaliado?	Tamanho dos mesocosmos	Número de réplicas	Tempo de estudo (dias)	Frequência da amostragem	Tipo do efluente utilizado	Comentários adicionais
Wang <i>et al.</i> (2014)	Estados Unidos	2	<i>Pontederia cordata</i> L.; <i>Schoenoplectus tabernaemontani</i>	Nutrientes (N, amônia, nitrito, nitrato, P, ortofosfato), clorofila-a	A - 0,6105 m ² Prof. - 0,46m	3	180	Dia 0 e dia 7	Rio poluído.	Efeitos da temperatura nas concentrações de PT e NT foram estudados pela equação de Arrhenius modificada. 180 dias no total com 6 estágios, 4 lotes em cada estágio e 7 dias em 1 lote. Plantas trocadas em cada estágio, e troca de água a cada lote (7 dias).

8. REFERÊNCIAS

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