Towards a New Nature in Cities: Understanding Novel Urban Ecosystems in the Anthropocene

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2022

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FOREWORD

According to the General Regulation of Doctoral Programs of the University of Porto (number 2, 4th Article) and the Decree Law 74/2006 (Article 31st, 24th of March) revised under the Decree law 230/2009 (14th of September), this thesis includes manuscripts published or in consideration for publication in peer-review scientific journals. Since these manuscripts result from collaborations with other authors, the candidate declares that she was the main responsible of the conception and the development of the research work, including the compilation, analysis, results, discussion and writing as in its current publication form.

The candidate was funded by the National Foundation for Science and Technology (FCT), through a Ph.D. Grant (SFRH/BD/130382/2017) and co-funded by the European Social Fund and by the National Ministry of Science, Technology and Higher Education, through the Regional Operational Program Norte, under Portugal 2020.

The candidate was also awarded a Fulbright Grant in the academic year 2018/2019, which allowed to conduct part of this research at the University of Massachusetts Amherst as a Visiting Researcher.

This research was developed in the context of the Doctoral Program in Landscape Architecture (School of Sciences of the University of Porto), which started in October 2017 and ended in January 2022.

The thesis was fully written in English. Chapters 1 and 8 were additionally translated into Portuguese.

NOTA PRÉVIA

Na elaboração desta tese, e nos termos do número 2 do Artigo 4º do Regulamento Geral dos Terceiros Ciclos de Estudos da Universidade do Porto e do Artigo 31º do D.L. 74/2006, de 24 de Março, com a nova redação introduzida pelo D.L. 230/2009, de 14 de Setembro, foi efetuado o aproveitamento de um conjunto coerente de trabalhos de investigação publicados ou submetidos para publicação em revistas internacionais indexadas e com arbitragem científica, os quais integram alguns dos capítulos da presente tese. Uma vez que os referidos trabalhos foram realizados com a colaboração de outros autores, a candidata declara que foi a principal responsável na conceção, obtenção, análise e discussão de resultados, e na elaboração da forma publicada destes trabalhos.

A candidata foi financiada pela Fundação para a Ciência e Tecnologia (FCT) através de uma bolsa de doutoramento (SFRH/BD/130382/2017) e cofinanciada pelo Fundo Social Europeu através do Programa Operacional Regional Norte, do Portugal 2020.

A candidata também recebeu uma Bolsa Fulbright no ano académico de 2018/2019, o que permitiu desenvolver parte desta investigação na Universidade de Massachusetts Amherst com o estatuto de Investigador Visitante.

O trabalho realizado no âmbito desta tese foi desenvolvido no contexto do plano doutoral em Arquitetura Paisagista (Faculdade de Ciências da Universidade do Porto), que se iniciou em outubro de 2017 e terminou em janeiro de 2022.

A tese foi integralmente escrita em inglês. Os capítulos 1 e 8 foram adicionalmente traduzidos para português.

ACKNOWLEDGEMENTS / AGRADECIMENTOS

As I write this text, I realize that I am about to conclude a work that results from four years of dedication and growth. The conclusion of this investigation represents the end of yet another stage that would not have been possible without the contribution of those who have supported me and made this journey brighter. To all of them, I extend my sincere gratitude.

First of all, I thank the National Foundation for Science and Technology (FCT) for granting me the Ph.D. grant (SFRH/BD/130382/2017) that allowed me to develop this research and also the Fulbright Commission Portugal for giving me the opportunity to travel to the United States of America in the prestigious *fulbrighter* condition.

Um especial agradecimento à minha orientadora, a Professora Doutora Cláudia Fernandes, por me ter incentivado a percorrer este caminho e ter sido uma presença constante em todos os momentos. Por me ter desafiado a estudar um tema complexo e difícil, mas igualmente estimulante. Pela partilha incansável de conhecimentos e por todas as horas de trabalho e dedicação que foram investidas para que esta fosse uma investigação bem-sucedida.

Also, I would like to express my deepest appreciation to my co-supervisor, Professor Emeritus Jack Ahern, for the wise words, valuable guidance, encouragement, and exciting conversations we shared throughout these four years. It was an absolute pleasure to meet you, and visiting you at UMass was an experience I will cherish forever.

Ao Professor Doutor Paulo Farinha-Marques, por tudo que me ensinou e ensina, de forma tão apaixonante, sobre o que é ser Arquiteta Paisagista. Também agradeço por disponibilizar os dados recolhidos no âmbito do projeto de investigação PTDC/AUR-URB/104044/2008 “Estrutura Verde Urbana: Estudo da Relação entre a Morfologia do Espaço Público e a Diversidade de Flora e Fauna na Cidade do Porto”, que foram imprescindíveis na execução deste trabalho.

Ao Professor Doutor João Honrado, pela partilha de conhecimentos e por todas as sugestões oportunas e desafiantes que em muito contribuíram para melhorar esta investigação.

To Professor Robert Ryan, for the support, insightful suggestions, and conversations essential to improve this investigation.

A todos os Professores do curso de Arquitetura Paisagista da Faculdade de Ciências da Universidade do Porto, que contribuíram para a minha formação e estiveram sempre disponíveis.

Ao Paulo Almeida, Iúri Frias e João Junqueira pela valiosa ajuda no trabalho de campo.

Aos meus colegas de doutoramento pela partilha de conhecimentos, desabafos e discussões estimulantes.

Aos restantes colegas do departamento de AP pelo companheirismo, horas de almoço e gargalhadas que tanta falta fizeram durante estes últimos dois anos de pandemia.

I am also grateful to the friends I made in Amherst for welcoming me so well and making my experience in the United States more special.

Ao Fausto e à Maria João, pelo carinho e motivação constantes.

À minha família, Mãe, Pai, André, Daniela e Boo, pelo apoio incondicional e pela paciência. Mãe e Pai, obrigada pelos valores que me transmitiram e por apoiarem todas as minhas decisões sem nunca duvidarem.

E ao Vítor. Dizer-te obrigada parece tão pouco. É um privilégio ter-te sempre ao meu lado.

ABSTRACT

Novel Urban Ecosystems emerge in response to anthropogenic disturbances in the context of the Anthropocene and are composed of novel combinations of species (native and non-native) that have never previously coexisted. As they emerge under extreme environmental conditions (e.g., drier, warmer, and highly disturbed habitats), they acquire the ability to perform original ecological functions and thrive under these conditions. The adaptive capacity of these ecosystems and their prevalence in urban green spaces make the Novel Urban Ecosystems concept particularly relevant for Landscape Architecture practice and for formulating response options to address climate change adaptation and mitigation in cities. Thus, this thesis aims to contribute to understanding the challenges and opportunities of Novel Urban Ecosystems in the scope of Landscape Architecture practice and research, namely its potential contribution to the design, planning and management of the urban green structure. Six studies are presented, aiming to respond to identified problems, namely: (i) to clarify and stabilize the Novel Urban Ecosystems concept and demonstrate its usefulness and relevance to the disciplinary area of Landscape Architecture; (ii) to create tools to measure ecological novelty in urban green spaces, allowing the application and integration of the concept in Landscape Architecture practice; and (iii) to understand the attitudes and preferences towards Novel Urban Ecosystems, which are determinant for the concept's acceptance, application and integration in the design, planning, and management of the urban green structure. Individually and as a whole, all the developed studies contributed to clarify the Novel Urban Ecosystems concept and highlighted the relevance of studying these ecosystems within the scope of Landscape Architecture. The results obtained allowed us to verify that the urban ecological novelty is present in all types of urban green spaces, but with different degrees (continuum of urban ecological novelty). The construction of a new methodology to assess ecological novelty in urban green spaces enabled the application and integration of this concept: i) in the planning and management of the urban green structure, and ii) in the design and management of urban green spaces, focusing on the floristic composition, structure, and functional diversity of plant communities. It was verified that the application and integration of the Novel Urban Ecosystems concept was mostly welcomed by professionals involved in the design, planning, and management of green spaces, and considered especially relevant to tackle the effects of climate change in cities. Overall, the conclusions, contributions and tools originated in this research can have practical implications in the way urban green spaces are perceived and intervened, and, in turn, can have a positive impact on the quality of life of the population, as well as the development and sustainability of cities.

Keywords: Climate change adaptation; Climate change mitigation; Human-Nature interactions; Native plants; Non-native plants; Porto, Portugal; Urban ecological novelty; Urban green spaces

RESUMO

Os Novos Ecossistemas Urbanos surgem em resposta a perturbações antrópicas no contexto do Antropocénico e são compostos por novas combinações de espécies (nativas e exóticas) que nunca tinham coexistido previamente. Ao emergirem em condições ambientais extremas (por exemplo, habitats mais secos, mais quentes e muito perturbados), adquirem competências para desempenhar funções ecológicas originais e prosperar nessas condições. A capacidade de adaptação destes ecossistemas e a sua prevalência nos espaços verdes urbanos fazem com que o conceito de Novos Ecossistemas Urbanos seja particularmente relevante para as áreas de atuação da Arquitetura Paisagista e para formular opções de resposta para abordar a adaptação e mitigação das alterações climáticas nas cidades. Desta forma, esta tese propôs-se a contribuir para a compreensão das oportunidades e desafios associados ao conceito de Novos Ecossistemas Urbanos, concretamente no âmbito da Arquitetura Paisagista e do seu potencial contributo para o desenho, planeamento e gestão da estrutura verde urbana. Para isso, seis estudos são apresentados, com o intuito de responder a problemáticas identificadas, nomeadamente: i) esclarecer e estabilizar o conceito de Novos Ecossistemas Urbanos e demonstrar a sua utilidade e relevância para a área disciplinar da Arquitetura Paisagista; ii) criar ferramentas para medir a novidade ecológica nos espaços verdes urbanos, permitindo a aplicação e integração do conceito nas áreas de atuação da Arquitetura Paisagista; e iii) compreender as atitudes e as preferências em relação a Novos Ecossistemas Urbanos, determinantes para a sua aceitação, aplicação e integração no desenho, planeamento e gestão da estrutura verde urbana. Individualmente e no seu conjunto, todos os estudos desenvolvidos contribuíram para esclarecer o conceito de Novos Ecossistemas Urbanos e salientaram a pertinência de estudar estes ecossistemas no âmbito da Arquitetura Paisagista. Os resultados obtidos permitiram constatar que a novidade ecológica urbana está presente em todos os tipos de espaços verdes urbanos, mas em diferentes graus (*continuum* de novidade ecológica urbana). A construção de uma nova metodologia para avaliar a novidade ecológica em espaços verdes urbanos possibilitou a aplicação e integração deste conceito: i) no planeamento e gestão da estrutura verde urbana e ii) no desenho e manutenção do espaço verde urbano, focando na composição florística, estrutura e diversidade funcional das comunidades de plantas. Verificou-se, ainda, que a aplicação e integração do conceito de Novos Ecossistemas Urbanos foi maioritariamente acolhida pelos principais intervenientes no espaço verde e considerada especialmente relevante para combater os efeitos das alterações climáticas nas cidades. De um modo geral, as conclusões, as contribuições e as ferramentas originadas nesta investigação podem ter implicações práticas na forma como os espaços verdes urbanos são percecionados e intervencionados, e, por sua vez, um impacto positivo na qualidade de vida da população, assim como no desenvolvimento e sustentabilidade das cidades.

Palavras-chave: Adaptação às alterações climáticas; Espaços verdes urbanos; Interações Homem-Natureza; Mitigação das alterações climáticas; Novidade ecológica urbana; Plantas exóticas; Plantas nativas; Porto, Portugal;

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GENERAL INTRODUCTION

“As we continue to force the world to change so quickly (…) An account that appreciates the full range of ecosystems that in fact make up the world is however more likely to be in a position to make meaningful contributions to the decisions we face today than one that neglects systems only because they more clearly bear the trace of human contact.” (Light, Thompson, & Higgs, 2013, p. 268)

Chapter 1 | General introduction

Capítulo 1 | Introdução geral

1.1. The Anthropocene and the emergence of Novel Ecosystems

1.1.1. A new geological epoch?

Planet Earth has witnessed the transition through various geological times and climate changes (Jackson, 2006; Jackson & Hobbs, 2009). However, increasing human pressure has been responsible for complex and intense changes at accelerated rates (Hobbs et al., 2006). As such, many scientists believe that the planet has entered a new geological epoch in which the role of humanity is undeniable, the Anthropocene[1] (Crutzen, 2006; Kueffer & Kaiser-Bunbury, 2014; Steffen, Crutzen, Mcneill, & Events, 2007; Steffen, Grinevald, Crutzen, & Mcneill, 2011). The term "Anthropocene," coined by the chemist Paul J. Crutzen and Eugene Stoermer in the early 21st century, has since been widely used by the scientific community and in various fields of knowledge to describe the influence of human activities in contemporary times (Cantrell, Martin, & Ellis, 2017; Crutzen, 2006; Kueffer & Kaiser-Bunbury, 2014; Steffen et al., 2007, 2011).

1.1. O Antropocénico e a emergência de Novos Ecossistemas

1.1.1. Uma nova época geológica?

O planeta Terra já testemunhou a transição de diversas épocas geológicas e mudanças climáticas (Jackson, 2006; Jackson & Hobbs, 2009). No entanto, a crescente pressão humana tem sido responsável por alterações complexas, intensas e a ritmos acelerados (Hobbs et al., 2006). Como tal, numerosos cientistas acreditam que o planeta entrou numa nova época geológica, o Antropocénico[2] (Crutzen, 2006; Kueffer & Kaiser-Bunbury, 2014; Steffen, Crutzen, Mcneill, & Events, 2007; Steffen, Grinevald, Crutzen, & Mcneill, 2011). O termo "Antropocénico", cunhado por Paul J. Crutzen e Eugene Stoermer no início do século XXI, tem sido, desde então, amplamente utilizado pela comunidade científica, e em várias áreas disciplinares, para descrever a influência global das atividades humanas na contemporaneidade (Cantrell, Martin, & Ellis, 2017; Crutzen, 2006; Kueffer & Kaiser-Bunbury, 2014; Steffen et al., 2007, 2011).

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[1] Although it has not yet been formally recognized by the International Union of Geological Sciences (IUGS) as the most recent geological epoch in the planet's history, its approval is actively underway (SQS, 2021).

[2] Apesar de não ter sido ainda formalmente reconhecida pela União Internacional de Ciências Geológicas (IUGS) como a mais recente época geológica na história do planeta, a sua aprovação encontra-se ativamente em curso (SQS, 2021).

Several dates have been pointed out in order to identify the moment of transition to the Anthropocene (S. L. Lewis & Maslin, 2015). Crutzen (2006) suggests that the Anthropocene may have emerged in the second half of the 18th century, coinciding with the beginning of the Industrial Revolution. The Industrial Revolution was one of the most significant milestones in civilization's progress, but it has also led to negative repercussions for the environment (Waters, Zalasiewicz, Williams, Ellis, & Snelling, 2014; Zalasiewicz, Williams, Haywood, & Ellis, 2011). These impacts intensified after the end of World War II (1945), as the peace and stability that followed allowed major developments in the communication, technology, and transportation sectors, stimulated the globalization of the economy and led to a significant increase in the world's population (MEA, 2005; Steffen et al., 2007).

Rapid population growth and access to mechanization drove the intensification of agriculture, leading to massive deforestation, habitat fragmentation and degradation, and an accelerated loss of biodiversity (Grimm et al., 2008; Higgs et al., 2014; Nelson et al., 2010; Vitousek, Mooney, Lubchenco, & Melillo, 1997). At the same time, increasing agricultural production relied on the overuse of fertilizers and pesticides, degrading soils, and contaminating biogeochemical cycles (Crutzen, 2006; Steffen et al., 2011).

To support the agricultural and industrial sectors in the 20th century, the extraction and burning of fossil fuels increased substantially and were responsible for the emission of

Várias datas têm vindo a ser apontadas para identificar o momento de transição para o Antropocénico (S. L. Lewis & Maslin, 2015). Crutzen (2006) sugere que o Antropocénico terá emergido na segunda metade do século XVIII, coincidindo com o início da Revolução Industrial. A Revolução Industrial foi um dos marcos mais significativos para o progresso civilizacional, mas originou também impactos negativos no meio ambiente (Waters, Zalasiewicz, Williams, Ellis, & Snelling, 2014; Zalasiewicz, Williams, Haywood, & Ellis, 2011). Estes impactos acentuaram-se após o final da Segunda Guerra Mundial (1945), na medida em que a paz e a estabilidade subsequentes permitiram grandes desenvolvimentos nos setores da comunicação, tecnologia e transportes, possibilitando a globalização da economia e um aumento significativo da população mundial (MEA, 2005; Steffen et al., 2007).

O rápido crescimento demográfico e o acesso à mecanização impulsionaram a intensificação da agricultura, provocando desflorestações massivas, a fragmentação e a degradação de habitats e a perda de biodiversidade (Grimm et al., 2008; Higgs et al., 2014; Nelson et al., 2010; Vitousek, Mooney, Lubchenco, & Melillo, 1997). A crescente produção agrícola estimulou, ainda, o uso excessivo de produtos fitofarmacêuticos (fertilizantes pesticidas e herbicidas), degradando os solos e contaminando os ciclos biogeoquímicos (Crutzen, 2006; Steffen et al., 2011).

Para suportar os setores da agricultura e da indústria no século XX, a extração e a queima de combustíveis fósseis aumentaram consideravelmente e foram responsáveis pela massive amounts of greenhouse gases (CO_2, CH_4, N_20, among others). The accumulation and concentration of these gases into the atmosphere has led to high pollution levels and a significant increase in the energy retained in the atmosphere, contributing to global warming and long-term changes in the Earth's weather patterns (climate change) (Gray, 2005). Significant changes in the global composition of the atmosphere, directly and indirectly, induced by human activities, have overridden the natural climate variability of the planet observed in the past (IPCC, 2014). Scientific evidence that proves the influence of human activities on climate change is gathered in the most recent report from the Intergovernmental Panel on Climate Change (IPCC, 2021).

Besides the increase in average temperatures, changes in precipitation patterns, increase in the occurrence of extreme weather events, and increase in the mean level of the sea are also expected (Harris, Hobbs, Higgs, & Aronson, 2006; IPCC, 2014; Williams & Jackson, 2007). These climate changes put the planet on an uncertain trajectory and drastically influence evolutionary and ecological processes such as species distribution, interaction, and behavior (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; Parmesan, 2006; Starzomski, 2013). The transformations observed in the context of the Anthropocene act at various spatial and temporal scales and in complex interactions, contributing to a reconfiguration of ecosystem processes and patterns and to the emergence of new

emissão de enormes quantidades de gases de efeito de estufa (CO_2, CH_4, N_20, entre outros). Por sua vez, a acumulação e concentração desses gases na atmosfera provocou níveis elevados de poluição e um aumento significativo da energia retida na atmosfera, contribuindo para o aquecimento global e para alterações de longo prazo nos padrões meteorológicos da Terra, isto é, alterações climáticas (Gray, 2005). As alterações significativas na composição global da atmosfera, originadas direta e indiretamente pelas atividades antrópicas, sobrepõem-se, atualmente, à variabilidade climática natural do planeta observada no passado (IPCC, 2014). A evidência científica que demonstra a influência das atividades humanas nas alterações climáticas encontra-se reunida no mais recente relatório do Painel Intergovernamental sobre Alterações Climáticas (IPCC, 2021).

Para além do aumento das temperaturas médias, prevêem-se também mudanças nos padrões de precipitação, o aumento da ocorrência de eventos climáticos extremos e o aumento do nível médio da água do mar (Harris, Hobbs, Higgs, & Aronson, 2006; IPCC, 2014; Williams & Jackson, 2007). Estas alterações climáticas colocam o planeta numa trajetória incerta e influenciam os processos evolutivos e ecológicos como a distribuição e o comportamento das espécies (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; Parmesan, 2006; Starzomski, 2013). Todas estas transformações observadas no contexto do Antropocénico atuam a várias escalas, espaciais e temporais, e em complexas interações, contribuindo para uma combinations of species that had never coexisted before (Ellis, 2015; Hobbs et al., 2006; Seastedt, Hobbs, & Suding, 2008; Vitousek et al., 1997; Williams & Jackson, 2007).

1.1.2. Novel combinations of species

Over many centuries, many plant species have been moved for food or ornamental purposes (Davis, 2018; Gaertner et al., 2017; Kueffer & Kull, 2017; Potgieter, Gaertner, O'Farrell, & Richardson, 2019; Shackleton et al., 2019), but also to perform specific ecological functions (Kueffer, Schumacher, Dietz, Fleischmann, & Edwards, 2010; Lugo, 2010; Mascaro, Hughes, & Schnitzer, 2012). Transportation development and technological advances observed in the 20th century facilitated human movement and global trade, which intensified the accidental or deliberated circulation of species (Del Tredici, 2014; Harris et al., 2006). Consequently, many species were dispersed to areas outside their natural distribution range, associating themselves with native communities (Hobbs et al., 2006; Knapp & Kühn, 2012). Eventually, some of the introduced species have adapted to the new conditions in which they were placed and have acquired the ability to overcome barriers that limited their reproduction and dispersal (Del Tredici, 2007; Richardson et al., 2000). The phenomenon of biotic homogenization[3] concerns the scientific community due to the

reconfiguração dos processos e padrões dos ecossistemas e para a emergência de novas combinações de espécies que nunca tinham coexistido previamente (Ellis, 2015; Hobbs et al., 2006; Seastedt, Hobbs, & Suding, 2008; Vitousek et al., 1997; Williams & Jackson, 2007).

1.1.2. As novas combinações de espécies

Ao longo dos séculos, diversas espécies de plantas têm sido movimentadas, não só para a produção de alimentos e para fins ornamentais (Davis, 2018; Gaertner et al., 2017; Kueffer & Kull, 2017; Potgieter, Gaertner, O'Farrell, & Richardson, 2019; Shackleton et al., 2019), mas também para desempenhar funções ecológicas específicas (Kueffer, Schumacher, Dietz, Fleischmann, & Edwards, 2010; Lugo, 2010; Mascaro, Hughes, & Schnitzer, 2012). O desenvolvimento dos transportes e os avanços tecnológicos observados no século XX facilitaram a movimentação humana e o comércio global, intensificando a circulação, acidental ou deliberada, de espécies (Del Tredici, 2014; Harris et al., 2006). Consequentemente, muitas espécies foram disseminadas para áreas fora da sua distribuição natural, associando-se com comunidades nativas (Hobbs et al., 2006; Knapp & Kühn, 2012). Algumas espécies exóticas acabaram por se adaptar a novas condições e ultrapassaram as barreiras que limitavam a sua reprodução e dispersão (Del Tredici, 2007; Richardson et al., 2000). Este fenómeno de

[3] Global and gradual process that diminishes floral and faunal distinctions among regions (Olden, LeRoy Poff, Douglas, Douglas, & Fausch, 2004).

associated risks of biological invasion, potentially leading to numerous negative impacts on ecological processes, human well-being, and the economy (Bonanno, 2016; Richardson et al., 2000; Schaefer, 2011; Simberloff, 2015).

Biotic homogenization, biological invasions, species status, and other related concepts have received growing attention in the scientific literature (Bonanno, 2016; Potgieter et al., 2017; Pyšek & Richardson, 2010; Richardson & Pyšek, 2006; Shackleton et al., 2019; Simberloff, 2015). However, the increasing amount of information on this subject can often lead to confusion in the definitions and language used (Gbedomon, Salako, & Schlaepfer, 2020; C. L. Lewis, Granek, & Nielsen-Pincus, 2019; Selge, Fischer, & van der Wal, 2011) and in the way all non-native species (invasive or otherwise) are perceived (Davis et al., 2011; Guiaşu & Tindale, 2018; Hill & Hadly, 2018; Kueffer & Kull, 2017).

To identify the status of plant species in Portugal, Marchante, Morais, Freitas, & Marchante (2014) relied on the conceptual framework proposed by Richardson et al. (2000), in which the ability to overcome geographical, environmental, and reproductive barriers determines the status

homogeneização biótica[4] tem vindo a preocupar a comunidade científica, devido aos riscos de invasão biológica associados e aos possíveis impactos negativos nos processos ecológicos, no bem-estar humano e na economia (Bonanno, 2016; Richardson et al., 2000; Schaefer, 2011; Simberloff, 2015).

A homogeneização biótica, as invasões biológicas, o estatuto das espécies e outros conceitos relacionados têm recebido grande destaque na literatura científica (Bonanno, 2016; Potgieter et al., 2017; Pyšek & Richardson, 2010; Richardson & Pyšek, 2006; Shackleton et al., 2019; Simberloff, 2015). No entanto, a crescente quantidade de informação sobre este assunto pode muitas vezes gerar confusão nas definições e linguagem utilizadas (Gbedomon, Salako, & Schlaepfer, 2020; C. L Lewis, Granek, & Nielsen-Pincus, 2019; Selge, Fischer, & van der Wal, 2011) e na forma como todas as espécies exóticas (invasoras ou não) são percecionadas (Davis et al., 2011; Guiaşu & Tindale, 2018; Hill & Hadly, 2018; Kueffer & Kull, 2017).

Para identificar o estatuto das espécies de plantas em Portugal, Marchante, Morais, Freitas, & Marchante (2014) basearam-se no enquadramento conceptual proposto por Richardson et al. (2000), no qual a capacidade de ultrapassar barreiras geográficas, ambientais e reprodutivas determina o estatuto e o risco

[4] Processo global e gradual que diminui as distinções florísticas e faunísticas entre as regiões (Olden, LeRoy Poff, Douglas, Douglas, & Fausch, 2004).

and ecological risk[5] of species in the new territory (Figure 1.1; Box 1.1).

ecológico[6] das espécies no novo território (Figura 1.1; Caixa 1.1).

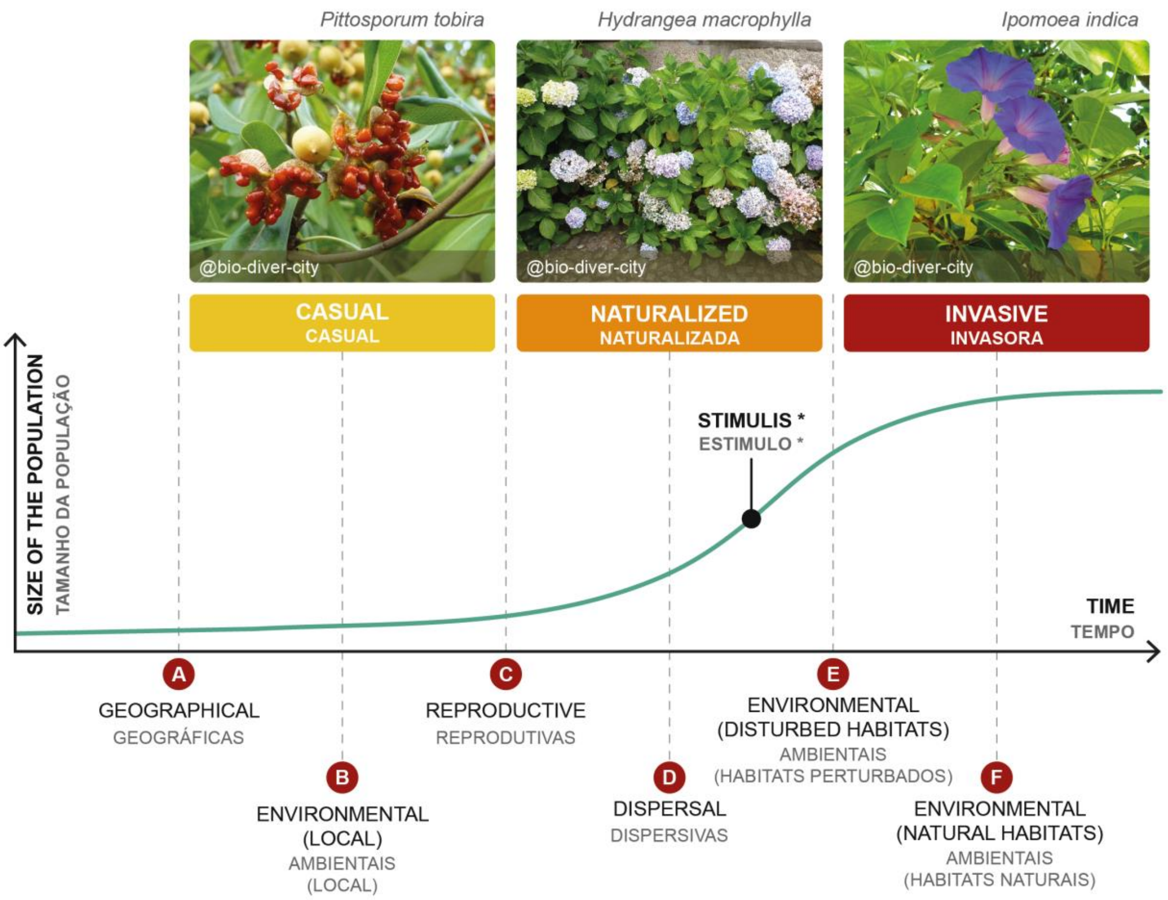

Figure 1.1. Process of introduction, naturalization, and invasion with a representation of the barriers that limit this process: (A) Geographical barriers; (B) Abiotic and biotic barriers at the site of introduction; (C) Reproduction barriers that prevent consistent offspring production; (D) Local and regional dispersal barriers; (E) Environmental barriers in vegetation modified by humans or dominated by exotic species; (F) Environmental barriers in natural or semi-natural vegetation; * *natural or anthropogenic disturbance.* Adapted from Fernandes, Teixeira, & Farinha-Marques (2018); Marchante et al. (2014); Richardson et al. (2000).

Figura 1.1. Processo de introdução, naturalização e invasão com uma representação das barreiras que limitam este processo: (A) Barreiras geográficas; (B) Barreiras abióticas e bióticas no local de introdução; (C) Barreiras de reprodução que previnem uma produção consistente de descendência; (D) Barreiras locais e regionais de dispersão; (E) Barreiras ambientais em vegetação modificada pelo Homem ou dominada por espécies exóticas; (F) Barreiras ambientais em vegetação natural ou seminatural; * *perturbação natural ou antropogénica.* Adaptado de Fernandes, Teixeira, & Farinha-Marques (2018); Marchante et al. (2014); Richardson et al. (2000).

[5] Risk of casual and naturalized non-native species becoming invasive (Marchante et al., 2014).

[6] Risco das espécies exóticas casuais e naturalizadas se tornarem invasoras (Marchante et al., 2014).

Box 1.1.

- **Native plants** (indigenous, autochthonous) – species that have occurred naturally in mainland Portugal for many years. Examples: *Quercus suber* (Cork oak), *Crataegus monogyna* (Hawthorn), *Helichrysum italicum* (Curry plant).
- **Non-native plants** (introduced, allochthonous) – species that were deliberately or accidentally introduced in mainland Portugal by human action and did not occur naturally there for many years. Examples: *Liriodendron tulipifera* (Tulip tree), *Camellia japonica* (Japanese camellia), *Vinca major* (Periwinkle).
- **Casual non-native plants** – non-native species that occasionally reproduce in a given area but do not form self-replacing populations. They depend on repeated introductions for their persistence. Examples: *Chamaecyparis lawsoniana* (Lawson cypress), *Pittosporum tobira* (Australian-laurel), *Zantedeschia aethiopica* (African lily).
- **Naturalized non-native plants** – non-native species that reproduce consistently and sustain populations over many life cycles without direct human intervention (or despite human intervention). Examples: *Cercis siliquastrum* (Judas tree), *Hydrangea macrophylla* (Bigleaf Hydrangea), *Acanthus mollis* (Artist's acanthus).
- **Invasive plants** – Naturalized non-native species that reproduce and expand rapidly over a large area without direct human intervention, producing significant changes in ecosystems. These species are identified in Portuguese legislation (Decreto-Lei n.º 92/2019, 2019), currently in effect. Examples: *Robinia pseudoacacia* (Black locust), *Cortaderia selloana* (Pampas grass), *Tradescantia fluminensis* (Spiderwort).

Caixa 1.1.

- **Plantas nativas** (indígenas, autóctones) – espécies que ocorrem naturalmente em Portugal Continental e que existem aí há milhares de anos. Exemplos: *Quercus suber* (Sobreiro), *Crataegus monogyna* (Pilriteiro), *Helichrysum italicum* (Erva-do-caril).
- **Plantas exóticas** (introduzidas, alóctones) – espécies que foram intencionalmente ou acidentalmente introduzidas em Portugal Continental por ação humana e que não existem aí há milhares de anos. Exemplos: *Liriodendron tulipifera* (Tulipeiro), *Camellia japonica* (Japoneira), *Vinca major* (Pervinca).
- **Plantas exóticas casuais** – espécies exóticas que se reproduzem ocasionalmente numa determinada área, mas que não formam populações auto-substituíveis, e que dependem de introduções repetidas para a sua persistência. Exemplos: *Chamaecyparis lawsoniana* (Cedro-branco), *Pittosporum tobira* (Pitósporo-da-China), *Zantedeschia aethiopica* (Jarro).
- **Plantas exóticas naturalizadas** – espécies exóticas que se reproduzem de forma consistente e sustentam populações ao longo de muitos ciclos de vida sem intervenção direta do homem (ou apesar da intervenção humana). Exemplos: *Cercis siliquastrum* (Olaia), *Hydrangea macrophylla* (Hidrângea), *Acanthus mollis* (Acanto).

Plantas invasoras – espécies exóticas naturalizadas que se reproduzem e expandem rapidamente numa área considerável sem a intervenção direta do Homem, desalojando espécies nativas e produzindo alterações significativas nos ecossistemas. Estas espécies estão identificadas no Decreto-Lei n.º 92/2019 (2019), atualmente em vigor. Exemplos: *Robinia pseudoacacia* (Robínia), *Cortaderia selloana* (Erva-das-Pampas), *Tradescantia fluminensis* (Erva-da-Fortuna).

Several factors may contribute to the success of non-native populations at the expense of native populations, such as habitat loss and land-use transformation (Kowarik, 2011) or the occurrence of climatic disturbances (Archer & Predick, 2008; Starzomski, 2013). Thus, it is uncertain whether invasive species cause the reduction of species diversity or if the sites with low species diversity are more easily invaded (Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009). In this sense, some authors have considered these species passengers rather than drivers of change, i.e., seen as a consequence rather than primarily responsible for changes in an ecosystem (MacDougall & Turkington, 2005; Vecchio, Pizzo, & Buffa, 2015; Ward, Pregitzer, Kuebbing, & Bradford, 2020; Wilson & Pinno, 2013).

Species that can adapt and thrive in new conditions generally have a core set of traits that enable them to take advantage of anthropogenic resources and extensively use the novel habitats. These characteristics include, for example, broad physiological tolerances, fast and short regeneration cycles, high resource acquisition, rapid reproduction and growth, and high survival rates (Knapp et al., 2012; Lugo, Winchell, & Carlo, 2018). The combination of these traits determines the ecological strategy of species (Grime, 1979; Box 1.2).

Vários fatores podem contribuir para o sucesso de populações exóticas em detrimento das populações nativas, como a perda de habitat e transformação do uso do solo (Kowarik, 2011) ou a ocorrência de perturbações climáticas (Archer & Predick, 2008; Starzomski, 2013). Desta forma, não é certo se as espécies invasoras causam a redução de diversidade de espécies ou se os locais com pouca diversidade de espécies são mais facilmente invadidos (Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009). Neste sentido, estas espécies são consideradas por alguns autores como *passengers* ao invés de *drivers* da mudança, ou seja, vistas como uma consequência e não como as principais responsáveis pelas alterações de um ecossistema (MacDougall & Turkington, 2005; Vecchio, Pizzo, & Buffa, 2015; Ward, Pregitzer, Kuebbing, & Bradford, 2020; Wilson & Pinno, 2013).

As espécies que conseguem adaptar-se e prosperar em novas condições têm, geralmente, características que lhes possibilitam tirar partido dos recursos antropogénicos e utilizar de forma extensiva os habitats. Estas características incluem, por exemplo, amplas tolerâncias fisiológicas, ciclos de regeneração rápidos e curtos, elevada aquisição de recursos, reprodução e crescimento rápidos, assim como altas taxas de sobrevivência (Knapp et al., 2012; Lugo, Winchell, & Carlo, 2018). A combinação destas características determina a estratégia ecológica das espécies (Grime, 1979; Caixa 1.2).

Box 1.2.

The ecological strategy or CSR model (Figure 1.2) proposed by Grime (1979) classifies plants in three functional types based the combination of traits they present (Knapp et al., 2012; Lugo et al., 2018; Schmidtlein, Feilhauer, & Bruelheide, 2012), namely according to their competitive ability (C), adaptation to severe stress (S), and adaptation to disturbances (R):

- **Competitors (C)** – fast-growing species that maximize their resources acquisition. Most of their energy is allocated to competition;
- **Stress-tolerators (S)** – slow-growing species with morphological and/or physiological adaptations to stress conditions. Most of their energy is allocated to maintenance of metabolic performance;
- **Ruderals (R)** – opportunistic and fast-growing species with short regeneration cycles that thrive in disturbed habitats and in early succession stages. Most of their energy and resources are allocated to dispersal and reproduction.

Caixa 1.2.

A estratégia ecológica ou modelo CSR (Figura 1.2) proposto por Grime (1979) classifica as plantas em três tipos funcionais com base na combinação de características que apresentam (Knapp et al., 2012; Lugo et al., 2018; Schmidtlein, Feilhauer, & Bruelheide, 2012), nomeadamente de acordo com a sua capacidade competitiva (C), adaptação a stress severo (S), e adaptação a perturbações (R):

- **Competidores (C)** – espécies de crescimento rápido que maximizam a aquisição de recursos. A maior parte da sua energia é alocada na competição;
- **Tolerantes ao stress (S)** – espécies de crescimento lento com adaptações morfológicas e/ou fisiológicas a condições de stress. A maior parte da sua energia é alocada à manutenção do desempenho metabólico;
- **Ruderais (R)** – espécies oportunistas e de crescimento rápido com ciclos de regeneração curtos que prosperam em habitats perturbados e em fases iniciais de sucessão. A maior parte da sua energia e recursos são alocados à dispersão e reprodução.

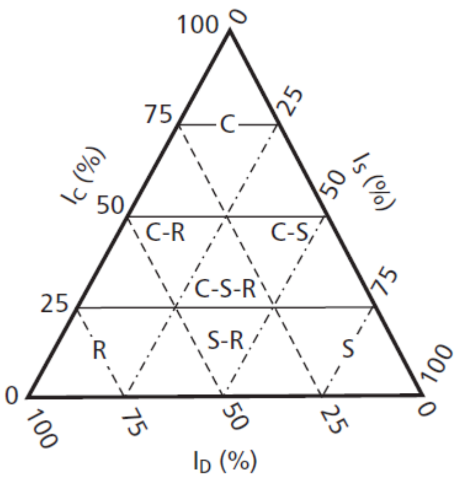

Figure 1.2. CSR triangle model demonstrating equilibrium between intensity of competition (I_C), intensity of stress (I_S), and intensity of disturbance (I_D). Image from Grime (1979).

Figura 1.2. Triângulo CSR demonstrando o equilíbrio entre a intensidade da competição (I_C), a intensidade do stress (I_S) e a intensidade da perturbação (I_D). Imagem retirada de Grime (1979).

Evidence suggests that many non-native species thrive in extreme conditions (drier, warmer, and highly disturbed habitats) (Knapp et al., 2012, 2008; Kowarik, 2008). Thus, new mixtures of native and non-native species that emerge after profound ecosystem transformation may be better adapted to new environmental conditions compared to previous combinations of native species only (Kowarik, 2011).

1.1.3. Novel Ecosystems

Novel Ecosystems (Figure 1.3) result from direct or indirect, deliberate or accidental changes, **human-induced** changes (changes in land-use, climate change, species movement), and present unique **species assemblages** composed of native and non-native species (Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013a; Hobbs, Higgs, & Harris, 2009; Radeloff et al., 2015; Tognetti, 2013; Truitt et al., 2015). The gain and/or loss of species results in communities with new a composition, structure, and functions, which can grant these ecosystems greater functional diversity, adaptive capacity, and resilience (Elmqvist et al., 2003; Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Light et al., 2013). During their development, Novel Ecosystems cross one or more **thresholds** (biotic, abiotic, or social), i.e., tipping points that shift the ecosystem's trajectory to an alternative state (Hallett et al., 2013; Harris et al., 2013; Hobbs, Higgs, & Hall, 2013b; Mascaro et al., 2013). This shift makes it very difficult to reverse the change and new trajectory. After crossing thresholds, it is very difficult to revert the ecosystem to the previous stage and

As evidências sugerem que muitas espécies exóticas prosperam em condições extremas (habitats mais secos, mais quentes e muito perturbados) (Knapp et al., 2012, 2008; Kowarik, 2008). Deste modo, as novas combinações de espécies nativas e exóticas (em proporções variáveis) que emergem após profunda transformação do ecossistema podem estar melhor adaptadas a novas condições ambientais em comparação com combinações anteriores compostas unicamente por espécies nativas (Kowarik, 2011).

1.1.3. Os Novos Ecossistemas

Os Novos Ecossistemas (Figura 1.3) resultam, assim, de alterações diretas ou indiretas, deliberadas ou acidentais, mas sempre motivadas por **atividades antrópicas** (mudanças no uso do solo, alterações climáticas, movimentação de espécies). Além disso, apresentam **combinações de espécies** únicas, compostas por espécies nativas e exóticas (Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013a; Hobbs, Higgs, & Harris, 2009; Radeloff et al., 2015; Tognetti, 2013; Truitt et al., 2015). O aumento e/ou perda de espécies cria comunidades com uma nova composição, estrutura e funções, o que pode conferir a estes ecossistemas maior diversidade funcional, capacidade de adaptação e resiliência (Elmqvist et al., 2003; Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Light et al., 2013). Durante o seu desenvolvimento, os Novos Ecossistemas ultrapassam um ou mais **limiares** (bióticos, abióticos ou sociais), isto é, pontos de viragem (*thresholds*) que desviam a sua trajetória para um estado alternativo (Hallett et al., 2013; Harris et al., 2013; Hobbs, Higgs, & Hall, 2013b;

trajectory. Novel Ecosystems persist and are **self-sustaining** in the new trajectory without constant and/or intentional human intervention (Higgs, 2017; Morse et al., 2014).

Mascaro et al., 2013). Após atravessarem estes limiares, é muito difícil reverter o ecossistema para o estádio e trajetória anteriores. Os Novos Ecossistemas persistem no novo estádio sem intervenção humana constante e/ou intencional, adquirindo **estabilidade** (*self-sustaining*) (Higgs, 2017; Morse et al., 2014).

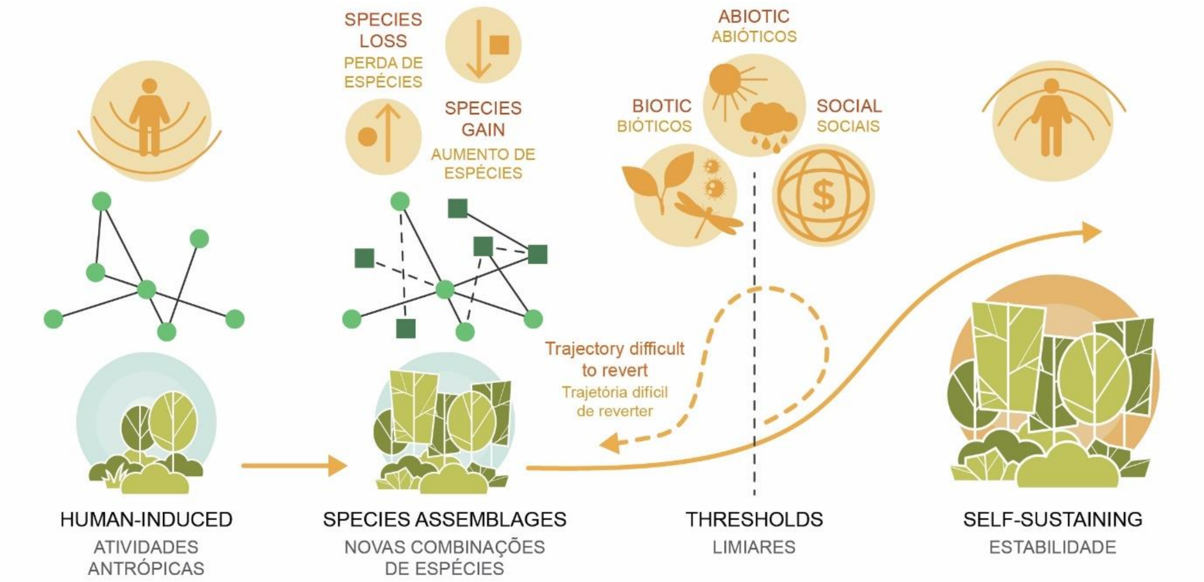

Figure 1.3. Emergence of Novel Ecosystems.

Figura 1.3. Emergência de Novos Ecossistemas.

Novel Ecosystems differ from previously known combinations of species by presenting ecological novelty, i.e., new elements or dynamics (for instance, a new species that changes the composition or structure of a community and performs a function that was not previously contemplated) (Bridgewater & Hemming, 2020; Heger et al., 2019; Hobbs et al., 2013b; Lugo et al., 2018).

Ao diferenciarem-se de combinações de espécies anteriormente conhecidas, os Novos Ecossistemas apresentam novidade ecológica, isto é, elementos ou dinâmicas novas, por exemplo, uma nova espécie que altera a composição ou a estrutura de uma comunidade e desempenha uma função que não estava antes a ser desempenhada (Bridgewater & Hemming, 2020; Heger et al., 2019; Hobbs et al., 2013b; Lugo et al., 2018).

Even though the emergence of Novel Ecosystems is not recent (Handel, 2015; Hobbs et al., 2009; Jackson, 2013; Williams & Jackson, 2007), the increasing anthropogenic

Embora a emergência de Novos Ecossistemas não seja recente (Handel, 2015; Hobbs et al., 2009; Jackson, 2013; Williams & Jackson, pressure at accelerated rates contributes to their spread across the globe (Hobbs et al., 2006; Lindenmayer et al., 2008). It is estimated that a large part of terrestrial and marine ecosystems are already, directly or indirectly, impacted by human actions (Vitousek et al., 1997) and that Novel Ecosystems currently occupy about one-third of the ice-free land surface of the planet (Ellis, 2015; Perring & Ellis, 2013).

Therefore, the Novel Ecosystems concept encompasses terrestrial (Lugo, 2009; Perfecto & Vandermeer, 2015; Sheffer, 2012) and aquatic ecosystems (Ibáñez et al., 2012; Moyle, 2014; Yakob & Mumby, 2011), plants (Fischer, Lippe, Rillig, & Kowarik, 2013; Jones, Monaco, & Rigby, 2015; Tognetti & Chaneton, 2012) and animals (Gandy & Rehage, 2017; Gawel, Rogers, Miller, & Kerr, 2018; Harborne & Mumby, 2011). This research focuses on terrestrial ecosystems, particularly ecosystems developing in the urban context.

1.2. Novel Ecosystems in cities: Novel Urban Ecosystems

Most of the world's population is concentrated in cities, so it is also in urban environments that human activities are mostly centralized and where anthropogenic disturbances are mostly experienced (MEA, 2005; Pincetl, 2017; Thomson & Newman, 2020). Climate change is particularly concerning in urban environments due to intense energy demand, waste heat, gas emissions, soil sealing, or reduction of green areas (Carter, Handley,

2007), a crescente pressão antrópica a ritmos acelerados contribui cada vez mais para a sua difusão pelo globo (Hobbs et al., 2006; Lindenmayer et al., 2008). Estima-se que grande parte dos ecossistemas terrestres e marinhos se encontre já, direta ou indiretamente, impactada pela ação humana (Vitousek et al., 1997) e que os Novos Ecossistemas ocupem atualmente cerca de um terço da superfície sem gelo do planeta (Ellis, 2015; Perring & Ellis, 2013).

O conceito de Novos Ecossistemas abrange, assim: ecossistemas terrestres (Lugo, 2009; Perfecto & Vandermeer, 2015; Sheffer, 2012) e aquáticos (Ibáñez et al., 2012; Moyle, 2014; Yakob & Mumby, 2011), plantas (Fischer, Lippe, Rillig, & Kowarik, 2013; Jones, Monaco, & Rigby, 2015; Tognetti & Chaneton, 2012) e animais (Gandy & Rehage, 2017; Gawel, Rogers, Miller, & Kerr, 2018; Harborne & Mumby, 2011). Esta investigação debruça-se sobre ecossistemas terrestres, particularmente os que se desenvolvem em contexto urbano.

1.2. Os Novos Ecossistemas nas cidades: Novos Ecossistemas Urbanos

A maior parte da população mundial concentra-se nas cidades, pelo que é também nos ambientes urbanos que as atividades humanas estão maioritariamente centralizadas e onde os efeitos das perturbações antropogénicas são particularmente sentidos (MEA, 2005; Pincetl, 2017; Thomson & Newman, 2020). As alterações climáticas são particularmente preocupantes nas cidades por causa de uma intensa utilização de energia, Butlin, & Gill, 2017; Gill, Handley, Ennos, & Pauleit, 2007; Grimm et al., 2008; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010; Wilby, 2007). On the other hand, cities are also privileged foci for the introduction and dispersal of plant species originating from other biogeographic contexts (Gaertner et al., 2017; Kowarik, 2011; van Kleunen et al., 2018), despite the challenging conditions urban areas offer for their establishment and survival (Del Tredici, 2007, 2014; Schmidt, Poppendieck, & Jensen, 2014). As such, Novel Ecosystems are widespread in urban environments, thus acquiring the designation of Novel Urban Ecosystems (Ahern, 2016; Hobbs et al., 2014; Kowarik, 2011; Lugo, 2010; Perring & Ellis, 2013).

Novel Urban Ecosystems find a privileged matrix for their expression in the green structure of cities. The urban green structure is the spatial and interconnected structure composed of urban green spaces (public or private, formal or informal), currently recognized as indispensable for the quality of life and well-being of urban dwellers (Beer, 2015; Farinha-Marques, Alves, Fernandes, Guilherme, & Gonçalves, 2018; Madureira, Andresen, & Monteiro, 2011). The green spaces that constitute the urban green structure can be of various types, and several categorization proposals are available in the literature (Ahern, 2016; M. Aronson et al., 2017; Del Tredici, 2010; Farinha-Marques et al., 2014; Gill et al., 2007; Kowarik, 2011, 2018).

emissão de gases, impermeabilização do solo ou redução de áreas verdes (Carter, Handley, Butlin, & Gill, 2017; Gill, Handley, Ennos, & Pauleit, 2007; Grimm et al., 2008; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010; Wilby, 2007). Por outro lado, as cidades são também focos privilegiados de introdução e dispersão de espécies de plantas originárias de outros contextos biogeográficos (Gaertner et al., 2017; Kowarik, 2011; van Kleunen et al., 2018), apesar das condições desafiantes que oferecem para a sua instalação e sobrevivência (Del Tredici, 2007, 2014; Schmidt, Poppendieck, & Jensen, 2014). Como tal, é nas cidades que os Novos Ecossistemas se encontram especialmente difundidos, adquirindo assim a denominação de Novos Ecossistemas Urbanos (Ahern, 2016; Hobbs et al., 2014; Kowarik, 2011; Lugo, 2010; Perring & Ellis, 2013).

Os Novos Ecossistemas Urbanos encontram na estrutura verde das cidades uma matriz privilegiada para a sua expressão. A estrutura verde urbana constitui a estrutura espacial e interligada de espaços verdes urbanos (públicos ou privados, formais ou informais), atualmente reconhecida como indispensável para a qualidade de vida e saúde das populações (Beer, 2015; Farinha-Marques, Alves, Fernandes, Guilherme, & Gonçalves, 2018; Madureira, Andresen, & Monteiro, 2011). Os espaços verdes que compõem a estrutura verde urbana podem ser de vários tipos, pelo que na literatura têm surgido várias propostas de categorização (Ahern, 2016; Aronson et al., 2017; Del Tredici, 2010; Farinha-Marques et al., 2014; Gill et al., 2007; Kowarik, 2011, 2018).

Although, theoretically, Novel Urban Ecosystems are more often associated with certain types of urban green spaces (e.g., vacant lands, wastelands, or post-industrial lands) (Del Tredici, 2010; Kowarik, 2011, 2019; Kowarik & von der Lippe, 2018), all types of urban green spaces can exhibit ecological novelty with varying degrees (Radeloff et al., 2015; Schittko et al., 2020), since they all exhibit distinct levels and rates of transformation, and are constantly subject to deliberate or accidental human actions (Kowarik, 2018).

Kowarik (1991, 2005, 2011, 2018) has proposed a long reflection on these matters through the "Four Natures approach". This approach synthesizes, in four main types, the whole diversity of Nature forms manifested within the impact area of cities, considering the inverse relationship between proximity to natural conditions and ecological novelty (Figure 1.4; Box 1.3).

The "Four Natures approach" later evolved, adopting designations close to the "Historic-Hybrid-Novel" framework proposed by Hobbs, Higgs, & Harris (2009), with slight differences in terminology: "Natural-Hybrid-Novel" (Kowarik & von der Lippe, 2018). The classifications used by Del Tredici (2010) and Ahern (2016) relate directly to the "Four Natures approach," although in these cases, there is no equivalent for "Nature 2" (Box 1.4).

Apesar de, teoricamente, os Novos Ecossistemas Urbanos estarem mais associados a certos tipos de espaços verdes (por exemplo, espaços verdes expectantes, terrenos baldios ou terrenos pós-industriais) (Del Tredici, 2010; Kowarik, 2011, 2019; Kowarik & von der Lippe, 2018), todos os tipos de espaços verdes urbanos podem exibir novidade ecológica urbana em diferentes graus (Radeloff et al., 2015; Schittko et al., 2020), na medida em que todos apresentam distintos níveis e ritmos de transformação, e estão constantemente sujeitos a uma ação humana deliberada ou acidental (Kowarik, 2018).

Kowarik (1991, 2005, 2011, 2018) tem vindo a propor uma longa reflexão sobre estas matérias através da "abordagem das Quatro Naturezas". Esta abordagem sintetiza em quatro grupos principais a diversidade de tipos de espaços verdes existentes nas cidades, considerando, para isso, a relação inversa entre a proximidade a condições naturais e a novidade ecológica (Figura 1.4; Caixa 1.3).

A “abordagem das Quatro Naturezas” evoluiu, adotando designações mais próximas do enquadramento “Histórico-Hibrido-Novo” proposto por Hobbs, Higgs, & Harris (2009), com ligeiras diferenças terminológicas: “Natural-Híbrido-Novo” (Kowarik & von der Lippe, 2018). As classificações utilizadas por Del Tredici (2010) e Ahern (2016) relacionam-se diretamente com a “abordagem das Quatro Naturezas”, ainda que nestes casos não seja proposto um equivalente para a “Natureza 2” (Caixa 1.4).

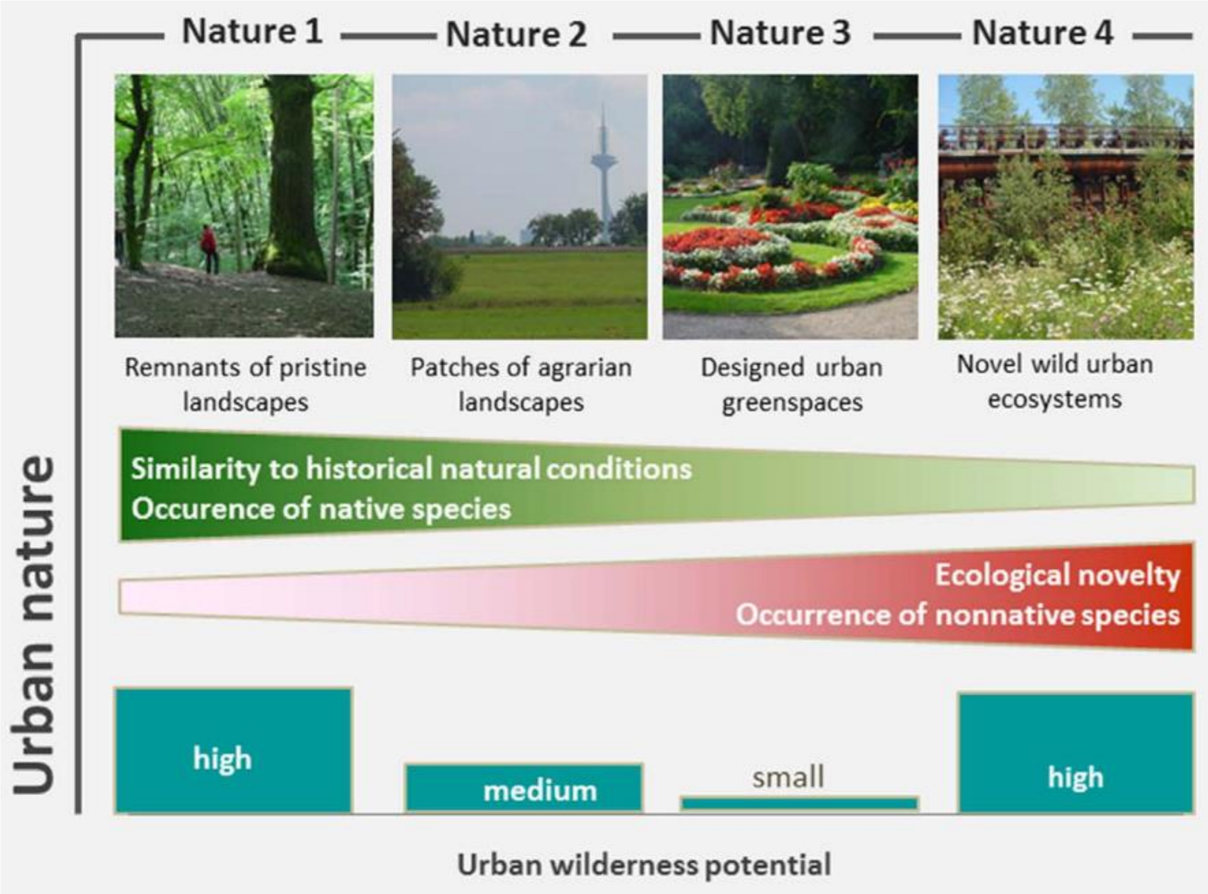

Figure 1.4. "Four Natures approach" in which the different types of urban green spaces are distinguished into four natures: Nature 1 (forests and wetlands); Nature 2 (meadows and pastures, cultivated fields, or intensively managed forests); Nature 3 (parks and gardens); Nature 4 (vacant lots, wastelands, industrial sites, and transport corridors). Image from Kowarik (2018).

Figura 1.4. "Abordagem das quatro Naturezas" em que os diferentes tipos de espaços verdes são distinguidos em quatro naturezas: Natureza 1 (florestas e zonas húmidas); Natureza 2 (prados e pastagens, campos de cultivo ou florestas geridas intensivamente); Natureza 3 (parques e jardins); e Natureza 4 (espaços verdes expectantes, terrenos baldios, zonas industriais abandonadas e corredores de transporte). Imagem retirada de Kowarik (2018).

Box 1.3.

- **Nature 1** – Remnants of pristine ecosystems (“original” Nature) or areas that, despite having already undergone some changes due to human impacts, still have a strong relationship with pristine ecosystems. Examples: forests and wetlands.
- **Nature 2** – Spaces that have emerged through traditional or modern agricultural and forestry practices. Examples: meadows and pastures, cultivated fields, or intensively managed forests.
- **Nature 3** – Designed spaces where vegetation is planted and maintained according to an initial intention. Examples: parks and gardens.

Nature 4 – Places where natural development occurs without planning or design following human-induced changes (**Novel Urban Ecosystems**). Examples: vacant lots, wastelands, industrial sites, and transport corridors.

Caixa 1.3.

- **Natureza 1** – Restos de ecossistemas pristinos (natureza “original”) ou áreas que, apesar de terem sofrido já algumas alterações devido a impactos humanos, têm ainda uma forte relação com ecossistemas pristinos. Exemplos: florestas e zonas húmidas.
- **Natureza 2** – Espaços que surgiram através de práticas agrícolas e florestais tradicionais ou modernas. Exemplos: prados e pastagens, campos de cultivo ou florestas geridas intensivamente.
- **Natureza 3** – Espaços desenhados, onde a vegetação é plantada e mantida de acordo com uma intenção inicial. Exemplos: parques e jardins.
- **Natureza 4** – Locais onde o desenvolvimento natural ocorre sem planeamento ou desenho intencional após alterações despoletadas por ação humana (**Novos Ecossistemas Urbanos**). Exemplos: espaços verdes expectantes, terrenos baldios, zonas industriais abandonadas e corredores de transporte.

Box 1.4
Caixa 1.4

Definition Definição	Terminologies Terminologias	
	Del Tredici (2010)	Ahern (2016)
Slightly disturbed habitats with mostly native vegetation, some associated invasive species, slightly disturbed native soils, and low to moderate management requirements (woodlands, wetlands or coastal areas, riparian corridors). Habitats pouco perturbados com vegetação maioritariamente nativa, algumas espécies invasoras associadas, solos nativos pouco perturbados e requerimentos de manutenção baixos a moderados (matas, zonas húmidas ou costeiras, galerias ripícolas).	**Remnant Native Landscapes** **Resquícios de Paisagens Nativas**	**Remnant / Restored Native** **Nativo Restante / Restaurado**
Spaces intentionally created and managed for human use, with cultivated vegetation, manipulated and rich soils, and moderate to high management requirements (public parks and gardens, residential or private gardens, spaces associated with equipment, cemeteries). Espaços intencionalmente criados e geridos para uso humano, com vegetação cultivada, solos manipulados e enriquecidos e requerimentos de manutenção moderados a altos (parques e jardins públicos, jardins residenciais ou privados, espaços associados a equipamentos, cemitérios).	**Managed Horticultural Landscapes** **Paisagens Hortícolas Ornamentais Geridas**	**Horticultural / Formal** **Hortícola Ornamental / Formal**
Abandoned spaces or spaces with poorly defined use and design, dynamic and spontaneous vegetation (native and non-native), disturbed and compacted soils with traces of previous uses and low to non-existent management requirements (vacant land, wasteland, post-industrial land, derelict land, abandoned parks and gardens). Espaços abandonados ou com um uso e desenho pouco definidos, vegetação dinâmica e espontânea (nativa e exótica), solos perturbados, compactados e com vestígios de usos anteriores e requerimentos de manutenção baixos a inexistentes (espaços verdes expectantes, terrenos baldios, terrenos pós-industriais, terrenos degradados, parques e jardins abandonados).	**Abandoned Ruderal Landscapes** **Paisagens Ruderais Abandonadas**	**Abandoned / Ruderal** **Abandonado / Ruderal**

In this context, it is also important to refer to the concept of “third landscape” proposed by Gilles Clément (2004) in his book “Manifest of the Third Landscape”. Clément’s third landscape

Neste contexto, importa também referir o conceito de “terceira paisagem”, proposto por Gilles Clément (2004) no seu livro “Manifesto da Terceira Paisagem”. A terceira paisagem de refers to abandoned, marginal, unused, transitional, or inaccessible spaces or fragments (wastelands, marshes, roadsides, or railroad embankments) that can be refuges for a large biological diversity that cannot find shelter elsewhere. Thus, the third landscape concept can find parallelism with the NUE concept, as already highlighted by some authors (Bakshi & Gallagher, 2020; Grose, 2014; Kowarik, 2021).

Figure 1.5 synthesizes how the main types of urban green spaces have been theoretically related to the NUE concept in the scientific literature.

The presence of green spaces in the urban matrix in diversity (genesis, history, age, species composition and structure, functionality) and with different degrees of ecological novelty allows the urban green structure to be more resilient and multifunctional (Buijs et al., 2019; Carter, 2018; Carter et al., 2017; EEA, 2016; Hansen, Olafsson, van der Jagt, Rall, & Pauleit, 2019; Klaus & Kiehl, 2021; Pauleit et al., 2019; Zölch et al., 2016). Even though there are urban green spaces with greater degrees of human influence, it is essential to value all manifestations of nature beyond the "original" nature (Nature 1), which is less influenced by human activities and generally perceived as the most "correct" nature (Kowarik, 2005).

Clément refere-se aos espaços ou fragmentos abandonados, marginais, sem exploração humana, de transição ou inacessíveis (terrenos baldios, pântanos, bermas de estradas ou taludes de ferrovias) e que, por isso, podem constituir refúgios para uma grande diversidade biológica que não encontra acolhimento noutro lugar. Desta forma, também no conceito de terceira paisagem se pode encontrar um paralelismo com o conceito de Novos Ecossistemas Urbanos, o que, recentemente, tem sido notado por alguns autores (Bakshi & Gallagher, 2020; Grose, 2014; Kowarik, 2021).

A Figura 1.5 sintetiza de que forma as principais categorias de espaços verdes urbanos têm sido teoricamente relacionados com o conceito de Novos Ecossistemas Urbanos na literatura científica.

A presença de espaços verdes na matriz urbana em diversidade (génese, história, idade, composição e estrutura das espécies, funcionalidade) e com diferentes graus de novidade ecológica urbana permite que a estrutura verde das cidades seja mais resiliente e multifuncional (Buijs et al., 2019; Carter, 2018; Carter et al., 2017; EEA, 2016; Hansen, Olafsson, van der Jagt, Rall, & Pauleit, 2019; Klaus & Kiehl, 2021; Pauleit et al., 2019; Zölch et al., 2016). Embora alguns espaços verdes urbanos apresentem maiores graus de influência humana, é essencial valorizar todas as manifestações de natureza além da natureza “original”, menos influenciada pelo Homem e que, geralmente, é percecionada como a natureza mais “correta” (Kowarik, 2005).

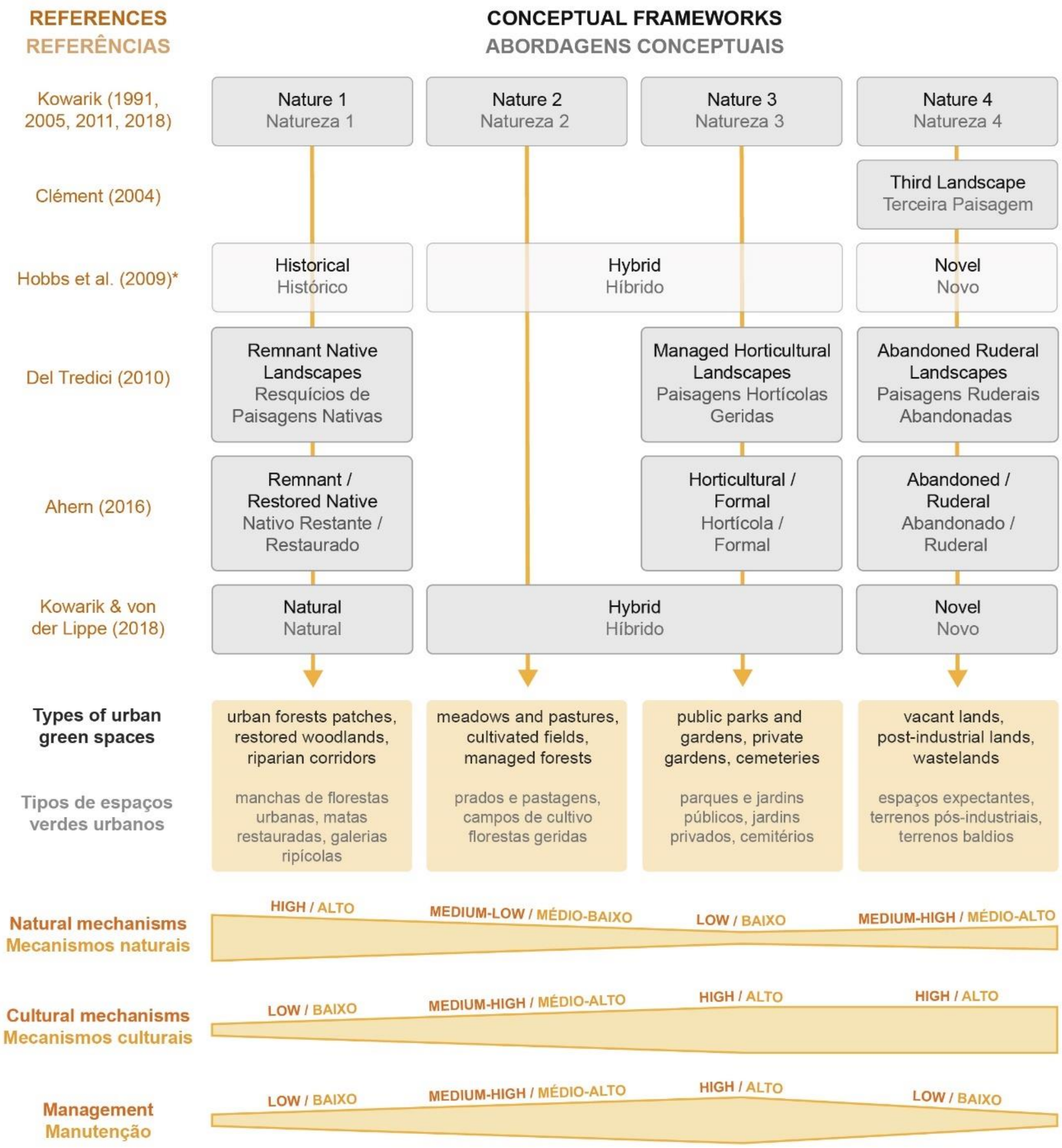

Figure 1.5. Relationship of conceptual frameworks in the literature and main categories of urban green spaces with the concept of Novel Urban Ecosystems. Each urban green space category is usually influenced, with different degrees, by natural mechanisms (e.g., ecological succession, soil formation, plant population dynamics) and cultural mechanisms (e.g., initial plantings, human uses and activities, traces of anthropogenic materials, introduced species), and subjected to distinct management levels. * *Conceptual framework by Hobbs et al. (2009) does not refer to the urban context.*

Figura 1.5. Relação dos enquadramentos conceptuais da literatura e principais categorias de espaços verdes urbanos com o conceito de Novos Ecossistemas Urbanos. Cada categoria de espaço verde urbano é geralmente influenciada, em diferentes graus, por mecanismos naturais (por exemplo, sucessão ecológica, formação do solo, dinâmica das populações vegetais) e mecanismos culturais (por exemplo, plantações iniciais, usos e atividades humanas, vestígios de materiais antropogénicos, espécies introduzidas), e sujeita a diferentes níveis de gestão. * *Proposta de Hobbs et al. (2009) não se refere ao contexto urbano.*

1.3. Problem, motivation, and objectives

As highlighted previously, Novel Urban Ecosystems emerge in response to anthropogenic disturbances, acquiring the ability to perform original ecological functions and thrive in extreme environments. These characteristics suggest that Novel Urban Ecosystems may also be better adapted to scenarios of environmental change, such as those predicted for climate (Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Kowarik, 2011; Light et al., 2013; Standish, Hobbs, & Miller, 2013; Starzomski, 2013).

Given the adaptive potential of Novel Urban Ecosystems, studying ecological novelty in urban green spaces can offer new clues regarding how these spaces can be designed, planned, and managed, taking advantage of the benefits that novel combinations of species can offer. The integration of these ecosystems into the urban green structure may determine their strength and resilience to respond to disturbances and minimize environmental problems that arise in the context of the Anthropocene (Klaus & Kiehl, 2021; Kowarik, 2018, 2019; Perring, Manning, et al., 2013; Standish, Hobbs, et al., 2013). The adaptive capacity of these ecosystems and their prevalence in the urban green structure make the concept of Novel Urban Ecosystems particularly relevant to Landscape Architecture practice (Ahern, 2016; Dooling, 2015; Kowarik, 2021; Sack, 2013).

1.3. Problemática, motivação e objetivos

Como salientado anteriormente, os Novos Ecossistemas Urbanos surgem em resposta a perturbações antrópicas, adquirindo competências para desempenhar funções ecológicas originais e prosperar nessas condições. Estas características sugerem que os Novos Ecossistemas Urbanos poderão também estar melhor adaptados a cenários de alteração ambiental, como, por exemplo, os previstos para o clima (Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Kowarik, 2011; Light et al., 2013; Standish, Hobbs, & Miller, 2013; Starzomski, 2013).

Tendo em conta o potencial adaptativo dos Novos Ecossistemas Urbanos, o estudo da novidade ecológica presente nos espaços verdes urbanos pode oferecer novas pistas em relação à forma como estes espaços podem ser desenhados, planeados e geridos, tirando partido das vantagens oferecidas pelas novas combinações de espécies que os constituem. A integração destes ecossistemas na estrutura verde urbana pode determinar a sua robustez e resiliência para responder a perturbações e minimizar os problemas ambientais que surgem no contexto do Antropocénico (Klaus & Kiehl, 2021; Kowarik, 2018, 2019; Perring, Manning, et al., 2013; Standish, Hobbs, et al., 2013). A capacidade de adaptação destes ecossistemas e a sua prevalência na estrutura verde urbana fazem com que o conceito de Novos Ecossistemas Urbanos seja particularmente relevante para as áreas de atuação da Arquitetura Paisagista (Ahern, 2016; Dooling, 2015; Kowarik, 2021; Sack, 2013).

Despite these attributes, the presence of non-native species in novel species assemblages, some invasive or with ecological risk (casual or naturalized), introduces in the concept its most controversial dimension (Davis et al., 2011; Pearce, 2015; Standish, Thompson, Higgs, & Murphy, 2013). Concern about invasive species has led groups of researchers to assume early on that all non-native species pose threats and are "guilty until proven innocent" (nativism paradigm), even when they have existed in cities for extended periods (Davis, 2018; Gaertner et al., 2017; Gbedomon et al., 2020; Guiaşu & Tindale, 2018; Kueffer, 2013).

Other concerns are also frequently mentioned, such as the absence of a stabilized, universal and consensual definition (Bridgewater & Hemming, 2020; Heger et al., 2020; Murcia et al., 2014; Simberloff, 2015), or even the practical usefulness of the concept that, for many authors, still lacks demonstration (J. Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016). Similarly, practical tools are still needed to identify Novel Urban Ecosystems or measure ecological novelty in urban green spaces (Harris et al., 2013; Morse et al., 2014; Tognetti, 2013; Trueman, Standish, & Hobbs, 2014).

Societal expectations (interests, values, memories, needs) can also clash with the expression Novel Urban Ecosystems may assume in the urban matrix, since these ecosystems may arise unintentionally and comprise spontaneous vegetation (Kowarik,

Apesar destes atributos, a presença de espécies exóticas nas novas combinações de espécies, algumas invasoras ou com risco ecológico (casuais ou naturalizadas), introduz no conceito de Novos Ecossistemas Urbanos a sua dimensão mais controversa (Davis et al., 2011; Pearce, 2015; Standish, Thompson, Higgs, & Murphy, 2013). A preocupação com espécies invasoras tem levado grupos de investigadores a assumir desde logo que todas as espécies exóticas representam ameaças (paradigma do nativismo), mesmo quando existem nas cidades há longos períodos (Davis, 2018; Gaertner et al., 2017; Gbedomon et al., 2020; Guiaşu & Tindale, 2018; Kueffer, 2013).

Outras preocupações são também frequentemente referidas, como a ausência de uma definição estabilizada, universal e consensual (Bridgewater & Hemming, 2020; Heger et al., 2020; Murcia et al., 2014; Simberloff, 2015), ou mesmo a utilidade prática do conceito que, para muitos autores, ainda carece de demonstração (J. Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016). Da mesma forma, são ainda necessárias ferramentas expeditas para identificar Novos Ecossistemas Urbanos ou para medir a novidade ecológica nos espaços verdes urbanos (Harris et al., 2013; Morse et al., 2014; Tognetti, 2013; Trueman, Standish, & Hobbs, 2014).

As expectativas da sociedade (interesses, valores, memórias, necessidades) podem igualmente colidir com a expressão que os Novos Ecossistemas Urbanos podem assumir na matriz urbana, uma vez que estes ecossistemas podem surgir de forma não

2018; Nassauer, 1995; Perring, Standish, & Hobbs, 2013). The acceptance, application, and integration of the concept of Novel Urban Ecosystems in cities may thus challenge the way urban green spaces are traditionally perceived and intervened (Bakshi & Gallagher, 2020; Kowarik, 2019, 2021).

The adaptive potential of Novel Urban Ecosystems and the numerous opportunities and challenges that remain unexplored regarding this concept were the main reasons that motivated this research. However, in order for the Novel Urban Ecosystems concept to be useful in the field of Landscape Architecture, it will be necessary to address the identified problems.

This thesis aims to contribute with practical tools, based on scientific evidence, to enable interventions in the urban green structure at various scales: from the planning and management (general) to the design and management of urban green spaces (particular). It also intends to raise awareness of professionals with responsibility in public green space (landscape architects, urban planners, decision-makers, among others) regarding Novel Urban Ecosystems.

Thus, the following objectives were identified:

- To contribute to the clarification and stabilization of the Novel Urban Ecosystems concept, reflecting on its usefulness and relevance within the scope of Landscape Architecture;
- To develop a tool to evaluate ecological novelty in urban green spaces, in order to contribute to the integration of this concept in

intencional e conter vegetação espontânea (Kowarik, 2018; Nassauer, 1995; Perring, Standish, & Hobbs, 2013). A aceitação, a aplicação e a integração do conceito de Novos Ecossistemas Urbanos nas cidades pode, deste modo, desafiar a forma como os espaços verdes urbanos são tradicionalmente percecionados e intervencionados (Bakshi & Gallagher, 2020; Kowarik, 2019, 2021).

O potencial adaptativo dos Novos Ecossistemas Urbanos, assim como as inúmeras oportunidades e desafios que se encontram ainda por explorar relativos a este conceito foram as principais razões que motivaram esta investigação. Contudo, para que o conceito de Novos Ecossistemas Urbanos possa ser útil nas áreas de atuação da Arquitetura Paisagista, será necessário abordar as problemáticas identificadas.

Pretende-se com esta tese contribuir com ferramentas práticas, baseadas em evidências científicas, que possibilitem intervenções na estrutura verde urbana a várias escalas: desde o planeamento e gestão (geral) até ao desenho e manutenção dos espaços verdes urbanos (particular). Além disso, deseja-se contribuir para a sensibilização e consciencialização dos profissionais com responsabilidade no espaço verde público (arquitetos paisagistas, urbanistas, decisores, entre outros) relativamente a Novos Ecossistemas Urbanos.

Deste modo, identificaram-se os seguintes objetivos:

- Contribuir para o esclarecimento e estabilização do conceito de Novos Ecossistemas the planning and management of the urban green structure;

- To understand how Novel Urban Ecosystems can inspire planting design and management proposals that promote adaptation and mitigation of climate change effects in urban green spaces;
- To build a database of plant species indicating the main attributes for ornamental quality and adaptive and mitigating capacities regarding the effects of climate change;
- To evaluate the attitudes and preferences of professionals involved in designing, planning, and managing green spaces regarding Novel Urban Ecosystems.

This research used the city of Porto as study area and its green structure as matrix and information support. In this way, it becomes pertinent to make a brief description and contextualization of the city, presenting also a synthesis of Porto's green structure nowadays and the categories of urban green spaces selected in the scope of this work.

Urbanos, refletindo na sua utilidade e relevância no âmbito da Arquitetura Paisagista;

- Desenvolver uma ferramenta para avaliar novidade ecológica em espaços verdes urbanos, de forma a contribuir para a integração deste conceito no planeamento e na gestão da estrutura verde urbana;
- Compreender de que forma os Novos Ecossistemas Urbanos podem inspirar propostas de plantação e estratégias de manutenção de espaços verdes urbanos, capazes de se adaptarem aos efeitos das alterações climáticas e/ou permitindo a sua mitigação.
- Construir uma base de dados de espécies de plantas indicando os principais atributos que lhes conferem qualidade ornamental, assim como capacidades adaptativas e mitigadoras em relação aos efeitos das alterações climáticas;
- Avaliar atitudes e preferências de profissionais envolvidos no desenho, planeamento e manutenção de espaços verdes em relação a Novos Ecossistemas Urbanos.

Esta investigação utilizou a cidade do Porto como área de estudo e a sua estrutura verde como matriz e suporte de informação. Desta forma, torna-se pertinente fazer uma breve descrição e contextualização da cidade, apresentando também uma síntese da estrutura verde do Porto na atualidade e as categorias de espaços verdes urbanos selecionados no âmbito deste trabalho.

1.4. Porto's urban green structure as a matrix for studying Novel Urban Ecosystems

1.4.1. Brief contextualization of the city of Porto

The city of Porto is located in the northwest of Portugal, southwest of Europe. It is geographically framed by the Douro River at the south and the Atlantic Ocean at the west (Figure 1.6). The proximity to the Atlantic Ocean ameliorates the climates' Mediterranean characteristics, with warm and rainy winters and dry and mild summers. The average annual temperature is 14.7°C (ranging from 5.0 to 16.8°C in winter and 14.1 to 25.0°C in summer), and the average annual precipitation is 1254 mm, occurring mainly during autumn and winter (IPMA, 2021).

1.4. A estrutura verde do Porto como matriz de estudo de Novos Ecossistemas Urbanos

1.4.1. Breve contextualização da cidade do Porto

A cidade do Porto localiza-se no Noroeste de Portugal, no Sudoeste da Europa, e está limitada a Sul pelo Rio Douro e a Oeste pelo Oceano Atlântico (Figura 1.6). Esta proximidade com o Oceano Atlântico ameniza as características mediterrânicas do clima, com invernos frescos e chuvosos e verões secos e temperados. A temperatura média anual é de 14.7°C (variando de 5.0 até 16.8°C no inverno e 14.1 até 25.0°C no verão) e a precipitação média anual é de 1254 mm, ocorrendo sobretudo durante o outono e inverno (IPMA, 2021).

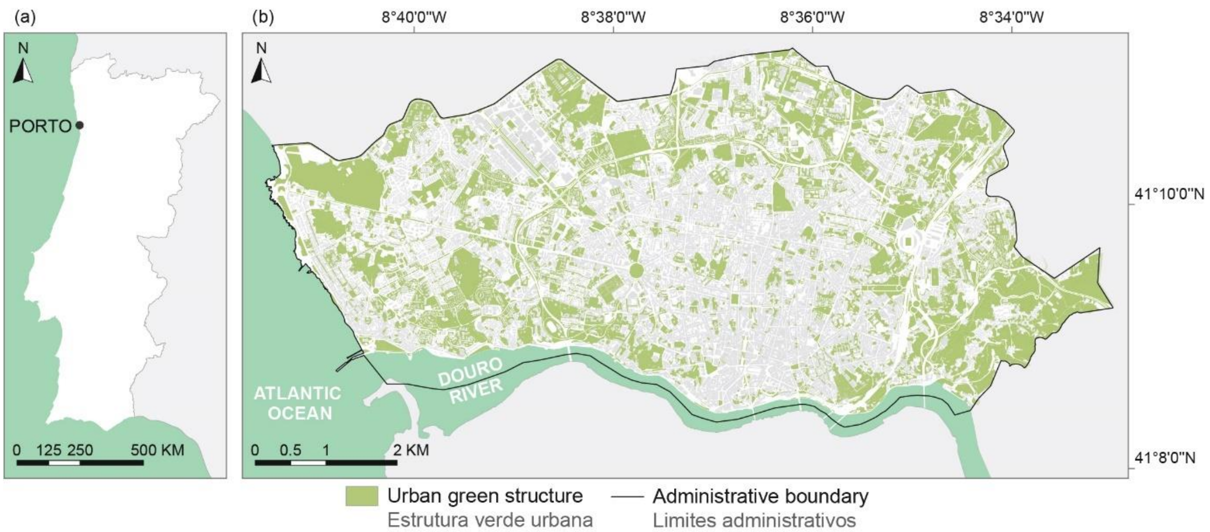

Figure 1.6. (a) Geographical location of the city of Porto in Portugal; (b) Porto's green structure.

Figura 1.6. (a) Localização geográfica da cidade do Porto em Portugal; (b) Estrutura verde da cidade do Porto.

The city of Porto is one of the oldest population and economic centers in Europe (CMP, 2016). With an area of approximately 41 km^2, it is the center of the second-largest metropolitan area in the country (Porto's Metropolitan Area), composed of 17 contiguous municipalities in an area of approximately 2040 km^2 and with about 1.7 million inhabitants (CMP, 2021).

Although the decentralization of the residential function to the metropolitan area has decreased the resident population in Porto since the 1980s, the population that uses the city during the day is high (Faria, Oliveira, Rocha, Lage, & Gomes, 2018). This phenomenon is largely due to the fact that Porto is one of the main economic forces of the Northern region and its central employment hub. The economic activity focuses mainly on the tertiary sector and the tourism sector in recent years (CMP, 2016).

The city's harbor past and its long history of world trade have enhanced the importation of non-native plants. In addition, there is a strong tradition of knowledge in horticulture and botany in Porto. Before implementing the education of Landscape Architecture in Portugal by Francisco Caldeira Cabral (1942), the city of Porto had already seen a significant development of the art of gardens. From the second half of the 19th century, there were already horticultural establishments dedicated to the commercialization of plants and the design and construction of gardens. That was the case of José Marques Loureiro's horticultural

O Porto é um dos mais antigos centros populacionais e económicos da Europa (CMP, 2016). Com uma área aproximada de 41 km^2, constitui o centro da segunda maior área metropolitana do país (Área Metropolitana do Porto), composta por 17 concelhos contíguos numa área aproximada de 2040 km^2 e com cerca 1.7 milhões de habitantes (CMP, 2021). Apesar da descentralização da função residencial para a área metropolitana ter vindo a resultar no decréscimo da população residente no Porto desde a década de 80, a população que efetivamente utiliza a cidade durante o dia é bastante elevada (Faria, Oliveira, Rocha, Lage, & Gomes, 2018). Isso deve-se muito ao facto de a cidade do Porto ser uma das principais forças económicas da região Norte e, por isso, o seu principal polo de emprego, centrando a sua atividade maioritariamente no setor terciário e, em anos mais recentes, no setor do turismo (CMP, 2016).

O passado portuário da cidade e a sua longa história de comércio mundial fomentaram a importação de plantas exóticas. Além disso, na cidade do Porto existe uma forte tradição de conhecimento da horticultura e botânica. Antes da implementação do ensino em Arquitetura Paisagista em Portugal por Francisco Caldeira Cabral (1942), já o Porto tinha assistido a um significativo desenvolvimento da arte dos jardins. A partir da segunda metade do século XIX, começaram a surgir estabelecimentos hortícolas que se dedicavam à comercialização de plantas e ao projeto e construção de jardins, como foi o caso do estabelecimento de horticultura de José Marques Loureiro, e outros que se seguiram (Marques, 2009).

establishment and others that followed (Marques, 2009).

The biogeographical, social, and historical contexts of the city of Porto offer unique conditions for the occurrence of native and non-native plant species, thus presenting ideal characteristics to support the development of this research project. This choice was also based on the possibility of taking advantage of a vast work of reflection, characterization, and mapping of the green structure of the city of Porto constructed in recent years (Farinha-Marques et al., 2018, 2015, 2014).

1.4.2. Porto's green structure: Evolution and current state

Porto's urban fabric results from a long process of development influenced by several urbanistic lines of thinking and by the biophysical characteristics of the territory (Carvalho, Bento, Costa, & Santos, 2018). Due to considerable economic and demographic growth in recent decades, the city of Porto has experienced a rapid process of urbanization to the point that it is even considered one of the fastest compared to other European cities (Climate-ADAPT, 2021). This accelerated urbanization process resulted in an increase in greenhouse gas emissions and drastic changes in land use, more specifically in a significant reduction of the city's green infrastructure (Monteiro & Madureira, 2009; Rafael et al., 2017, 2016).

At the end of the 19th century, Porto's green infrastructure occupied about 75% of its area

Desta forma, os contextos biogeográfico, social e histórico da cidade do Porto oferecem condições únicas para a ocorrência de espécies de plantas nativas e exóticas, apresentando, por isso, características ideais para apoiar o desenvolvimento deste projeto de investigação. Esta escolha baseou-se também na possibilidade de tirar partido de um vasto trabalho de reflexão, caracterização e mapeamento da estrutura verde da cidade do Porto, que tem vindo a ser construído nos últimos anos (Farinha-Marques et al., 2018, 2015, 2014).

1.4.2. Estrutura verde da cidade do Porto: Evolução e Atualidade

O tecido urbano da cidade do Porto resulta de um longo processo de desenvolvimento influenciado não só por diversas correntes de pensamento urbanístico, mas também pelas características biofísicas do território (Carvalho, Bento, Costa, & Santos, 2018). Devido a um grande crescimento económico e demográfico nas últimas décadas, a cidade do Porto experienciou um processo rápido de urbanização, considerado um dos mais rápidos quando comparado com outras cidades europeias (Climate-ADAPT, 2021). Este acelerado processo de urbanização resultou também num aumento das emissões de gases de efeito de estufa e em mudanças drásticas no uso do solo, mais concretamente numa redução significativa da estrutura verde da cidade (Monteiro & Madureira, 2009; Rafael et al., 2017, 2016).

No final do século XIX, a estrutura verde da cidade do Porto ocupava cerca de 75% da sua área, uma vez que o centro urbano, ainda since a vast rural belt surrounded the small urban center. In successive years, the city's intense urban growth caused a significant green space decrease and, in parallel, led to an intense fragmentation of the green infrastructure. Agricultural areas were drastically reduced as the city lost its rural character. Other types of urban green spaces (namely, public parks and gardens) grew and gained more prominence due to the urgent need to create green areas for leisure and contact with Nature (Madureira et al., 2011).

The reduction and fragmentation of Porto's green infrastructure over the years, combined with other factors (e.g., excessive sealing and disruption of hydrological dynamics), compromises the metabolic functioning of the city, making it vulnerable to the effects of climate change (Climate-ADAPT, 2021; Madureira et al., 2011; Monteiro & Madureira, 2009; Rafael et al., 2017, 2016).

Porto's green infrastructure currently occupies about 31.6% of its surface area. It includes a wide variety of urban green spaces types distributed throughout the urban matrix with different dimensions and purposes (Farinha-Marques et al., 2018, 2014): vacant lands (25.6%), green spaces associated with institutional buildings (16.1%), public parks and gardens (14.7%), green spaces associated with residential buildings (11.6%), agricultural fields (8.6%), urban woodlands (7.7%), private green spaces with heritage value (5.7%), green spaces associated with main roadways (5.0%), green spaces associated with streets (5.0%).

bastante reduzido, estava rodeado por um enorme cinturão rural. O intenso crescimento urbano da cidade no século XX resultou numa diminuição significativa dos seus espaços verdes e, paralelamente, conduziu a uma intensa fragmentação da estrutura verde. As áreas destinadas à agricultura foram drasticamente reduzidas à medida que a cidade perdia o caráter rural, permitindo que outras categorias de espaços verdes urbanos, nomeadamente parques e jardins públicos, crescessem e ganhassem mais destaque em consequência da urgente necessidade de criar áreas verdes de lazer e de contacto com a natureza (Madureira et al., 2011).

A redução e a fragmentação da estrutura verde, aliadas a outros fatores (por exemplo, a excessiva impermeabilização e a perturbação da dinâmica hidrológica), interferem com o funcionamento metabólico da cidade, aumentando a vulnerabilidade aos efeitos das alterações climáticas (Climate-ADAPT, 2021; Madureira et al., 2011; Monteiro & Madureira, 2009; Rafael et al., 2017, 2016).

Atualmente, a estrutura verde do Porto ocupa cerca de 31.6% da sua área superficial e inclui uma grande variedade de tipos de espaços verdes urbanos distribuídos pela matriz urbana da cidade com diferentes dimensões e finalidades (Farinha-Marques et al., 2018, 2014): espaços verdes expectantes (25.6%), espaços verdes associados a equipamentos (16.1%), parques e jardins públicos (14.7%), espaços verdes associados a urbanizações (11.6%), espaços verdes de cultivo (8.6%), matas urbanas (7.7%), espaços verdes privados com valor

In the context of this work, efforts were concentrated on three urban green spaces categories suggested by the literature about Novel Urban Ecosystems (Figure 1.5; chapter 1.2): urban woodlands, parks and gardens, and vacant lands.

1.4.3. Selected urban green spaces categories for studying Novel Urban Ecosystems

In the city of Porto, the urban green spaces categories selected for this work (urban woodlands, parks and gardens, and vacant lands) present a varied distribution and representativeness and occupy together almost half (47.4%) of the surface area of Porto's green structure (Farinha-Marques et al., 2018). These three categories are essentially distinguished based on their land-use history, the composition and structure of the plant communities, and the management regimes to which they are subjected and/or require (Ahern, 2016; Del Tredici, 2014; Kowarik, 2005, 2011).

Urban woodlands refer to green spaces without an explicit spatial organization of the green cover and with a percentage of tree cover equal to or greater than 70% (Farinha-Marques et al., 2018). This category may include spaces that are not accessible to the public and remnants of native woodlands prior to urbanization, thus associating with the concept of "Nature 1". On the other hand, it can be related to the concept of "Nature 2" (Figure 1.5, chapter 1.2) if they are remnants of productive forests (Kowarik, 2011). Without

patrimonial (5.7%), espaços verdes associados a eixos de circulação (5.0%), espaços verdes associados a ruas (5.0%). No contexto deste trabalho, os esforços concentraram-se em três categorias de espaços verdes urbanos sugeridos pela literatura relacionada com o conceito de Novos Ecossistemas Urbanos, como anteriormente referido (Figura 1.5, capítulo 1.2): matas urbanas, parques e jardins, espaços verdes expectantes.

1.4.3. Espaços verdes urbanos da cidade do Porto selecionados para o estudo de Novos Ecossistemas Urbanos

Na cidade do Porto, os tipos de espaços verdes urbanos selecionados para este trabalho (matas urbanas, parques e jardins, espaços verdes expectantes) apresentam uma distribuição e representatividade variada, e, em conjunto, ocupam quase metade (47.4%) da área da estrutura verde urbana (Farinha-Marques et al., 2018). Estas três categorias reúnem espaços verdes urbanos com características muito diferentes, distinguindo-se essencialmente pela sua história de uso do solo, pela composição e estrutura das suas comunidades de plantas e pelos regimes de manutenção (Ahern, 2016; Del Tredici, 2014; Kowarik, 2005, 2011).

As **matas urbanas** referem-se a espaços verdes sem organização espacial explícita do coberto vegetal e com uma percentagem de cobertura arbórea igual ou superior a 70% (Farinha-Marques et al., 2018), podendo incluir espaços que não são acessíveis ao público. Esta categoria pode conter remanescências de matas nativas anteriores a processos de urbanização, associando-se assim ao conceito de "Natureza 1" management focused on their preservation, these sites can be dominated by non-native species (Ahern, 2016; Del Tredici, 2014).

Urban woodlands in the city of Porto comprise 127 spaces that occupy 7.7% of the urban green structure area and are essentially distributed in the peripheral zone of the city, mainly in the east (Figure 1.7).

Public parks and gardens comprise the publicly accessible green spaces that are intentionally created and managed for direct public use. They are characterized by manufactured soils and organized vegetation planted for aesthetic, social, and recreational enhancement (Ahern, 2016; Del Tredici, 2014; Talal, Santelmann, & Tilt, 2021). Thus, they associate with the concept of "Nature 3" (Kowarik, 2011) and equivalents (Figure 1.5, chapter 1.2). They mainly present diverse and balanced assemblages of native and non-native species (Farinha-Marques et al., 2015, 2014). Occasionally non-native species dominate, especially species with distinctive ornamental characters (*Camellia japonica, Rhododendron indicum*). In the scope of this work, this category also includes landscaped squares, i.e., squares with at least 35% permeable surface also with direct public use and recreational function (Farinha-Marques et al., 2018).

ou associar-se ao conceito de "Natureza 2" (Figura 1.5, capítulo 1.2) caso se tratem de remanescências de matas de produção (Kowarik, 2011). Sem uma gestão focada na sua preservação, estes locais podem ser dominados por espécies exóticas (Ahern, 2016; Del Tredici, 2014).

Na cidade do Porto foram sinalizados 127 espaços correspondentes a matas urbanas que representam 7.7% da área da estrutura verde urbana e se distribuem essencialmente na zona periférica da cidade, principalmente a oriente (Figura 1.7).

Os **parques e jardins públicos** compreendem os espaços verdes de acesso público intencionalmente criados e geridos para uso público direto. São caracterizados pela presença de solos antrópicos e vegetação organizada e plantada para valorização estética, social e recreativa (Ahern, 2016; Del Tredici, 2014; Talal, Santelmann, & Tilt, 2021). Desta forma, associam-se ao conceito de "Natureza 3" (Kowarik, 2011) e equivalentes (Figura 1.4, capítulo 1.2). Apresentam maioritariamente misturas diversas e equilibradas de espécies nativas e exóticas (Farinha-Marques et al., 2015, 2014), ocorrendo ocasionalmente um predomínio de espécies exóticas, especialmente espécies com caráter ornamental distintivo (*Camellia japonica*, *Rhododendron indicum*). No âmbito deste trabalho, nesta categoria foram também incluídas as praças ajardinadas, ou seja, praças com pelo menos 35% de superfície permeável com uso público direto e função recreativa (Farinha-Marques et al., 2018).

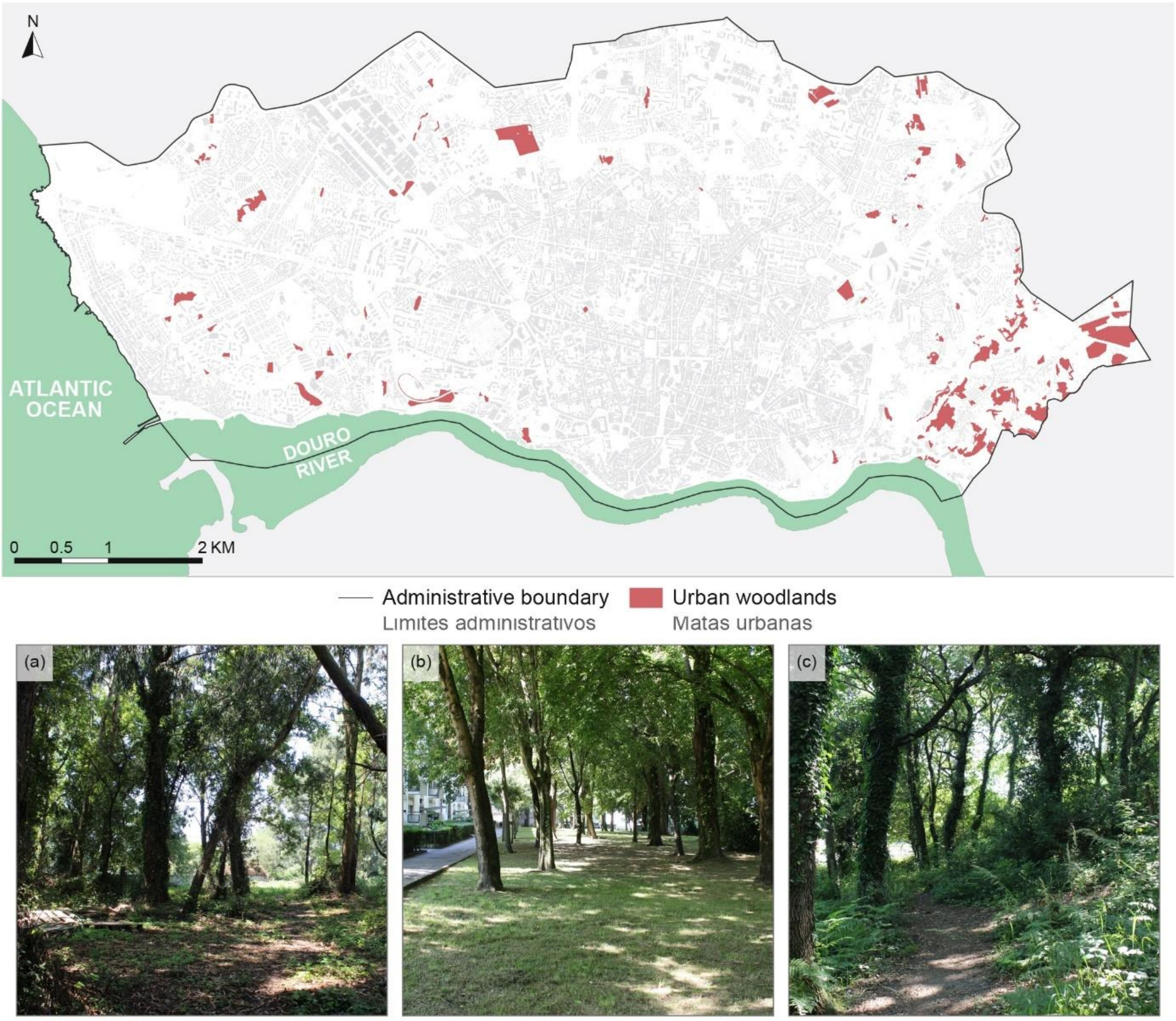

Figure 1.7. Location of urban woodlands in the city of Porto. Examples: (a) possible remnants of productive woodlands dominated by non-native species (*Eucalyptus globulus*); (b) woodlands in the proximity of residential areas dominated by non-native species (*Acer negundo, Quercus rubra*) evidencing the cut herbaceous coating but without an explicit spatial design and organization and; (c) possible remnants of native woodlands and currently dominated by native species (*Quercus robur, Quercus suber*). See Appendix II for more details – study sites 01, 08, and 12.

Figura 1.7. Localização de matas urbanas na cidade do Porto. Exemplos: (a) possíveis remanescências de matas produtivas dominadas por espécies arbóreas exóticas (*Eucalyptus globulus*); (b) matas na proximidade de áreas residências, dominadas por espécies arbóreas exóticas (*Acer negundo*, *Quercus rubra*), evidenciando o revestimento herbáceo cortado, mas sem um desenho e organização espacial explícito; (c) possíveis remanescências de matas nativas e atualmente dominadas por espécies arbóreas autóctones (*Quercus robur*, *Quercus suber*). Ver Apêndice II para mais detalhes – locais de estudo 01, 08 e 12.

In the city of Porto, parks and gardens are represented in 108 spaces, occupying 14.7% of the total area of Porto's green structure

Na cidade do Porto foram sinalizados 108 espaços correspondentes a parques e jardins públicos que ocupam 14.7% da área total da

(Figure 1.8). Their distribution in the city is varied, although less prominent in the north and more prominent in the west, mainly due to larger spaces like the City Park and Serralves Park.

estrutura verde (Figura 1.8). Estes espaços estão distribuídos por toda a cidade, notando-se uma carência a norte, sobretudo no lado oriental, e uma prevalência de espaços de maiores dimensões como o Parque da Cidade e o Parque de Serralves na zona ocidental.

Figure 1.8. Location of parks, gardens and landscape squares with in the city of Porto. Examples: (a) Passeio Alegre Garden (*Araucaria heterophylla*, *Phoenix canariensis*); (b) Pasteleira Park (*Quercus rubra*, *Rhododendron indicum*); (c) Velásquez Square (*Magnolia x soulangeana*, *Camellia japonica*). See Appendix II for more details – study sites 19, 22, and 38.

Figura 1.8. Localização de parques, jardins e praças ajardinadas de acesso público na cidade do Porto. Exemplos: (a) Jardim do Passeio Alegre (*Araucaria heterophylla*, *Phoenix canariensis*); (b) Parque da Pasteleira (*Quercus rubra*, *Rhododendron indicum*); (c) Praça Velásquez (*Magnolia x soulangeana*, *Camellia japonica*). Ver Apêndice II para mais detalhes – locais de estudo 19, 22 e 38.

Finally, **vacant lands** result from incomplete or interrupted urbanization processes. They refer to abandoned outdoor spaces with no obvious programmed function or explicit human use (Farinha-Marques et al., 2018; Portela-Pereira, Neto, Soares, & Talhé Azambuja, 2018). These spaces, which can be public or private, are usually widely distributed in cities (Rupprecht, Byrne, Garden, & Hero, 2015). Many of these spaces comprise ruderal communities colonized by spontaneous vegetation, typically in the early stages of ecological succession, with low management requirements and often with high capacity to provide services and host high levels of biodiversity (Bonthoux, Brun, Di Pietro, Greulich, & Bouché-Pillon, 2014; Brun, Di Pietro, & Bonthoux, 2018; Del Tredici, 2010; Li, Fan, Kühn, Dong, & Hao, 2019; Vega, Schläpfer-Miller, & Kueffer, 2021). In some cases, they may also be punctuated with shrubs and trees, especially when they result from the abandonment of agricultural areas or landscaped residential areas. When tree cover exceeds 70%, these spaces are considered urban woodlands (Ahern, 2016; Farinha-Marques et al., 2018). Thus, they present great floristic and structural variability and dynamics, characterized by the presence of generalist species that survive poor, disturbed, and/or compacted soils (Del Tredici, 2014). Vacant lands can be associated with the concept of "Nature 4" proposed by Kowarik (2011) and the concept of third landscape developed by Clément (2004), theoretically the closest to the Novel Urban Ecosystems concept (Figure 1.5 chapter 1.2).

Por fim, os **espaços verdes expectantes** resultam de processos de urbanização incompletos ou interrompidos, correspondendo a espaços abandonados onde não existe uma função programada óbvia ou uma utilização humana explícita (Farinha-Marques et al., 2018; Portela-Pereira, Neto, Soares, & Talhé Azambuja, 2018). Estes espaços, que podem ser públicos ou privados, encontram-se, no geral, amplamente distribuídos nas cidades (Rupprecht, Byrne, Garden, & Hero, 2015). Muitos destes espaços constituem comunidades ruderais, colonizadas por vegetação espontânea, maioritariamente nas fases iniciais da sucessão ecológica, com necessidades muito reduzidas de manutenção e muitas vezes com grande capacidade de fornecer serviços e acolher níveis elevados de biodiversidade (Bonthoux, Brun, Di Pietro, Greulich, & Bouché-Pillon, 2014; Brun, Di Pietro, & Bonthoux, 2018; Del Tredici, 2010; Li, Fan, Kühn, Dong, & Hao, 2019; Vega, Schläpfer-Miller, & Kueffer, 2021). Em alguns casos, podem também ser pontuados com arbustos e árvores, sobretudo quando resultam do abandono de áreas agrícolas ou de espaços residenciais ajardinados. Quando o coberto arbóreo excede 70%, estes espaços são considerados matas urbanas (Ahern, 2016; Farinha-Marques et al., 2018). Desta forma, apresentam à partida uma grande heterogeneidade e dinâmicas florísticas e estruturais, caracterizadas pela presença de espécies generalistas que sobrevivem a solos pobres, perturbados e/ou compactados (Del Tredici, 2014). Associam-se, assim, ao conceito de "Natureza 4" proposto por (Kowarik, 2005, 2011), teoricamente o mais próximo do conceito de Novos Ecossistemas Urbanos, mas também ao conceito de terceira paisagem desenvolvido por Clément (2004) (Figura 1.5, capítulo 1.2).

Vacant lands are the most representative category in the city of Porto, occupying a quarter of the total area of the green structure (25.6%), spread in 743 spaces. These spaces are distributed throughout the city but more prominent in the peripheral and eastern zone (Figure 1.9).

The high number and heterogeneity of the spaces that constitute the three categories under study imposed, for fieldwork operationality purposes, the selection of a representative sample of these spaces. Thus, a representative sample of 85 green spaces was selected through a stratified random sampling design using ArcGIS 10.6 software (ESRI, 2011). The number of green spaces (study sites) selected for each urban green space category was proportional to the surface area that the category occupies in the city, resulting in a final sample with 14 urban woodlands, 26 parks and gardens, and 45 vacant lands (Figure 1.10). See Appendix 4A (chapter 4) for more details about the adopted methodology.

Esta é a categoria mais representativa na cidade do Porto, tendo sido identificados 743 espaços que ocupam um quarto da área total de estrutura verde (25.6%). Os espaços verdes expectantes distribuem-se por toda a cidade, mas é evidente a prevalência de espaços de maiores dimensões na zona norte e oriental (Figura 1.9).

O elevado número e heterogeneidade dos espaços que constituem as três categorias em estudo impôs, para efeitos de operacionalidade do trabalho de campo, a seleção de uma amostra representativa desses espaços. Deste modo, foi selecionada uma amostra de 85 espaços verdes através de um desenho amostral estratificado aleatório, utilizando o software ArcGIS 10.6 (ESRI, 2011). O número de espaços verdes (locais de estudo) selecionados para cada categoria de espaço verde urbano foi proporcional à superfície que a categoria ocupa na cidade, resultando numa amostra final com 14 matas urbanas, 26 parques e jardins públicos e 45 espaços verdes expectantes (Figura 1.10). Ver Apêndice 4A (capítulo 4), para mais detalhes acerca da metodologia adotada.

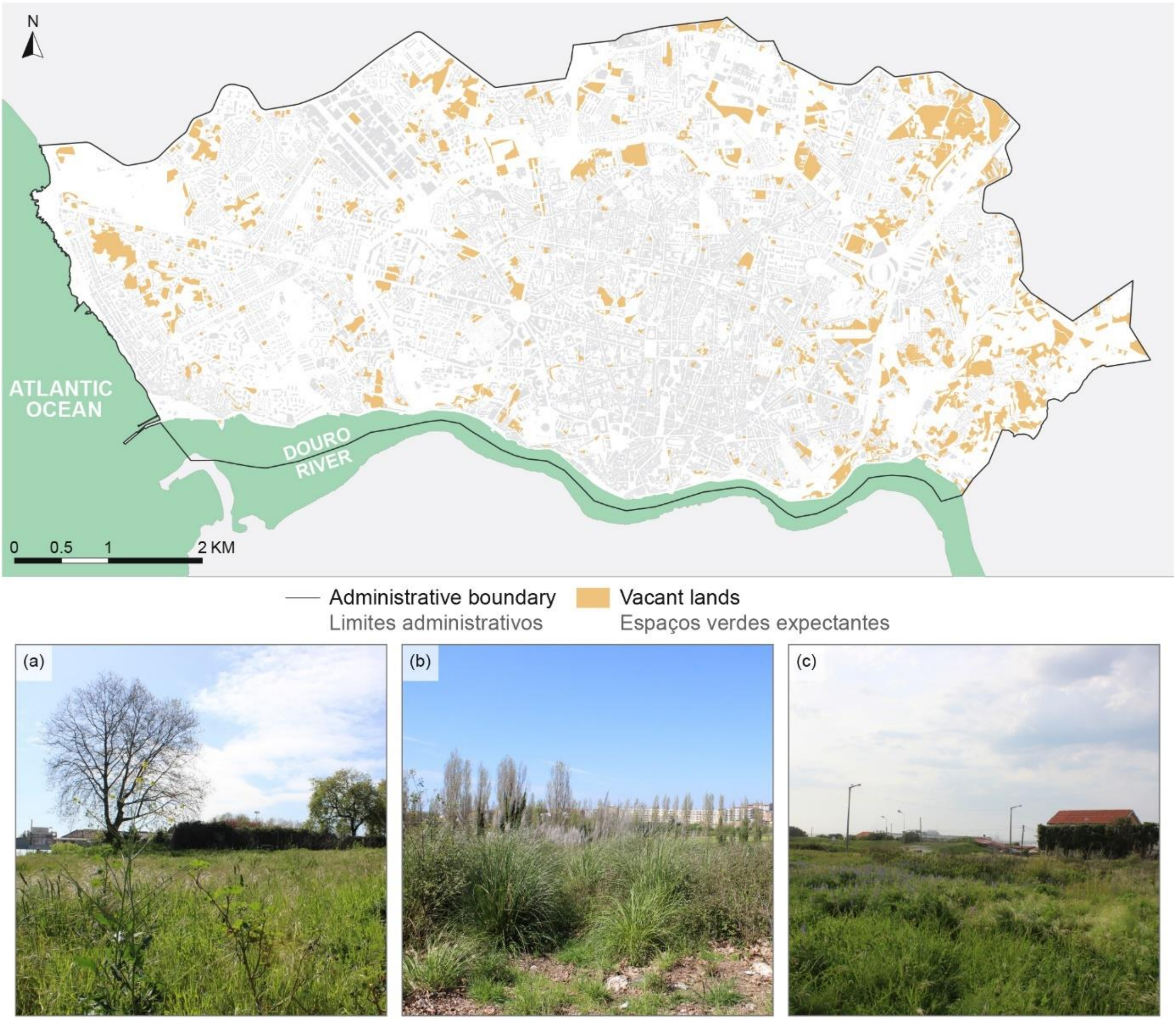

Figure 1.9. Location of vacant lands in the city of Porto. Examples: (a) vacant lands with balanced assemblages of native and non-native species; (b) vacant lands dominated by native species (*Bromus diandrus, Echium plantagineum*); (c) vacant lands dominated by non-native species (*Cortaderia selloana, Oenothera glazioviana*). See Appendix II for more details – study sites 44, 60, and 70.

Figura 1.9. Localização de espaços verdes expectantes na cidade do Porto. Exemplos: (a) espaços verdes expectantes com combinações equilibradas de espécies nativas e exóticas; (b) espaços verdes expectantes dominados por espécies nativas (*Bromus diandrus*, *Echium plantagineum*); (c) espaços verdes expectantes dominados por espécies exóticas (*Cortaderia selloana, Oenothera glazioviana*). Ver Apêndice II para mais detalhes – locais de estudo 44, 60 e 70.

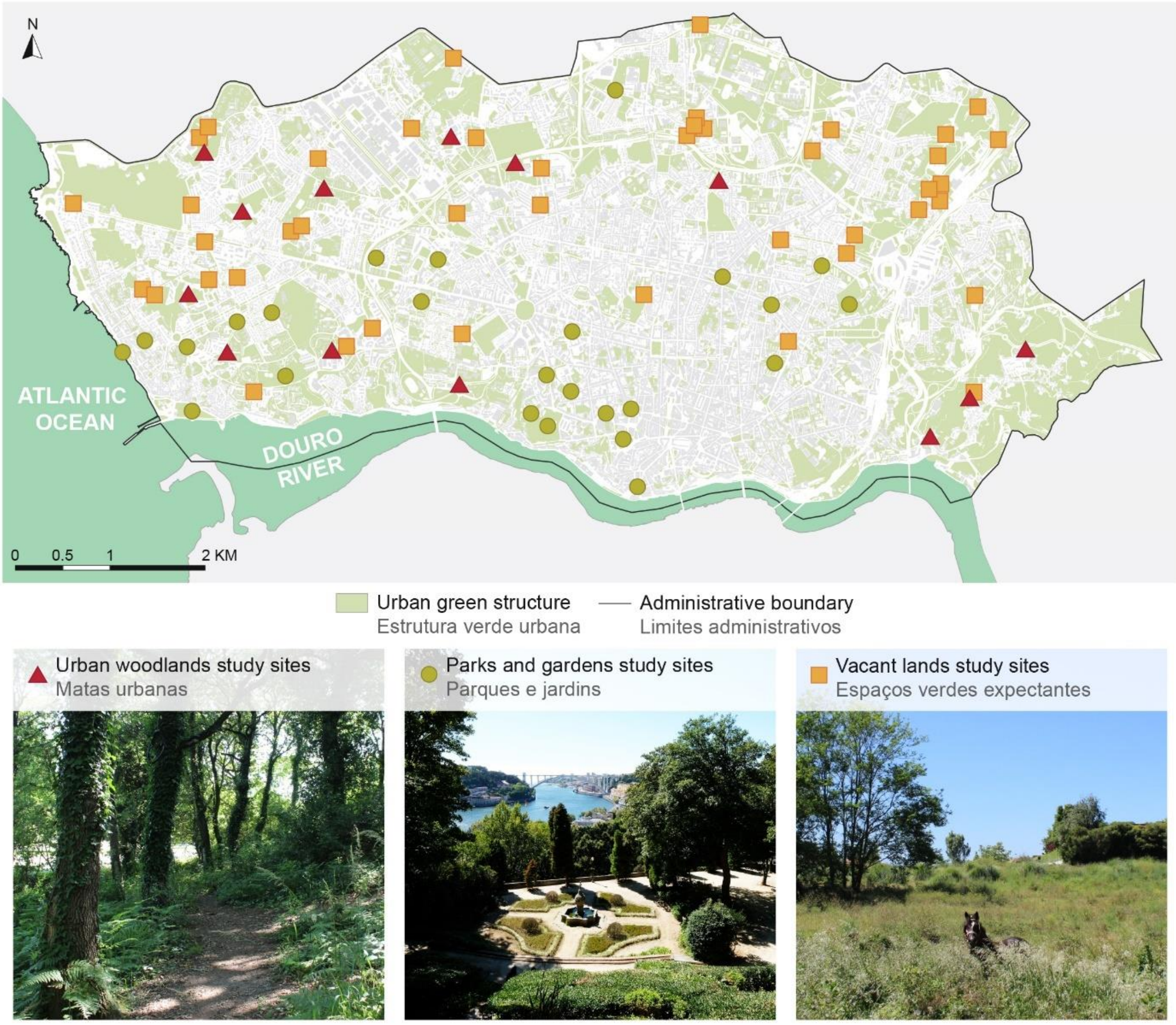

Figure 1.10. Urban green spaces selected and respective study sites: 14 urban woodlands, 26 parks and gardens, and 49 vacant lands.

Figura 1.10. Espaços verdes urbanos selecionados na cidade do Porto e respetivos locais de estudo: 14 matas urbanas, 26 parques e jardins públicos e 49 espaços verdes expectantes.

Data collection and systematization methods used in the thesis

For the 85 selected study sites, two types of data were collected: human influence data (land-use history, level of maintenance, and intensity of urbanization) and vegetation data (through floristic surveys).

Métodos de recolha e sistematização de dados utilizados na tese

Para os 85 locais de estudo selecionados recolheram-se dois tipos de dados: dados de influência humana (história do uso do solo, nível de manutenção e intensidade de urbanização) e dados de flora e vegetação (através de inventários florísticos).

Regarding the human influence data, a set of variables were first identified that are relevant in the context of the Novel Urban Ecosystems concept and contributed to evaluating the urban ecological novelty in chapter 4. Thus, each study site was assessed regarding maintenance level (Ahern, 2016; Hallett et al., 2013; Higgs, 2017; Mascaro et al., 2013; Morse et al., 2014), the percentage of impervious area in their surroundings (an indicator of urbanization intensity) (Knapp et al., 2012; Kowarik, 2011; Perring, Manning, et al., 2013), and the history of land use (Hobbs et al., 2006, 2009; Lugo & Helmer, 2004; Radeloff et al., 2015). The level of maintenance was qualitatively assessed, and the percentage of impervious area in the surroundings of the study sites was determined with a 250 m buffer (Figure 1.11) using ArcGIS 10.6 software (ESRI, 2011).

To determine the previous land-use (land-use history), three temporal moments were identified that had accessible cartography or aerial photographs (Figure 1.12):

- Telles Ferreira's cartography from 1892, accessible in an interactive format at the Porto City Council website (https://mipweb.cm-porto.pt/);
- Aerial photograph from 1939, accessible in digital format on the Porto Municipal Archive (http://gisaweb.cm-porto.pt);
- Google Map from 2018, accessible through Google Earth (https://earth.google.com/web/).

Em relação aos dados de influência humana, primeiro identificaram-se as variáveis a analisar com relevância no contexto do conceito de Novos Ecossistemas Urbanos e que contribuíram para avaliar a novidade ecológica urbana no capítulo 4. Desta forma, avaliou-se para cada local de estudo o tipo de manutenção (Ahern, 2016; Hallett et al., 2013; Higgs, 2017; Mascaro et al., 2013; Morse et al., 2014), a percentagem de área impermeável na sua envolvente (indicador da intensidade de urbanização) (Knapp et al., 2012; Kowarik, 2011; Perring, Manning, et al., 2013) e a história do uso do solo (Hobbs et al., 2006, 2009; Lugo & Helmer, 2004; Radeloff et al., 2015). O tipo de manutenção foi avaliado qualitativamente e a percentagem de área impermeável na envolvente dos locais de estudo foi determinada com um buffer de 250 m (Figura 1.11), utilizando o software ArcGIS 10.6 (ESRI, 2011).

De modo a determinar os tipos de uso dos solos anteriores (história de uso do solo), identificaram-se três momentos temporais para os quais estavam disponíveis cartografia ou fotografias aéreas (Figura 1.12):

- Carta de Telles Ferreira de 1892, acessível em formato interativo no site da Câmara Municipal do Porto (https://mipweb.cm-porto.pt/);
- Fotografia aérea de 1939, acessível em formato digital no Arquivo Municipal do Porto (http://gisaweb.cm-porto.pt);
- Mapa Google de 2018, acessível no site Google Earth (https://earth.google.com/web/).

Figure 1.11. Calculation of the percentage of impermeable area in the surroundings of Marquês de Pombal Square Garde, with a 250 m buffer (93% impermeable area).

Figura 1.11. Cálculo da percentagem de área impermeável na envolvente do Jardim da Praça Marquês de Pombal, com um buffer de 250 m (93% de área impermeável).

Figure 1.12. Comparison of land-uses in José Roquete Garden: (a) land-use on Telles Ferreira's cartography from 1892 – agricultural land; (b) land use on aerial photography from 1939 – agricultural land; (c) current land use on Google Map from 2018 – public garden.

Figura 1.12. Comparação de usos de solo no Jardim José Roquete: (a) uso do solo na Carta de Telles Ferreira de 1892 – terrenos de cultivo; (b) uso do solo na fotografia aérea de 1939 – terrenos de cultivo; (c) uso do solo atual no Mapa Google de 2018 – jardim público.

Floristic surveys in public parks and gardens had previously been carried out within the research project "Urban Green Structure: Study of the relationship between public space morphology and flora and fauna diversity in the city of Porto" (PTDC/AUR-URB/104044/2008), producing a very complete and robust database. Therefore, it was decided to use this material to develop this work. Spaces significantly different from the other parks and gardens of the city of Porto were excluded from this research, as is the case of City Park and Serralves Park, identified as outliers (Farinha-Marques, Fernandes, Gaio, Costa, & Guilherme, 2016). And, also, the Botanical Garden, especially for its collector character.

During April and May 2018, floristic surveys were conducted for the remaining 59 green spaces, referring to urban woodlands and vacant lands, following the same methodology to ensure consistency in the adopted procedures (Farinha-Marques et al., 2015, 2017). Data on species diversity (species richness) and cover (percentage occupied by each plant species) were collected following the methodology of Braun-Blanquet, de Bolòs, & Jo (1979) (more details available in chapter 4). Then, the species were organized according to a set of variables and traits selected within the scope of this work, such as life form (Raunkiær, 1934; Tognetti, 2013; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018), origin, status in Continental Portugal (casual, naturalized, or invasive) (Knapp et al., 2012; Kowarik & von der Lippe, 2018; Marchante et al., 2014; Schittko et al., 2020; Wilsey et al., 2009), flowering periods

Os inventários florísticos em parques e jardins públicos tinham sido já realizados no âmbito do projeto de investigação "*Estrutura Verde Urbana: Estudo da Relação entre a Morfologia do Espaço Público e a Diversidade de Flora e Fauna na Cidade do Porto*" (PTDC/AUR-URB/104044/2008), originando uma base de dados muito completa e robusta, pelo que se optou por utilizar este material no desenvolvimento deste trabalho. Foram excluídos desta investigação espaços significativamente diferentes dos restantes parques e jardins públicos da cidade do Porto, como é o caso do Parque da Cidade e do Parque de Serralves, identificados como *outliers* (Farinha-Marques, Fernandes, Gaio, Costa, & Guilherme, 2016). E, ainda, o Jardim Botânico, sobretudo pelo seu caráter colecionista.

Durante os meses de abril e maio de 2018 foram realizados inventários florísticos para os restantes 59 espaços verdes, referentes a matas urbanas e espaços verdes expectantes, seguindo a mesma metodologia de forma a garantir a coerência nos procedimentos adotados (Farinha-Marques et al., 2015, 2017). Foram recolhidos dados sobre a diversidade de espécies (riqueza de espécies) e cobertura (percentagem ocupada por cada espécie vegetal), seguindo a metodologia de Braun-Blanquet, de Bolòs, & Jo (1979) (mais detalhes sobre este procedimento estão disponíveis no capítulo 4). Em seguida, as espécies foram organizadas de acordo com um conjunto de variáveis e características selecionadas no âmbito deste trabalho como, por exemplo, informações sobre a forma de vida (Raunkiær, 1934; Tognetti, 2013; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018), região de

(Perring et al., 2012; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015), ecological strategy (Fischer, Von der Lippe, & Kowarik, 2013; Lugo et al., 2018).

The collected vegetation data allowed us to study the plant communities' structure, composition, and functions at the 85 selected study sites. In turn, this information contributed to assessing these sites' urban ecological novelty (chapter 4) and inspiring the development of planting design and management strategies (chapter 5). The information collected regarding plant attributes was additionally condensed into a database (chapter 6).

origem e estatuto das plantas em Portugal Continental (casuais, naturalizadas ou invasoras) (Knapp et al., 2012; Kowarik & von der Lippe, 2018; Marchante et al., 2014; Schittko et al., 2020; Wilsey et al., 2009), períodos de floração (Perring et al., 2012; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015), estratégia ecológica (Fischer, Von der Lippe, & Kowarik, 2013; Lugo et al., 2018).

Os dados de flora e vegetação recolhidos permitiram estudar a estrutura, composição e funções das comunidades vegetais presentes nos 85 locais de estudo selecionados. Por sua vez, esta informação contribuiu para avaliar a novidade ecológica urbana nestes locais (capítulo 4) e para inspirar a elaboração de esquemas de plantação e estratégias de manutenção (capítulo 5). A informação recolhida referente às características e atributos das plantas foi adicionalmente condensada numa base de dados (capítulo 6).

1.5. Thesis structure

The thesis is structured in eight chapters (Figure 1.13): an initial chapter with a general introduction (**chapter 1**), where the theoretical and conceptual framework that underlies this research was presented, followed by an introduction to the green structure of Porto as a support matrix for the investigation of Novel Urban Ecosystems. The following six chapters (**chapters 2-7**) correspond to each of the scientific articles developed within the research, culminating with a general discussion and final conclusions (**chapter 8**).

1.5. Estrutura da tese

A tese encontra-se estruturada em oito capítulos (Figura 1.13): um capítulo inicial com uma introdução geral (**capítulo 1**), onde se apresentou o enquadramento teórico e conceptual que fundamentou esta investigação e a estrutura verde do Porto como matriz de suporte para a investigação de Novos Ecossistemas Urbanos. Os seis capítulos seguintes (**capítulos 2-7**) correspondem a cada um dos artigos desenvolvidos no âmbito da investigação, culminando com uma discussão geral e conclusões finais (**capítulo 8**).

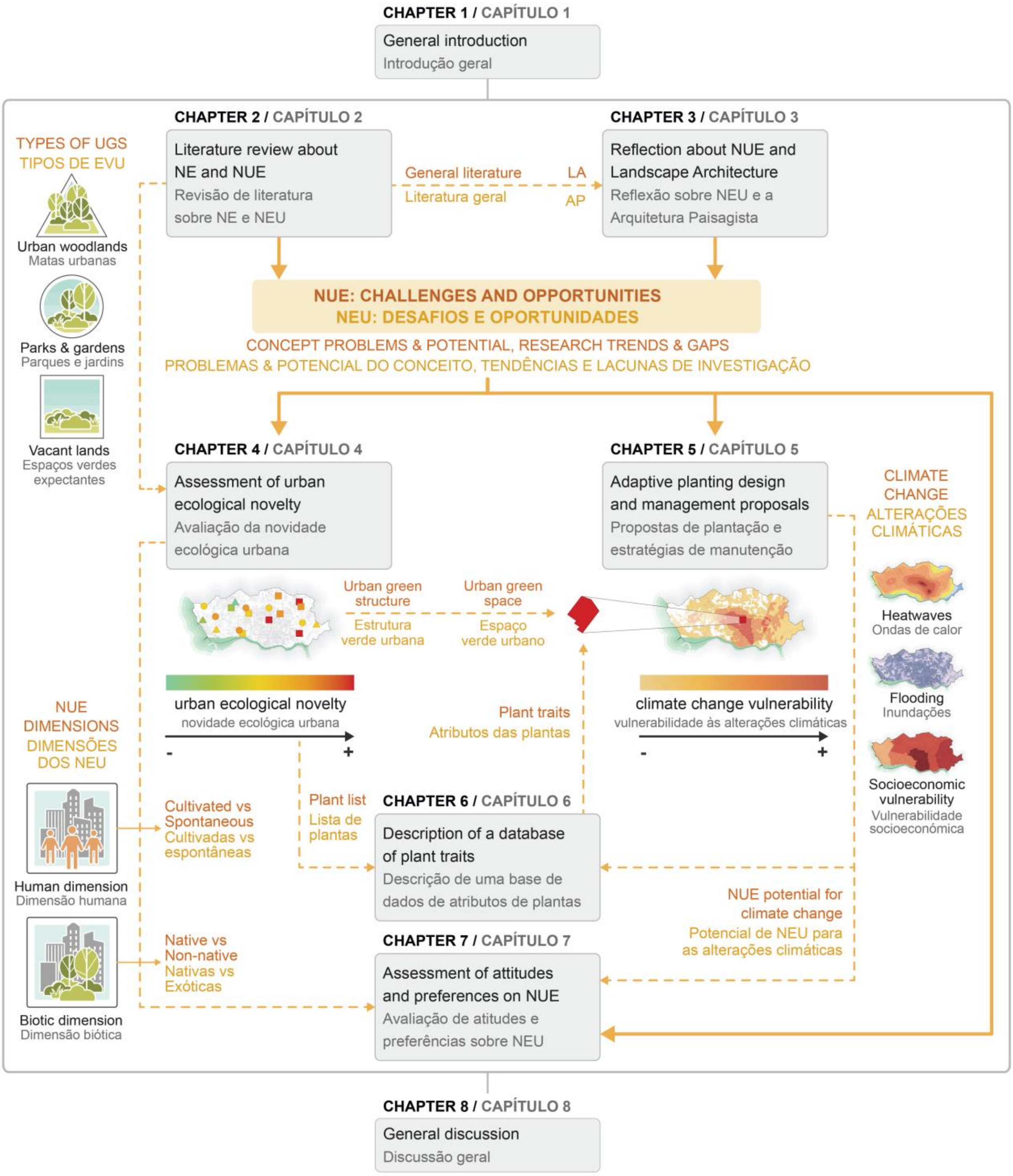

Figure 1.13. Thesis structure.

Figura 1.13. Estrutura da tese.

In this chapter (**chapter 1**), the central subject of this thesis was presented and contextualized, referring to the problems, motivations, and objectives driving the development of an investigation focused on the Novel Urban Ecosystems concept within the scope of a doctoral thesis in Landscape Architecture. The selection of the city of Porto as a privileged area for the study of Novel Urban Ecosystems was also justified. The urban green structure was characterized, contextualizing this information within the scope of previous research and describing the adopted methods for the data collection that supported the elaboration of chapters 4, 5, and 6. The chapter ended with the presentation of the thesis structure.

The urgency to clarify the Novel Urban Ecosystems concept determined the need to develop an extensive literature review. This review, presented in **chapter 2**, aimed to examine the evolution and relevance of the concept in the urban and non-urban context, identify key criteria for its definition, and establish research gaps and perspectives. For that, a systematic literature review methodology was adopted supported by the open-access guidelines from Collaboration for Environmental Evidence - CEE (2018), a standard protocol with pre-established criteria that detail all review steps.

Chapter 3 discussed the contribution of Landscape Architecture to the debate and understanding of Novel Urban Ecosystems and the usefulness and relevance of the concept for the practice and research of this

No presente capítulo (**capítulo 1**), apresentou-se e contextualizou-se a temática central desta tese, referindo-se os problemas, motivações e objetivos que originaram e impulsionaram o desenvolvimento de uma investigação focada no conceito de Novos Ecossistemas Urbanos no âmbito de um doutoramento em Arquitetura Paisagista. Fundamentou-se também a escolha da cidade do Porto como área privilegiada para o estudo dos Novos Ecossistemas Urbanos. Caracterizou-se a estrutura verde da cidade, contextualizando esta informação no âmbito de investigações anteriores e descreveram-se os métodos adotados na recolha dos dados que suportaram a elaboração dos capítulos 4, 5 e 6. O capítulo terminou com a apresentação da estrutura da tese.

A urgência de clarificar o conceito de Novos Ecossistemas Urbanos determinou a necessidade de desenvolver uma revisão extensiva da literatura. Esta revisão, apresentada no **capítulo 2**, teve como objetivos examinar a evolução e a relevância do conceito no contexto urbano e não-urbano, identificar critérios fundamentais para a sua definição e explorar lacunas e caminhos de investigação. Para isso, adotou-se uma metodologia de revisão sistemática da literatura apoiada nas orientações de livre acesso da *Collaboration for Environmental Evidence* – CEE (2018), um protocolo padrão com critérios pré-estabelecidos que guiam com detalhe todos os passos da revisão.

No **capítulo 3** discutiu-se o contributo da Arquitetura Paisagista para o debate e compreensão de Novos Ecossistemas Urbanos e disciplinary area. In this chapter, these relationships weew explored based on the analysis and critique of Landscape Architecture projects of different types, selected by an evident connection with the concept, not always assumed or recognized.

In the two following chapters (chapters 4 and 5), the practical dimension of the Novel Urban Ecosystems concept in cities was investigated, using the green structure of the city of Porto as a support matrix. In this way, new methodologies and tools were developed and tested to enable this analysis at two scales: at the scale of the urban green structure planning and management (chapter 4) and the scale of the urban green space, focusing on the floristic composition, structure, and functional diversity of plant communities (chapter 5).

Thus, in **chapter 4**, a new methodology was proposed to assess urban ecological novelty based on two essential dimensions of the Novel Urban Ecosystems concept: the human dimension and the biotic dimension. This methodology was tested in the city of Porto in three types of green spaces identified in the literature review (chapter 2) as the most relevant for an assessment of ecological novelty: urban woodlands, parks and gardens, and vacant lands. Study sites were defined through a stratified random sampling selection, and human influence data (land-use history, urbanization intensity, and maintenance level) and biotic data (plant species richness and cover) were collected. The characterization of the green spaces regarding their urban ecological novelty

a utilidade e a relevância do conceito de Novos Ecossistemas Urbanos para a prática e investigação desta área disciplinar. Neste capítulo, estas relações foram exploradas tendo por base a análise e crítica de projetos de Arquitetura Paisagista de diferentes tipos, selecionados pela evidente ligação com o conceito, ainda que nem sempre assumida ou reconhecida.

Nos dois capítulos subsequentes (capítulos 4 e 5) investigou-se a dimensão prática do conceito de Novos Ecossistemas Urbanos nas cidades, utilizando a estrutura verde da cidade do Porto como matriz de suporte. Desta forma, desenvolveram-se e testaram-se novas metodologias e ferramentas que possibilitaram esta análise a duas escalas: à escala do planeamento e gestão da estrutura verde urbana (capítulo 4) e à escala do espaço verde urbano, focando-se na composição florística, estrutura e diversidade funcional das comunidades de plantas (capítulo 5).

Assim, no **capítulo 4** propôs-se uma nova metodologia para avaliar a novidade ecológica urbana com base em duas dimensões essenciais do conceito de Novos Ecossistemas Urbanos: a dimensão humana e a dimensão biótica. Esta metodologia foi testada na cidade do Porto em três tipos de espaços verdes identificados na revisão de literatura (capítulo 2) como os mais relevantes para uma avaliação da novidade ecológica: matas urbanas, parques e jardins e espaços verdes expectantes. Recorrendo a uma seleção amostral estratificada aleatória, definiram-se os locais de estudo onde se recolheram dados de influência humana (história de uso do solo, intensidade de urbanização e allowed to discuss the implications and advantages of the methodology for a more informed urban green structure planning and management in the context of the Anthropocene.

In **chapter 5,** a framework was proposed to design and manage the urban green spaces instructed by species attributes concerning the adaptation and mitigation of climate change effects. The proposed methodology followed an "adaptive strategy" that allows for continuous evaluation of the feasibility and effectiveness of proposals to minimize uncertainty and enable more robust, adjustable interventions informed by the theoretical and practical knowledge being acquired (Ahern, Cilliers, & Niemelä, 2014; Felson & Pickett, 2005; Kato & Ahern, 2008; Lister, 2007; Pickett, Cadenasso, & Grove, 2004). Additionally, it was intended to explore the adaptive potential of floristic communities arising under extreme environmental conditions, analyzing the attributes of the plant species that constitute the green spaces with the higher ecological novelty, identified in chapter 4. For this, the developed methodology was applied in the city of Porto, starting by identifying climate change scenarios and the places in the city most vulnerable to the main climate hazards. The planting designs and management strategies developed in this chapter illustrated how to intervene in plant communities in an experimental way, taking advantage of Novel Urban Ecosystems and building fundamental knowledge to face the effects of climate change.

nível de manutenção) e dados bióticos (riqueza e cobertura das espécies de plantas). Neste capítulo, a caracterização dos espaços verdes quanto à sua novidade ecológica urbana permitiu discutir as implicações e vantagens desta metodologia para um planeamento e gestão da estrutura verde urbana mais informado no contexto do Antropocénico.

No **capítulo 5** propôs-se uma metodologia para gerir o coberto vegetal de espaços verdes urbanos mais informada quanto aos atributos das espécies relativamente à adaptação e mitigação dos efeitos das alterações climáticas. A metodologia proposta seguiu uma “estratégia adaptativa” que permite avaliar continuamente a viabilidade e eficácia das propostas, com vista a minimizar a incerteza e possibilitar intervenções mais robustas, ajustáveis e informadas pelos conhecimentos teóricos e práticos que vão sendo adquiridos (Ahern, Cilliers, & Niemelä, 2014; Felson & Pickett, 2005; Kato & Ahern, 2008; Lister, 2007; Pickett, Cadenasso, & Grove, 2004). Adicionalmente, explorou-se o potencial adaptativo de comunidades florísticas que surgem em condições ambientais extremas, recorrendo aos atributos das espécies de plantas que compõem os espaços verdes com maior novidade ecológica, identificados no capítulo 4. Para isso a metodologia desenvolvida foi aplicada no contexto da cidade do Porto, começando por identificar os cenários de alterações climáticas e os locais da cidade mais vulneráveis aos principais riscos climáticos. Os esquemas de plantação e estratégias de manutenção desenvolvidos neste capítulo ilustraram como se pode intervir em comunidades de plantas de forma experimental, Next, **chapter 6** described the process of building a plant database that comprises relevant information for the adaptation and mitigation of climate change effects in the context of Northwest Portugal. The list of species that integrated this database was obtained from the floristic surveys carried out in the green spaces of the city of Porto that revealed higher urban ecological novelty (chapter 4), assuming that these communities are better adapted to the effects of climate change in the city of Porto. The species included in this list were classified according to a set of attributes to assist and guide the preparation of the planting design and management proposals developed in chapter 5.

In **chapter 7**, landscape professionals' perception was assessed regarding the Novel Urban Ecosystems concept and their willingness to integrate the concept into their professional practice. For this purpose, an online questionnaire was used since it allows collecting information in a more expedient, economical, unbiased, and anonymous way, translating into more honest answers (Babbie, 2007). The questionnaire assessed attitudes and preferences based on the human and biotic dimensions of the Novel Urban Ecosystems concept (chapter 4). To evaluate the human dimension, respondents were surveyed regarding the intentionality of plants in urban green spaces (cultivated vs. spontaneous). To assess the biotic dimension, respondents were surveyed regarding the origin of the plants (native vs. exotic). Respondents' opinion was also

tirando partido das vantagens dos Novos Ecossistemas Urbanos e construindo conhecimento fundamental para enfrentar os efeitos das alterações climáticas.

De seguida, no **capítulo 6** descreveu-se o processo de construção de uma base de dados de plantas que condensou informação relevante para a adaptação e mitigação dos efeitos das alterações climáticas, no contexto do Noroeste de Portugal. A lista de espécies que integrou esta base de dados foi obtida a partir dos inventários florísticos realizados nos espaços verdes da cidade do Porto que revelaram maior novidade ecológica (capítulo 4), partindo do pressuposto de que estas espécies estão melhor adaptadas aos efeitos das alterações climáticas na cidade do Porto. As espécies incluídas nesta lista foram classificadas de acordo com um conjunto de atributos, de forma a auxiliar e orientar a elaboração das propostas de plantação e estratégias de manutenção desenvolvidas no capítulo 5.

No **capítulo 7** avaliou-se a recetividade de profissionais envolvidos no desenho, planeamento e gestão de espaços verdes em relação ao conceito de Novos Ecossistemas Urbanos e a sua predisposição para o integrar na sua prática profissional. Para isso, recorreu-se a um questionário online que permite recolher informação de forma mais expedita, económica, imparcial e anónima, o que pode traduzir-se também em respostas mais honestas (Babbie, 2007). O questionário avaliou atitudes e preferências com base nas dimensões humana e biótica do conceito de Novos Ecossistemas Urbanos (capítulo 4). Para avaliar a dimensão humana os respondentes foram inquiridos em considered concerning the potential of the Novel Urban Ecosystems concept for climate change adaptation and mitigation in cities (chapter 5). The chapter ended reflecting on the implications of the obtained results for the wider adoption and appropriation of the concept of Novel Urban Ecosystems.

Finally, **chapter 8** discussed the results and contributions of this thesis in an integrated way, demonstrating how all the previous chapters are articulated in the search for answers to the established objectives. It also reflected on the research limitations and problematizes some recommendations for future research.

The references of this work are listed at the end of each chapter.

relação à intencionalidade das plantas nos espaços verdes urbanos (cultivadas *vs.* espontâneas). Para avaliar a dimensão biótica os respondentes foram inquiridos em relação à origem das plantas (nativas *vs*. exóticas). Também se avaliou a opinião dos respondentes especificamente em relação ao potencial do conceito de Novos Ecossistemas Urbanos para a adaptação e mitigação das alterações climáticas nas cidades (capítulo 5). O capítulo concluiu com uma reflexão sobre as implicações dos resultados obtidos para a adoção e apropriação mais generalizada do conceito de Novos Ecossistemas Urbanos.

Por fim, o **capítulo 8** discutiu de forma integrada os resultados e contributos desta tese, demonstrando como todos os capítulos anteriores se articulam na procura de respostas para os objetivos estabelecidos. Refletiu-se ainda a respeito das limitações encontradas e problematizaram-se algumas recomendações para investigações no futuro.

As referências deste trabalho surgem no final de cada capítulo.

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2

CHAPTER 2 |

NOVEL ECOSYSTEMS: A REVIEW OF THE CONCEPT IN NON-URBAN AND URBAN CONTEXTS

“Novel ecosystems defy easy categorization, however, because they mix and match traditionally positive and negative properties: they are diverse but invaded, neglected but resilient, new but natural, anthropogenic but wild. Novel ecosystems thus confront the simple binaries that permeate conservation discourse.” (Yung, Schwarze, Carr, Chapin III, & Marris, 2013, p. 248)

Chapter 2 | Novel Ecosystems: A review of the concept in non-urban and urban contexts

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Article published as a review article in *Landscape Ecology*

Type of article: Review article
Journal Impact Factor (2020): 3.848

Citation: Teixeira, C. P., & Fernandes, C. O. (2020). Novel ecosystems: a review of the concept in non-urban and urban contexts. *Landscape Ecology*, 35(1), 23–39.
https://doi.org/10.1007/s10980-019-00934-4

Abstract

Anthropogenic changes (e.g., climate change, land-use change, species introductions, etc.) are reshaping ecosystems processes and patterns and causing an intense reorganization of the Earth's biotic systems. As a result, unprecedented combinations of species are emerging, forming ''novel ecosystems''. The goals of this work are: (1) to examine the history and relevance of the novel ecosystems concept in non-urban and urban contexts, and (2) to evaluate what has been the focus of the research about the novel ecosystems concept in non-urban and urban contexts. Through an extensive systematic review, we collected 548 records published between 1997 and 2018. After applying inclusion/exclusion criteria the final database comprised 255 relevant records that were further examined and classified according to the scope of this review. Our results demonstrated that research referring to the novel ecosystems concept has been mainly focused on non-urban areas. Still, there is a growing interest in exploring this concept in the urban domain. The definition and criteria used to describe novel ecosystems have been transforming over the years. Research has been mainly targeted on multiple taxonomic groups and plants, on terrestrial ecosystems, and conducted in North America. Overall, restoration ecology, conservation, biodiversity, ecosystem services, and climate change have been the most discussed topics in the novel ecosystems' literature. Our review confirms that the application of the novel ecosystems concept to urban areas is pertinent and auspicious. Future research should seek to understand the limits and differences of novel ecosystems in non-urban and urban contexts.

Keywords: Anthropocene; Conceptual framework; Novel ecosystems; Systematic review; Urban context

2.1. Introduction

Over the past years, human actions and movement, technological advances, and global trade have emerged as drivers of change, allowing the spread and introduction of species into regions that would probably never have been reached in different circumstances (Harris, Hobbs, Higgs, & Aronson, 2006; Hobbs et al., 2006). These rapid transformations have contributed to a biotic globalization and, consequently, to the reconfiguration of ecosystem processes and patterns (Ellis, 2015). As a result, new species combinations are emerging throughout the globe, forming what is being designated as ‘‘novel ecosystems’’ (sensu Hobbs et al., 2006).

Due to anthropogenic factors and by the addition and/or loss of species (species migrations, introductions, and extinctions), these systems are unprecedented and composed by an assemblage of native and non-native organisms that may have never coexisted before (Higgs, 2017; Seastedt, Hobbs, & Suding, 2008). Nevertheless, the movement and introduction of species is not a recent phenomenon and has occurred for many millennia (Hobbs et al., 2006). Many non-native species were intentionally introduced (legally or illegally) to increase or restore specific ecosystem services, to produce goods and food, and even for ornamental purposes (Potgieter, Gaertner, O’Farrell, & Richardson, 2019; Wilsey, Daneshgar, & Polley, 2011). Whereas other introduced species were accidentally transported to new regions through shipping products such as timber or fruit, ballast water, by hitchhiking on people traveling, etc. (Daniel Simberloff, Parker, & Windle, 2005). Some introduced species adapted to the new conditions in which they were placed and acquired the ability to overcome barriers that were limiting their reproduction and dispersion (Kowarik, 2011; Richardson et al., 2000).

Also, ecosystems have been experiencing periodic changes over the past millennia in response to disturbances (Hobbs, Higgs, & Harris, 2009; Williams & Jackson, 2007). Thus, novel ecosystems are novel in the sense that recent and increasing human pressure has been responsible for complex and accelerated rates of change (Hobbs et al., 2006; Lindenmayer et al., 2008). Since the effects caused by the human agency on the planet are becoming more and more pervasive (Ellis, 2013; Hobbs et al., 2009; Kueffer & Kaiser-Bunbury, 2014), many scientists are accepting that the planet has entered a new geological epoch labeled as ‘‘Anthropocene’’ (sensu Crutzen, 2006).

Given important issues and concerns raised by the emergence of novel ecosystems and the effects of the Anthropocene, this concept has been mostly discussed within the restoration ecology and conservation biology disciplines (Guan, Kang, & Liu, 2018; Hobbs, 2013; Hobbs et al., 2009; e.g., Lindenmayer et al., 2008; Perring, Standish, & Hobbs, 2013). The challenges posed by novel ecosystems are transforming the foundations of these disciplines. Traditionally, ecosystems are managed and preserved according to historical references (Seastedt et al., 2008). Nevertheless, the idea that it is possible, realistic and desirable to return to a historical state (i.e., prior to human-induced disturbances) is being widely questioned (Hobbs, Hallett, Ehrlich, & Mooney, 2011; Hobbs et al., 2009; Perring, Standish, et al., 2013; Seastedt et al., 2008). Recovering historical conditions (abiotic and/or biotic) in a particular area may even have several undesirable consequences. Besides entailing an enormous amount of resources and effort, it may lead to the creation of ill-adapted populations that are more susceptible to future changes, including climate change and local extinction of species (Millar, Stephenson, & Stephens, 2007; Perring, Standish, et al., 2013).

This way, new paradigms are arising due to the emergence of novel ecosystems. According to Dooling (2015), rather than restoring previous conditions, the challenge of the moment is to realign the systems for present and future conditions so that organisms respond adaptively to change. Develop a unique and efficient method to manage novel ecosystems will, therefore, be an extremely difficult and possibly ineffective task (Seastedt et al., 2008). Not only will a combination of approaches be required to achieve multiple objectives (Hobbs et al., 2014), but actions will have to be adapted to each context (Kueffer, Schumacher, Dietz, Fleischmann, & Edwards, 2010). A more integrated, dynamic and flexible approach will allow managers to consider several options in different scenarios and will enable them to make more efficient decisions that are anchored in the current reality of rapid ecosystem change (Hobbs et al., 2014).

However, it is important to safeguard that more flexible methods do not imply the abandonment of all previously established values and guidelines, but rather consider several possibilities to deal with an uncertain future (Hobbs et al., 2009; Standish, Thompson, Higgs, & Murphy, 2013). Hobbs et al. (2006) argue that currently less affected areas must be conserved first and resources should not be spent to recover systems that are less likely to recover. In this respect, the identification of novel ecosystems can be extremely useful to avoid the misuse of scarce resources on attempts to return these systems to historical conditions (Perring, Standish, et al., 2013).

In the urban context, the effects of human agency and the Anthropocene can be even more pronounced (Schmidt, Poppendieck, & Jensen, 2014), since cities are artificial and deeply constructed systems where human population is more concentrated (MEA, 2005; Perring, Manning, et al., 2013). Urban areas result from diverse and complex interactions between socioeconomic factors and biophysical processes (Schaefer, 2011) and are constantly exposed to a variety of disturbances (Schmidt et al., 2014). Due to transport networks and human activities and preferences, cities are often the entry points of many introduced species (Gaertner et al., 2017; Perring, Manning, et al., 2013). Additionally, urban ecosystems have different physical and chemical properties in contrast with non-urban areas, which highly influences species distribution and ecosystems functioning (Kowarik, 2011; Perring, Manning, et al., 2013). This way, as a whole, urban areas have been usually considered novel in relation with their non-urban counterparts (Kowarik, 2011), because novelty tends to manifest and be widespread in these populated regions (Hobbs et al., 2014). However, when analyzing cities in a more detailed scale, urban areas are comprised by a variety of fragmented habitats with different degrees of novelty, land-use legacy, and pace of transformation (Kowarik, 2011; Perring, Manning, et al., 2013).

Over recent years the novel ecosystems concept has been largely discussed (Chapin III & Starfield, 1997; Davis et al., 2011; Higgs, 2017; Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013c; Lugo, 2009). The definition and value of novel ecosystems have been questioned (e.g., Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016; Murcia et al., 2014; D Simberloff, 2015), generating divergent opinions within the scientific community and triggering an intense debate around the concept. This debate often generates more misunderstanding instead of providing elucidation about the concept, so a review of the literature about novel ecosystems is fundamental. Previous studies have already reviewed the concept regarding different aspects (Collier & Devitt, 2016; Perring, Standish, et al., 2013), but systematic reviews usually provide a more inclusive overview of topics.

In this sense, a systematic review about novel ecosystems and novel urban ecosystems may be useful to provide a much-needed clarification about the concept definition, history, and value, as well as to reflect on future research opportunities and challenges. This way, the specific goals of this systematic review are (1) to examine the history and relevance of the novel ecosystems concept in non-urban and urban contexts and (2) to evaluate what has been the focus of the research about the novel ecosystems concept in non-urban and urban contexts.

2.2. Methods

2.2.1. Literature search

This systematic review was conducted following the guidelines provided by the CEE (2018). The literature search was performed in ISI Web of Science Core Collection, Scopus, and ScienceDirect using the search terms ‘‘novel ecosystems’’ OR ‘‘novel urban ecosystems’’. The time span of the search corresponded to ‘‘all years’’ to 2018 and the searches were conducted in April 2019. Records retrieved from each search database were combined and stored in the referencing software EndNote X8 where duplicate records were removed, resulting in a total of 548 unique records.

Inclusion/exclusion criteria were applied by screening individually each record at two distinct stages. First, the title and abstract were examined to identify potentially relevant records, and then the full text was reviewed. For a record to be considered as relevant it had to discuss and explore the concept (and not just mention it), contribute to a better understanding of novel ecosystems and/or provide case studies or examples of novelty around the globe. This process resulted in a database with 232 relevant records.

To ensure a comprehensive review of the literature about the subject, additional searches were performed in Google Scholar using the same search terms. The full text of the first 50 hits was assessed and relevant records that were absent from the database were added. The reference lists of the records of the database were also examined – snowballing method (see CEE 2018 for details). Relevant records that were absent from the database were included, resulting in a final database with 255 records (Figure 2.1; see Appendix 2A for details on the literature search process and on the inclusion/exclusion criteria used). Although there was an effort to collect all the relevant literature about this concept, we note that this may not have been completely possible for two main reasons: (1) in an earlier phase the concept had other designations such as ‘‘synthetic ecosystems’’ (Odum, 1962) and ‘‘emerging ecosystems’’ (Milton, 2003), and (2) since the term ‘‘novel ecosystem’’ has been disapproved by some researchers it may exist other publications about the concept that are simply using other terminology.

2.2.2. Literature review and data analysis

The full text of each record from the final database (n = 255) was reviewed to address the objectives of this work (Figure 2.1). To examine the history and relevance of the novel ecosystems concept in non-urban and urban contexts (objective 1) we started by analyzing individually each record. Then we were able to classify each record according to the context: records focused on non-urban contexts (which we associated with the broader concept, i.e., novel ecosystems), and records focused on the urban context (which we associated with novel urban ecosystems). Even records that were not retrieved using the keyword ‘‘novel urban ecosystems’’ on the literature search could have been classified as records focused on the urban context. We created a line graph with the number of published records per year, distinguishing the context of the records (non-urban and urban) with colors. We also represented differently 42 records that constitute the book chapters of a seminal book about the concept (Hobbs et al., 2013c) using column bars. Otherwise, the total number of records in the year 2013 would be biased and anomalous (note that the book and the 42 chapters were retrieved individually from the search databases, comprising a total of 43 records within the overall 255 records of the final database). To examine more closely how the concept has been altering through time, we identified key records that provided a conceptual framework and a definition of novel ecosystems in non-urban and urban contexts. These definitions were organized in a table and examined against a set of criteria proposed by Morse et al. (2014).

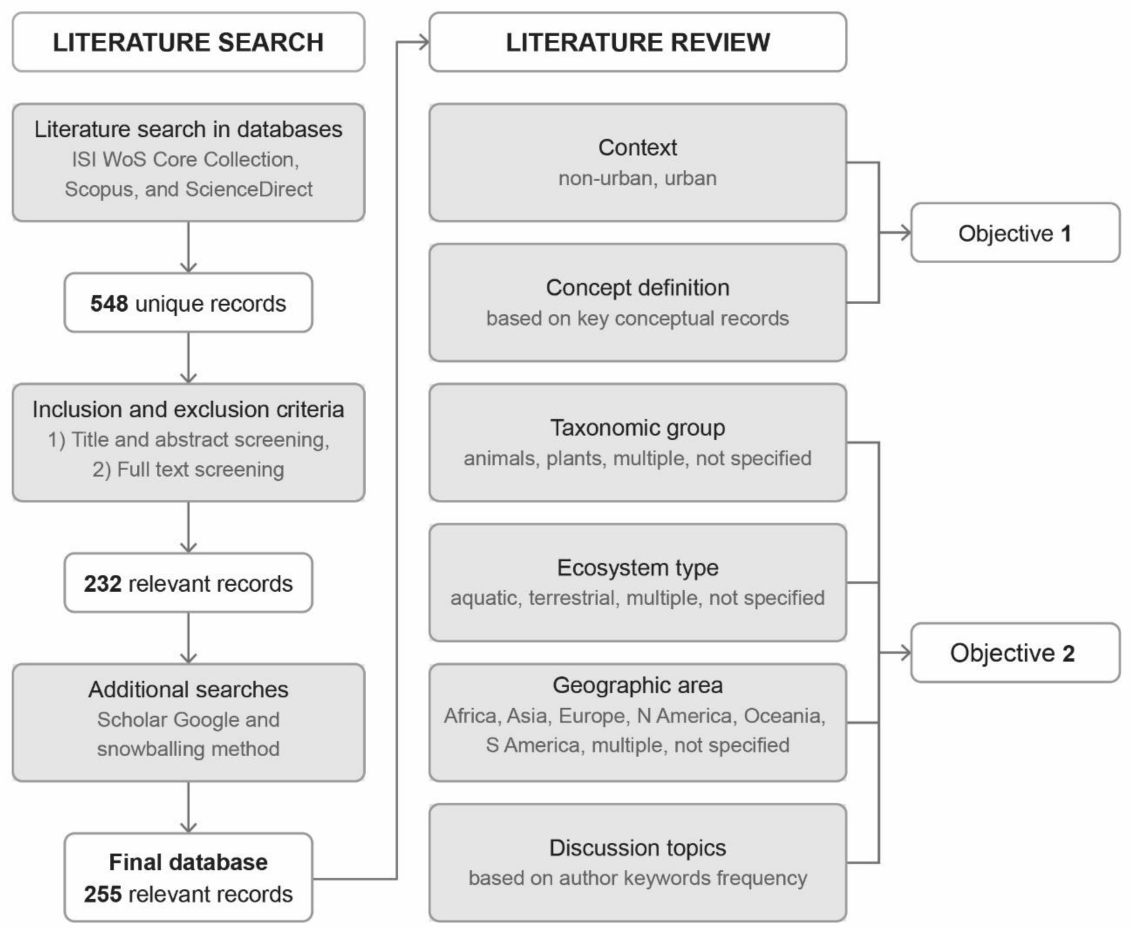


Figure 2.1. Literature search and literature review process. We first searched for records in ISI Web of Science Core Collection, Scopus, and ScienceDirect. To select relevant records, inclusion and exclusion criteria were applied at two distinct stages. Additional searches were conducted using Scholar Google and the snowballing method. The final database was reviewed and classified according to the context and concept definition (to address objective 1), taxonomic groups, ecosystem types, geographic areas, and discussion topics (to address objective 2).

To evaluate what has been the focus of the research about the novel ecosystems concept in non-urban and urban contexts (objective 2), first, each record was classified according to three categories: taxonomic groups, ecosystem types, and geographic areas (see Table 2.1). We created stacked bar graphs with the number of published records per year for each category. Records focused on non-urban contexts were placed on the top and records focused on the urban context were placed in the bottom. The 42 book chapters from the comprehensive book (Hobbs et al., 2013c) were represented separately by column bars. Additionally, to analyze with more detail the geographic areas of the records, we created a map with the geographic distribution of the studies. We have only included in the map the studies that provided details on the specific location (n = 136), therefore the remaining studies conducted on multiple geographic areas and without specified location (n = 119) were not included. Finally, we identified which have been the most discussed topics in the literature regarding the concept in non-urban and urban contexts, by analyzing the frequency of author keywords of the records. We used the software VOSviewer 1.6.11 (van Eck & Waltman, 2010) to generate maps in which author keywords frequency were represented (see Appendix 2B).

Table 2.1. Categories (taxonomic groups, ecosystem types, and geographic areas) and corresponding classes used to classify the records of the final database (n = 255).

Categories	Classes
Taxonomic groups	
What is the taxonomic group of focus?	Plants, Animals, Other taxa, Multiple (i.e., more than one taxonomic group), Not specified (i.e., no taxonomic groups are specified or referred)
Ecosystem types	
What is the ecosystem type of focus?	Aquatic, Terrestrial, Multiple (i.e., more than one ecosystem type and/or ecotones), Not specified (i.e., no ecosystem types are specified or referred)
Geographic areas	
What is the geographic area of focus?	Africa, Antarctica, Asia, Europe, North America, South America, Oceania, Multiple (i.e., more than one geographic area, regions within more than one continent and/or when the focus is the entire globe), Not specified (i.e., no geographic areas are specified or referred)

2.3. Results and discussion

2.3.1. History and relevance of the concept in non-urban and urban contexts

The final database included 255 records distributed through 22 years of publications, from 1997 to 2018 (Figure 2.2). The high number of publications in a short period of time highlights how recent, yet trendy, the novel ecosystem concept is. The majority of the records (87.1%) were focused on non-urban contexts and the remaining 12.9% were targeted on the urban context.

The ‘‘novel ecosystems’’ term was first used about two decades ago (Chapin III & Starfield, 1997), but only later the first definition of the concept emerged in a seminal paper by Hobbs et al. (2006), placing novel ecosystems in the spotlight. In the origin and formulation of the concept, other terms were used to designate the concept even though they have not persisted in the literature. From Hobbs et al. (2006) paper it is possible to verify that the concept was based on what Howard T. Odum (1962) had described as ‘‘synthetic ecosystems’’ and it was initially discussed at a workshop held in Granada in 2002 in which the term ‘‘emerging ecosystems’’ (Milton, 2003) was the one predominantly agreed. After 2006, as the concept inspired interest among researchers, the number of records increased noticeably every year. In 2013, a comprehensive book emerged "*Novel ecosystems: Intervening in the new ecological world order*" (Hobbs et al., 2013c) as a result of a workshop held in Pender Island (Canada), in 2011, in which 50 researchers from several parts of the world and from different research backgrounds were gathered to discuss the concept. Even though the 42 chapters that comprise this book were displayed separately in Figure 2.2, 2013 still was the year with the higher number of records so far. Nonetheless, the interest in the concept persisted in the following years to date.

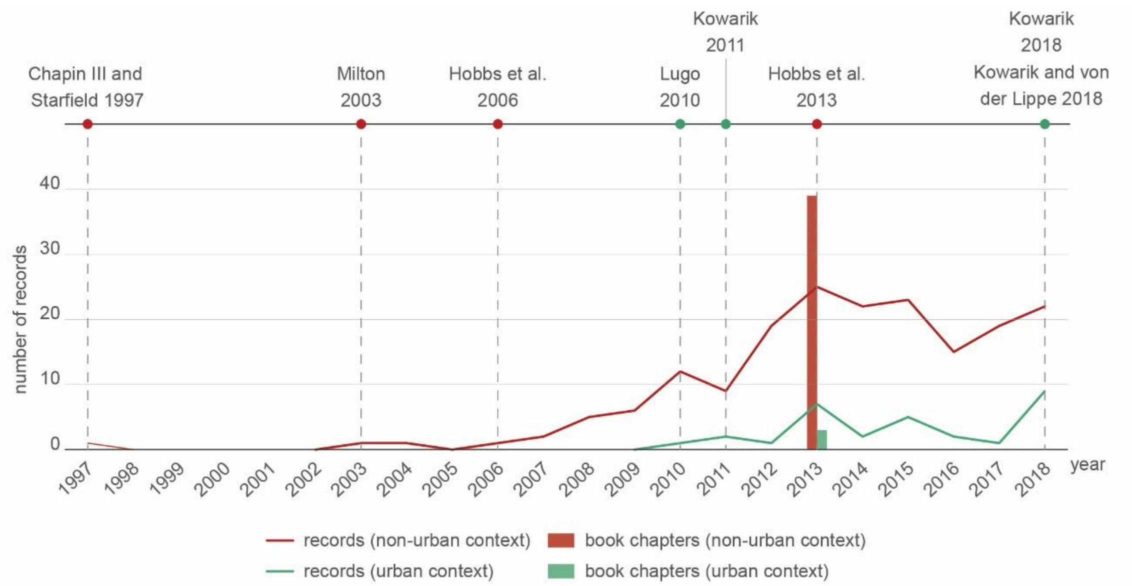


Figure 2.2. The number of published records per year (from 1997 to 2018). Records focused on non-urban contexts are represented in red and records focused on the urban context are represented in blue. The number of records per year is represented by lines and the 42 book chapters from the comprehensive book (Hobbs et al., 2013c) are represented by column bars. Key moments in the evolution of the concept are highlighted and discussed with more detail in the text.

Although Hobbs et al. (2006) make reference to the urban context, the concept was only objectively applied to the urban domain in 2010 (Lugo, 2010). The term ‘‘novel urban ecosystems’’ was first employed by Kowarik (2011), highlighting the pertinence and urgency of discussing the concept in cities. Afterward, the number of publications increased and in Hobbs et al. (2013) book a total of 3 book chapters were already focused on urban areas (Perring, Manning, et al., 2013; Seastedt, 2013; Seastedt, Hartley, & Nippert, 2013). From 2014 to 2017, the number of records remained constant. In 2018 it increased again, which demonstrates a recent growing interest in studying novel ecosystems in urban areas. This concept might have started to be applied to the urban context because novelty tends to manifest in cities (Hobbs et al., 2014) and also because cities contain highly altered ecosystems. Moreover, growing concerns about the future effects of climate change and other anthropogenic effects (e.g., introduction of species, land-use change, urbanization, etc.) demand the discussion of this subject on the urban context.

Over the years, many researchers urged to provide a concise and thorough definition of novel ecosystems. 12 key records that provided a conceptual framework and a definition of novel ecosystems in non-urban and urban contexts were identified and organized in Table 2.2. For each record the definition of the concept was extracted and examined against a set of criteria proposed by Morse et al. (2014):

- *Human-induced*: novel ecosystems result from human-induced changes;
- *Species assemblages*: novel ecosystems have new species assemblages and abiotic conditions (i.e., new ecosystem composition, structure, and function);
- *Self-sustaining*: novel ecosystems are persistent and self-sustaining (i.e., do not depend on continued human intervention for their maintenance);
- *Thresholds*: novel ecosystems have crossed ecological thresholds that are practically irreversible.

Regarding the ‘‘human-induced’’ criterion, the majority of the definitions referred that novel ecosystems result from human-induced changes (‘‘anthropogenic drivers’’, ‘‘human agency’’, ‘‘by virtue of human influence’’, etc.). However, Morse et al. (2014) considered that human-induced change must be direct (whether intentional or unintentional), and indirect human agency (e.g., climate change, ocean acidification, and nitrogen deposition) should not be considered a driver of novelty. On the other hand, Radeloff et al. (2015) did not consider human agency as a criterion to identify novel ecosystems, since the influence of mankind on ecosystems is now so pervasive.

‘‘Species assemblages’’ was the only criterion referred in all the definitions. Novel ecosystems present new abiotic conditions and unprecedented species compositions that consequently change ecosystem functions, processes, patterns, interactions, etc. These novel assemblages of species comprise native and non-native organisms (Higgs, 2017) and resulted from human-induced changes such as species introductions, extinctions, colonization, land-use change, and climate change (Ahern, 2016; Hobbs et al., 2006, 2013c, 2009).

The ‘‘self-sustaining’’ criterion was only referred in some definitions (Higgs, 2017; Hobbs et al., 2006, 2013c; Morse et al., 2014). This criterion states the idea that, even though novel ecosystems result from anthropogenic drivers, they are self-organizing and do not need or depend on continued human intervention to manifest novel qualities. This is subjective and hard to identify

(Morse et al., 2014; Radeloff et al., 2015) especially because even managed or human-engineered ecosystems can reveal spontaneous dynamics such as the emergence of new species and their interactions (Backstrom, Garrard, Hobbs, & Bekessy, 2018).

The ‘‘thresholds’’ criterion has only emerged in 2009 (Hobbs et al., 2009), but persisted in some of the following definitions (Higgs, 2017; Hobbs et al., 2013c; Morse et al., 2014), particularly for non-urban contexts. This criterion reflects the idea that novel ecosystems have crossed ecological thresholds that are practically irreversible, constraining the system from returning to a previous state (i.e., the historical state). Although this idea has been considered useful for management frameworks, the ability to identify and measure ecological thresholds is still very limited (Hobbs, Higgs, & Hall, 2013d). Moreover, the capacity to restore a system will mostly depend on the available resources rather than on intrinsic properties of an ecosystem (Radeloff et al., 2015). Hobbs et al. (2013a) also argue that with enough effort, even systems that have experienced massive changes can be reversed at some extent, so the change will only be irreversible in a practical sense when resources, institutional will and social barriers prevent the reversal.

Table 2.2. Evolution of the concept definition through time in non-urban and urban contexts. The information is organized chronologically from 2003 to 2018. See Appendix 2C for the complete version of this table.

Reference	**Context**	**Criteria**			
		Human-induced	Species assemblages	Self-sustaining	Thresholds
Milton (2003)	Non-urban	X	X		
Hobbs et al. (2006)	Non-urban	X	X	X	
Hobbs et al. (2009)	Non-urban	X	X		X
Kowarik (2011)	Urban	X	X		
Hobbs et al. (2013c)	Non-urban	X	X	X	X
Morse et al. (2014)	Non-urban	X*	X	X	X
Radeloff et al. (2015)	Non-urban		X		
Truitt et al. (2015)	Non-urban	X	X		
Ahern (2016)	Urban	X	X		
Higgs (2017)	Non-urban	X	X	X	X
Kowarik (2018)	Urban	X	X		
Kowarik & von der Lippe (2018)	Urban	X	X		X

** Only direct human-induced change*

While some researchers defended that novelty occurs along a continuum or a gradient of ecological novelty (Corlett, 2014; Radeloff et al., 2015), others suggested that a more categorical classification of systems is helpful to identify if a system is novel or not (Hobbs, Higgs, & Hall, 2013a; Kowarik & von der Lippe, 2018). The definition provided by Radeloff et al. (2015) defends the idea that novelty exists along a continuum and that some ecosystems are more novel than others, i.e., novelty is everywhere with varying degrees. Other definitions also place novel ecosystems along a gradient of ecological novelty, still providing a categorization of systems sometimes with clear break-points, other times with more gradual distinctions between the systems.

For instance, Hobbs et al. (2006) placed novel ecosystems in the middle of a gradient between wild and intensively managed systems, since the authors considered that novel ecosystems result either from the degradation of wild ecosystems or from the abandonment of intensively managed systems. This idea was preceded by Milton (2003) but has not persisted in the following definitions.

The ‘‘historical-hybrid-novel’’ gradient emerged in 2009 (Hobbs et al., 2009) and prevailed in the succeeding definitions from the same group of authors (Higgs, 2017; Hobbs et al., 2013c). In this case, the authors considered that novel ecosystems should be always compared to a historical reference in which novelty represents a clear departure from a historical condition (Hobbs et al., 2013d). In this gradient, historical ecosystems represent systems that remain within their historical range of variability, hybrid ecosystems are biotically and/or abiotically different from the historical state but still able to return to a historical condition, and, finally, novel ecosystems are biotically and/or abiotically different from the historical state and have crossed a threshold that practically prevents it to return to a historical state (Hallett et al., 2013; Hobbs et al., 2009). When using this gradient, historical states should be accurately defined with a clear reference to a time and space, which not always is the case (Hobbs et al., 2013d).

Regarding the urban context, a different gradient was proposed by Kowarik (2011, 2018): the Four Natures Approach (Kowarik, 2005). This author defends urban ecosystems are submitted to different degrees of human-induced alteration resulting in a gradual transformation of remnants of pristine landscapes (‘‘nature of the first kind’’), into patches of agrarian landscapes (‘‘nature of the second kind’’), into designed urban green spaces (‘‘nature of the third kind’’), and, finally, into novel urban ecosystems (‘‘nature of the fourth kind’’). Later Kowarik (2018) established a clear relationship between the ‘‘Four Natures Approach’’ and the ‘‘historical-hybrid-novel’’ gradient that evolved to the gradient: ‘‘natural-hybrid-novel’’ (Kowarik & von der Lippe, 2018). See Figure 2.3 for an illustrative synthesis.

The definition of novel ecosystems has been highly transforming over the years and a clear distinction between the definition on non-urban and urban contexts is still in need. The constant transformation of the concept definition is usually considered one of the sources of controversy about the concept (Aronson et al., 2014; Kattan et al., 2016; Murcia et al., 2014; D Simberloff, 2015). Critics also suggest that even the terminology used (‘‘novel’’) may confer a character of innovation and improvement regarding previous ecosystems (historical ecosystems) and, therefore, influencing how society and decision makers perceive these systems (Aronson et al., 2014; Kattan et al., 2016). Researchers that criticize the concept are also concerned that the acceptance of novel ecosystems will lead to irreversible biodiversity losses through uncontrolled species invasions (Light, Thompson, & Higgs, 2013). Simultaneously, they worry that decision makers will eventually reduce investments in conservation and that land managers will renounce restoration even when it is feasible (Murcia et al., 2014).

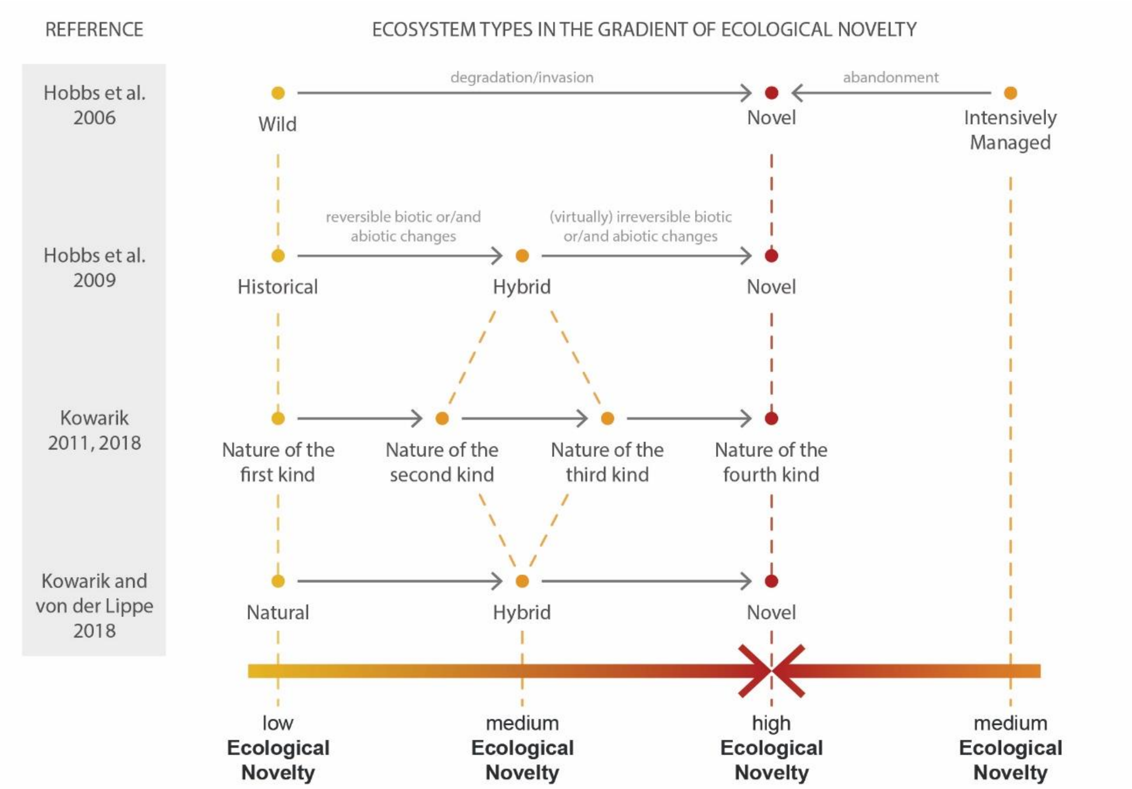


Figure 2.3. Gradients of ecological novelty based on the following publications: Hobbs et al. (2006, 2009), Kowarik (2011, 2018), Kowarik and von der Lippe (2018). Grey arrows represent the transition between types of ecosystems. Dashed lines connect types of ecosystems from different publications that are parallel. The gradient of ecological novelty is represented at the bottom of the figure, varying between low to high ecological novelty.

However, the various authors that recognize the concept share many of these concerns (Standish, Thompson, et al., 2013). Acknowledging the existence of novel ecosystems does not imply that managers cease to control invasive species or that traditional conservation and restoration practices are completely replaced from now on (Hobbs, Higgs, & Hall, 2013b; Light et al., 2013). The widespread adoption of novel ecosystems should be cautious, nonetheless, the discussion of this subject is urgent to clarify misunderstandings and concerns (Standish, Thompson, et al., 2013) (see Appendix 2D for more detailed information about the controversial aspects of novel ecosystems).

The novel ecosystems concept allows the valuation of species or communities of species that are usually considered to eradication (Starzomski, 2013). It provides opportunities for experimentation that may inform management practices in the future and develop important tools to face uncertain scenarios of change (Light et al., 2013; Radeloff et al., 2015; Standish, Thompson, et al., 2013). According to Light et al. (2013), novel ecosystems may have more species richness, contribute to increase resilience and even assist conservation efforts. Moreover, novel ecosystems can provide services such as degraded land reclamation, watershed protection, carbon sequestration and storage, habitat for rare and native species, resources, recreational opportunities, and even new ecosystem services that we still do not know (Ahern, 2016; Collier, 2014; Hobbs et al., 2014; Light et al., 2013; Mascaro, Hughes, & Schnitzer, 2012).

In the urban context, the concept can get even more relevance. The majority of the world's population lives now in urban settlements and people are increasingly experiencing nature in cities (Kowarik, 2011; MEA, 2005). Novel assemblages of species are already living and thriving in the extreme conditions of cities (Kowarik, 2011), which suggests that they may be pre-adapted to current urban climates, therefore, offering models to support climate change adaptation. This way, novel urban ecosystems can be deliberately integrated into urban planning and designed to play a key role in creating more resilient cities and in adapting to future climate changes (Ahern, 2016; Light et al., 2013). Moreover, given ongoing ecosystem transformations experienced in cities, it may not be practical or desirable to restore urban areas according to historical references (Sack, 2013; Standish, Hobbs, & Miller, 2013). This way, interventions on urban ecosystems may depend on the degree of novelty: spaces with lower levels of novelty can be restored to enhance native communities for instance, whereas spaces with higher levels of novelty can be manipulated to provide more ecological, cultural, and aesthetic services (Perring, Manning, et al., 2013; Sack, 2013).

2.3.2. Research focus of the concept in non-urban and urban contexts

The results of the classification of the records according to taxonomic groups, ecosystem types, and geographic areas for non-urban and urban contexts were represented in Figure 2.4.

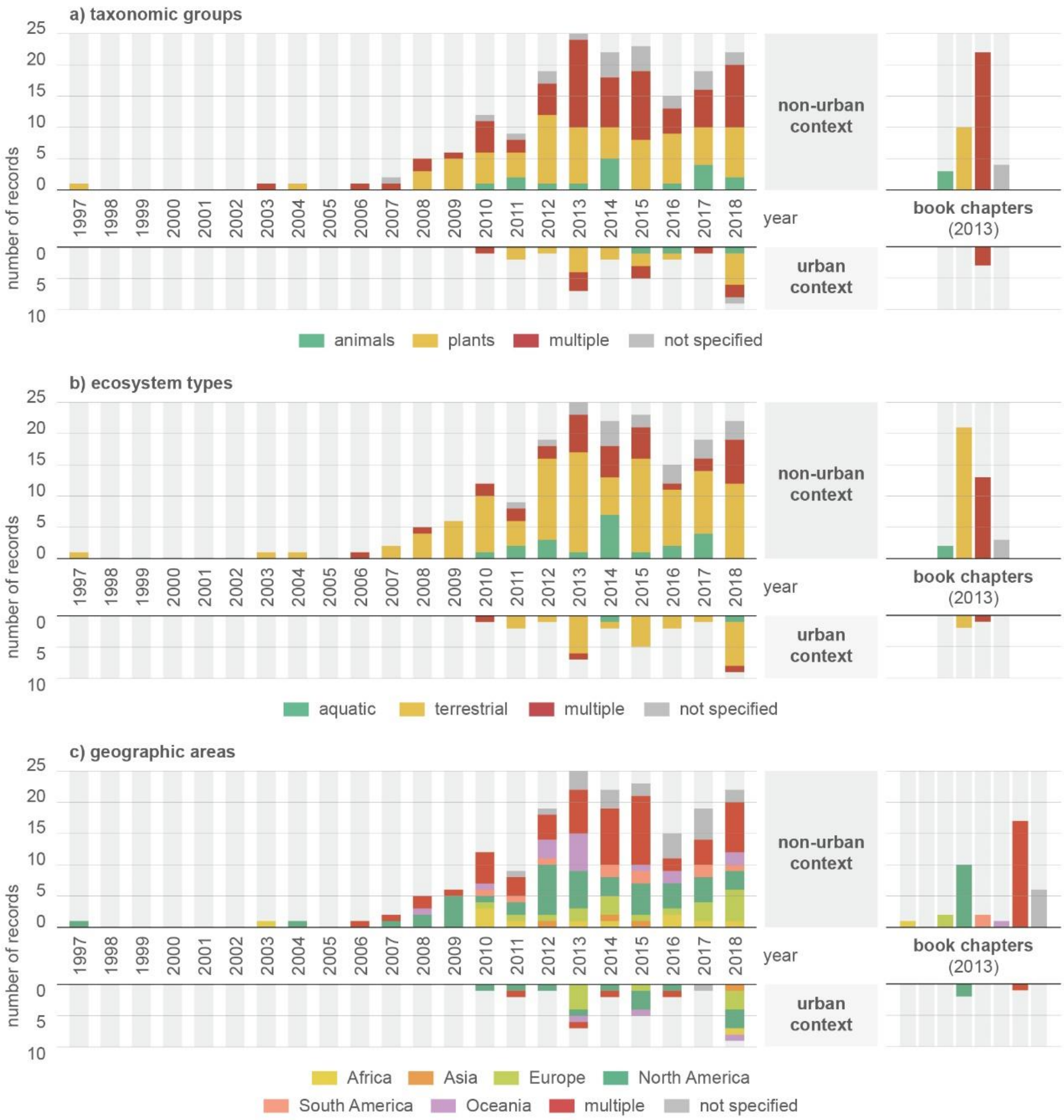


Figure 2.4. The number of published records per year (from 1997 to 2018) by category: a) taxonomic groups, b) ecosystem types, and c) geographic areas. Records are represented in stacked bar graphs (records focused on non-urban contexts are on the top and records focused on the urban context are in the bottom). The 42 book chapters from the comprehensive book (Hobbs et al., 2013c) are represented separately by column bars.

Taxonomic groups

On non-urban contexts, the majority of the records are focused on multiple taxonomic groups (41.9%), followed by plants (37.8%) and animals (9.0%), with the remaining 11.3% representing records that had no specified taxonomic group of focus. In urban contexts, the majority of the records are focused on plants (45.5%), followed by multiple taxonomic groups (42.4%) and animals (3.0%), with the remaining 9.1% representing records that had no specified taxonomic group of focus (Figure 2.4a). Records focused on multiple taxonomic groups emerged almost every year. Records focused on plants were also observed almost every year, occasionally targeting specific plant species (e.g., Kueffer et al., 2010), but often discussing plant communities. Records focused on animals were less frequent (especially on the urban context), encompassing a variety of animal classes such as birds (e.g., Pias, Fletcher Jr., & Kitchens, 2016), mammals (e.g., Müller, Dahm, Bøcher, Root-Bernstein, & Svenning, 2017), and fish (e.g., Harborne & Mumby, 2011).

Ecosystem types

On non-urban contexts, the majority of the records are focused on terrestrial ecosystems (58.6%), followed by multiple (21.2%) and aquatic ecosystems (10.4%), with the remaining 9.8% representing records that had no specified ecosystem type of focus. In urban contexts, the majority of the records are also focused on terrestrial ecosystems (81.9%), followed by multiple (12.1%) and aquatic ecosystems (6.0%) (Figure 2.4b). Records focused on terrestrial ecosystems emerged almost every year, targeting for instance forests (e.g., Lugo & Helmer, 2004), grasslands (e.g., Tognetti, 2013), and former mine sites (e.g., Doley & Audet, 2013). Records focused on multiple ecosystem types were also observed almost every year and included both terrestrial and aquatic ecosystems (e.g., Evers et al., 2018) or ecotones such as riparian ecosystems (e.g., Catford et al., 2013). Records focused on aquatic ecosystems were less frequent (especially on the urban context), focusing for instance on wetlands (e.g., Prospere, McLaren, & Wilson, 2016), rivers and streams (e.g., Ibáñez et al., 2012), and coral reefs (e.g., Graham, Cinner, Norström, & Nyström, 2014).

Geographic areas

On non-urban contexts, the majority of the studies were conducted on multiple geographic areas (33.8%), followed by North America (25.2%), Europe (9.0%), Oceania (7.7%), South America (5.4%), Africa (5.4%), and Asia (1.4%), with the remaining 12.1% representing studies that had no specified geographic area of focus. In urban contexts the majority of the studies were conducted in North America (42.4%), followed by Europe (24.3%), multiple geographic areas (15.2%), Oceania (9.1%), South America (3.0%), and Asia (3.0%), with the remaining 3.0% representing studies that had no specified geographic area of focus (Figures 2.4c, 2.5). Studies involving multiple geographic areas or with global focus emerged every year since 2006. Studies conducted on North America emerged almost every year, including in the earliest record (Chapin III & Starfield, 1997). Studies conducted in Europe and South America emerged almost every year since 2010 (Quine & Humphrey, 2010; Tognetti, Chaneton, Omacini, Trebino, & León, 2010). Studies conducted in Asia were scarce (e.g., Pethiyagoda, 2012). Note that our geographic results could be biased since we exclusively collected records written in English.

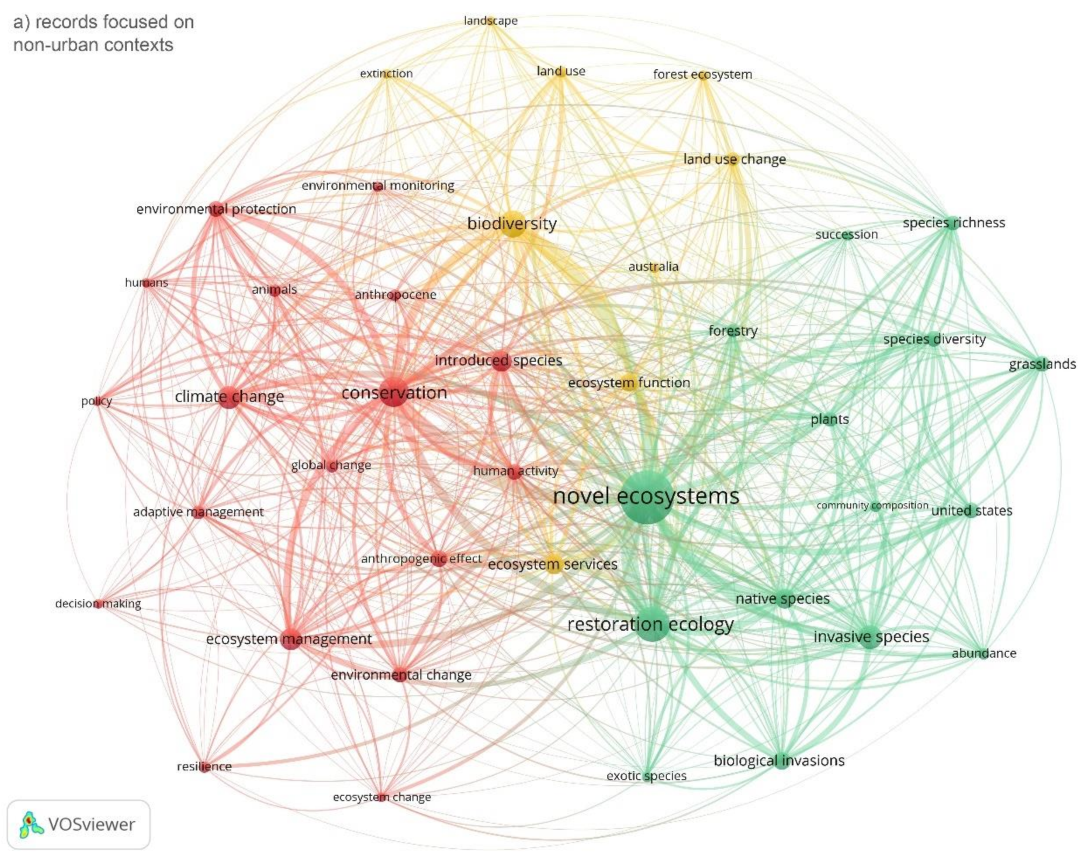
A predisposition for studying certain types of novel ecosystems in specific parts of the globe was verified. For instance, novel forests have been largely studied in Puerto Rico (Lugo, 2010; e.g., Lugo & Helmer, 2004), Hawaii (e.g., Mascaro et al., 2012) and Seychelles (e.g., Kueffer et al., 2010). Novel grasslands have been investigated in several parts of the USA such as the Blackland Prairie region of Texas (e.g., Wilsey et al., 2011) and also in Inland Pampa, Argentina (e.g., Tognetti, 2013). In Australia, several studies concerning industrial landscapes have been conducted (e.g., Erskine & Fletcher, 2013). Studies in the urban context referring to ecosystems as ''novel'' have been mostly conducted in Germany (e.g., Kowarik & von der Lippe, 2018) and in the USA (e.g., Beals, Hartley, Prevéy, & Seastedt, 2014).

Figure 2.5. Geographic distribution of the studies that provided details on the location (n = 136). The remaining studies conducted on multiple geographic areas and without specified location (n = 119) were not included in the map. The size of the circles is proportional to the number of records and colors in the pie charts represent the distribution of the records in non-urban contexts and urban contexts. Countries with a higher number of studies are captioned.

2.3.3. Discussion topics

Based on author keywords, the main discussion topics regarding novel ecosystems in non-urban and urban contexts were identified. 18 records of the final database (n = 255) did not provide author keyword information, so this analysis was made based on 237 records (93%). On the whole, there were a total of 1705 author keywords (1478 author keywords belonging to records focused on non-urban contexts and 305 author keywords belonging to records focused on the urban context). Two maps with author keywords frequency information (Figure 2.6) were generated using the open-source software VOSviewer 1.6.11 (van Eck and Waltman 2010).

Regarding the records focused in non-urban contexts, we verified that, apart from the keyword ‘‘novel ecosystems’’, ‘‘restoration ecology’’, ‘‘conservation’’, and ‘‘biodiversity’’ were the most frequent keywords, representing the three clusters formed in Figure 2.6a. Thereby, these were the most discussed topics in the examined literature. The keyword ‘‘restoration ecology’’ (blue cluster) appears closely linked to the species assemblages and invasions subject (‘‘invasive species’’, ‘‘biological invasions’’, ‘‘native species’’, and ‘‘exotic species’’). The keyword ‘‘biodiversity’’ (yellow cluster) is more associated with keywords such as ‘‘ecosystem services’’ and ‘‘ecosystem function’’. And the keyword ‘‘conservation’’ (red cluster) is more connected to keywords that reflect human-induced changes such as ‘‘climate change’’, ‘‘introduced species’’, ‘‘anthropogenic effect’’, ‘‘human activity’’, and ‘‘Anthropocene’’. On the other hand, this group of keywords is also highly linked to keywords that reflect human management and action towards the negative anthropogenic effects (‘‘ecosystem management’’, ‘‘adaptive management’’, ‘‘decision making’’, and ‘‘policy’’).



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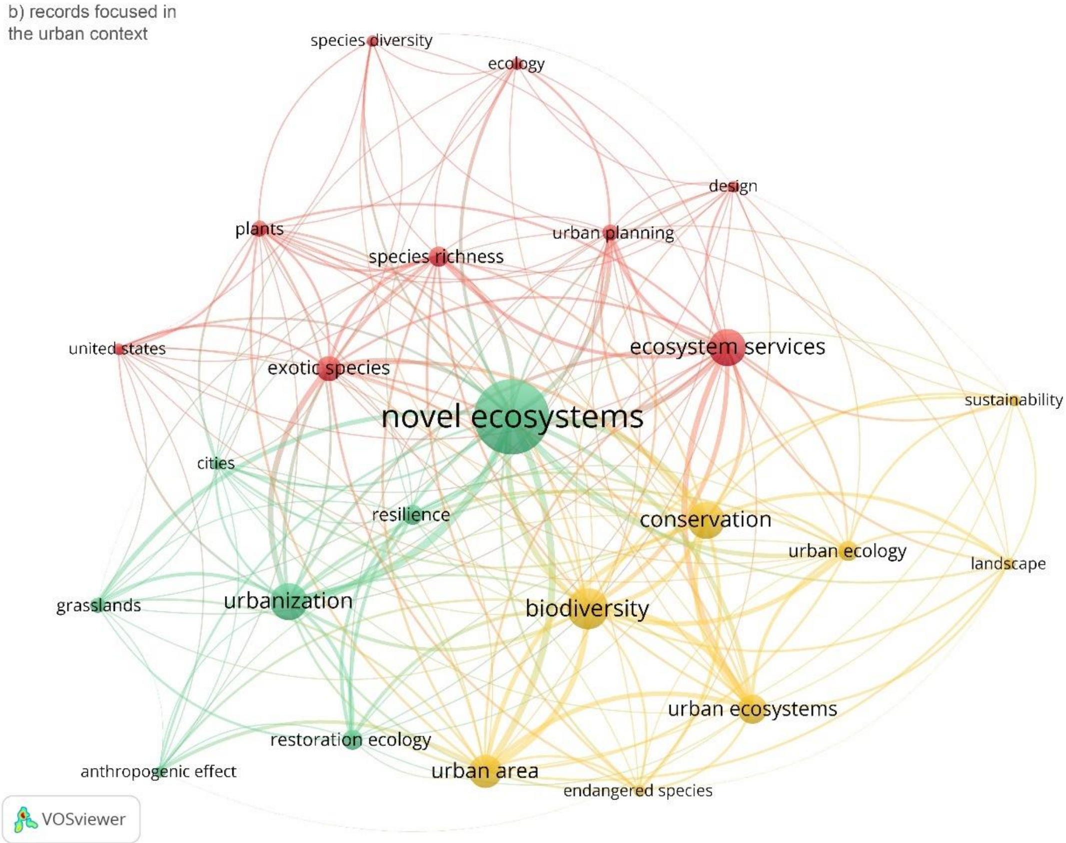

Figure 2.6. Co-occurrence network of author keyword map generated using the software VOSviewer 1.6.11 (van Eck & Waltman, 2010): a) for records focused on non-urban contexts and b) for records focused on the urban context. Each circle represents a keyword and the size of the circle varies according to the frequency of the keyword (i.e., the larger the circle the higher the frequency). The distance between circles and the established networking represented by lines characterizes the relation between keywords (i.e., keywords that are closer and have stronger links are more relatable). Colors are determined by the cluster to which the keyword belongs, which was automatically determined by the software based on the previous information.

Regarding the records focused in urban contexts, we verified that apart from the keyword ‘‘novel ecosystems’’, ‘‘biodiversity’’, ‘‘urbanization’’, and ‘‘ecosystem services’’ were the most frequent keywords, representing the three clusters formed in Figure 2.6b. Thereby, these were the most discussed topics in the novel urban ecosystems’ literature. The keyword ‘‘biodiversity’’ (yellow cluster) appears closely linked to the keyword ‘‘conservation’’. The keyword ‘‘urbanization’’ (blue cluster) is mostly associated with keywords such as ‘‘resilience’’, and ‘‘restoration ecology’’. Finally, the keyword ‘‘ecosystem services’’ (red cluster) appears closely related to keywords such as ‘‘design’’, ‘‘urban planning’’, and ‘‘exotic species’’.

The examined literature has been mostly discussed within the restoration ecology and conservation biology disciplines. These disciplines often focus on the topic of biological invasions which is considered one of the major drivers of novelty (Hobbs et al., 2006; Richardson & Gaertner, 2013). Likewise, species origins and colonization are central discussion topics regarding the concept since novel species assemblages are the product of an intense reorganization of the Earth's biotic systems (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Climate change is also frequently discussed, once it influences drastically evolutionary and ecological processes such as the distribution, interaction, and behavior of species (Starzomski, 2013). Biodiversity is a recurrent discussion topic in both non-urban and urban contexts, but we verified that the discussion about ecosystem services, non-native species, urbanization, resilience, design, and urban planning gets a greater emphasis on the urban context. Cities generally have greater plant species richness compared to rural environments due to the high heterogeneity of habitats and the presence of a high number of non-native species (Kowarik, 2011), which in turn influences the delivery of services and enhances cities' resilience. Additionally, design and urban planning have been considered important tools to promote cultural, aesthetic and regulating services (Chen, Wang, & Jia, 2018; Perring, Manning, et al., 2013; Sack, 2013).

2.4. Conclusion

This extensive systematic review intended to evaluate the existing literature that uses the terms ''novel ecosystems'' and/or ''novel urban ecosystems''. A considerable, yet recent, amount of literature was examined. This work excludes publications that only mention the term ''novel ecosystems'' without discussing it or contributing to the understanding of the concept. Nevertheless, relevant literature about the concept might as well have been excluded since the concept had different designations and also because it may exist research about this subject that uses other terminology.

Based on the examined literature, a thorough description of the history and relevance of the concept in non-urban and urban contexts was provided, as well as an evaluation of what has been the focus of the research on this subject. The definition and criteria used to describe novel ecosystems have been transforming over the years. Research on this subject has been mainly targeted on multiple taxonomic groups and plants, on terrestrial ecosystems, and has been mainly conducted in North America. Overall, the most discussed topics in the examined literature were restoration ecology, conservation, biodiversity, ecosystem services, and climate change. Although novelty occurring in the urban domain was not profoundly explored in the original elaboration of the concept (Perring, Manning, et al., 2013), this review confirms that the application of the concept to urban areas is not only pertinent but also necessary and opportune.

There has been less research investment in the urban context, but we believe that this is where the concept can get more clarification and future research opportunities.

Although over the last 22 years research has produced relevant findings, there are still many unanswered questions. For instance, is everything novel in cities or urban ecosystems are comprised of different degrees of ecological novelty? Do we need a different definition and criteria to identify novel urban ecosystems? More information is needed to fully understand if the concept gets different limits in the city since urban ecosystems are constantly changing and have the constant presence of human-agency. Future research should continue this dialogue and address the clarification of the concept by creating and testing methodologies to classify and measure novelty in non-urban and urban contexts. Challenges posed by novelty should not overshadow the opportunities of researching these ecosystems, especially in urban areas. Novel ecosystems might become the new normal and novel urban ecosystems an unavoidable component of contemporary cities where most of the world’s population now lives.

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Supplementary material

Appendix 2A. Details on the literature search process and inclusion/exclusion criteria used.

This systematic review was conducted according to the guidelines provided by the CEE (2018), and following the subsequent steps (Figure 2A.1):

Step 1. Literature search in databases

The literature search was performed using the search terms “novel ecosystems” OR “novel urban ecosystems” in the following search engines: ISI Web of Science Core Collection, Scopus, and ScienceDirect. The time span of the search corresponded to all years to 2018 and the searches were conducted in April 2019. This process resulted in 1074 initial records (see Table 2A.1 for more details on the literature search in databases).

Table 2A.1. Details on the literature search in databases.

Database	Web of Science Core Collection (at: http://webofknowledge.com/)
Search terms	"novel ecosystem*" OR "novel urban ecosystem*"
Search within	Topic (searches title, abstract, author keywords, and keywords plus)
Time span	All years to 2018
Hits	433 hits
Database	Scopus (at: https://www.scopus.com/)
Search terms	"novel ecosystem" OR "novel urban ecosystem"
Search within	Article title, Abstract, Keywords
Time span	All years to 2018
Hits	522 hits
Database	ScienceDirect (at: https://www.sciencedirect.com/)
Search terms	"novel ecosystem" OR "novel urban ecosystem"
Search within	Title, abstract or author-specified keywords
Time span	All years to 2018
Hits	119 hits

Step 2. Removal of duplicates

The 1074 records retrieved from each database were combined and stored in the referencing software EndNote X8 where 526 duplicate records were identified and removed. This process resulted in 548 unique records.

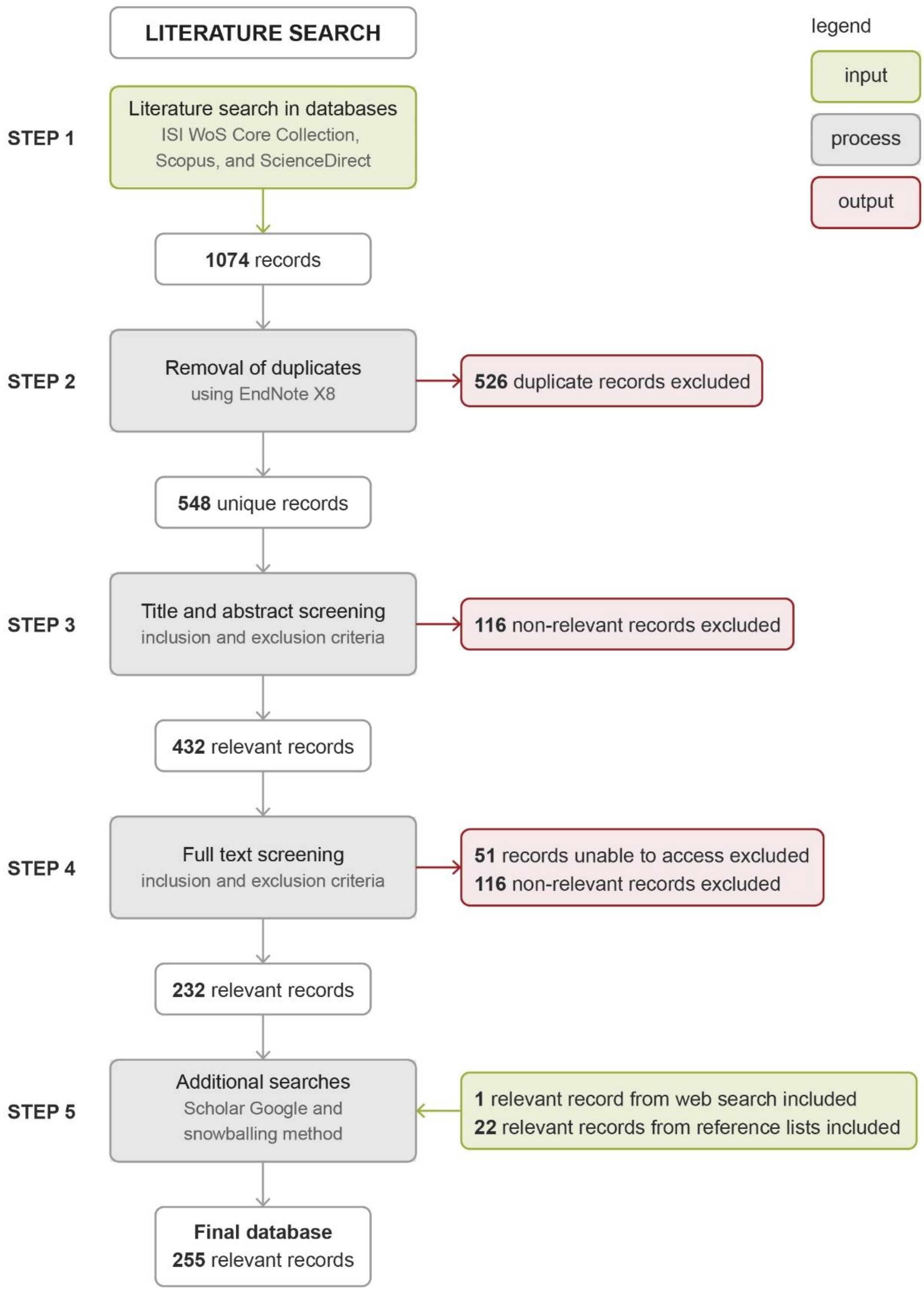

Figure 2A.1 Details on the literature search process. Diagram based on the guidelines provided by the (CEE (2018).

Step 3. Abstract and title screening

In order to screen records for relevance, we first examined individually the abstract and title of each of the 548 records and applied inclusion/exclusion criteria. We considered the novel ecosystems concept as it was first described in literature by Hobbs et al. (2006, p. 2): "*Novel ecosystems (also termed 'emerging ecosystems', e.g. see Milton, 2003) have species compositions and relative abundances that have not occurred previously within a given biome. The key characteristics are (1) novelty: new species combinations, with the potential for changes in ecosystem functioning; and (2) human agency: ecosystems that are the result of deliberate or inadvertent human action, but do not depend on continued human intervention for their maintenance*". Records that apparently were focused on the concept and records with insufficient information (e.g., records with the abstract absent) were considered as potentially relevant – 432 potentially relevant records included. Thereby, we excluded records that, even though had the terms "novel ecosystems" OR "novel urban ecosystems", clearly departed from this concept and/or were clearly from unrelated research areas (e.g., Medicine and Computer Sciences) – 116 non-relevant records excluded. This resulted in a database with 432 records.

Step 4. Full text screening

Then, we examined individually the full text of each of the 432 potentially relevant records and applied inclusion/exclusion criteria. For a record to be considered as relevant it had to discuss and explore the concept (and not just mention it), contribute to a better understanding of novel ecosystems and/or provide case studies or examples of novelty around the globe – 232 relevant records included. Regarding the type of references, we included books, book chapters, encyclopedias, conference proceedings, and journal articles (book reviews, brief/short communications, commentaries, concept papers, editorials, essays, forum articles, insights, letters, notes, opinion articles, perspectives, research articles, reports, reviews, synthesis). Regarding language restrictions, we included records written in English, Spanish, or Portuguese if only the English terms "novel ecosystems" OR "novel urban ecosystems" were at least referred in the title, abstract or keywords of the record. Thereby, we excluded records unable to access the full text (51 records excluded) and records that were not sufficiently focused on the concept (records that only mention the concept) – 149 non-relevant records excluded. This process resulted in a database with 232 records.

Step 5. Additional searches

Finally, to ensure a comprehensive review of the literature about this subject, we additionally performed a web literature search in Scholar Google using the same search terms and time span (see Table 2A.2 for more details on the web literature search). We examined the full text of the first 50 hits retrieved by Scholar Google and included relevant records that were absent from the database – 1 relevant record included. Then, we also adopted the snowballing method in which the reference lists of the relevant records were screened for relevance by examining first the available information (e.g., title and authors) and, only then, examining the full text if the new records were potentially relevant and absent from the database (see CEE 2018 for more details) – 22 relevant records included. This process resulted in a final database with 255 records. Although there was an effort to collect all the relevant literature about this concept, we note that this may not have been completely possible for two reasons: 1) in an earlier phase the concept had other designations such as “synthetic ecosystems” (Odum, 1962) and “emerging ecosystems” (Milton, 2003), and 2) since the term "novel ecosystem" has been disapproved by some researchers it may exist other publications about the concept that are simply using other terminology.

Table 2A.2. Details on the web literature search in Scholar Google.

Database	Scholar Google (at: https://scholar.google.pt/)
Search terms	"novel ecosystem" OR "novel urban ecosystem"
Time span	All years to 2018
Hits	the first 50 hits checked at full text

References

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Appendix 2B. Author keywords frequency analysis using the software VOSviewer 1.6.11 (van Eck & Waltman, 2010).

In order to assess which have been the most discussed topics in the literature regarding the novel ecosystem concept in non-urban and urban contexts, we analyzed the author keywords frequency of the records. 18 records of the final database (n=255) did not provide author keyword information, so this analysis was made based on 237 records (93%). Using the open-source software VOSviewer 1.6.11 (van Eck & Waltman, 2010) two maps based on bibliographic data were generated: one based on the records focused on non-urban contexts (n=205) and other based on the records focused in the urban-context (n=32). We used data from reference manager files (RIS files) and then we selected the co-occurrence analysis of author keywords, in which the relatedness of the terms was determined based on the number of records in which the terms occurred together. For each map, we had to determine a minimum number of occurrences of a keyword. Since the number of available records was so different for non-urban and urban contexts, we opted to select a minimum of 7 occurrences for records focused on non-urban contexts and a minimum of 3 occurrences for records focused in the urban-context. Additionally, the VOSviewer software allows the use of a “thesaurus file” for data cleaning. Using this file, we were able to merge redundant keywords, i.e., words with the same meanings. For instance, we merged inflected forms of a word (e.g., plant, plants) and also words that were clearly synonyms or related (e.g., invasive species, invasive plants). The most frequent keywords are presented in Table 2B.1.

Table 2B.1. Frequency of author keywords in non-urban contexts, urban context, and in both (total). The table is organized by the total frequency.

Keyword	Frequency in non-urban contexts	Frequency in urban contexts	Total frequency
Novel ecosystems	113	18	131
Restoration ecology	58	5	63
Conservation	45	9	54
Ecosystems	47	5	52
Biodiversity	38	10	48
Invasive species	31	2	33
Ecosystem services	22	9	31
Climate change	28	1	29
Ecosystem management	26	1	27
Introduced species	25	2	27
Native species	22	2	24
Ecology	20	3	23
Biological invasions	20	2	22
Anthropogenic effect	17	3	20

(Continued …)

Keyword	Frequency in non-urban contexts	Frequency in urban contexts	Total frequency
Ecosystem function	19	1	20
Grasslands	16	4	20
Species diversity	16	3	19
Species richness	14	5	19
Plants	14	4	18
United States	15	3	18
Environmental change	16	1	17
Environmental protection	15	1	16
Exotic species	9	6	15
Human activity	15	-	15
Resilience	10	5	15
Land use change	13	1	14
Animals	11	2	13
Forestry	13	-	13
Adaptive management	12	-	12
Global change	11	1	12
Anthropocene	10	1	11
Australia	9	2	11
Community composition	10	-	10
Decision making	7	2	9
Urbanization	-	9	9
Ecosystem change	7	1	8
Forest ecosystem	8	-	8
Urban area	-	8	8
Policy	7	-	7
Urban ecosystems	-	7	7
Design	3	3	6
Sustainability	3	3	6
Urban ecology	-	5	5
Urban planning	-	4	4
Cities	-	3	3

Results and discussion were presented in the main text.

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Appendix 2C. Evolution of the concept definition through time in non-urban and urban contexts.

The information is organized chronologically from 2003 to 2018. Criteria were determined based on the literature that defines novel ecosystems: Human-induced (**HI**) – novel ecosystems result from human-induced changes; Species assemblages (**SA**) – novel ecosystems have new species assemblages and abiotic conditions (i.e., new ecosystem composition, structure, and function); Self-sustaining (**SS**) – novel ecosystems are persistent and self-sustaining (i.e., do not depend on continued human intervention for their maintenance); and Thresholds (**T**) – novel ecosystems have crossed ecological thresholds that are practically irreversible.

REFERENCE	CONTEXT	DEFINITION	CRITERIA			
			HI	SA	SS	T
(Milton, 2003)	Non-urban	*"An [Emerging Ecosystem] was defined at the Granada workshop as 'An ecosystem whose species composition and relative abundance have not previously occurred within a given biome'. (…) … all definitions had in common an initial, often short-lived, anthropogenic driver of persistent biological and physical change and emergence of novel combinations of species."*	X	X		
(Hobbs et al., 2006)	Non-urban	*"Novel ecosystems … have species compositions and relative abundances that have not occurred previously within a given biome. The key characteristics are (1) novelty: new species combinations, with the potential for changes in ecosystem functioning; and (2) human agency: ecosystems that are the result of deliberate or inadvertent human action, but do not depend on continued human intervention for their maintenance. (…) These types of ecosystems can be thought of as occupying a zone somewhere in the middle of the gradient between 'natural' or 'wild' ecosystems, on one hand, and intensively managed systems on the other hand."*	X	X	X	
(Hobbs, Higgs, & Harris, 2009)	Non-urban	*"… systems whose characteristics have changed as a result of human modification of 'wild' or 'natural' systems or the abandonment of previously managed systems, particularly abandoned agricultural lands. (…) A novel ecosystem … is one in which the species composition and/or function have been completely transformed from the historic system: such a system might be composed almost entirely of species that were not formerly native to the geographic location or that might exhibit different functional properties, or both. (…) three main types of system state: (i) historical, within which ecosystems remain within their historical range of variability; (ii) hybrid, within which ecosystems are modified from their historical state by changing biotic and/or biotic characteristics; and (iii) novel, within which systems have been potentially irreversibly changed by large modifications to abiotic conditions or biotic composition."*	X	X		X

(Continued …)

REFERENCE	CONTEXT	DEFINITION	CRITERIA HI	CRITERIA SA	CRITERIA SS	CRITERIA T
(Kowarik, 2011)	Urban	*"Although cities as a whole can easily be seen as novel systems contrasting with rural surroundings, scaling down to the habitat level shows significant differences. … urban regions usually present a mosaic of fragmented habitats that differ conspicuously in their history and their pace and level of transformation from pristine to urban ecosystems. … types of ecosystems that can occur within urban areas, reflecting different human-mediated transformation stages… (…) … can be conceptualized simply as different kinds of nature that reflect the transformation of pristine environmental conditions due to urbanization ("the four natures approach" …). In terms of urban novelty, emerging ecosystems on previously built-up areas or heavily changed urban land are novel ("nature of the fourth kind") …"*	X	X		
(Hobbs, Higgs, & Hall, 2013)	Non-urban	*"A system of abiotic, biotic and social components (and their interactions) that, by virtue of human influence, differ from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management. Novel ecosystems are distinguished from hybrid ecosystems by practical limitation (a combination of ecological, environmental and social thresholds) on the recovery of historical qualities. (…) … the definition [illustrates] the relationship between historical, hybrid and novel ecosystems, based on the degree of change from historical conditions and reversibility of that change."*	X	X	X	X
(Morse et al., 2014)	Non-urban	*"A novel ecosystem is a unique assemblage of biota and environmental conditions that is the direct result of intentional or unintentional alteration by humans, i.e., human agency, sufficient to cross an ecological threshold that facilitates a new ecosystem trajectory and inhibits its return to a previous trajectory regardless of additional human intervention. The resulting ecosystem must also be self-sustaining in terms of species composition, structure, biogeochemistry, and ecosystem services. A defining characteristic of a novel ecosystem is a change in species composition relative to ecosystems present in the same biome prior to crossing a threshold. (…) We hold that indirect anthropogenic stresses … should not be considered drivers of novel ecosystem formation."*	X*	X	X	X
(Radeloff et al., 2015)	Non-urban	*"We do not use human agency as a criterion for novelty because the effects of human agency on contemporary ecosystems are now so pervasive that there is no meaningful way to identify ecosystems lacking any human touch… (…) We define novelty as the degree of dissimilarity of a system … (…) This means novelty exists along a continuum, and while it is pervasive, it is much higher in some places than others. (…) Novelty occurs in multiple dimensions, both abiotic and biotic. (…) Biotic novelty can result from changes in species composition, structure, or ecological processes. (…) Novelty is everywhere, but at varying degrees…"*		X		
(Truitt et al., 2015)	Non-urban	*"We propose the following working definition of novel ecosystems: an ecosystem modified by anthropogenic drivers (changes in hydrologic, nutrient, physical, or biotic conditions) during historic or present time that substantially changes ecosystem functioning."*	X	X		

***** *Only direct human-induced change*

(Continued …)

REFERENCE	CONTEXT	DEFINITION	CRITERIA			
			HI	SA	SS	T
(Ahern, 2016)	Urban	*"Here, I offer a "working" definition of novel urban ecosystems as: Ecosystems that persist or arise in cities, resulting from - and structured by - intentional or indirect human management actions (including inaction/abandonment); with unique species composition and structure influenced by biotic introductions and invasions; and that provide a suite of ecosystems services / disservices resulting from interactions of the biota with the altered abiotic urban environment."*	X	X		
(Higgs, 2017)	Non-urban	*"Novel ecosystems are identified by three characteristics ... First, they comprise native and exotic organisms, often operating under biophysical conditions and selection pressures distinctly different from those that existed prior to significant human disturbance. Second, novel ecosystems are persistent, having developed metastable population, community, and landscape conditions that are both new and ongoing without extensive human intervention. Third, in practical terms, novel ecosystems cannot be restored to historical conditions ... (…) … a novel ecosystem exists at significant distance from historical ecosystems that are typically the focus of restoration ecology. In between historical and novel ecosystems are hybrid ecosystems that comprise historical and novel elements."*	X	X	X	X
(Kowarik, 2018)	Urban	*"Urban systems are subject to different degrees of human interference, leading to a stepwise transformation of pristine ecosystems to novel urban ecosystems... The "Four Natures approach" (Kowarik, 1992) narrows down the variety of transformational stages in urban settings to four major types … (…) … [and] predates the novel ecosystem concept of Hobbs et al. (2013), but maps to it easily: Nature 1 parallels Hobbs "historical ecosystems", Nature 4 clearly corresponds to "novel ecosystems", while "hybrid ecosystems" largely overlap with Natures 2 and 3. The trajectory of manifestations of Nature 1 to those of Nature 4 can thus be arranged along a gradient of ecological novelty, in terms of both novel habitats and novel species assemblages since the abundance of nonnative species usually increases with ongoing transformation."*	X	X		
(Kowarik & von der Lippe, 2018)	Urban	*"Novel ecosystems: Human-mediated ecosystems emerging mostly after built structures have replaced previous ecosystems; profound shifts in abiotic or biotic conditions prevent (Hobbs et al., 2013) or slow conversion towards the historical state. We differentiate two subtypes of novel ecosystems here: (1) immature novel ecosystems that are largely shaped by recent human disturbances or continued disturbance regimes; (2) mature novel ecosystems that are still affected by irreversibly altered site conditions but are currently largely modulated by natural ecosystem processes rather than recent or ongoing anthropogenic disturbances."*	X	X		X

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Appendix 2D. Controversy and criticism: concerns and misunderstandings about the novel ecosystems concept discussed in the literature.

Arguments from researchers that are against the concept (middle column) versus arguments from researchers that advocate the concept (right column).

Concerns and/or Misunderstandings	Arguments from researchers that are against the concept	Arguments from researchers that advocate the concept
Definition of the concept	• The novel ecosystems concept is inaccurately defined, ambiguous, poorly developed and is constantly mutating (Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016; Murcia et al., 2014; Simberloff, 2015). • No quantitative criteria to characterize novel ecosystems has been developed (Aronson et al., 2014; Simberloff, 2015).	• The development of a concept is ongoing and empirical evidence to support the novel ecosystems concept is increasing (Hobbs, Higgs, & Harris, 2014). • The definitions of concepts in restoration ecology are usually succinct and broad in scope (Miller & Bestelmeyer, 2017). • The novel ecosystems definition has been evolving but the foundations of the definition remain the same. Criticism is a crucial component in the development of new concepts and frameworks (Higgs, 2017).
"Novel" terminology	• The term "novel" has a positive connotation and sends a message of scientific improvement over historical ecosystems, which may cause confusion (Aronson et al., 2014; Kattan et al., 2016; Murcia et al., 2014). • A large number of citations about novel ecosystems may simply reflect a social contagion phenomenon instead of evidence that the concept has become a useful framework for restoration practice (Kattan et al., 2016).	• The term "novel" simply names a type of ecosystem that is not historical (instead of using the pejorative label "degraded") and allows for practitioners to justify alternative goals when restoration is not practical or desirable (Miller & Bestelmeyer, 2016). • The keyword "novel ecosystems" is already well established in the scientific community and has been largely cited in journal articles since 2006 (Miller & Bestelmeyer, 2016). The keyword "novel ecosystems" has been cited 352 times in journal articles since 2006 (excluding articles with Richard Hobbs as an author). These numbers are based on a literature search of titles, abstracts, and keywords, which suggests that the topic of novel ecosystems is central to the content of these articles rather than merely reflecting a social contagion phenomenon (Miller & Bestelmeyer, 2017).

(Continued …)

Concerns and/or Misunderstandings	Arguments from researchers that are against the concept	Arguments from researchers that advocate the concept
Value of the concept	• It is not necessary to develop new labels to define transformed ecosystems as it will only generate confusion and may influence people to abandon attempting restoration if it is difficult and expensive (Aronson et al., 2014). • The novel ecosystems concept has little pragmatic value and does not provide new insight on how to deal with modified ecosystems (Kattan et al., 2016). • The novel ecosystems concept is not a useful theory or framework as it offers general approaches to restoration that are already established principles in ecological restoration (Kattan et al., 2016).	• Novel ecosystems will probably be more appreciated in coming years, given the critical role they will likely play in adapting to a warmer world and providing benefits to people, innovative management approaches, increased resilience, etc. (Light, Thompson, & Higgs, 2013). • The concept provides pragmatism and supports conservation aims (Hallett et al., 2013). • The novel ecosystems concept is finding traction with practitioners who deal and struggle with altered ecosystems on a daily basis (Hobbs et al., 2014). • Practitioners need guidance to prioritize their actions and many find the novel ecosystems concept useful for framing what they observe in the fieldwork (Hobbs et al., 2014). • The concept provides an opportunity to revisit theories and frameworks in order to adapt them to the relentless ecosystems change (Radeloff et al., 2015).
Questioning traditional Restoration and Conservation	• The novel ecosystems concept advocates that 'traditional' conservation and restoration approaches should be reformulated and that embracing novelty is the way to move forward (Kattan et al., 2016; Murcia et al., 2014). • Novel ecosystems might undermine initiatives and diminish investments intended to protect or restore natural ecosystems and for that reason, scientists should be cautious when embracing novelty (Murcia et al., 2014). • The possibility that novel ecosystems can be molded to yield ecosystem services is in its earliest infancy whereas ecological restoration has been progressing (Simberloff & Vitule, 2014). • Successful restoration projects were implemented in areas that could have been considered novel (Aronson et al., 2014).	• Valuing novel ecosystems should not necessarily entail disvaluing other types of ecosystems with less of a human imprint (Light et al., 2013). • The novel ecosystems concept offers new restoration opportunities when the decision to recover the historic condition may not be the best alternative, and allows a discussion of the options available based on priorities and the likelihood of success of different of interventions (Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Hobbs et al., 2014; Miller & Bestelmeyer, 2017; Standish, Thompson, Higgs, & Murphy, 2013). • Embracing novelty does not advocate a completely new paradigm in restoration and it does not mean that all current efforts in conservation and restoration will be abandoned (Hobbs et al., 2014; Miller & Bestelmeyer, 2017). The concept will not replace restoration, in contrast it will expand available options (Higgs, 2017).

(Continued …)

Concerns and/or Misunderstandings	Arguments from researchers that are against the concept	Arguments from researchers that advocate the concept
Ecosystems that "lower the bar"	• The novel ecosystems concept lowers the bar and may provide a 'license to trash' that will legitimize the tendency of society to ignore negative environmental and ecological impacts in the long term (Murcia et al., 2014). • The idea that novel ecosystems are inevitable (and even desirable) encourages to delay the prevention of several harmful environmental impacts rather than to undertake new approaches and to devote new resources (Simberloff, 2015).	• In a rapidly changing world, nature must be conserved in its many forms, including entirely unprecedented patterns (Hobbs et al., 2014). • Novel Ecosystems should not always be viewed as "degraded" ecosystems but, instead, as ecosystems that are different from what was there before and not necessarily in need of restoration (Hobbs, 2016).
Irreversible thresholds	• The novel ecosystems concept relies on the idea that an ecological threshold has been irreversibly crossed. However, crossing a threshold does not imply irreversibility. Restoration efforts have demonstrated that many thresholds can be crossed back with appropriate efforts (Murcia et al., 2014). • Ecological restoration is an emerging field that has not yet achieved the scientific maturity to decide when an ecosystem cannot be reversed to a historical state (Murcia et al., 2014). • Barriers to restoration based on socioeconomic and political limitations should not be confused with ecological thresholds (Aronson et al., 2014). • The argument that novel ecosystems are inevitable is incorrect because the claim that we can do nothing to redress anthropogenic changes is unwarranted. There is no evidence that any particular ecosystem cannot be restored as the impediments are not scientific and technological but economic and political (Simberloff, 2015).	• Even if barriers in restoration are frequently socioeconomic rather than ecological, these factors are rarely separable in practice (Hobbs et al., 2014). • While it may be theoretically possible to intervene in virtually any ecosystem, the effort required (cost and chance of success) is what constitutes the main barrier (Hobbs et al., 2014). • Several changes may be irreversible in practical terms due to resources, institutional will, policy settings and other social factors (Hobbs, Higgs, & Hall, 2013).

(Continued …)

Concerns and/or Misunderstandings	Arguments from researchers that are against the concept	Arguments from researchers that advocate the concept
Embracing non-native species	• Recent research shows that many introduced species have consequences for entire ecosystems that are initially subtle. Many non-native species persist harmlessly in restricted areas and numbers for an extended period before suddenly spreading across the landscape (Simberloff & Vitule, 2014). • Attempts to control non-native species based on currently perceived impacts rather than the origin of the species is a risky strategy because our knowledge about invasion impacts is still limited (Simberloff & Vitule, 2014).	• Management frameworks that include novel ecosystems do not entail that invasive species will be left unmanaged and measures to prevent the spread of invasive species into new regions will not be important (Perring, Standish, & Hobbs, 2013; Standish et al., 2013). • Since the presence of non-native species in ecosystems is unavoidable, it will be important to distinguish invasive (or potentially invasive) species from species that are not invasive and not likely to become invasive in the future (Standish et al., 2013). • The removal of all introduced species would not only be unfeasible but also undesirable. This way, there is support for prioritization of non-native species control on the basis of their impacts, and valuable benefits that introduced species perform in ecosystems (Miller & Bestelmeyer, 2016). • The acknowledgement of non-native species by proponents of the novel ecosystem concept tend to focus on recognizing positive impacts of these species in altered ecosystems, regardless of their origin (Miller & Bestelmeyer, 2016).

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3

CHAPTER 3 |

NOVEL URBAN ECOSYSTEMS: OPPORTUNITIES FROM AND TO LANDSCAPE ARCHITECTURE

"The dichotomies that separate people from nature, and native from non-native species, present contradictions that landscape architects must resolve if they hope to have a lasting impact on the environments they design." (Del Tredici, 2014)

Chapter 3 | Novel Urban Ecosystems: Opportunities from and to Landscape Architecture

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Article published as a short communication in *Land*

Type of article: Short communication
Journal Impact Factor (2020): 3.395

Citation: Teixeira, C. P., Fernandes, C. O., & Ahern, J. (2021). Novel Urban Ecosystems: Opportunities from and to Landscape Architecture. *Land*, 10(8), 844.
https://doi.org/10.3390/land10080844

Abstract

Novel assemblages of biotic, abiotic, and social components resulting from human-induced actions (e.g., climate change, land-use change, species movement) have been labeled as “Novel Ecosystems”, or “Novel Urban Ecosystems” when emerging in urban contexts. This concept has been shifting perspectives among some scientists and making them question traditional values about human-nature interactions in a rapidly changing era dominated by anthropogenic actions (Anthropocene). Controversial dimensions surrounding the Novel Ecosystems and Novel Urban Ecosystems terms may be preventing the evolution and further research of these concepts. The environmental problems that our society will soon face support a search for innovative solutions and transdisciplinary efforts. For that reason, this discussion should not cease, rather should expand to other fields of knowledge that can contribute with pertinent insights and collaborations. This way, this short communication aims to reflect on the opportunities from Landscape Architecture to the discussion, research, and application of the novel ecosystem concepts in the real world, particularly in the urban landscape, and also reflect on the opportunities of this debate to the Landscape Architecture field. Ultimately, Landscape Architecture can contribute with innovative and creative perspectives, acceding valuable and advanced tools, facilitating dialogues between fields of knowledge, and bridging gaps between science, people, and nature.

Keywords: Anthropocene; Concept; Controversy; Design; Human-Nature interactions; Landscape; Novel Ecosystems; Transdisciplinarity

3.1. Introduction

Over the last decades a concept has emerged to describe unprecedented combinations (and interactions) of biotic, abiotic, and social components resulting from human-induced actions (e.g., climate change, land-use change, or species movements), but with a tendency to manifest novel qualities without, or in spite of, extensive human intervention (Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013a; Morse et al., 2014). “Novel Ecosystems” (NE) are challenging conventional conservation and restoration practices and raising controversial questions in the scientific community (Light, Thompson, & Higgs, 2013; Standish, Thompson, Higgs, & Murphy, 2013). The debate around this concept aims mostly at defining appropriate management, restoration, and conservation targets in a rapidly changing era dominated by anthropogenic actions (i.e., the Anthropocene) (Reid & Aronson, 2017). In the urban context, the concept is being referred to as “Novel Urban Ecosystems” (NUE) and has gained a renewed relevance since ecological novelty is widespread in urban landscapes, where the impacts of human actions are more profound and prevalent (Hobbs, Higgs, Hall, et al., 2014; Kowarik, 2011; Teixeira & Fernandes, 2020).

Although some researchers recognize the usefulness of these concepts (NE and NUE) in the Anthropocene context without pre-established value judgments (Hobbs, Higgs, & Hall, 2013c; Lugo, Winchell, & Carlo, 2018; Mascaro et al., 2013; Perring et al., 2013; Standish, Thompson, et al., 2013), others are against them, raising numerous reservations and concerns about the emergence and propagation of these ecosystems (Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016; Murcia et al., 2014; Simberloff, 2015). The controversy involving NE and NUE irremediably influences researchers’ and practitioners’ perceptions about this subject and may prevent the concepts from being further applied or investigated at a more advanced level. For that reason, the debate around NE and NUE should continue and should even expand to include other disciplines across the natural and social sciences, arts, and humanities (Heger et al., 2019; Naveh, 2007; Standish, Thompson, et al., 2013).

This short communication aims to reflect on the possible opportunities from Landscape Architecture to this debate, and, on the other hand, reflect on the opportunities of this exciting debate to the Landscape Architecture field, particularly in the urban context (NUE), where the connection with the discipline is most relevant. We argue that Landscape Architecture can contribute to the understanding and clarification of this concept mainly in urban contexts. The horticultural, ecological, and design knowledge and skills of the profession can support the investigation of these ecosystems in the real world and facilitate the integration of the NUE concept in the planning, design, and management of the urban landscape. Additionally, the NUE concept can also be relevant for the evolution of the discipline, especially by promoting a professional practice more grounded and focused on solving environmental problems emerging worldwide in the “new” age of the Anthropocene, and therefore able to keep up with current hot topics and innovation pathways.

To address these objectives, it is important, however, to explain and synthesize the most consistent and dominant controversial aspects of this concept by presenting the arguments both researchers’ factions have used in the literature, namely resorting to published papers that have initiated an ongoing action-reaction discussion. This short communication is structured to address these objectives as follows:

- First, we present a background of the most controversial dimensions of the general NE concept, which in most cases can be extrapolated to the concept in the urban context (NUE) as well. We focus particularly on the concept’s definition and terminology, pragmatism and utility, and concerns and misunderstandings;
- Then, we present arguments that support the opportunities from and to Landscape Architecture, briefly resorting to examples that demonstrate how the profession has already contributed to this subject.

3.2. Controversial dimensions of the Novel Ecosystems concept

Controversy arises mostly related to the general NE concept as it emerged first in the literature and the dissemination of these types of ecosystems in non-urban areas are considered more problematic to conservation and restoration efforts (Aronson et al., 2014; Kattan et al., 2016; Murcia et al., 2014; Simberloff, 2015). In urban areas, NUE are increasingly being assumed as already largely widespread (Hobbs, Higgs, Hall, et al., 2014; Kowarik, 2011; Perring & Ellis, 2013) and occurring in different degrees of urban ecological novelty throughout urban green spaces (Schittko et al., 2020; Teixeira, Fernandes, Ahern, Honrado, & Farinha-Marques, 2021). Although NUE still needs clarification and further research, the concept appears to be gaining acceptance and increasing relevance among researchers and practitioners compared to the NE concept.

3.2.1. Definition and terminology

Even though it describes a not-so-novel phenomenon, the original and general concept of NE emerged in the scientific literature just over two decades ago (Handel, 2015; Heger et al., 2019; Mascaro et al., 2013) and was later applied to the urban context (NUE) (Kowarik, 2011; Lugo, 2010). The concept’s acceptance in the literature has been quite problematic as several authors have attempted to define it differently, causing some authors to argue against the concept (Hobbs et al., 2006, 2013a; Hobbs, Higgs, & Harris, 2009; Morse et al., 2014; Radeloff et al., 2015; Truitt et al., 2015). The opposing faction claims that the general NE concept is inaccurately defined, ambiguous, continuously mutating, and poorly developed as no quantitative criteria to characterize NE have yet been developed (Aronson et al., 2014; Kattan et al., 2016; Murcia et al., 2014; Simberloff, 2015). Still, advocates of NE tend to remind readers that the development of an ecological concept is an ongoing process that requires the support of empirical evidence (Hobbs, Higgs, & Harris, 2014) and that debate is a crucial component in the development of other concepts and frameworks (Higgs, 2017). Although these criticisms have been pointed out to the concept, in general, the same necessarily applies to the concept in the urban context. In that sense, recent studies have started to address these criticisms, namely seeking a common language (Heger et al., 2020, 2019), reviewing the concept in both non-urban and urban contexts (Teixeira & Fernandes, 2020), quantifying levels of ecological novelty in cities (Schittko et al., 2020; Teixeira et al., 2021), and assessing the role of ecological novelty in the conservation of urban biodiversity (Kowarik & von der Lippe, 2018; Planchuelo, von Der Lippe, & Kowarik, 2019).

There are also reservations concerning the terminology used. The term “novel” was adopted in 1997 (Chapin III & Starfield, 1997) and later largely accepted after Hobbs and colleagues’ seminal paper (Hobbs et al., 2006). According to some authors (Aronson et al., 2014; Kattan et al., 2016; Murcia et al., 2014), this term suggests a positive connotation and may send a conflicting message. Nevertheless, the term is merely designating a new “novel” kind of ecosystem that emerged through human-induced changes without using a pejorative label (Miller & Bestelmeyer, 2016).

3.2.2. Pragmatism and utility

Another often-debated topic refers to the actual utility of NE and NUE. In that sense, some researchers defend that the general NE concept has little pragmatic value as it does not provide new insights or breakthrough approaches on how to deal with highly transformed ecosystems (Kattan et al., 2016). Nevertheless, not only are the NE and NUE concepts pertinent to raise awareness about emergent and urgent topics (e.g., global urbanization, climate change, and species introductions), but they may have an active role in the search for answers and solutions (Heger et al., 2019).

NE and NUE support conservation aims (Kowarik, 2011; Kowarik & von der Lippe, 2018; Light et al., 2013; Planchuelo et al., 2019), even though a clear policy context is still lacking (Bridgewater & Hemming, 2020). Importantly, NE and NUE help to prioritize restoration, planning, and management actions across different contexts (urban, non-urban, and in-betweens), taking into consideration the available resources (Hobbs, Higgs, & Harris, 2014). Restoration to nontangible pristine conditions seems an unrealistic endeavor for many contexts and conditions, not just because of the associated efforts and costs but also due to the complex ecological relationships emerging in these ecosystems, especially in urban settings. The concepts allow practitioners to justify alternative goals when the restoration is not practical or desirable and helps to reserve restoration efforts for worthy locations where restoration to historical conditions may still be feasible (Hobbs, Higgs, & Harris, 2014; Miller & Bestelmeyer, 2016). Even though these ecosystems emerge from intentional and unintentional human influence, they do not require human management to provide ecological functions (Morse et al., 2014) and essential ecosystem services (e.g., degraded land reclamation, watershed protection, carbon sequestration/storage, habitat for rare and native species, stormwater management, climate mitigation, and recreational opportunities) that are comparable to other types of ecosystems (Collier, 2014; Hobbs, Higgs, & Harris, 2014; Kowarik & von der Lippe, 2018; Planchuelo et al., 2019).

3.2.3. Concerns and Misunderstandings

Researchers who are against the concepts have also pointed out a wide list of concerns. They fear that accepting NE and NUE will lead to irreversible biodiversity losses, uncontrolled species invasions, and unpredictable climate change effects (Light et al., 2013). Simultaneously, they are concerned that decision-makers will eventually reduce investments in nature conservation or that land managers will renounce restoration even when it is feasible (Aronson et al., 2014; Miller & Bestelmeyer, 2016). Much of these concerns are related to the fact that NE and NUE have theoretically crossed ecological thresholds to the point that returning them to a previous ecological state is highly challenging. Critics argue that crossing a threshold does not imply irreversibility (Murcia et al., 2014), and barriers to restoration based on socioeconomic and political limitations should not be confused with ecological thresholds (Aronson et al., 2014; Simberloff, 2015). Nevertheless, NE and NUE are not described as irreversible, rather as difficult to reverse or reversible only with significant resources and efforts (Hobbs et al., 2006, 2009; Miller & Bestelmeyer, 2016). Likewise, even if barriers to restoration are frequently socioeconomic (resources, institutional will, policy settings, and other social aspects) rather than ecological, these factors are rarely separable in practice (Hobbs, Higgs, & Hall, 2013d; Hobbs, Higgs, & Harris, 2014).

The NE and NUE concepts question traditional conservation and restoration approaches. Researchers against these concepts argue that these ecosystems “lower the bar” and will legitimize society’s tendency to ignore negative environmental impacts in the long term (Murcia et al., 2014). Nevertheless, Hobbs, (2016) questions the assumption that these ecosystems can always be viewed as “degraded” and argues that some altered systems are simply different from what existed previously and not necessarily damaged or in need of restoration. Even though critics of the concept agree that anthropogenic changes are accelerating, they defend that attempts to control non-native species based on currently perceived impacts rather than the origin of the species are a risky strategy since knowledge about biological invasion is still limited (Simberloff & Vitule, 2014). Valuing NE and NUE do not necessarily entail devaluing other types of ecosystems (Light et al., 2013). And acknowledging their existence does not imply that managers cease to control invasive species and that traditional conservation and restoration practices are completely replaced from now on (Hobbs, Higgs, & Hall, 2013b; Standish, Thompson, et al., 2013). The NE and NUE concepts will expand options and allow discussion of solutions based on priorities and the likelihood of success of different interventions (Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Higgs, 2017; Hobbs, Higgs, & Harris, 2014; Miller & Bestelmeyer, 2017; Standish, Thompson, et al., 2013). This discussion should be stimulated once many of these concerns are founded on misunderstandings and, in some cases, prejudice (Standish, Thompson, et al., 2013).

3.3. Opportunities from and to Landscape Architecture

The challenges raised by NE and NUE are already triggering the reformulation of methodologies and paradigms in ecology (Hobbs, Higgs, Hall, et al., 2014) and highlighting the need for cooperation between fields of knowledge to solve the complex issues society will increasingly face (Seastedt, Hobbs, & Suding, 2008; Standish, Hobbs, & Miller, 2013). When debating new theories and concepts that can help respond to emerging environmental problems, it is imperative to welcome a myriad of perspectives and to combine efforts from different disciplines (Johnson & Hill, 2002). A collaborative learning process between scientists and practitioners is critical to producing effective knowledge and common language on multiple fronts, contexts, and scales (Bakshi & Gallagher, 2020; Heger et al., 2020, 2019; Johnson & Hill, 2002; Musacchio, 2009; Nassauer & Opdam, 2008).

Landscape Architecture is, in its essence, a collaborative and interdisciplinary profession that is able to engage various areas of knowledge (sciences, arts, and humanities) to address and understand its object of study (Grose, 2014). As such, this field is equipped with a much-needed holistic and flexible perspective upon the various layers that form a landscape: its history, memory, and evolution, as well as its ecological, cultural, and socio-economic characteristics (Grose, 2014). Additionally, the field of Landscape Architecture has been building relevant knowledge and vast experience about the urban landscape for many years, including the dynamics of native and non-native plants assemblages, from both theoretical and practical points of view (Grose, 2014; Kowarik, 2021; Sack, 2013). Many Landscape Architects have substantial knowledge and skills with the physical characteristics, processes, and dynamics of the urban environment including grading and drainage, soils and structures, vegetation analysis, design and management, and the human experience and value of the environment. This holistic perspective and acquired knowledge are valuable when studying complex systems such as NUE (Naveh, 2007), namely contributing to the resolution of the previously identified controversial dimensions of the concept.

NUE are socio-ecological systems emerging in profoundly constructed landscapes, where mankind and nature collide in highly complex ways that are difficult to fully understand. Even though the human agency is inextricably linked to NUE genesis, it is still crucial to understand how people perceive these ecosystems. Will people accept or value new forms of urban nature? Otherwise, the integration and accommodation of NUE in urban environments will not be easy nor viable (Bakshi & Gallagher, 2020; Kowarik, 2018). The successful implementation of new ideas, concepts, and solutions requires that people's perspectives are considered, even promoting their engagement and participation at different stages of the process (Sack, 2013). As cities offer limited space for urban nature and ecological novelty is largely widespread in urban settlements, it is arguably increasingly urgent to promote more contact and access to NUE. In the context of the Anthropocene, NUE can be relevant sources of benefits to the population's well-being and quality of life while also supporting fundamental ecological processes to local fauna and flora (Ahern, 2016; Kowarik, 2018; Standish, Hobbs, et al., 2013).

Nevertheless, urban dwellers may not be prepared yet to fully embrace NUE, which implies that these ecosystems must be reshaped according to societal expectations while also striving to meet critical ecological and economic goals that are often misaligned (Bakshi & Gallagher, 2020; Gobster, Nassauer, Daniel, & Fry, 2007; Klaus & Kiehl, 2021; Nassauer, 1995; Nassauer & Opdam, 2008). It may be helpful to educate people and explain what NUE represents, their potential opportunities, and the role of society in their creation. But mostly, it will be critical to consider people's interests, values, and preferences in this discussion, such as what they like or dislike, what they need, and the benefits they will mostly value in urban green spaces (e.g., beauty, biodiversity, well-being, health, or comfort) (Del Tredici, 2014; Klaus & Kiehl, 2021; Kowarik, 2018). Understanding people's social values, preferences, and attitudes towards NUE can inform and support their design, planning, or management, thereby increasing their general acceptance and successful integration in political agendas (Bridgewater & Hemming, 2020; Bridgewater & Yung, 2013; Kowarik, 2018; Kowarik, Straka, Lehmann, Studnitzky, & Fischer, 2021). To this end, studies using well-established approaches from the social sciences, such as questionnaires often assembled with photographs or photo-manipulations (Rupprecht & Byrne, 2014), are being implemented to understand urban dwellers' perceptions, preferences, or attitudes and then inform practitioners (Kowarik et al., 2021; Lewis, Granek, & Nielsen-Pincus, 2019; Mathey, Arndt, Banse, & Rink, 2018; Rupprecht, 2017; Włodarczyk-Marciniak, Sikorska, & Krauze, 2020).

Accommodating people's interests and ecological principles through design is fundamental to Landscape Architecture practice (Del Tredici, 2014; Nassauer & Opdam, 2008). Design is a powerful tool to imprint and synthesize cultural values, tradition, memory, and beauty in a landscape to make its ecological function and value visually recognizable to users (Felson & Pickett, 2005; Gobster et al., 2007; Nassauer, 1995). Through design, the positive aspects, ecological processes, and functions of NUE can be enhanced, and its negative aspects can be mitigated or eliminated (Box 3.1) (Bakshi & Gallagher, 2020; Klaus & Kiehl, 2021; Teixeira et al., 2021).

Design can also be a relevant tool for NUE investigation (e.g., understand the ecosystems' dynamics and evolution, quantify ecological novelty and aesthetic quality, test design and management options, etc.). Innovative strategies and solutions to approach novel systems can be conceptualized through "designed experiments" that allow collaboration between researchers and practitioners, exchange of knowledge, and complementation of experimentation techniques (Felson & Pickett, 2005; Nassauer & Opdam, 2008). According to Felson & Pickett, (2005), "designed experiments" can be developed as socially and politically desirable projects to respond to the specific dilemmas of a particular location and enable a harmonious melding of the scientific process with artistic, aesthetic, cultural, political, ecological, and/or social goals (Box 3.2) (Ahern, 2011; Bakshi & Gallagher, 2020; Johnson & Hill, 2002; Musacchio, 2009; Sack, 2015). "Designed experiments" can be integrated with routine urban construction and maintenance, reducing or eliminating the cost of experiments. Thereafter, the success and performance of design experiments can be evaluated to improve the delivery of selected ecosystem services and mitigate disservices, minimizing risks and uncertainties, and creating a learning loop that allows adjustment of strategies as new knowledge, data, and measurements are obtained (Ahern, 2016; Felson & Pickett, 2005; Klaus & Kiehl, 2021).

Box 3.1. Landscape Park Duisburg-Nord (Germany).

The Landscape Park Duisburg-Nord (Latz+Partner, 1990–2002) (Latz+Partner, 2021), once a degraded and abandoned industrial site, is now a public park that combines cultural and ecological objectives and brings people closer to a novel nature (Bakshi & Gallagher, 2020; Sack, 2013). The Landscape Park represents an example of a groundbreaking design project in Germany that embodies the opportunities of designing and managing NUE in post-industrial landscapes (Kowarik, 2021). Since its creation, the park has inspired other design projects worldwide (e.g., Völklinger Hütte World Heritage in Germany, Lago Ex-SNIA in Italy, Hongmei Cultural Creative Park in China, and Nowadays in the USA) (Ahern, 2016; Kowarik, 2021; Latz+Partner, 2021), originating a new aesthetic vision where disruptive and wild landscape fragments are merged in the proposed design rather than being obliterated (Figure 3.1a). This way, instead of giving this place a completely new identity, the industrial past was reinterpreted, celebrating and preserving the region's history and memory for future generations and for supporting economic activity including tourism. Roads, railways, and spontaneous vegetation already present in the site were integrated into the project's proposal, and new uses and purposes were assigned to existing structures and equipment (Figure 3.1b-e).

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Even though biotic and abiotic thresholds have been crossed, the variety of habitats in the park has welcomed a vast diversity of flora and fauna species and novel combinations of native and non-native plants are supporting multiple and essential ecological processes (Keil, 2019; Sack, 2013).

Figure 3.1. (a) The post-industrial landscape and scenery at the Landscape Park Duisburg-Nord; (b) Vegetation evolving and taking over existing elements; (c-e) Railways, machinery, old pipes, and industrial structures merged into the landscape and coexisting with the involving novel plant communities. Reprinted (Figure 3.1d-e) with permission from ref. (Latz+Partner, 2021). Copyright 2021 Michael Latz-Fotografie.

The implementation of designed experiments in complex environments that are virtually impossible to replicate in controlled settings represents an opportunity to observe the unexpected outcomes resulting from human-nature interactions in NUE, or NE (Box 3.3) (Bakshi & Gallagher, 2020). Monitoring NUE dynamics in the real and challenging urban world is a step forward in urban ecology to understand how these ecosystems will respond and evolve based on different design options or management measures, and when exposed to a variety of urban drivers of change or types of public use. For instance, based on observations of his implemented projects (e.g., Parc André Citroën in Paris and Parc Henri Matisse in Lille), the Landscape Architect Gilles Clément tested combinations of species and design approaches that later informed his theoretical work about abandoned spaces that are welcoming to biological diversity (third landscape) (Bakshi & Gallagher, 2020; Grose, 2014).

In collaboration, scientists, and practitioners can test and monitor the integration of NUE in the green infrastructure of cities, which allows for the reinforcement of a network of multifunctional urban green spaces for increased biodiversity, ecological connectivity, and public access (Klaus & Kiehl, 2021). Since the 1970's Landscape Architects have developed practices for the remediation of contaminated urban environments, knows as "brownfields" (e.g., Gas Works Park in Seattle, Seattle, WA, USA). In this respect, Kowarik (2021) provides evidence from a variety of NUE from distinct backgrounds (e.g., vacant lots, fortresses, railway areas, etc.) that, after multi-targeted designed interventions and vegetation management (e.g., focusing on biodiversity conservation, cultural heritage, nature experience, and environmental education) have become accessible to people and integrated into Berlin's urban green infrastructure. Examples from Berlin distanced from the traditional design of urban green spaces include the Natur-Park Südgelände and, in the "Green Belt Berlin", the Mauerpark and the Park am Nordbahnhof (Bakshi & Gallagher, 2020; Kowarik, 2019). These former undervalued vacant lands and transportation links in Berlin were transformed into green spaces fundamental to the urban biodiversity and ecological connection while also providing invaluable functions to Berlin's inhabitants. Their design was conceived reflecting largely on their history (e.g., preserving remnants of railways, walls, and historical pavement), integrating existing ruderal plant communities and mature native and non-native tree stands and creating path systems for visitors' access (Kowarik, 2019, 2021).

Box 3.2. Wild Gardens at the University of Porto (Portugal).

In former vacant lands within the campus of the School of Sciences of the University of Porto (Portugal), two sets of small-scale experimental gardens with different characteristics and conditions were installed between 2009–2010 (Farinha-Marques, Fernandes, & Guilherme, 2016; Farinha-Marques, Fernandes, & Teixeira, 2018). The Wet Wild Garden at the north (Figure 3.2a) and the Dry Wild Garden at the south (Figure 3.2b) were created combining ecological and aesthetical goals with low cost and minimum intervention. The project design took advantage of existing vegetation and construction materials left behind in the site and resorting to the plantation of strategic native species (e.g., *Quercus suber*, *Fraxinus angustifolia*, *Arbutus unedo*). Native and non-native spontaneous vegetation was welcomed in the garden over time, eliminating aggressive invasive herbaceous species that were limiting native species development. Inspired by natural ecological succession and through an adaptive and sustainable design and management, these novel urban ecosystems have been evolving and providing biodiversity, habitat, and resources to wildlife (e.g., reptiles, birds, butterflies), contact with nature for the academic community and visitors, and a chance to learn and experience with a living laboratory.

(Continued …)

So far, these wild gardens have allowed the designers to closely survey and monitor flora and fauna dynamics, evolution, performance, and interactions. And to test materials, management strategies (e.g., cut or no cut, irrigation or no irrigation), and new forms of aesthetic stimulation.

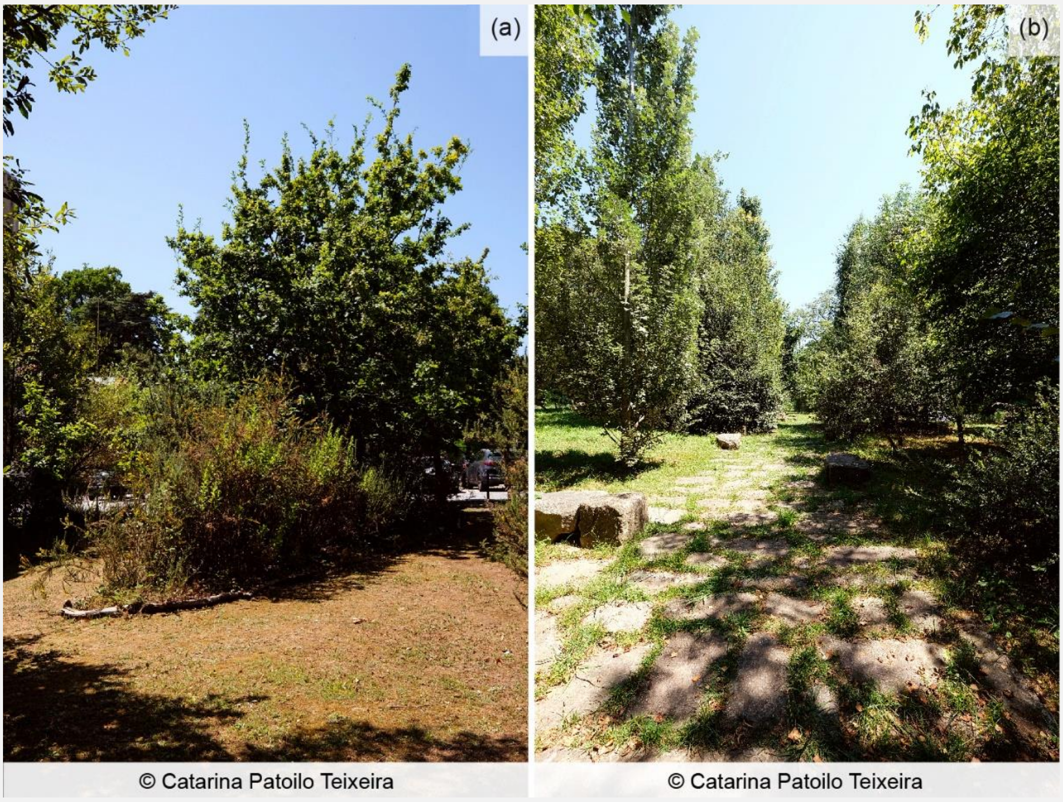

Figure 3.2. (a) Wet Wild Garden – Dead tree logs were used to delimitate areas to cut and areas for natural regeneration; (b) Dry wild garden – Paths were created using reclaimed materials such as granite stones and the tree and shrub layers were gradually developed resorting to strategic plantings carried out by Landscape Architecture students.

Opportunities for experimentation also arise to investigate the involvement of urban dwellers in the design experiment, communicating the project goals and benefits for the surrounding community, consequently encouraging public and political support (Felson & Pickett, 2005). Or to assess NUE potential in the face of uncertain and context-specific climate change effects, extreme weather, or other environmental stresses (Ahern, 2016; Del Tredici, 2020; Light et al., 2013). The emergence of novel assemblages of species is either limited or facilitated by extreme abiotic and biotic conditions that act as environmental filters, making NUE pre-adapted to the location where they emerge and, in many cases, also able to mitigate the negative impacts at the base of its origin (e.g., pollution or hot and drier conditions) (Bakshi & Gallagher, 2020; Del Tredici, 2020). Existing and spontaneous vegetation can be accommodated and enhanced in the designs instead of replaced, ensuring that the plant communities are more tolerant and adapted to extreme urban conditions, while also providing models to address climate change adaptation and mitigation (Kowarik, 2021). In the USA, an undeveloped section of the Liberty State Park in Jersey City constitutes an opportunity to design and manage NUE integrating the existing vegetation already adapted to the local conditions (Bakshi & Gallagher, 2020). Even though this former railway site is contaminated with high metal concentrations, the novel assemblages of species that evolved there display great functional diversity and are pre-adapted to the site's environmental stress (i.e., the plants can either avoid or sequester the soil metals) (Bakshi & Gallagher, 2020; Gallagher et al., 2018).

Experimentation through design can support the development of methods and tools to identify and quantify NUE across different types of urban green spaces, thereby assisting the evolution and acceptance of this concept, contributing to a clearer definition of NUE, and strengthening the pertinence and utility of the concept to address contemporary environmental problems such as climate change and pollution. Therefore, this decisive link and common ground between science, nature, and society, ecology and aesthetics, can be established through design in Landscape Architecture (Bakshi & Gallagher, 2020; Gobster et al., 2007; Nassauer & Opdam, 2008). Without bridging these gaps, the successful application of the NUE concept in urban landscapes and urban policies will be limited, and the NUE utility and relevance will remain questionable by critics of the concept (Kattan et al., 2016).

Box 3.3. Hart-Miller Island in the Chesapeake Bay, Baltimore, Maryland (USA).

The project "Seeding Specificity: Materials and Methods for Novel Ecosystems" by Mahan Rykiel Associates' (2021) team shows how restoration strategies for novel ecosystems can be designed and calibrated based on *in situ* experimentation and considering the specificities of a real and challenging project site, soils, and floristic palette. By investigating seed germination rates in Hart-Miller Island in the Chesapeake Bay, Baltimore, Maryland (USA), the team used the research findings to develop customized seed mixtures and a seeding plan for this landscape constructed from sediment. First, field research was conducted to assess the biogeochemical systems of the project's site as a natural analog reference site was lacking (Figure 3.3a). Then, collected data informed the restoration strategy (Figure 3.3b), which intended to design a living landform to diversify the plant community structure and to stratify the site's geohydrology. The planting design was organized into three types of grasses and forbs species assemblages (wet specialists, generalists, and dry specialists) with different heights and selected based on the species' tolerances (moisture, pH, and invasive pressure) to survive the complex conditions of Hart-Miller Island.

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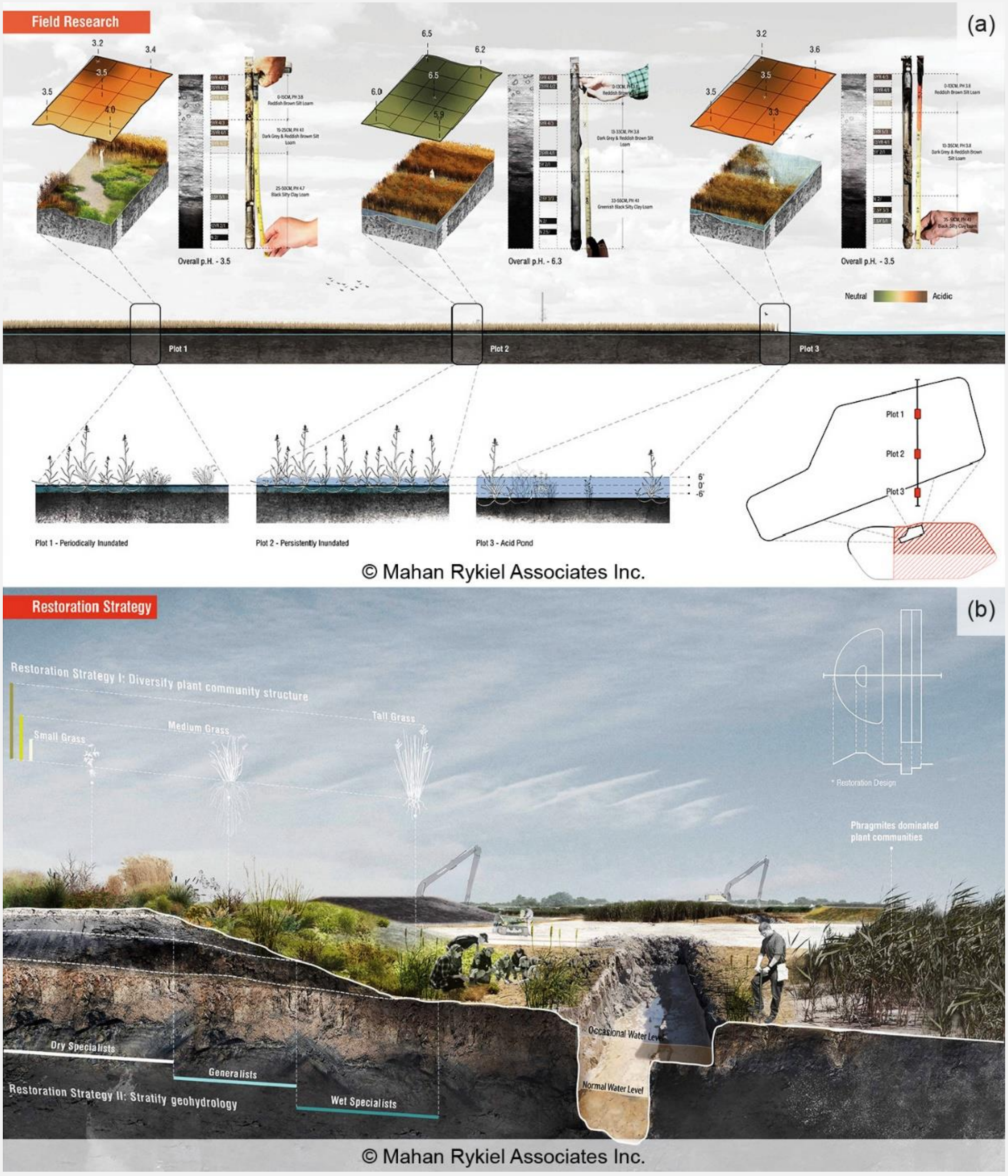

Figure 3.3. Project working images and diagrams regarding (a) field research and (b) restoration strategy. Reprinted with permission from ref. (Mahan Rykiel Associates, 2021). Copyright 2021 Mahan Rykiel Associates Inc.

In the same way, Landscape Architecture can contribute to this discussion and the application of the concept in urban landscapes, NUE can also be regarded as an opportunity in this field. Even though Landscape Architects have already been working with novel assemblages of species and environmental conditions in the past (without labeling them NUE) (Ahern, 2016; Grose, 2014; Kowarik, 2019, 2021; Sack, 2013), the NUE concept and terminology is still largely unknown among Landscape Architects. The application of the NUE concept has not yet found its clear way to the practical activity, as traditional and outdated conceptions of nature may be limiting progress (Bakshi & Gallagher, 2020). We briefly mention some promising examples where Landscape Architecture has already contributed to this subject. It is, however, urgent that Landscape Architecture continues to embrace the design and management of new forms of urban nature, positioning the field in a current and highly relevant debate and emphasizing the profession's role in promoting socially resilient cities in this age of humans, the Anthropocene.

3.4. Concluding remarks

Even though NUE are widespread worldwide and may soon become an unavoidable reality, many challenges and barriers still prevent their acceptance (Perring & Ellis, 2013). Although it may be easier to ignore NUE because they are different, inconvenient, or a wake-up call regarding humanity's role, we can opt to recognize them as opportunities for welcoming new forms of urban nature and for research and experimentation that will inform future paths (Light et al., 2013; Standish, Thompson, et al., 2013). We argue that unanswered questions represent opportunities in which Landscape Architecture may contribute with creative perspectives. Ultimately, the spectrum of Landscape Architecture action can cross many areas of knowledge, accede useful tools, facilitate dialogues, create new designs and design approaches, and bridge existing gaps between science, people, and nature.

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4

CHAPTER 4 |

URBAN ECOLOGICAL NOVELTY ASSESSMENT: IMPLICATIONS FOR URBAN GREEN INFRASTRUCTURE PLANNING AND MANAGEMENT

"In the Anthropocene, fortress conservation is a doomed enterprise. Humans are an inescapable part of the landscape. There are no pristine ecosystems and no blueprints for what they might be. Any vision of the pristine past that we choose will require constant tending." (Pearce, 2015, p. 249)

Chapter 4 | Urban ecological novelty assessment: Implications for urban green infrastructure planning and management

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Article published as a research article in *Science of the Total Environment*

Type of article: Research article
Journal Impact Factor (2020): 7.963

Citation: Teixeira, C. P., Fernandes, C. O., Ahern, J., Honrado, J. P., & Farinha-Marques, P. (2021). Urban ecological novelty assessment: Implications for urban green infrastructure planning and management. *Science of The Total Environment*, 773, 145121. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.145121

Abstract

Urban areas are continuously subjected to anthropogenic transformations that result in the emergence of novel urban ecosystems. To prepare for and respond to contemporary negative environmental impacts (e.g., climate change, land-use change, biological invasions), it is increasingly urgent to plan and adapt cities' green infrastructure. Accordingly, the inclusion of the novel ecosystems concept in urban planning and management is pertinent and necessary. Nevertheless, identification or measurement of ecological novelty has been challenging and can be problematic without the appropriate methods. The objectives of this study are to 1) develop and test a methodology to assess novelty in urban ecosystems grounded on the combination of both human and biotic dimensions of the novel ecosystems concept, and 2) discuss the implications that urban ecological novelty assessment can have for future urban green infrastructure planning and management. In contrast to other proposed methods, this assessment considers the human dimension of the concept as equally important as the biotic dimension, once the human presence is pervasive and a fundamental component of urban landscapes. The proposed working methodology was tested in Porto, Portugal, in study sites with contrasting human-induced transformation pathways and plant species assemblages, thus theoretically representing different degrees of urban ecological novelty. The methodology developed in this work is straightforward and can be adjusted and replicated to other cities according to available data and tools. Above all, the assessment of urban ecological novelty can inform future urban planning and management and assist in investigating novel urban ecosystems.

Keywords: Biotic change; Human agency; Methodological framework; Novel urban ecosystems; Social-ecological systems; Urban green spaces

4.1. Introduction

4.1.1. Urban ecological novelty assessment – challenges and opportunities

Ecosystems emerging after human-induced changes and composed of unprecedented species assemblages are commonly referred to as "novel ecosystems" (Hobbs et al., 2006). Over the last two decades, this concept has been extensively referenced in the literature (Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013b; Hobbs, Higgs, & Harris, 2009; Lugo, Winchell, & Carlo, 2018). Moreover, there is a growing interest in researching novel ecosystems, particularly in urban contexts (Ahern, 2016; Fischer, Von der Lippe, & Kowarik, 2013; Kowarik, 2011, 2018; Lugo et al., 2018; Teixeira & Fernandes, 2020). The identification or measurement of ecological novelty has been a challenge since the concept emerged in the literature relatively recently, and, to date, has been mainly focused on non-urban contexts (Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Morse et al., 2014; Tognetti, 2013; Trueman, Standish, & Hobbs, 2014). There are multiple approaches and perspectives regarding what makes an ecosystem novel. Without appropriate quantitative metrics, tools, and methods to assess urban ecological novelty, the application of the concept in urban planning and management remains problematic.

Previous studies have outlined a set of criteria to identify novel ecosystems, although not all authors consider all the criteria in their definitions (Morse et al., 2014; Teixeira & Fernandes, 2020; Truitt et al., 2015). One common idea among all the definitions in the literature is the fact that novel ecosystems are human-mediated, originating from biotic and/or abiotic change. Some authors also suggest that novel ecosystems have to cross one or more critical thresholds (biotic, abiotic, and/or social thresholds) that make it very difficult or unfeasible to restore the ecosystem to previous (historical) conditions (Higgs, 2017; Mascaro et al., 2013; Morse et al., 2014). And after thresholds are crossed, the novel ecosystems should be able to persist without, or in spite of, extensive human intervention (Higgs, 2017; Morse et al., 2014).This logic argues that even though novel urban ecosystems result from human-induced changes, they do not depend on ongoing human intervention for their maintenance (Hallett et al., 2013; Hobbs et al., 2006). Nevertheless, thresholds and self-perpetuation can be difficult to observe and measure, and they should be considered on appropriate timescales that are not yet well established (Hallett et al., 2013; Hobbs, Higgs, & Hall, 2013a; Morse et al., 2014; Radeloff et al., 2015). In novel urban ecosystems, the concept of self-perpetuation may be challenged by management actions. Managed systems can also present novel biotic elements, spontaneity, and uncontrolled species interactions or invasions (Lundholm, 2015; Perring, Manning, et al., 2013), therefore manifesting ecological novelty.

Another challenge in measuring novelty concerns the need to compare the (potentially novel) ecosystem after the human-induced alteration against a reference system representing the conditions prior to the change (Harris et al., 2013; Trueman et al., 2014). When choosing a reference system, there are two options: determining historical site conditions or using a modern reference site (Harris et al., 2013; Trueman et al., 2014). The determination of an appropriate reference system is inherently challenging (Harris et al., 2013; Hobbs et al., 2014). For instance, historical data may not exist for a particular location. Even if historical data exist for a given location, they may not cover all or sufficient variables to properly quantify the degree of transformation (Radeloff et al., 2015). Also, the acquisition methods of historical and contemporary data may differ, making the comparison inconsistent (Tognetti, 2013). An appropriate modern reference system may not exist if human-induced changes are extensive and widespread in the analyzed region (Harris et al., 2013; Trueman et al., 2014), which may be the most common scenario in urban landscapes. Additionally, change can occur at a rapid pace and be ongoing, making it difficult to study an ecosystem that is continuously changing and has an unstable trajectory (Morse et al., 2014).

Despite limitations, the assessment of novelty in urban ecosystems is pertinent and necessary, especially for the planning and management of cities' green infrastructure. The urban green infrastructure can exist as an urban matrix or an interconnected network of urban green spaces, which influences the city's ecological functionality (Beer, 2015; Benedict & McMahon, 2002). Urban green spaces exhibit different levels and paces of transformation, and because they exist in an urban environment, they are constantly subject to deliberate or accidental, beneficial or harmful human agency (Del Tredici, 2007; Hobbs et al., 2006; Kowarik, 2011; Mascaro et al., 2013; Perring, Manning, et al., 2013). As such, urban green spaces not only support multiple functions, designs, and biotic compositions, but they also hold varying degrees of novelty. The “Four Natures” approach (Kowarik, 2011, 2018; Kowarik & von der Lippe, 2018) organizes urban green spaces as a continuum of ecological novelty according to a gradient of human-mediated transformation: Nature 1 refers to remnants of ecosystems that have environmental conditions and species assemblages similar to historical benchmarks (e.g., Urban Woodlands, Wetlands); Nature 2 embodies agrarian or silvicultural landscapes that are still able to return to historical conditions (e.g., Agricultural Fields, Cultivated Woodlands); Nature 3 represents designed and managed green spaces (e.g., Parks and Gardens); and finally Nature 4 represents the novel ecosystems that emerge after a human-mediated change in ecosystem development (e.g., Vacant Lands, Wastelands, Industrial sites).

Planning and management play a fundamental role in the process of establishing the goals and priorities of the city as a whole, to reduce uncertainty or risk and to guarantee that the population has access to all the resources and services that it deems necessary. The planning and management process starts with the assessment of the components of the urban green infrastructure. Combined, the many elements of a city allow the development of cohesive and comprehensive plans that summarize not only the best practices (e.g., the integration of green-grey infrastructure, the connection between green spaces, the promotion of green space functions and services, the inclusion of the public in the planning and management process) but also address the difficult challenges that cities will face in the future (e.g., climate change adaptation and mitigation, biodiversity protection, social cohesion) (Hansen, Olafsson, van der Jagt, Rall, & Pauleit, 2019). Ultimately, planning and management determines how urban green spaces are configured and how robust and resilient the aggregate urban green infrastructure will be to respond to disturbance (Novotny, Ahern, & Brown, 2010). Recent literature about urban green infrastructure planning and management has not yet started to focus nor include the novel urban ecosystems concept in its scope of research (e.g., Buijs et al., 2019; Hansen et al., 2019; Hansen & Pauleit, 2014; Pauleit et al., 2019; Pauleit, Liu, Ahern, & Kazmierczak, 2011). However, the degree of novelty in urban ecosystems conveys information that can outline and be useful to prioritize actions that should be taken into consideration in urban green infrastructure planning and management decision-making (Clement & Standish, 2018; Morse et al., 2014; Perring, Manning, et al., 2013; Truitt et al., 2015).

4.1.2. Rationale, objectives, and paper outline

Since the differences between urban and non-urban novel ecosystems are increasingly understood and accepted, we argue that the identification or the assessment of novelty in urban ecosystems should be explicitly adapted to the urban environment. Most studies that aim to assess novel ecosystems or measure novelty have focused solely on measuring the dissimilarities of biotic and/or abiotic conditions (e.g., Radeloff et al., 2015; Schittko et al., 2020; Tognetti, 2013; Trueman et al., 2014; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018; Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009). In contrast, here we propose to attribute weight to the two dimensions of the novel urban ecosystems concept (human agency and biotic change) that have been consistently present in the concept's definitions over the years (see Morse et al., 2014; Teixeira & Fernandes, 2020). In cities, human agency is fundamental to ecosystem disturbance rather than an external component. Therefore, we consider the human dimension as equally important as the biotic dimension to understanding novelty in urban ecosystems. The unprecedented assemblages of species and the unprecedented combinations of abiotic factors that define ecological novelty are largely influenced by human activities (e.g., global trade, species introductions, land-use change, urbanization, climate change), which in turn are more profoundly manifested in cities. In this way, we are establishing a clear relationship with urban green infrastructure planning and management, in the sense that green infrastructure is also inherently human-manipulated. We assume that novelty can be understood as a continuum defined by time and space and that systems deliberately created and under ongoing human intervention or management can still encompass ecological novelty – for example, Nature 3 (Parks and Gardens). This understanding sets aside the need to determine thresholds (Heger et al., 2019) and reinforces the idea that novelty in urban ecosystems expresses a range of combinations of human agency (e.g., evidence of management or changes in land-use) as well as biotic and/or abiotic changes.

To address these ideas, the objective of this article is to develop a methodology to assess ecological novelty in urban ecosystems grounded in both human and biotic dimensions of the novel ecosystems concept. The biotic dimension of this work is focused exclusively on the plant communities of the urban green infrastructure since they are the foundation of urban ecosystems. The paper is structured as follows:

- First, we present a proposed methodological framework to assess ecological novelty in urban environments;
- Then, we test the applicability of the working methodology and illustrate it in the city of Porto, Portugal, across several types of urban green spaces, theoretically representing different degrees of novelty;
- Finally, based on the results, we discuss (1) how urban ecological novelty is currently represented in Porto; (2) what are the implications that the assessment of urban ecological novelty can have for future urban green infrastructure planning and management; and finally, (3) what are the main attributes and limitations of the proposed methodology.

Ultimately, we aim to propose a tool that will enable the inclusion of novelty in urban ecosystems as part of an overt, explicit, and replicable method of planning and management of cities.

4.2. Methods

4.2.1. Urban ecological novelty assessment

4.2.1.1. Overview of the methodology

The proposed working methodology was developed for application in the urban environment and combines the human and biotic dimensions of the novel ecosystems concept. The five-step procedure is outlined in Figure 4.1 and starts with (1) the characterization of the urban green infrastructure, in which urban green spaces (UGS) categories are identified, mapped, and classified. Secondly, a sampling design is produced (2) in order to select a representative sample of study sites based on the targeted UGS categories. Then, surveys are performed (3) to collect human agency data and biotic data for the selected study sites. Based on the collected data, two indexes (Human Agency Novelty Index and Biotic Novelty Index) are calculated (4), which combine to define (5) the Urban Ecological Novelty Index and allow the assignment of each study site to an Urban Ecological Novelty Quadrant.

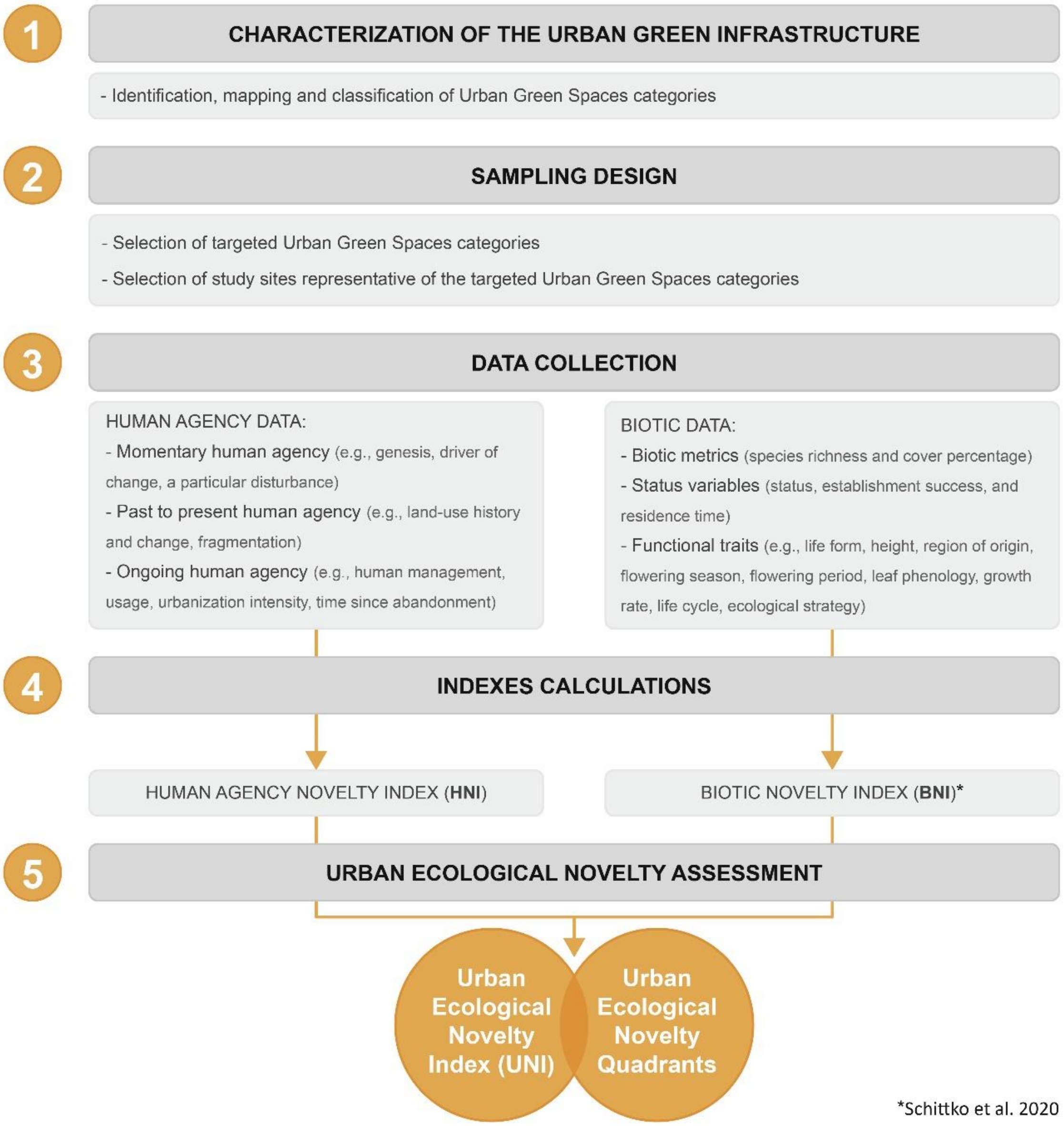

Figure 4.1. Conceptual diagram of the research methodology.

4.2.1.2. Description of the methodology

After a detailed characterization of the study area's urban green infrastructure, study sites must be selected for the application of the methodology. The selected study sites should include representative locations of one or more UGS categories of the study area, depending on the scope and coverage of the methodology application. After the study sites are defined, surveys must be conducted to collect both human agency and biotic data, which will allow the calculation of indexes and, ultimately, determine a degree of urban ecological novelty.

Human Agency Novelty Index

Regarding the human agency dimension, a set of variables must be defined based on the theoretical foundations of the novel ecosystems concept and regarding different time scales of human-mediated transformation as exemplified ahead. Variables may be both continuous or categorical and can be determined by the available data in the study area as long as they relate directly to the novel urban ecosystems concept. Additionally, a level of novelty (low, medium, or high) must be assigned to each variable class based on the concept's premises. Human agency that causes novelty can occur at different periods and durations of time, so variables can refer to the transformation that occurs at a specific moment in time (e.g., genesis, driver of change, a particular disturbance), the incremental transformation occurring throughout a given period of time (e.g., land-use history and change, fragmentation), and finally, the ongoing transformation which is the outcome of a constant human presence (e.g., human management, usage, urbanization intensity, time since abandonment). After each study site is classified according to the established variables, the Human Agency Novelty Index (HNI) is calculated based on the level of novelty each variable represents. For categorical variables, a score is assigned to each level (0 – low; 0.50 – medium; 1 – high). For continuous variables, the exact decimal value can be used. The HNI is then calculated as the sum of the scores from all variables:

$$HNI = \text{score of variable } 1 + \ldots + \text{score of variable } n$$

Biotic Novelty Index

Regarding the biotic dimension, plots in the study sites for floristic surveys must be first determined considering the sites' complexity. For instance, the same site may include different habitats and species diversity, so the number of surveys in each study site should reflect the appropriate level of heterogeneity. The floristic surveys must register species richness and cover percentage data. It is also crucial that the identified plant species are classified according to their status in the study area (i.e., native or non-native) and residence time (native, archeophyte, neophyte, or, if known, the year of introduction). Additionally, the plant species must be classified according to a set of functional traits (Schittko et al., 2020). The traits can be both continuous or categorical and should be selected based on their relevance to the novel ecosystems concept. Species richness and cover are traditionally used to assess novelty in species assemblages, but these metrics lack information about the novel functions that new species bring to the system. To overcome this limitation, the procedure to calculate the Biotic Novelty Index (BNI) proposed by Schittko et al. (2020) was considered in this methodology. The method, which is based on Rao's

Quadratic Entropy, stands out from other traditional ways of measuring biotic novelty (based on richness, abundance, or diversity indexes) since it takes into consideration how long the new species have been residents and if they are functionally novel (Schittko et al., 2020). The new traits that non-native species include in the species pool are crucial since they reshape the ecosystem and affect fundamental processes and species interactions (Hobbs et al., 2006; Tognetti, 2013). Additionally, since the different time spans of coexistence of native and non-native species are considered, the BNI solves an important issue: the lack of historical floristic data. Following Schittko et al. (2020), in order to calculate the BNI for each study site, it is necessary to have a numeric matrix of trait values (species × traits), a numeric vector with the years since introduction for each species in the region of interest and a numeric community matrix of species cover (sites × species).

Urban Ecological Novelty Index

Finally, Urban Ecological Novelty is computed as the combination of Human Agency Novelty Index (HNI) and Biotic Novelty Index (BNI). The new Urban Ecological Novelty Index (UNI) is then calculated for each site as the arithmetic mean of the normalized values of HNI and BNI; UNI thus ranges between 0 and 1. Based on the normalized values of HNI and BNI, each study site should be additionally placed in one of four Urban Ecological Novelty Quadrants (Figure 4.2) that translate a gradient of novelty (low, medium or high). Study sites presenting high HNI and high BNI will encompass higher urban ecological novelty, and vice-versa. Study sites with an intermediate level of urban ecological novelty may be equally novel, but for different motives (either because of the human dimension or the biotic dimension). Therefore, both the index (UNI) and the assignment to an Urban Ecological Novelty Quadrant are fundamental and complementary in the proposed methodology.

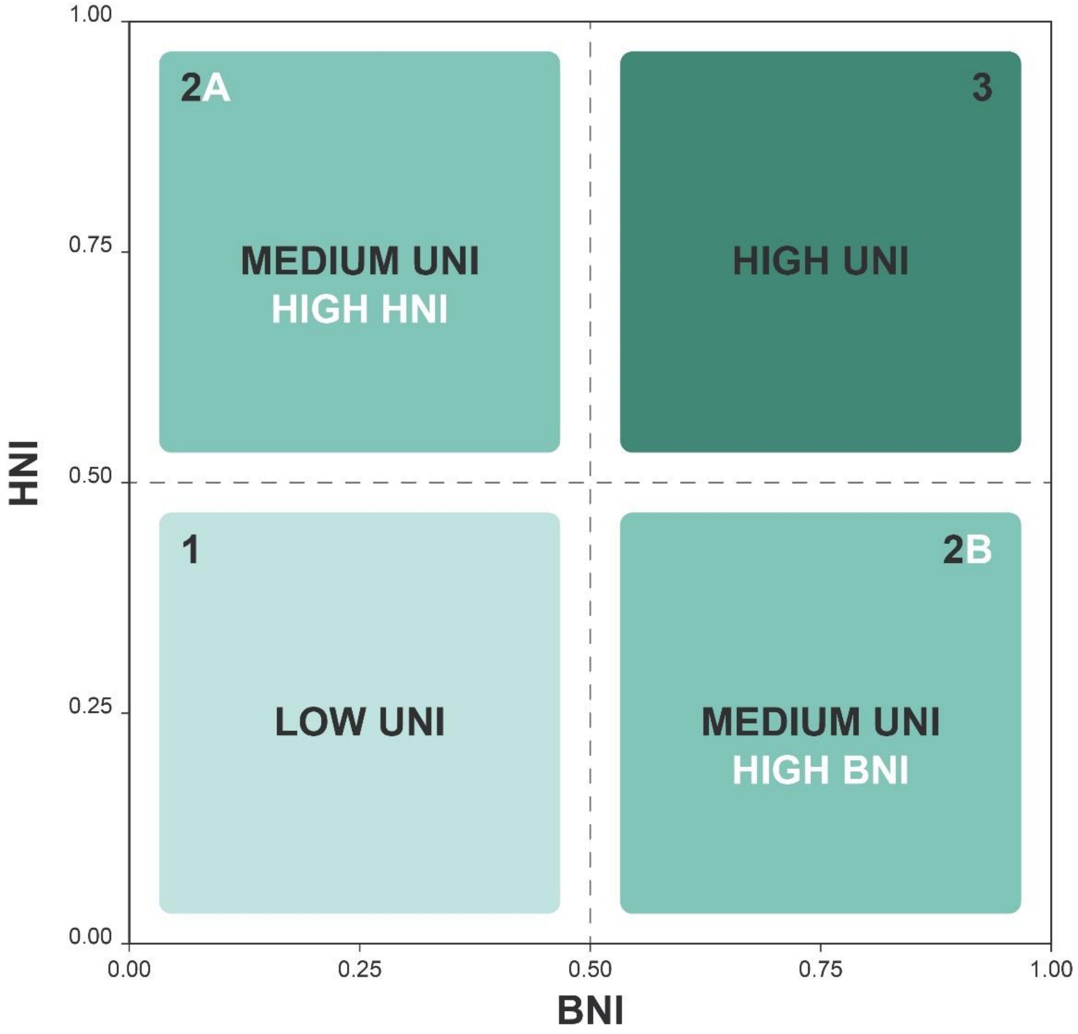

Figure 4.2. Conceptual diagram of the Urban Ecological Novelty Quadrants (1, 2A, 2B and 3) according to the normalized values of HNI and BNI.

4.2.2. Application of the methodology to Porto, Portugal

4.2.2.1. Study area and study sites

The methodology was tested in the city of Porto, located in northwestern Portugal (Figure 4.3a). The city covers 4140 ha and is the second-largest urban agglomeration of the country and the center of a metropolitan area with circa 1.7 million inhabitants. The city has an Atlantic (sub-Mediterranean) climate with warm winters and dry and mild summers. As a port-city with a history of world trade, Porto has received extensive botanical introductions. Additionally, its geographic position at the confluence of two natural elements, the Douro River and the Atlantic Ocean, offers unique conditions for the occurrence of a diverse set of both native and non-native plant species.

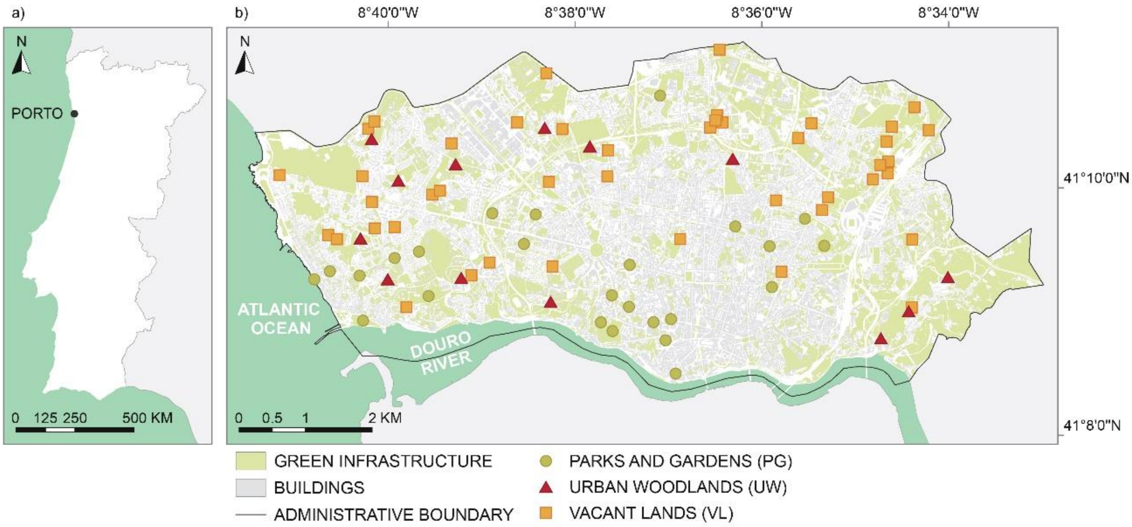

Figure 4.3. (a) Location of the city of Porto in Portugal; (b) Selected study sites in the city of Porto: 26 Parks and Gardens (PG), 14 Urban Woodlands (UW), and 45 Vacant Lands (VL).

According to Madureira, Andresen, & Monteiro, (2011), at the end of the 19th century, Porto had a small urban center surrounded by a large green belt mostly composed of agricultural and woodland areas. At that time, the urban green infrastructure was mainly rural, homogeneous, and covered more than 75% of the city's surface. In the 20th century, this green infrastructure was dramatically reduced and fragmented through urbanization. As a result, agricultural and woodland areas significantly reduced or were abandoned, giving place to other land-uses or vacant lands that are currently distributed mostly in the city's peripheral areas. On the other hand, other urban green spaces (UGS) categories emerged during the last century, and public Parks and Gardens increased mainly in the city's center (Madureira et al., 2011). Today, Porto's green infrastructure covers about 31.6% of the city's surface and includes a variety of urban green spaces (UGS) scattered throughout the urban fabric (Farinha-Marques, Alves, Fernandes, Guilherme, & Gonçalves, 2018; Farinha-Marques et al., 2014). Porto's green infrastructure has been studied, characterized, and mapped in recent decades. Currently, there is not a comprehensive planning and management instrument that strategically regulates Porto's green spaces as a whole. Existing planning and management programs only feature a few green spaces with exceptional ecological, cultural, or patrimonial interest.

To test the methodology, we focused on three UGS categories that, together, represent almost half of Porto's green infrastructure (47.4%): Parks and Gardens (14.1%), Urban Woodlands (7.7%), and Vacant Lands (25.6%). These three UGS categories were selected because they exhibit distinct human-induced transformation pathways, different plant species assemblages, and the full range of human management varying from intensive to low/absent maintenance regimes (Ahern, 2016; Del Tredici, 2010, 2020). Accordingly, in theory, they associate directly with the novelty continuum of urban ecosystems according to the “Four Natures” Approach (i.e., Urban Woodlands – Nature 1, Parks and Gardens – Nature 3, and Vacant Lands – Nature 4) (Kowarik, 2011, 2018).

In order to assess urban ecological novelty across the selected UGS categories, a representative sample of 85 study sites was determined using a stratified random sampling design implemented in ArcGIS 10.6 (ESRI, 2011). The number of selected study sites for each UGS category was proportional to the surface area that the category occupies in the city: 26 Parks and Gardens (PG), 14 Urban Woodlands (UW), and 45 Vacant Lands (VL) (Figure 4.3b; see Appendix 4A for details).

4.2.2.2. Data collection, processing, and analysis

Human Agency Novelty Index

The human agency variables selected to test the methodology in the city of Porto are presented in Table 4.1 (see Appendix 4B for a detailed version).

Table 4.1. List of selected human agency variables, respective classes and supporting references.

Variables	**Classes**	**References**
Previous land-use	Same land-use, other land-uses – vegetation, other land-uses – construction	(Hobbs et al., 2006, 2009; Kowarik, 2011; Lugo & Helmer, 2004; Radeloff et al., 2015)
Level of management	High, medium, low/absent	(Ahern, 2016; Hallett et al., 2013; Higgs, 2017; Hobbs et al., 2006; Kowarik, 2011; Lugo & Helmer, 2004; Mascaro et al., 2013; Morse et al., 2014; Perring, Manning, et al., 2013)
Surrounding impervious surface percentage	0–100 %	(Knapp et al., 2012; Kowarik, 2011; Perring, Manning, et al., 2013)

Previous land-use was assessed by interpreting the intersection of recent satellite imagery with available historical land-use data of the city of Porto. Open access cartography from 1892 and aerial photographs from 1939 were used in this assessment. Current management was evaluated through on-site observations and previous studies of Porto's UGS (Farinha-Marques, Fernandes, Gaio, Costa, & Guilherme, 2016; Farinha-Marques et al., 2014). Each site was qualitatively classified according to the level of management, which indicates the degree of human intervention applied to maintain its character and appearance or, contrarily, absence of management. Surrounding impervious surface percentage was used as an indicator of urbanization intensity, which gives information about surrounding human pressure on the study sites and is closely related with other transformation forces such as fragmentation, soil compaction, and alteration of hydrology and vegetation cover (Hobbs et al., 2006; Lugo & Helmer, 2004; Lugo et al., 2018; Perring, Manning, et al., 2013). This indicator was determined by calculating the percentage of sealed surface within a buffer of 250 m around each study site using ArcGIS 10.6 (ESRI, 2011).

A level of novelty (low, medium, or high) was attributed to each human agency variable class. For categorical variables (previous land-use and level of management), a score was assigned (0 – low; 0.50 – medium; 1 – high) to each level. For the percentage of surrounding impervious surface, the exact decimal value was used (e.g., 63% of impervious surface scored 0.63). Study sites that previously had other land-uses were considered to have experienced greater land-use transformation and, consequently, to have a higher level of novelty. Additionally, if the previous land-use had built construction elements, it would entail more transformation when compared to previous land-uses that had solely vegetation (Del Tredici, 2010).

Regarding the level of management, since novel ecosystems are mostly considered to be self-sustaining and able to persist without, or in spite of, extensive human intervention (Hallett et al., 2013; Higgs, 2017; Morse et al., 2014), study sites that do not have an ongoing human intervention for their maintenance (i.e., low/absent level of management) were considered to have a higher level of novelty. Finally, study sites with higher impervious surface percentages in their surroundings were considered to have a higher level of novelty since urbanization has an enduring effect on the emergence of urban ecological novelty. The HNI was then calculated as the sum of the scores from the three variables (previous land-use, level of management, and percentage of impervious surface), placing each study site in a gradient of human agency novelty (ranging between 0 and 3).

Biotic Novelty Index

Floristic surveys were conducted in each study site to assess species richness and cover percentage, following Braun-Blanquet, de Bolòs, & Jo (1979) methodology. The number of floristic surveys in each study site was determined by the diversity of habitats (i.e., study sites with more diversity of habitats had more floristic surveys performed). The habitats of each study site were identified and mapped in ArcGIS 10.6 (ESRI, 2011) using the Urban Habitats Biodiversity Assessment (UrHBA) methodology (Farinha-Marques et al., 2015, 2017). Depending on the habitat, shape, and plant composition, floristic surveys were performed in plots of 1 × 2 m for linear habitats, 2 × 2 m for habitats only with an herbaceous layer, and 5 × 5m for habitats with herbaceous, shrub, and tree layer. In this way, the UrBHA methodology allowed the consideration of heterogeneity within each study site, as study sites with diverse habitats may encompass different complexity, species diversity, and consequently varying degrees of biotic novelty. The biotic variables and traits selected to test the methodology in the city of Porto are presented in Table 4.2 (see Appendix 4C for a detailed version). Functional data were retrieved from various online databases and sources.

The implementation of the BNI proposed by Schittko et al., (2020) was crucial since a comparison with a reference system prior to the change is usually required when studying novelty, and for the city of Porto, those records do not exist. The traits listed in Table 4.2 were used to assess pairwise functional diversity using the Gower distance since it allows the utilization of mixed data types (Schittko et al., 2020). Regarding the years since introduction, an estimated value was given to each residence time category (native, archeaophytes, and neophyte).

Table 4.2. List of selected biotic variables and traits, respective classes and supporting references.

Variable / Trait	Classes	References
Status	Native, non-native, successful established non-native	(Knapp et al., 2012; Kowarik & von der Lippe, 2018; Tognetti, 2013; Wilsey et al., 2009)
Residence time	Archeaophyte, neophyte	(Schittko et al., 2020)
Life form	Hydrophyte/helophyte, geophyte, therophyte, hemicryptophyte, chamaephyte, phanerophyte	(Perring et al., 2012; Tognetti, 2013; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015; Vanstockem et al., 2018)
Height	0–110 m	(Fischer et al., 2013; Perring et al., 2012; Schittko et al., 2020; Van Mechelen et al., 2015)
Region of origin	Cosmopolitan, Eurasia and North Africa, Europe, Outside Europe, Mediterranean and Macaronesia, Endemic, Uncertain origin	(Wilsey et al., 2009)
Flowering season	Winter/early spring, Spring/early summer, Summer/early fall, Fall/early winter, All year	(Van Mechelen et al., 2015)
Flowering period	1–12 months	(Perring et al., 2012)
Ecological strategy	C, R, S, CR, CS, SR, CSR	(Fischer et al., 2013; Lugo et al., 2018; Schittko et al., 2020; Van Mechelen et al., 2015)

Urban Ecological Novelty Index

The UNI was computed for each study site by combining both HNI and BNI calculations. The study sites were also placed in one of the four Urban Ecological Novelty Quadrants, which provides a comprehensive understanding of how each study site is positioned on a gradient of urban ecological novelty. Non-parametric tests such as Kruskal-Wallis test, Mann–Whitney–Wilcox U test, and Fisher's Exact test were used to assess the significant differences of the variables analyzed across the three UGS categories. All statistical analyses were conducted in the open-source software R 1.2.1335 (R Core Team, 2019).

4.3. Results

4.3.1. Human agency novelty

Results regarding the human agency data are summarized in Table 4.3. Fisher's Exact test and Kruskal-Wallis test results showed significant differences between the three UGS categories for all human agency data and HNI (Figure 4.4a). HNI ranged from 0.658 (Min) to 2.936 (Max), and, on average, was significantly higher on VL study sites and significantly lower on UW and PG study sites.

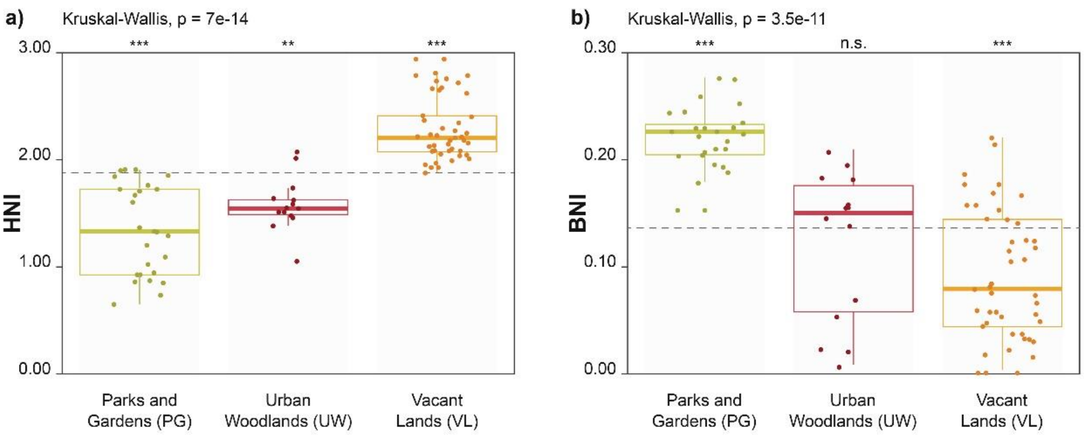

Figure 4.4. Boxplots of the relation between the UGS categories and the (a) HNI and (b) BNI. Kruskal-Wallis test was used for statistical comparison between the UGS categories and the indexes. Mann-Whitney-Wilcox U tests were used for statistical comparison of each UGS category against the indexes base-mean (dashed line). Significance levels: *p < 0.05; **p < 0.01; ***p <0.001.

4.3.2. Biotic novelty

Results regarding the biotic data are also summarized in Table 4.3. A total of 559 plant taxa were recorded across the 85 study sites. Kruskal-Wallis test results showed significant differences between the three UGS categories for most species data (except for the percentage of richness and cover of successful established non-native species) and BNI (Figure 4.4b). BNI ranged from 0.000 (Min) to 0.277 (Max), and, on average, was significantly higher on PG study sites and significantly lower on VL study sites, placing UW study sites in an intermediate position.

Table 4.3. Summary of human agency data and biotic data across all study sites, Parks and Gardens (PG), Urban Woodlands (UW), and Vacant Lands (VL). Fisher's Exact test (F) for categorical variables and Kruskal-Wallis test (K) for continuous variables were used for statistical comparison between the UGS categories.

	All sites (n=85)	PG sites (n=26)	UW sites (n=14)	VL sites (n=45)	Test/ Sign.
HUMAN AGENCY DATA					
Previous land-use, N (%)					F***
Same land-use	15 (17.65)	9 (34.62)	6 (42.86)	0 (0.00)	
Other land-uses – vegetation	51 (60.00)	11 (42.31)	7 (50.00)	33 (73.33)	
Other land-uses – construction	19 (22.35)	6 (23.08)	1 (7.14)	12 (26.67)	
Level of management, N (%)					F***
Low/absent	51 (60.00)	0 (0.00)	6 (42.86)	45 (100.00)	
Medium	14 (16.47)	6 (23.08)	8 (57.14)	0 (0.00)	
High	20 (23.53)	20 (76.92)	0 (0.00)	0 (0.00)	
Surrounding impervious surface, Mean (SD)	67.73 (14.70)	79.38 (11.38)	55.12 (8.19)	64.92 (13.29)	K***
BIOTIC DATA					
% of Species richness, Mean (SD)					
Native	76.90 (14.23)	61.48 (11.17)	78.13 (12.53)	85.43 (7.12)	K***
Non-native	15.27 (12.50)	30.38 (10.20)	11.27 (7.90)	7.78 (4.76)	K***
Successful established non-native	7.83 (5.53)	8.14 (3.48)	10.60 (8.75)	6.80 (4.84)	K
% of Species cover, Mean (SD)					
Native	62.87 (26.55)	35.64 (13.71)	61.99 (25.81)	78.89 (18.17)	K***
Non-native	25.66 (25.08)	53.77 (16.95)	25.31 (21.23)	9.53 (12.86)	K***
Successful established non-native	11.47 (13.34)	10.59 (9.90)	12.70 (14.46)	11.56 (14.62)	K

4.3.3. Urban ecological novelty

Kruskal-Wallis test results showed no significant differences between the three UGS categories for the UNI (Figure 4.5a). UNI ranged from 0.193 (Min) to 0.853 (Max), and, on average, was higher on PG and VL and significantly lower on UW. Regarding the Urban Ecological Novelty Quadrants (Figure 4.5b), the majority of VL study sites are placed in Quadrant 2A (medium UNI with high HNI), whereas the majority of PG study sites are placed in Quadrant 2B (medium UNI with high BNI). UW study sites are present in the four Quadrants but mostly on Quadrant 1 (low UNI) and Quadrant 2A (medium UNI with high HNI). Representing the Quadrant 3 (high UNI) we find mainly VL study sites.

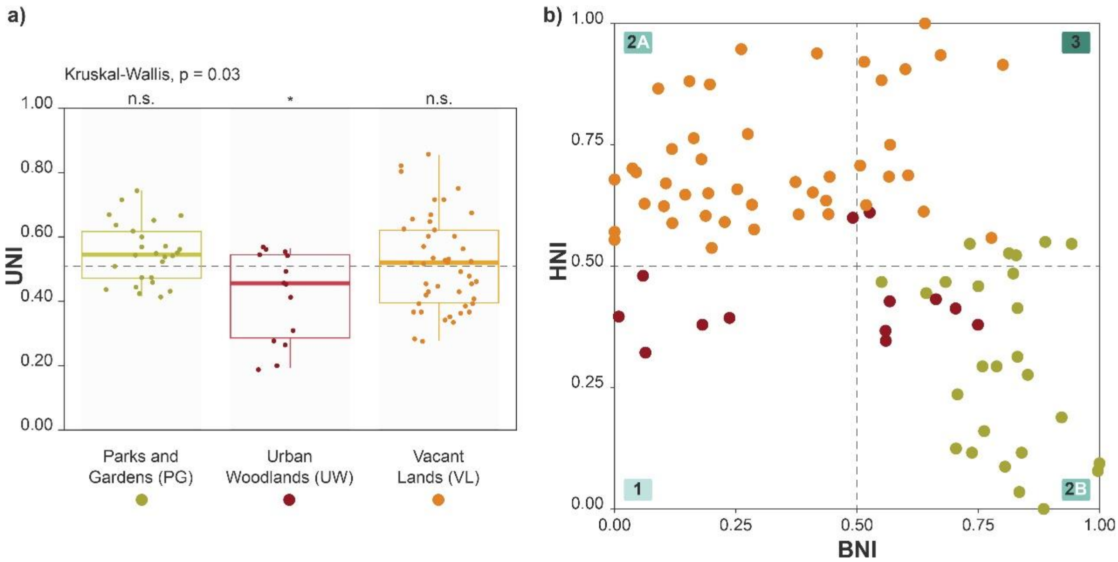

Figure 4.5. (a) Boxplot of the relation between the UGS categories and the UNI. Kruskal-Wallis test was used for statistical comparison between the UGS categories and the index and Mann– Whitney–Wilcox U tests were used for statistical comparison of each UGS category against the index base-mean (dashed line). Significance levels: *p <0.05; **p < 0.01; ***p <0.001. (b) Scatterplot with the position of the study sites in one of the four Urban Ecological Novelty Quadrants (1, 2A, 2B or 3) according to the standardized values of HNI and BNI.

Both PG and VL study sites presented, on average, higher results for the UNI. PG study sites tended to score lower results for HNI and higher results for BNI, and for VL study sites exactly the opposite was verified. UW study sites occupied intermediate positions in both HNI and BNI indexes and for the UNI, on average, lower results. This way, study sites with the lower UNI results belong to UW, whereas the study sites with the higher UNI results belong to VL (blue triangles and red squares respectively in Figure 4.6a). Accordingly, the study site with the lowest UNI result (Figure 4.6d) is a UW in Quadrant 1 in which native species cover dominates. On the other hand, the study site with the highest UNI result (Figure 4.6g) is a VL in Quadrant 3 in which a balanced proportion of native, non-native, and successful established non-native species cover is verified.

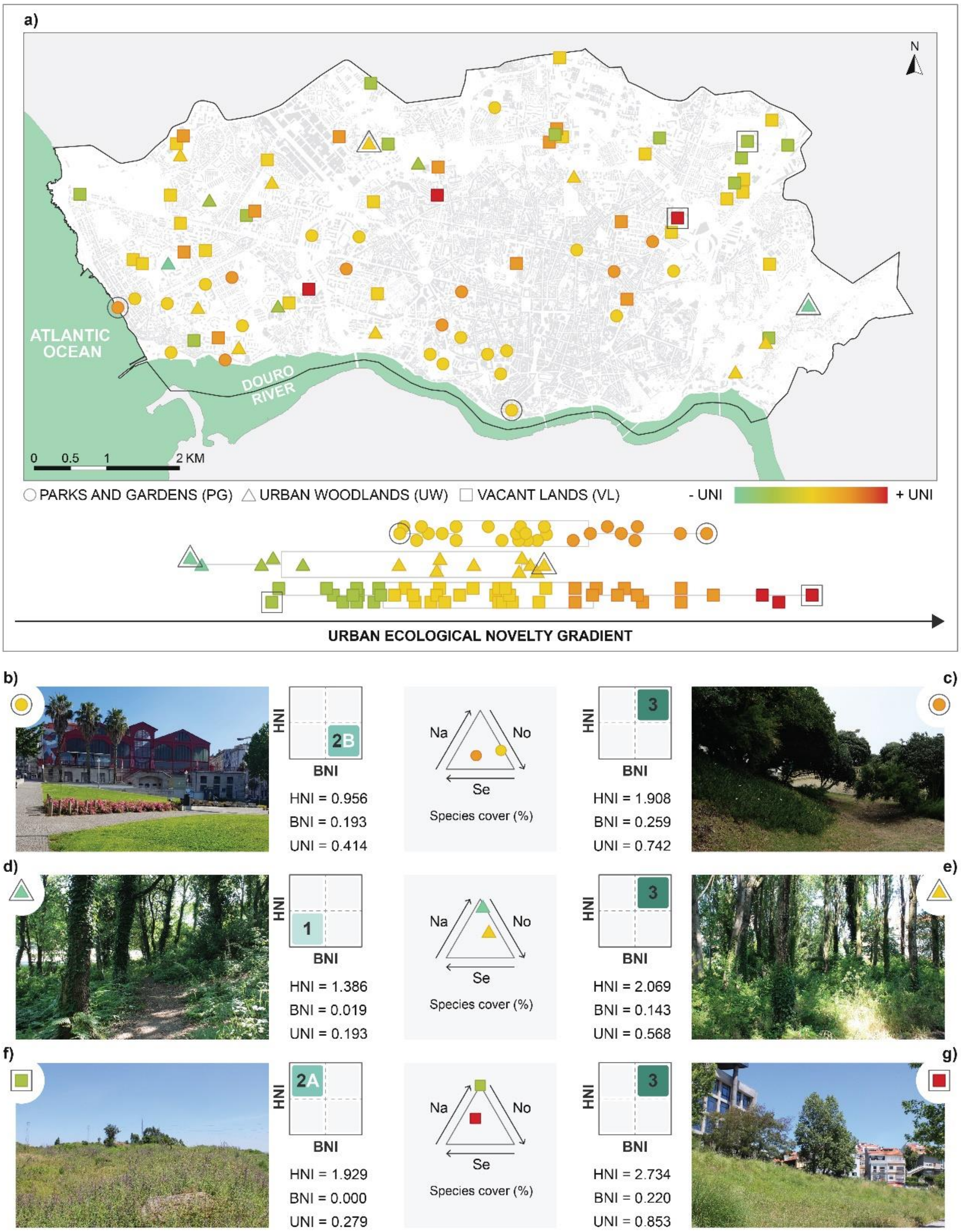

Figure 4.6. (a) Results of the UNI for all study sites positioned in the map of the city of Porto and in a gradient of urban ecological novelty; (b-g) Study sites with the lowest and highest results for the UNI for each UGS category with information about all the indexes (HNI, BNI, and UNI), the Urban Ecological Novelty Quadrant (1, 2A, 2B or 3) and a triangle plot of the percentage of species cover for native (Na), non-native (No), and successful established non-native (Se) species.

Nonetheless, there are also examples of study sites with lower and higher UNI results for all the UGS categories (Figure 4.6b-g). Lower UNI results are positioned in Quadrant 1, with low HNI and low BNI (Figure 4.6b, d, f). Higher UNI results are placed in Quadrant 3, with high HNI and high BNI (Figure 4.6c, e, g). Intermediate UNI results are either located in Quadrant 2A or 2B. VL study sites with medium level of urban ecological novelty tend to be placed in Quadrant 2A, while PG study sites with medium level of urban ecological novelty tend to be located in Quadrant 2B.

4.4. Discussion

4.4.1. Urban ecological novelty in the city of Porto

Vacant Lands (VL) study sites are relatively recent in the city of Porto. Additionally, all VL study sites resulted from abandonment and have low/absent management, which may explain the higher results for the HNI. Although the majority of Urban Woodlands (UW) study sites also have low or absent management, a considerable portion has the same land-use (42.86%), and the average percentage of impervious surfaces in this UGS category is the lowest (55.12%), thereby explaining lower results for the HNI. A considerable number of Parks and Gardens (PG) study sites have the same land-use (34.62%), and the majority has a high level of management (76.92%). This may explain the lower results for the HNI, even though this UGS category has the highest average percentage of impervious surface (79.38%).

PG study sites have a more balanced proportion of native and non-native species regarding both richness and cover, which may explain the higher results for the BNI. In these study sites, the percentage of native species richness and cover is lower than other UGS categories (61.48% and 35.64%, respectively). Consequently, there is a higher diversity of species with different status and providing different ecological functions. Also, PG study sites have a higher diversity of habitats. On the other hand, VL and UW study sites are mostly composed of native species in terms of both richness and cover, which explains, *per se*, lower results for the BNI. VL and UW study sites that had higher BNI results were the ones with a more balanced proportion between native and non-native species richness and cover or those in which the non-native flora introduced increased functional diversity.

Based on evidence from Porto, it was possible to verify that the isolated indexes (HNI and BNI) have their own trends and tend to be symmetrical. Consequently, when the two indexes are combined (UNI), the differences in results are leveled and camouflaged. This outcome supports the need to complement the UNI information with the assignment of the study sites to an Urban

Ecological Novelty Quadrant, as it is useful to determine which dimension of the novel ecosystems concept contributed more to an increased degree of urban ecological novelty.

4.4.2. Implications for urban green infrastructure planning and management

Besides testing a methodology to access urban ecological novelty, this study also intended to discuss the implications of this assessment for future urban green infrastructure planning and management. The green infrastructure of cities is inherently diverse, multifunctional, and, as confirmed by this study, exhibits different degrees of urban ecological novelty (Beer, 2015; Kowarik, 2011, 2018; Kowarik & von der Lippe, 2018). Alongside the land transformation and the emergence of novel combinations of species, the UGS become more and more complex and different from the UGS's public memory. To keep track of the relentless change in cities, it is necessary to understand the urban green infrastructure in all its dimensions. In the same way other aspects of the UGS are considered fundamental factors to inform planning and management decisions (e.g., the biodiversity they feature, if they are accessible to the majority of the population, the services provided, the patrimonial and unique values they bear), an additional layer referring to urban ecological novelty should be considered in planning and management policies and decisions. Otherwise, decision-makers, landscape architects, and urban planners will not consider those novel facets of the UGS when taking the required measures to strengthen, prepare and adapt urban green infrastructure to local and global dynamics (e.g., urbanization, land-use change, climate change) and to guarantee the desired suite of ecosystem services that UGS can provide. Mapping the UGS according to the degree of urban ecological novelty will contribute to a more informed planning and management decisions in line with specific goals and strategies, leading to a more informed, intentional, robust, and resilient urban green infrastructure. Since, for the case of Porto, a comprehensive planning and management program for the urban green infrastructure does not exist, it is urgent that such relevant instruments are produced, incorporating the novel urban ecosystems concept into the equation.

The urban ecological novelty of UGS is not necessarily defined by the UGS category to which it belongs. Evidence from Porto verified that, within a UGS category, study sites can still display different gradients of urban ecological novelty. UGS with lower and higher degrees of urban ecological novelty (Quadrants 1 and 3) will have specific roles in the urban green infrastructure. Their identification will support the establishment of different planning and management objectives. A clear distinction of goals is vital to target efforts, enabling more sustainable use of indispensable resources (Perring, Standish, & Hobbs, 2013).

Sites with lower urban ecological novelty (Quadrant 1) have not yet undergone extensive human-mediated transformations and/or experienced an intense shift in the species composition. These sites represent important reservoirs of native species and should be conserved and protected (Perring, Manning, et al., 2013; Trueman et al., 2014). In the example from Porto, those will mostly refer to UW study sites representing the few locations in the city that still hold remnants of native woodlands.

Sites with medium urban ecological novelty have either experienced extensive human-mediated transformations but without deep shifts in the species community (Quadrant 2A), or vice-versa (Quadrant 2B). These spots represent important locations to understand why the two dimensions have inverse trends or to examine them separately. The majority of study sites in the example from Porto are placed in this intermediate degree of urban ecological novelty.

Finally, sites with higher urban ecological novelty (Quadrant 3) have already been subjected to intensive human-induced changes and/or present unprecedented species compositions (due to addition and/or loss of species). In these sites, restoration to previous conditions is no longer feasible nor advisable since it can have negative consequences (Perring, Standish, et al., 2013). These locations present a mix of both native and non-native species, where non-native flora often dominates. However, there are a variety of opportunities and services that these novel assemblages of species may provide in the future (e.g., mitigation of climatic extremes, stormwater management, and sequestration of carbon) since they are already adapting and thriving in the harsh conditions of urban environments (Ahern, 2016; Collier, 2014; Del Tredici, 2010, 2020; Lugo et al., 2018; Perring, Manning, et al., 2013). In this way, hotspots of urban ecological novelty may have a clear place in the green infrastructure of the city. In the example from Porto, those will mainly refer to VL study sites with a balanced proportion of native and non-native species.

Recent studies have acknowledged that novel urban ecosystems can contribute to urban biodiversity conservation (Kowarik & von der Lippe, 2018). Sites with higher urban ecological novelty can function as urban laboratories that provide the possibility to further study the ongoing dynamics between these novel compositions of species that have never coexisted before, in an adaptive, learn-by-doing approach (Knapp et al., 2012; Light, Thompson, & Higgs, 2013). The study of novel urban ecosystem will also enable the discovery of species fragilities and adaptations, offering models that support, for instance, climate change mitigation via carbon sequestration and adaptation by contributing to urban tree canopy cover and reducing the urban heat island effect (Ahern, 2016; Dooling, 2015). Several global change forces are drivers of urban ecological novelty (i.e., climate change, air quality, urban hydrology), so their study will certainly contribute to developing strategies to mitigate the adversities that cities face today and guarantee a much-needed understanding of an unprecedented and uncertain reality.

The generated knowledge regarding sites with higher urban ecological novelty will, in turn, offer insights to manage these UGS at a finer, more local scale. For instance, it is in these locations that several ecosystem services can be enhanced through careful design and planning (Ahern, 2016; Dooling, 2015; Perring, Manning, et al., 2013; Sack, 2013). However, it is necessary to wisely consider which services are intended to be maximized in each space, avoiding potential disservices such as displacement of native or endemic species, the emergence of invasive species, respiratory allergies, or landscapes considered to be unattractive (Ahern, 2016). Many non-native species present in these novel combinations of species are responsible for performing indispensable ecological, historical, and cultural services for the city's metabolism.

Acceptance of novel urban ecosystems in cities, however, does not mean that areas with high concentrations of invasive species should be left uncontrolled (Standish, Thompson, Higgs, & Murphy, 2013). Similar to what has been done in some cities, novel urban ecosystems can become important landmarks with combinations of native and non-native species capable of support multiple ecological and cultural processes. The *Landschaftspark* in Duisburg-Nord (Germany) is an example of a once degraded and abandoned novel urban ecosystem, that today includes public parks that offer different services and bring people closer to a re-established nature in the city (Del Tredici, 2010; Felson & Pickett, 2005; Sack, 2013). They enable reconnection with nature and challenge the population's acceptance and aesthetic sense by exposing people to new paradigms regarding the way UGS are designed, perceived, and experienced.

4.4.3. Attributes and limitations of the methodology

The Urban Ecological Novelty Assessment proposed in this study is focused on the urban environment where the human presence is pervasive, therefore establishing a clear relationship with the human-induced genesis of novel ecosystems that are, foremost, social-ecological systems. This way, it distances itself from other existing methodologies related to the novel ecosystems concept because, conversely, human agency is not regarded only as a driver of change but also as an active-ongoing transforming element of urban landscapes.

The proposed methodology intends to place urban green spaces in a continuum of urban ecological novelty and it is grounded on the interception of two dimensions (the human and the biological dimension), which together result in dynamic transformations that, ultimately, generate novel urban ecosystems. Specific ecological thresholds are not quantified in this assessment, but self-perpetuation is indirectly evaluated through the analysis of ongoing human-induced transformation (e.g., human management and usage). Nevertheless, we did not exclude from this assessment the systems under ongoing human intervention or management since we believe they can still encompass urban ecological novelty.

The methodology attributes to a given urban green space a value of urban ecological novelty ranging from 0 to 1 (UNI index) and, combined with the placement of the urban green space in one Urban Ecological Novelty Quadrant, it is possible to assess which dimension of the novel ecosystems concept is contributing more to an increase of novelty. Even though differences between the urban green spaces are gradual, the outcomes resulting from the application of the methodology translate a level of urban ecological novelty (low, medium or high), which can relate directly with other existing gradients such as the “natural-hybrid-novel” proposed recently by Kowarik & von der Lippe (2018).

Thus, this tool facilitates the prioritization and decision-making of planning and management actions in the city where the methodology is applied. As previously mentioned, locations with low novelty will be assigned to a set of specific actions and goals, while locations with higher novelty will entail different agendas. Besides its utility in planning and management, this tool can also be valuable from a research point of view. Locations with higher degrees of urban ecological novelty are and will be increasingly common in cities, which means that these areas should be urgently investigated. In this sense, the tool will be useful not only for urban planners, landscape architects, urban ecologists, and decision-makers but also for researchers interested in study novel urban ecosystems.

After testing the methodology in the city of Porto, we have verified its practical applicability and determined the potential advantages and limitations of this assessment. Overall, the proposed working methodology is original and addresses a straightforward way to assess urban ecological novelty. We believe it can be adjusted and replicated to other urban contexts according to available data and tools, as well as the different UGS categories present that are of interest to assess. On the other hand, the lack of data for the city of Porto was an obstacle in this study. Biotic and abiotic change are often linked and act synergistically (Hobbs et al., 2006, 2009; Mascaro et al., 2013; Radeloff et al., 2015). Yet, it was not possible to accede abiotic variables such as temperature and precipitation. The lack of floristic historical data was overcome with the utilization of the BNI proposed by Schittko et al. (2020), but, if available, it would have been useful in the development of the assessment. Recent research on novel urban ecosystems has been stating that engineered green spaces (e.g., green infrastructure such as green roofs, green walls, rain gardens) are exemplary cases of novelty (Heger et al., 2019; Van Mechelen et al., 2015). Nevertheless, study sites from this UGS category were not tested since they are almost nonexistent in the city of Porto. The few examples are private and inaccessible. Finally, the study only addresses urban novelty regarding plants and terrestrial ecosystems, but novelty may also arise from animals and in aquatic ecosystems. Despite limitations, lessons learned from Porto met our initial expectations and reinforced the original and fundamental ideas of this research.

4.4. Conclusion

Overall, we conclude that urban green spaces are positioned differently in the urban ecological novelty gradient, presenting different levels and paces of human-mediated transformation (human agency novelty), as well as different species assemblages (biotic novelty). We acknowledge that the methodology applied in this work may represent only one of many ways to assess urban ecological novelty. Still, we believe it is a valid method since we explicitly included the most important aspects of the novel ecosystems concept that are repetitively stated in the literature.

Nowadays, most urban areas have already studied, characterized, and mapped their urban green infrastructure. Concerns raised in the last decades regarding the urban environment (e.g., climate change adaptation and mitigation, biodiversity loss, public health, and environmental justice) motivated cities to develop extensive and relevant work to know and evaluate the urban green infrastructure in its many facets and produce informed and reliable planning and management instruments. We believe that the proposed working methodology can be replicated and adapted in a straightforward way to other urban geographical areas since, in many cases, the necessary data already exists. The data has just not yet been analyzed from the perspective of urban ecological novelty, which we argue is very pertinent and urgent.

Future research could address the inclusion of abiotic variables in this assessment. Additionally, floristic data surveyed in the city of Porto should be registered in platforms such as the Global Biodiversity Information Facility – GBIF (https://www.gbif.org/), supporting the creation of a consistent database that can be used in future generations of studies. These kinds of efforts today will support constant monitoring of the flora of Porto and be extremely useful in the future since the study of urban ecological novelty would benefit if carried for longer periods of time (Morse et al., 2014).

Future works could also explore with more detail and even finer scales the actual management, planning, and design guidelines that can be implemented in cities to take advantage of novel urban ecosystems opportunities. Design guidelines can also be developed as “safe-to-fail” designed experiments that build a “learning loop” and respond to the specific dilemmas of a particular location (Ahern, 2011, 2016; Felson & Pickett, 2005). In this sense, adapted designs are understood as hypotheses rather than proven solutions, and the risk of failure is *a priori* understood and accepted. Importantly, the performance of the UGS and the adapted designs should be monitored to evaluate strategies to improve the delivery of ecosystem services, to mitigate the disservices, and to raise public awareness to support new strategies or methods.

Above all, this study highlights that the urban ecological novelty assessment can be useful to guide urban planning and management to achieve specific ecosystem service goals. We believe the proposed working methodology will prove to be an essential tool to inform decision-makers and assist landscape architects and urban planners in facing the profound constraints and uncertainty inherent to the Anthropocene. The methodology also represents a starting point to rigorously investigate novel urban ecosystems in their real-time and incredible complex emerging contexts.

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Supplementary material

Appendix 4A. Sampling design: selection of 85 study sites from three Urban Green Spaces (UGS) categories – Parks and Gardens, Urban Woodlands, and Vacant Lands.

In this work, we explored three UGS categories from Porto's green infrastructure: Parks and Gardens (PG), Urban Woodlands (UW), and Vacant Lands (VL). These three UGS categories were selected because they associate directly with the urban ecological novelty continuum according to the "Four Natures" Approach (i.e., Urban Woodlands – Nature 1, Parks and Gardens – Nature 3, and Vacant Lands – Nature 4) (Kowarik, 2011, 2018). Accordingly, they exhibit distinct human-induced transformation narratives, different species assemblages, and the full range of human management varying from intensive to low/absent maintenance regimes (Ahern, 2016; Del Tredici, 2010, 2020).

Polygons belonging to PG, UW, and VL were isolated in ArcGIS 10.6 (ESRI, 2011) and analyzed in terms of area and proportion considering only the three UGS categories (Table 4A.1). Since 29 Parks and gardens of the city of Porto were already analyzed in previous works by Farinha-Marques et al. (2015, 2014), resulting in a very robust analysis, we selected 26 study sites (three outliers were excluded) from this database to establish continuity with prior analysis. This continuity was only possible since we used the same method in this study, such as the analysis of habitats and the floristic surveys' performance.

Table 45A.1. Details about the selected Urban Green Spaces (UGS) categories: Parks and gardens (PG), Urban woodlands (UW), and Vacant lands (VL).

UGS category	Number of polygons	Minimum Area (m^2)	Maximum Area (m^2)	Mean Area (m^2)	Standard deviation (m^2)	Sum Area (m^2)	Proportion
PG	108	370.0	637 625.5	17 750.2	64 167.5	1 917 017.0	30.6 %
UW	127	600.8	86 552.1	7 923.9	11 490.8	1 006 335.5	16.1 %
VL	743	206.4	58 770.7	4 496.1	6 766.4	3 340 615.8	53.3 %
TOTAL						**6 263 968.32**	**100.0 %**

Study sites from the remaining UGS categories (UW and VL) were determined by a stratified random sampling design using ArcGIS 10.6 (ESRI, 2011). The number of UW and VL study sites was defined by the proportion that each UGS category represented in the total sum area (Table 4A.1). Since we had already selected 26 Parks and Gardens representing a proportion of 30,6%

of the total sum area, we assumed that for this work a total of 85 study sites were needed (26 ÷ 30.6% = 85 study sites). Resulting in the following number of study sites per UGS category:

- Parks and Gardens (PG): 85 x 30.6% = 26 study sites;
- Urban Woodlands (UW): 85 x 16.1% = 14 study sites;
- Vacant Lands (VL): 85 x 53.3% = 45 study sites.

Polygons from the three UGS categories (PG, UW, and VL) have high variability in area, i.e., there is a huge difference between the minimum and maximum areas, although larger areas are less frequent (mean area). In order to manage the floristic surveys with existing resources, polygons from UW and VL (n=870) with areas greater than the standard deviation area were excluded from the sampling (n=186) (Table 4A.1). From the remaining polygons population (n=684), a stratified random selection of 14 UW study sites and 45 VL study sites was performed automatically. The selected study sites (n=59) were analyzed with orthophoto imagery and on-site visit confirmations to assess: accessibility, safety, and remaining in a vacant state since many Vacant Lands were being transformed into construction sites. Selected study sites that did not fulfill these requirements were excluded from the sampling, and a new random selection was made to replace the missing study sites. This process was repeated until all the selected study sites were considered safe, accessible, and representative of their UGS category. See Figure 4A.1 for the location of the 85 study sites in the city of Porto.

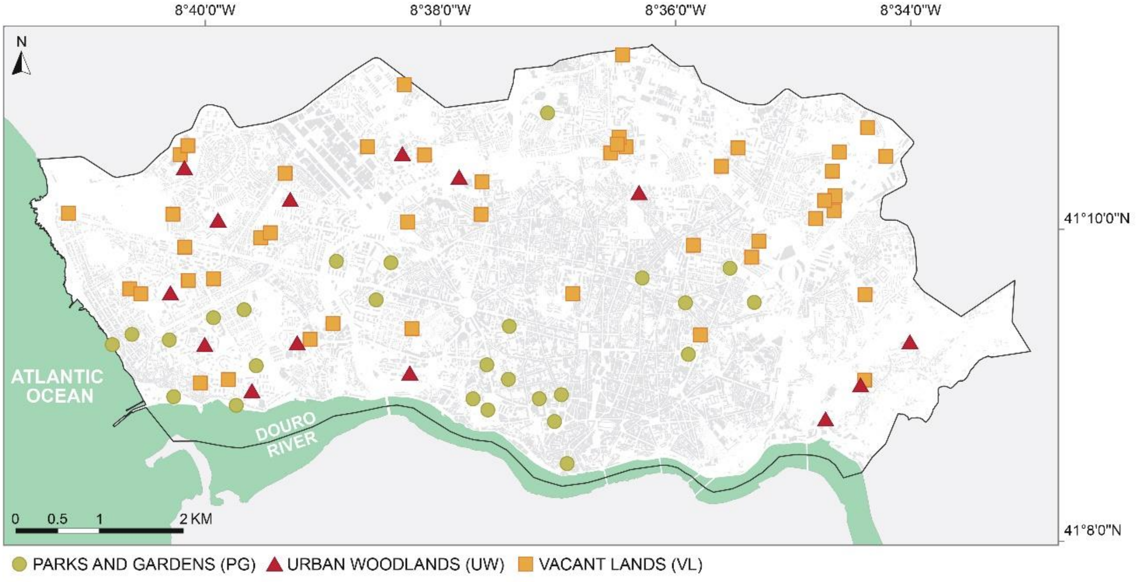

Figure 4A.1. Location of the 85 study sites in the city of Porto – 26 Parks and Gardens (PG), 14 Urban Woodlands (UW), and 45 Vacant Lands (VL).

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Appendix 4B. Table with the list of selected human agency variables, description, respective classes, rationale, relationship with ecological novelty, and supporting references.

Variable	Description	Classes (level of ecological novelty)	Rationale, relationship with ecological novelty and references
Previous land-use	Study site land-use in 1892 or 1939	• **Same land-use** (low level of ecological novelty) – if the land-use has not changed since 1892 or 1939 • **Other land-uses – vegetation** (medium level of ecological novelty) – if the study site was previously an agricultural field or a woodland • **Other land-uses – construction** (high level of ecological novelty) – if the previous land-use was constructed (e.g., house, building, square, etc.)	The previous land-use has a significant effect on the present ecosystem structure and species composition (Lugo & Helmer, 2004). Since land-use change is considered a driver of novelty (Hobbs et al., 2006; Hobbs, Higgs, & Harris, 2009; Kowarik, 2011; Radeloff et al., 2015), we assumed that more land-use change encompasses more ecological novelty.
Level of management	The degree of human intervention applied to maintain the study sites' character and appearance or the absence of management	• **High** (low level of ecological novelty) **–** if there's a high degree of human intervention in order to maintain the study sites' character and appearance • **Medium** (medium level of ecological novelty) **–** if there's an intermediate degree of human intervention in order to maintain the study sites' character and appearance • **Low/absent** (high level of ecological novelty) **–** if there's a low degree of human intervention in order to maintain the study sites' character and appearance or even absence of management	The cessation of management/abandonment is a key characteristic of novelty in the literature (Hobbs et al., 2006; Kowarik, 2011; Lugo & Helmer, 2004). Since novel ecosystems should be able to persist without, or in spite of, extensive human intervention (Hallett et al., 2013; Higgs, 2017; Morse et al., 2014), we assumed that a low or absent level of management encompasses more ecological novelty. Nevertheless, in this work, we argue that systems with ongoing management can still manifest urban ecological novelty (even if lower), as some researchers also consider that management and human design can be drivers of novelty (Ahern, 2016; Hobbs et al., 2006; Mascaro et al., 2013; Morse et al., 2014; Perring et al., 2013).
Surrounding impervious surface	The percentage of sealed surface in the surroundings of each study site (within a buffer of 250 m)	• Values ranging from **0** (low level of ecological novelty) to **100 %** (high level of ecological novelty)	The percentage of surrounding impervious surface was used as an indicator of urbanization intensity (Knapp et al., 2012). Since urbanization is considered a driver of novelty (Kowarik, 2011; Perring et al., 2013) and has an enduring effect on the emergence of novel urban ecosystems, we assumed that a higher percentage of surrounding impervious surface encompasses more ecological novelty.

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Appendix 4C. Table with the list of selected biotic variables and traits, description, respective classes, supporting references, and online databases and source references from which they were collected.

Variable / Trait	Description	Classes	References	Databases and Source References
Status	Status to Portugal (only mainland)	• **Native** – plant taxon native to Portugal • **Non-native** – plant taxon non-native to Portugal • **Successful established non-native** – plant taxon non-native to Portugal and successfully established in the territory according to Richardson et al. (2000) (i.e., casual, naturalized, or invasive non-native)	(Knapp et al., 2012; Kowarik & von der Lippe, 2018; Tognetti, 2013; Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009)	Flora-On (2020), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), Marchante, Morais, Freitas, & Marchante (2014)
Residence time	Time since non-native species were first introduced in Portugal	• **Archeaophytes** – non-native plant taxon introduced before the discovery of the New World (circa 1500 AC) • **Neophytes** – non-native plant taxon introduced after the discovery of the New World (circa 1500 AC)	(Schittko et al., 2020)	Flora-On (2020)
Life form	Plant life form according to Raunkiær (1934) referring to the vertical position of vegetative buds (as an adaptation to climatic conditions)	• **Hydrophyte/Helophyte** – plants which have their surviving buds situated under water, above or below the soil surface • **Geophyte** – plants which have their surviving buds situated within the soil often on storing organs • **Therophyte** – plants whose entire shoot dies after seed production and which survive through only their seeds • **Hemicryptophyte –** plants which have their surviving buds situated close to the ground surface on herbaceous shoots, protected by foliage or dead leaves • **Chamaephyte –** plants which have their surviving buds situated close to the ground surface on herbaceous shoots or only slightly lignified shoots, protected by parts of the plant itself and/or by snow cover • **Phanerophyte –** plants which have their surviving buds in branches which project freely into the air	(Perring et al., 2012; Tognetti, 2013; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018)	Flora Digital de Portugal (2020), Flora-On (2020), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), TRY (Bragazza, 2009; Campetella et al., 2011; Choat et al., 2012; Ciccarelli, 2015; Dressler, Schmidt, & Zizka, 2014; Fitter & Peat, 1994; Kattge et al., 2020; Kleyer et al., 2008; Kühn, Durka, & Klotz, 2004; Moretti & Legg, 2009; Roy, Hill, & Preston, 2004)

(Continued …)

Variable / Trait	Description	Classes	References	Databases and Source References
Height	Expected maximum height [m]	• Values ranging from **0 – 110 m**	(Fischer, Von der Lippe, & Kowarik, 2013; Perring et al., 2012; Schittko et al., 2020; Van Mechelen et al., 2015)	Brickell (1999), Castroviejo (1986-2015), eFloras (2020), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), Moreira (2008), Plants For A Future (2020)
Region of origin	Region of origin and distribution of the taxon	• **Cosmopolitan** – plant taxon originated in both or one hemisphere of the globe (includes subcosmopolitan taxa) • **Eurasia and North Africa** – plant taxon originated from Eurasia and/or North Africa • **Europe** – plant taxon originated from Europe • **Outside Europe** – plant taxon originated from outside Europe (i.e., Asia, Africa, Oceania, North America, and South America) • **Mediterranean and Macaronesia** – plant taxon originated from Mediterranean and/or Macaronesia region • **Endemic** – plant taxon originated from the southwest Mediterranean region (i.e., Iberian Peninsula, South France, Northwest Africa and Macaronesia) (includes subendemic taxa) **Uncertain origin** – plant taxon with uncertain origin (includes hybrid and cultivar species)	(Wilsey et al., 2009)	Brickell (1999), Castroviejo (1986-2015), eFloras (2020), Flora Digital de Portugal (2020), Plants For A Future (2020)
Flowering season	Season in which flowering begins	• **Winter/early spring** – bloom begins in January, February, or March • **Spring/early summer** – bloom begins in April, May, or June • **Summer/early fall** – bloom begins in July, August, or September • **Fall/early winter** – bloom begins in October, November, or December • **All year** – bloom is all year long	(Van Mechelen et al., 2015)	Brickell (1999), eFloras (2020), Flora Digital de Portugal (2020), Flora-On (2020), Moreira (2008), Plants For A Future (2020)

(Continued …)

Variable / Trait	Description	Classes	References	Databases and Source References
Flowering period	Duration of bloom [months]	• Values ranging from **1 – 12 months**	(Perring et al., 2012)	eFloras (2020), Flora Digital de Portugal (2020), Moreira (2008), Plants For A Future (2020)
Ecological strategy	Ecological strategy according to Grime (1979)	• **C** – Competitors; trees, shrubs and forbs with highly competitive power due to their morphological and/or physiological characters and life history traits • **R** – Ruderals; usually annual, weedy plant species which produce many seeds and can easily colonize pioneer habitats • **S** – Stress-tolerators; species with only slow growth and morphological and/or physiological adaptations to conditions that may be in either very rare or overabundant • **CR** – intermediate type between Competitors and Ruderals • **CS** – intermediate type between Competitors and Stress-tolerators • **SR** – intermediate type between Stress-tolerators and Ruderals • **CSR** – Intermediate type between Competitors, Stress-tolerators, and Ruderals, usually rosette plants or small, perennial species which can utilize spatial-temporal niches and have an intermediate life span	(Fischer et al., 2013; Lugo, Winchell, & Carlo, 2018; Van Mechelen et al., 2015; Vanstockem et al., 2018)	Grime (1979), TRY (Gachet, Véla, & Tatoni, 2005; Kattge et al., 2020; Kühn et al., 2004)

Rationale

Status is a crucial part of every study focused on the novel ecosystem concept and the establishment success and residence time have also been considered important variables in recent works (Kowarik & von der Lippe, 2018; Schittko et al., 2020). Besides the presence, or even dominance, of non-native species in novel communities, equally important is to understand if the novel species brings new functions to the system. This is why a set of functional traits that inform an understanding of plant adaptations was thoughtfully selected. Raunkiær (1934) life forms classification is based on the vertical position of the vegetative buds, giving specific information about the morphological adaptations of plants to survive the unfavorable season. Plant height is closely related with other traits, such as life span, and affects important variables such as the ability to compete for light and carbon sequestration capacity (Moles et al., 2009). Plant region of origin informs about which biogeographic region a specific plant originates from and, therefore, is adapted to. Flowering phenology reflects the reproductive period of plants, i.e., the moment in which plants allocate a large part of their energy to form reproductive structures that will determine seed dispersal (Fernandes, 2009). Finally, the ecological strategy or CSR model proposed by Grime (1979) classifies plants in functional types based on competitive ability, adaptation to severe stress, and adaptation to disturbances (Schmidtlein, Feilhauer, & Bruelheide, 2012).

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5

CHAPTER 5 |

ADAPTIVE PLANTING DESIGN AND MANAGEMENT FRAMEWORK FOR URBAN CLIMATE CHANGE ADAPTATION AND MITIGATION

"To the extent that we are comfortable with patterns in the landscape (biodiversity) leading to processes that we need/enjoy (…) then we may accept changed background patterns to maintain those processes and functions (…). Novel ecosystems explicitly allow for this, and this pragmatism may be their greatest strength in providing a framework for management in the face of climate change." (Starzomski, 2013, pp. 96–97)

Chapter 5 | Adaptive planting design and management framework for urban climate change adaptation and mitigation

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Article submitted and currently under review (following acceptance with minor revisions) as a research article in *Urban Forestry & Urban Greening.*

Type of article: Research article
Journal Impact Factor (2020): 4.537

Citation: Teixeira, C. P., Fernandes, C. O., & Ahern, J. Adaptive planting design and management framework for urban climate change adaptation and mitigation. *Urban Forestry & Urban Greening. (**Under Review – following acceptance with minor revisions**)*

Abstract

Implementing measures to adapt and mitigate climate change effects in cities has been considered increasingly urgent since the quality of life, health, and well-being of urban residents is threatened by this change. Novel communities of plant species that emerge and thrive in the harsh conditions of cities may represent a promising opportunity to address climate change adaptation and mitigation through the planting design and management of urban green spaces. The objective of this study is to develop an adaptive planting design and management framework. The proposed framework is grounded on previous adaptive approaches and focuses on the opportunities emerging from novel plant communities in urban conditions. The framework comprises three main steps (1 - Climate change assessment, 2 - Plant species database, and 3 - Planting design/management procedure). A proposal on how the framework could be tested was developed for the city of Porto, Portugal. Still, the application of the framework can also be adjusted to other urban contexts, offering a starting point for experimentation and assessment of plants' adaptation and mitigation capacities through design and management. As lack of knowledge and uncertainty about climate change limits global capacity to implement robust adaptation and mitigation strategies, building knowledge in an adaptive way and context-specific locations will be of paramount interest to tackle climate change in cities.

Keywords: Heatwaves; Novel urban ecosystems; Plant traits; Pluvial flooding; Urban biodiversity; Urban green spaces

5.1. Introduction

Climate change negatively affects urban areas' livelihood and sustainability, threatening the quality of life, health, and well-being of urban residents (IPCC, 2021). Due to a population concentration in cities, the heat island effect, and the impacts of anthropogenic activities, urban areas are often considered to be both the most vulnerable to climatic events and those that more significantly contribute to climate change (Rosenzweig, Solecki, Hammer, & Mehrotra, 2010). For that reason, the implementation of measures to tackle climate change in cities has been considered increasingly urgent (Zölch, Maderspacher, Wamsler, & Pauleit, 2016). The complexity of urban ecosystems makes responding to climate change more challenging and difficult (Carter, 2018). Still, urban areas are also centers of economic and political power, thus gathering the ideal conditions to test and implement innovative solutions (Carter, Handley, Butlin, & Gill, 2017; Rosenzweig et al., 2010). Cities have inherent characteristics that create opportunities to prepare for current and future conditions and to reduce greenhouse gas production (Hami, Abdi, Zarehaghi, & Maulan, 2019; van Staden, 2014).

Besides the projected changes in temperature or precipitation, climate change is also indirectly responsible for dramatic changes in ecosystems' patterns and processes (IPCC, 2021). The modification of the urban abiotic conditions decreases species fitness, affects their physiological, reproductive, and phenological responses, and disrupts interactions at the community level (Hunter, 2011; Starzomski, 2013). Driven by these effects, species shift their distribution patterns and reorganize themselves into unprecedented novel combinations, leading to the emergence of Novel Urban Ecosystems (Kowarik, 2011). In the same way that the effects of climate change are more intense in cities, for similar reasons, ecological novelty is also widespread in urban areas (Hobbs et al., 2014; Kowarik, 2011; Perring et al., 2013).

Even though Novel Urban Ecosystems are driven by climate change, this concept can provide insights on how to understand and manage climate change impacts on species, communities, and ecosystems (Starzomski, 2013). Novel combinations of native and non-native species are already thriving in challenging urban environmental conditions, despite human intervention or management, suggesting that these ecosystems are well prepared to handle climate change effects. In this way, Novel Urban Ecosystems may be "pre-adapted" to future climates and environmental stresses (Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Standish, Hobbs, & Miller, 2013) and, in some cases, perhaps better prepared than previous combinations of native species only (Kowarik, 2011).

In response to increasing global urbanization, cities are progressively implementing green infrastructure and nature-based solutions to deliver specific ecosystem functions (Carter, 2018;

Carter et al., 2017; EEA, 2016; Zölch et al., 2016). A multifunctional network of green spaces in cities can support both ecological and social goals (Klaus & Kiehl, 2021). Additionally, informed selection and combination of specific plant species in the urban space can be explored due to its potential crucial role in adapting and reducing climate change effects in cities (Dunnett & Hitchmough, 2004; Espeland & Kettenring, 2018; Hunter, 2011).

Growing concern and urgency in preparing cities for current and future environmental conditions (adaptation) and in minimizing the impacts and causes of climate change (mitigation) has led several authors to contribute important planting design and management guidelines grounded on ecological theory, scientific evidence, and specifically focused on climate change-related problems and impacts (e.g., Alizadeh & Hitchmough, 2019; Hami et al., 2019; Hunter, 2011; Köppler & Hitchmough, 2015; Rainer & West, 2015). Nevertheless, these guidelines may remain limited due to the uncertainty and context specificity of climate change effects. The increasing ambiguity of climate change demands innovation and experimentation (Felson & Pickett, 2005; Kato & Ahern, 2008). Therefore, urban areas can function as living laboratories to build unprecedented, local, context-specific knowledge and understanding (Light, Thompson, & Higgs, 2013).

This way, this article aims to develop an adaptive planting design and management framework and test how it could be applied in the city of Porto, Portugal. The proposed framework is grounded on previous adaptive environmental approaches for management (Holling, 1978), planning (Ahern, Cilliers, & Niemelä, 2014; Kato & Ahern, 2008) and design (Felson & Pickett, 2005; Lister, 2007): a strategy that allows learning from context-specific experience in order to create more robust, flexible, and adjustable proposals informed by the theoretical and practical knowledge gained. The framework also builds on existing planting design and management guidelines for climate change adaptation and mitigation while also focuses on the opportunities emerging from novel plant communities already thriving in the extreme urban conditions.

5.2. Adaptive planting design and management framework

The adaptive framework assists the development of planting design and management proposals based on the assumed plants' potential to adapt and mitigate climate change effects in order to make urban areas more comfortable, healthier, and safer for people. Following an adaptive approach, the feasibility, effectiveness, and risks of the planting design and management decisions can be evaluated post-planting. This way, gaps in scientific knowledge can be bridged through experimentation in a more realistic and complex urban landscape (Felson & Pickett, 2005). This way, there is an increasing opportunity to minimize uncertainty, maximize resilience, and create a learning loop that will adjust the strategies whenever necessary, for example, as new data becomes available or when implemented strategies are not succeeding as expected (Kato & Ahern, 2008; Pickett, Cadenasso, & Grove, 2004).

The framework aims to be applied in existing urban green spaces with varying degrees of urban ecological novelty (Teixeira, Fernandes, Ahern, Honrado, & Farinha-Marques, 2021), which can include interventions in parks and gardens, urban woodlands, or in smaller-scale or neglected green spaces that had not been formally recognized and planned for public use before (i.e., informal green spaces), such as vacant lands, street verges, traffic islands, or brownfields (Klaus & Kiehl, 2021).

The proposed adaptive planting design and management framework (Figure 5.1) starts with (1) the assessment of climate change effects expected in the study area that can be actively addressed using plants or through planting design or management. Secondly, (2) a plant species database is produced to collect and classify a set of plant species for their capacity to adapt and mitigate climatic extremes. Finally, (3) the planting design and management procedure is developed with the following steps: i) definition and prioritization of design and management goals to respond to climate change problems in the study area; ii) assessment of the current status of the intervention site to examine the required modifications; iii) selection of plant species to remove, monitor, keep, or add; iv) combination of plant species to increase redundancy and diversity; and v) elaboration of the monitoring protocol to evaluate the effectiveness of the proposals after implementation. All the steps in the framework must be coordinated in an iterative process and adjusted whenever necessary.

5.2.1. Climate change assessment

Understanding the climate change projections expected for the study area is an essential starting-point for developing context-specific and city-scale strategies. Global and regional climate change projections have been recently documented by IPCC (2021). More detailed projections should also be investigated since there is a growing understanding that climate change effects are mainly experienced locally (Aguiar et al., 2018), especially those affecting human comfort: temperature, ventilation, and humidity (Geiger, Aron, & Todhunter, 1995).

Climate change hazards will represent different risks depending on how prepared the study area and its inhabitants are to handle climate change effects. This way, it is helpful to evaluate the most concerning climate change risks in the study area considering its current response capacity. Patterns of vulnerability regarding climate change scenarios are not homogeneously distributed in cities (Carter, 2018). Thus, priority areas and sub-populations targeted for climate change adaptation and mitigation should also be identified (Carter et al., 2017).

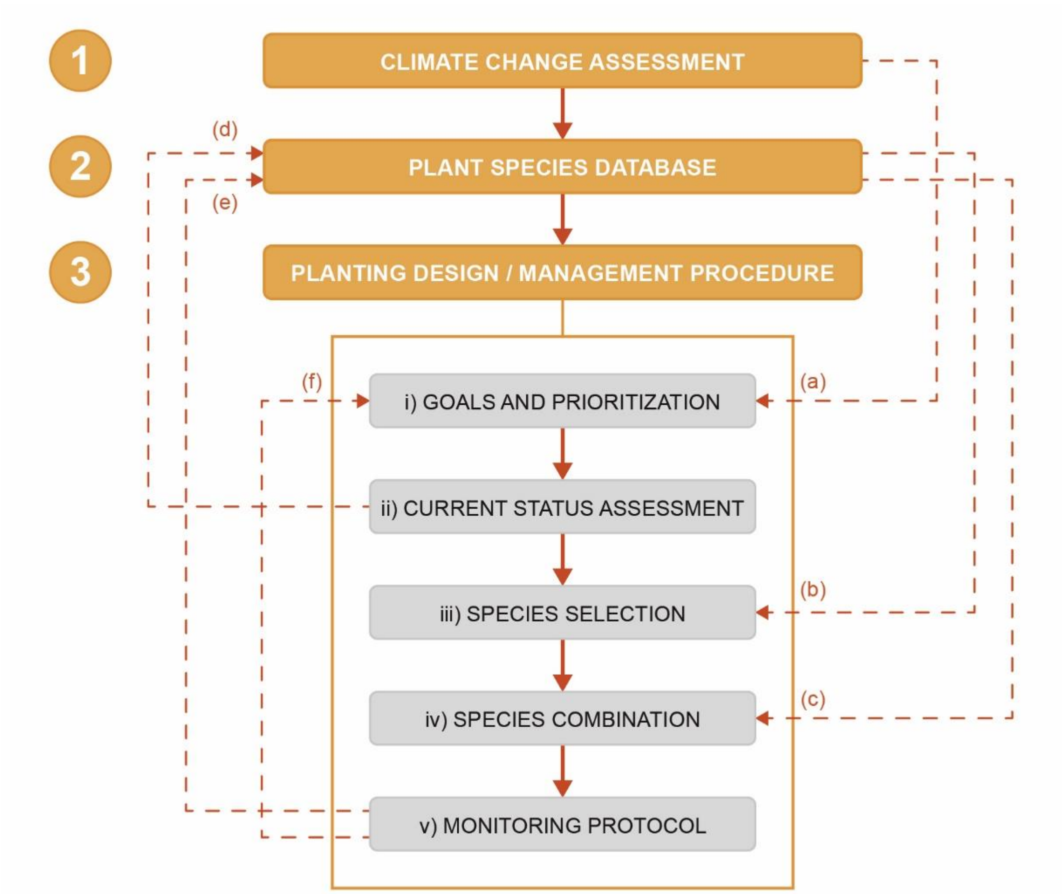


Figure 5.1. Conceptual diagram of the proposed framework. Main sequence of steps (bold arrow) and secondary and dynamic links between steps (dashed arrow). (a) The climate change assessment will instruct the definition of goals; (b, c) The plant species database will instruct both species selection and combination; (d, e) New species can be included in the database following the current status assessment (i.e., species that exist in the intervention area) and monitoring process (i.e., new species that emerge in the intervention area over time); (f) The monitoring process can as well dictate the need to redefine goals.

5.2.2. Plant species database

The database assembles the set of plant species to work with in the following steps of the framework. It should include (but not be limited by) species that are already occurring in the study area. Following an adaptive approach, assisted migration (Hughes et al., 2008) of particular beneficial plant species could also be tested assuming that the experiment is closely monitored and held in a controlled setting (e.g., in botanical gardens or research plots to assess how adapted plants are to the climate, the risk of becoming invasive, and potential negative and positive impacts or traits). In this case, assisted migration does not have to be necessarily about non-native plants, as it can target native plants from other parts of the study area's country that are more adapted to certain environmental conditions.

Species included in the database must be organized and classified according to traits that will facilitate their selection and combination (Hunter, 2011; Vogt et al., 2017), including climate adapting traits (e.g., tolerances to extreme conditions) and mitigating traits (e.g., canopy density and size). It is important to ensure that the database contains species with varied habits, life cycles, functions, and origins.

Although a native-species-only policy is often emphasized in the literature as a crucial step to ensure an optimum level of biodiversity, we urge that in urban areas, mixtures of native and non-native species may be better prepared to cope with climate change (Ahern, 2016; Del Tredici, 2020; Kowarik, 2011; Standish et al., 2013). The use of a vast selection of both native and non-native species will ensure a wide range of response to climate change problems, so excluding from the start the species based on their origin may only decrease the potential of the proposals (Alizadeh & Hitchmough, 2019; Davis et al., 2011).

5.2.3. Adaptive planting design and management procedure

i) Goals and prioritization

Based on the climate change projections, risks, and priority areas for the study area, it is essential to define goals to solve one or more context-specific problems (Hunter, 2011; Windhager, Simmons, & Blue, 2011). Goals must address both adaptation and mitigation concerns. Encouraging biodiversity should always be an underlying goal since overall ecosystems' diversity, health, and resilience will determine the ecosystem capacity to survive change and perform essential functions (Hunter, 2011). Likewise, aesthetic quality should not be disregarded as it plays an important role in people's perception and well-being.

Proposals should be set to respond to a wide range of problems, which is not always easy to achieve (Windhager et al., 2011). This way, it may be helpful to prioritize goals, anticipate potential ecosystem conflicts and problems, and identify eventual trade-offs (Ahern et al., 2014). Prioritization should depend on climate change projections' risks in both short- and long-term and rely on social and political discernment (e.g., available resources, cost-benefits, probability of success, public acceptance) (Hobbs et al., 2014).

ii) Current status assessment

The next step comprises the assessment of the current status of the area we intend to intervene on. This assessment should collect data about the species present at the intervention area such as the plant list, species richness and cover. If they are not yet contemplated there, the plant species in the intervention area must be included in the database (step 2). Afterwards, it will be possible to assess which of the targeted traits needed to achieve the established goals are already present, lacking, or underrepresented.

iii) Species selection

Based on the combined information from all of the previous steps, species selection will involve four operations: remove, monitor, keep, or add.

Harmful and undesirable species should be removed considering both expert and public perspectives (Dunnett & Hitchmough, 2004). Depending on the species, context, and legislation, these can include, for instance, excessively dominant invasive species, damaged species (i.e., diseased, spoiled, or broken), or species with unwanted features (i.e., dangerous for people or posing high public health risks) (Del Tredici, 2020). Removing such species should be gradual and calculated. For instance, there are situations where invasive species are already performing vital ecosystem functions or could be useful to achieve particular management conditions, even only as temporary solutions.

On the other hand, species that can be problematic in the future should be closely monitored and flagged instead of removed from the start. Otherwise, the adaptation potential of this species would be overlooked and experimentation and creativity in the design and management process would be compromised (Fernandes, Teixeira, & Farinha-Marques, 2018). These can include, for instance, species that have higher risk of becoming invasive (Marchante, Morais, Freitas, & Marchante, 2014) or mature invasive species (e.g., fully developed trees). Likewise, species that can be perceived as an indicator of neglect should also be kept and monitored following interventions that enhance their appearance and care (Nassauer, 1995).

Species already occurring in the intervention site that are more beneficial than harmful should be kept. For example, desirable and advantageous spontaneous vegetation can be maintained or integrated in the proposals at different stages (Bakshi & Gallagher, 2020; Dunnett & Hitchmough, 2004; Kowarik, 2018; Kühn, 2006). Spontaneous vegetation is generally tolerant and pre-adapted to the extreme conditions of urban environments and, therefore, offering potentially valuable contributions for climate change adaptation and mitigation (Del Tredici, 2020).

Finally, targeted species can be added to perform specific and critical functions, either absent functions that we wish to include in a particular location or selected functions that we intend to maximize (Ahern, 2016; Klaus & Kiehl, 2021; Perring et al., 2013). It may also refer to the inclusion of more cosmopolitan species, species with wider ranges of tolerances and functions, or species that require minimal management (Del Tredici, 2020).

iv) Species combination

The way species are assembled will be crucial for the desired outcome. When combining species, it is imperative to consider the species dynamics, ecological compatibility, and habitat preferences in the long-term. For instance, assemblages of species with very distinct growth rates (fast and slow-growing) or heights (short and tall) may lead to higher levels of incompatibility if other features of the species (e.g., shade tolerance, phenology, growth season) are overlooked (Dunnett & Hitchmough, 2004; Köppler & Hitchmough, 2015; Rainer & West, 2015). Plant species combinations should ultimately aim to increase redundancy and diversity as much as possible, once this is infrastructural to provide multiple ecosystem functions (Hunter, 2011; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015).

Functional redundancy will ensure that the same function or trait (e.g., shading or drought tolerance) is provided by more than one species in the plant community and, therefore, throughout different seasons (Elmqvist et al., 2003). Functional diversity will increase the number of ecological functions the system can perform throughout the year and decrease the risk of collapsing due to environmental disturbances and climatic changes (Alizadeh & Hitchmough, 2019; Dunnett & Hitchmough, 2004). Lastly, physical configurations and the vertical structural complexity of plant communities (e.g., layers, height, shape) will determine the variety of shelter and refuge opportunities for wildlife (Hunter, 2011; Threlfall et al., 2017; Van Mechelen et al., 2015). It will also influence the capacity to mitigate climatic extremes and increase human comfort since it will largely determine the microenvironment around plants (e.g., temperature, airflow, precipitation) and energy exchanges.

v) Monitoring protocol

This framework represents an ongoing, dynamic, and nonlinear process that allows a constant learning loop and the adjustment of steps and decisions whenever necessary or pertinent. In the future, new and more recent climate change data may be available. Likewise, the plant species database may also expand, allowing the integration of other relevant species. Performance analysis can dictate the necessity to refine the initially established goals and priorities and force alterations. This way, the monitoring protocol should aim to measure if the proposals are performing and adapting as expected, allowing ongoing adjustments based on updated information and upcoming challenges (Ahern et al., 2014; Kato & Ahern, 2008). To this end, monitoring plots and transects could be permanently field-marked to enable monitoring over time to observe evolution in the context of actual climate change.

5.3. Application of the framework to Porto, Portugal

5.3.1. Study area

We developed a proposal on how the framework could be tested in Porto, a city located in the coastal area of northern Portugal. The city of Porto is geographically framed by two natural elements, the Atlantic Ocean at the west and the Douro River at the south. With 4140 ha, Porto is the center of the country’s second-largest metropolitan area, with 1.7 million inhabitants. The city has an Atlantic (sub-Mediterranean) climate with warm and rainy winters and dry and mild summers.

In the last decades, Porto has experienced a rapid urbanization process associated with demographic and economic growth, resulting in drastic changes in land-use and an overall increase in greenhouse gas emissions (Monteiro & Madureira, 2009; Rafael et al., 2016). The high rate of urbanization of Porto has resulted in a massive reduction of green areas (Madureira, Andresen, & Monteiro, 2011). These factors make the city highly vulnerable to climate change effects despite the influence of sea breezes and the proximity to the Douro River (Monteiro & Madureira, 2009).

The elaboration of a “Strategic Municipal Plan for Climate Change Adaptation” (SMPCCA) for Porto (CMP, 2016) was a critical starting point to address these relevant challenges at a local level. The plan presents an overview of Porto’s current and future climate change situation but lacks a more focused and localized myriad of adaptation and mitigation options regarding the green infrastructure.

5.3.2. Climate change assessment in Porto

Porto’s climate change projections until the end of the 21st century (Appendix 5A) include an increase in average temperature, leading to more frequent and intense heatwaves. Annual average precipitation is expected to decrease, resulting in severe droughts. Nonetheless, extreme precipitation events and winter storms are expected to increase (CMP, 2016). Based on the projected climate changes and on what is already considered Porto’s major climate change risks today, the SMPCCA (CMP, 2016) identifies the main priority risks for Porto in the medium- and long-term: heatwaves (associated with high temperatures) and pluvial flooding (related to extreme precipitation events).

These priority risks were spatially assessed through maps (Figure 5.2a, b) obtained from open-source reports developed in the scope of the Porto’s Master Plan review process (Monteiro, Madureira, Fonseca, & Velho, 2018). Additionally, since socio-economic factors strongly influence the cities' overall susceptibility to climate change risks (Carter et al., 2017), we developed a map to identify which areas in Porto have more socio-economic vulnerability (Figure 5.2c). For that, we considered the following aspects: resident population under four and over 65 years old, resident population with higher education, resident population with their own accommodation, an average monthly wage, and unemployment rate (CMP, 2016).

The most concerning areas for each priority risk and socio-economic vulnerability were overlapped using ArcGIS 10.6 (ESRI, 2011) to determine the overall priority areas for climate change adaptation and mitigation in Porto (Figure 5.2d). Areas with an overlap of three priority risks were considered to have overall high priority. Areas with an overlap of two priority risks were supposed to have medium priority. Lastly, areas without priority risks' overlapping were considered to have low priority.

According to Figure 5.2, it is possible to verify that the areas with the greatest heat anomalies are mostly co-incident with the socioeconomic vulnerability, mainly located in the city center. Hence, it is also where there is a higher priority to implement adaptation and mitigation measures. Higher impermeability and lower share of green spaces in this area of the city may explain these results (Hami et al., 2019). Still, areas with either medium or low priority should not be overlooked if there is an opportunity to implement measures in these areas.

5.3.3. Plant species database

To elaborate the database, we selected 287 plant species from a list of species already occurring in Porto, more precisely in urban green spaces with high urban ecological novelty levels (Teixeira et al., 2021). Traits were selected with a particular focus on adaptation, mitigation, and ornamental characteristics (see chapter 6).

Plants' capacity to adapt and survive climate change will depend on their fitness to the site conditions (temperature, water, soil, or light), on their ability to perform across a range of environmental conditions (plasticity), and also on their tolerance to withstand current and future extreme environmental conditions (e.g., heat, drought, pollution) (Dunnett & Hitchmough, 2004; Hunter, 2011). On the other hand, plants' mitigation capacity will relate directly to their potential to minimize negative impacts such as heatwaves and pluvial flooding.

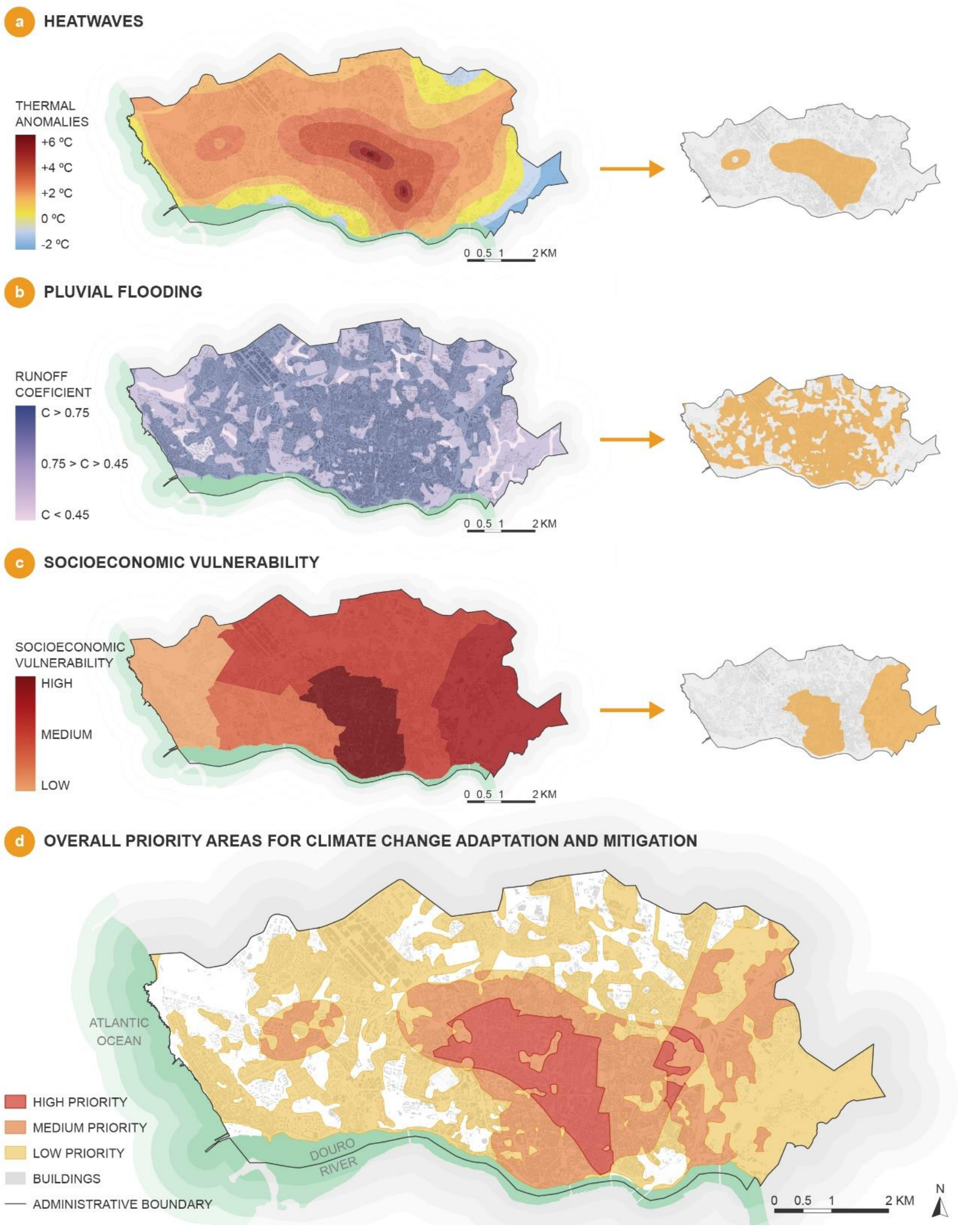


Figure 5.2. Priority risks spatially assessed in Porto regarding: a) heatwaves (Monteiro et al., 2018); b) pluvial flooding (Monteiro et al., 2018); c) socio-economic vulnerability (CMP, 2016); and d) overall priority areas for climate change adaptation and mitigation in Porto.

The constructed database (chapter 6) includes a wide array of species with different habits, life cycles, and functions. It also includes species with different origins and distribution ranges as it is composed of 177 native species and 110 non-native species. From the set of non-native plants, 6 are casual (i.e., non-native species that occasionally reproduce in a given area but do not form self-replacing populations), 7 are naturalized (i.e., non-native species that reproduce consistently and sustain populations over many life cycles without, or in spite of, direct human intervention), and 16 are invasive (i.e., naturalized non-native species that reproduce and expand rapidly over a large area without direct human intervention, producing significant changes in ecosystems) in the Continental Portugal territory (Decreto-Lei n.º92/2019, 2019; Marchante et al., 2014; Richardson et al., 2000). Following the “Practical Guide for the Identification of Invasive Plants in Portugal” (Marchante et al., 2014) casual and naturalized species were also categorized according to the risk of becoming invasive (low, medium, or high), whereas invasive species were categorized according to their invasive gravity in the territory (low, medium, or high).

This database represents a starting point and should continue to be developed, so other relevant species can be included over time. Although it was created for Porto’s case, the database may include species that can be used in regions with similar environmental conditions and dynamics, especially if the species have a wide range of adaptation, distribution or do not entail ecological risk.

5.3.4. Adaptive planting design and management proposals

The final step of the framework was demonstrated in Porto by addressing the previously identified priority risks (i.e., heatwaves and pluvial flooding). For that, we selected two intervention sites formerly surveyed and resorting to the maps in Figure 5.2 (i.e., high priority areas). Then, for each intervention site, we defined adaptation and mitigation goals (Table 5.1) and assessed the current status (Appendix 5B). Two prototype proposals were developed and illustrated through sections (Figure 5.3 and Figure 5.4) that show the current situations (before intervention) and the planting design and management proposals (after intervention). The main plant palette is incorporated in each figure with the following information about the species: action, layer, status, and targeted adaptation traits.

The complete plant palettes for each proposal are present in Appendix 5B and only include species from the database (chapter 6). Added species serve to illustrative purposes since other species can also represent good options. Traits information about each species refers only to data that we were able to access. Thereby, we do not exclude the possibility that some of the referenced species can have more tolerances or functions apart from the identified. Finally, we compared the before and after situations to quantify improvement and understand which variables and traits were suppressed or minimized and which were achieved or maximized (Table 5.3).

Table 5.1. Adaptation and mitigation goals to address climate change priority risks in Porto, plant traits and trait values involved, supporting references, and potential performance metrics to evaluate their effectiveness and success.

Climate change priority risk	Goals	Traits (trait values) and examples	References	Potential performance metrics *
Heatwaves	**Adaptation –** Improve tolerance and plasticity to withstand heat and drought.	• Heat tolerance (tolerant) – e.g., *Cedrus atlantica, Ligustrum ovalifolium, and Bergenia cordifolia* tolerate heat; • Temperature hardiness plasticity (more than 4 hardiness zones) – e.g., *Populus nigra*, *Hedera helix*, and *Poa pratensis* tolerate and range between 7 hardiness zones; • Drought tolerance (tolerant) – e.g., *Arbutus unedo*, *Tamarix gallica*, and *Foeniculum vulgare* tolerate drought; • Light plasticity (more than 1 light type) – e.g., *Ligustrum vulgare*, *Camellia japonica*, and *Acanthus mollis* tolerate 3 light types (full sun, partial sun/shade, and full shade).	Del Tredici (2020), Hunter (2011), Vogt et al. (2017)	• ↓annual number of species unable to resist extreme heat events (number/year) • ↑overall green cover (area or %) • ↑tree canopy (area or %) • ↑vertical layers (number) • ↓air or surface temperature (degrees or %) • ↑annual atmospheric CO_2 sequestration (weight/year) • ↑quality of visitor experience and thermal comfort (surveys)
	Mitigation – Regulate temperature by maximizing: shade, wind ventilation, evapotranspiration, and carbon sequestration and storage.	• Height and width (high values) – e.g., *Platanus hispanica*, *Cedrus atlantica*, and *Quercus robur* are large and wide (more shade); • Crown density (high) – e.g., *Acer pseudoplatanus*, *Magnolia grandiflora*, and *Pinus pinea* have dense crowns (stronger shade); • Crown height (high values) – e.g., *Pinus pinaster*, *Liriodendron tulipifera*, and *Quercus rubra* do not have the crown close to the ground (more ventilation); • Crown shape (variable) – e.g., *Ligustrum lucidum* has a round shape and *Pinus pinea* has an umbrella shape (more shade than plants with pyramidal and columnar shapes); • Foliage persistence (variable) – e.g., *Metrosideros excelsa* is evergreen (shade throughout the year) and *Fraxinus angustifolia* is deciduous (summer shade); • Evapotranspiration rate (high) – e.g., *Alnus glutinosa*, *Acer pseudoplatanus*, and *Sambucus nigra* have high rates of evapotranspiration.	Brown (2010), Hami et al. (2019), Kennen & Kirkwood (2015), Santiago et al. (2019), Van Mechelen et al. (2015), Windhager et al. (2011)	

(Continued …)

Climate change priority risk	Goals	Traits (trait values) and examples	References	Potential performance metrics *
Pluvial flooding	**Adaptation –** Improve tolerance and plasticity to withstand waterlogging, drought, pollution.	• Waterlogging tolerance (tolerant) – e.g., *Alnus glutinosa*, *Salix atrocinerea*, and *Cyperus longus* tolerate waterlogging; • Drought tolerance (tolerant) – e.g., *Thuja plicata*, *Ulex europaeus*, and *Ophiopogon japonicus* tolerate drought; • Pollution tolerance (tolerant) – e.g., *Castanea sativa*, *Sambucus nigra*, and *Agrostis capillaris* tolerate pollution; • Soil moisture plasticity (more than 1 soil moisture type) e.g., *Platanus hispanica*, *Acer negundo*, and *Stenotaphrum secundatum* tolerate 3 soil moisture types (dry, fresh, and moist); • Life form (suitable to the habitat) – e.g., *Apium nodiflorum*, *Cyperus esculentus*, and *Lythrum salicaria* are suitable to aquatic conditions (hydrophytes).	Del Tredici (2020), Hunter (2011), Vogt et al. (2017)	• ↓annual number of species unable to resist extreme precipitation events (number/year) • ↓impervious surface (area or %) • ↑flood storage (volume or %) • ↓annual frequency of localized flooding events (number of events/year) • ↓annual costs associated with flooding events (currency/year) • ↓ area affected by erosion (area or percent)
	Mitigation – Manage stormwater and reduce the risk of flooding and landslide by maximizing: stormwater interception (slow water movement), stormwater infiltration and storage, erosion control.	• Height and width (high values) – e.g., *Liriodendron tulipifera*, *Castanea sativa*, and *Quercus rubra* are large and wide (more water interception); • Crown density (high) – e.g., *Populus nigra*, *Robinia pseudoacacia*, and *Pinus pinaster* have dense crowns (more water interception); • Foliage persistence (variable) – e.g., *Camellia japonica* is evergreen (water interception throughout the year) and *Liriodendron tulipifera* is deciduous (water interception in summer); • Multi-stem development (yes) – e.g., *Metrosideros excelsa*, *Magnolia stellata*, and *Camellia japonica* have multiple stems (more water interception); • Stem flexibility (high) – e.g., *Paspalum dilatatum*, *Holcus lanatus*, and *Festuca rubra* have flexible stems (slow water movement and more infiltration); • Leaf area, anatomy and shape (variable) – e.g., *Cercis yunnanensis* has large leaves with trichomes (more water interception and storage) and *Ligustrum lucidum* has small leathery leaves with no trichomes (less water interception and storage).	Espeland & Kettenring (2018), Hami et al. (2019), Kennen & Kirkwood (2015), Van Mechelen et al. (2015), Xiao & McPherson (2016), Yan, Wang, Liao, Xu, & Wan (2021), Windhager et al. (2011)	↑annual amount of pollutants removed (weight/year)

↑ (increase in); ↓ (decrease in).

* *based on Rainer & West (2015)* and LAF (2018)

Proposal to address heatwaves

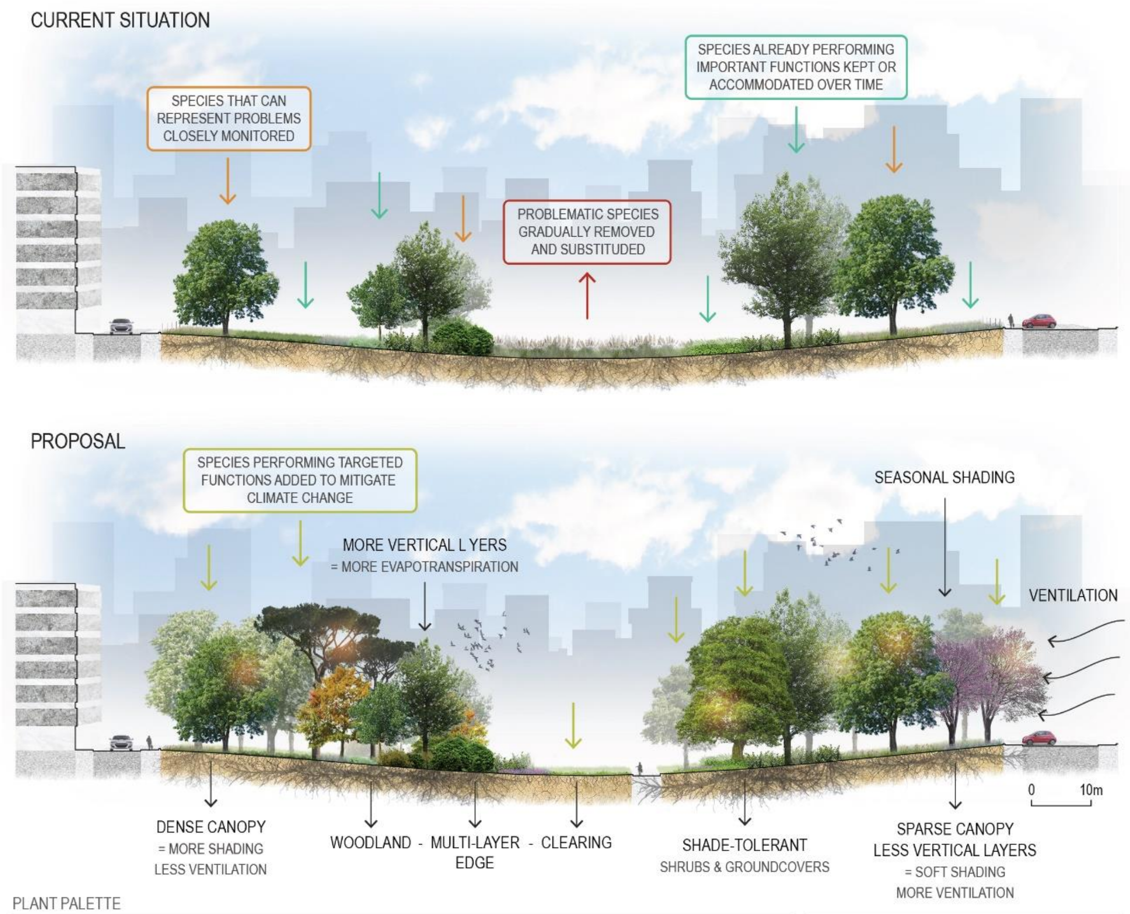
To address heatwaves, the main goals of the first proposal (Figure 5.3) were to adjust the plant community to heat and drought (adaptation) and to regulate the temperature (mitigation) to improve human comfort. This proposal is located where positive thermal anomalies reach up to a magnitude of + 5 degrees and where there is a greater distance to the sea, a lower share of green spaces, and higher impermeability.

Regarding the current situation, we propose the gradual removal and substitution of excessively dominant invasive species that already represent high gravity in the Portuguese territory such as *Cortaderia selloana*. This species grows vigorously and forms dense clusters that dominate the herbaceous layer, takes over the available resources in the area, and can impede fauna circulation (Marchante et al., 2014).

Other invasive species with lower gravity were kept and flagged to be closely monitored. For instance, *Acer negundo* is well adapted and tackling the heatwaves problem, but the species was recently identified as an invasive plant in Portuguese legislation (Decreto-Lei n.º92/2019, 2019), so its expansion in the territory requires caution. Species with risk of becoming invasive (i.e., casual and naturalized) were also kept and flagged to be monitored (*Pittosporum tobira*, *Acanthus mollis*).

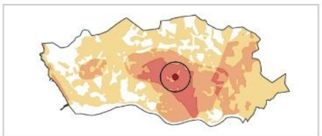
We also propose monitoring native plants with an infesting behavior and features that can be perceived as an indicator of neglect (*Rubus ulmifolius*, *Pteridium aquilinum*). Other species in the current situation providing more benefits than problems (e.g., *Hedera helix*, *Populus nigra*) were kept and marked to be accommodated over time, as they have spontaneously emerged in this location. Finally, we propose the addition of 11 species with key traits to achieve and maximize the established goals.

This proposal mainly focuses on improving three factors that influence human comfort during heat events: shade, ventilation, and evapotranspiration (Table 5.1). This way, we increased the canopy cover in most of the intervention area as it will provide shade and improve evapotranspiration (Zölch et al., 2016). Canopy cover can also allow airflow beneath (Brown, 2010; Windhager et al., 2011), if trees are correctly positioned in relation to the prevailing wind direction and if the understory remains relatively open (Table 5.2). For instance, Pinus pinaster provides an elevated canopy (i.e., not close to the ground), allowing airflow and thermal regulation at the human scale. In that sense, planting locations, arrangements, patterns, and the orientation according to surrounding elements (e.g., other plants or buildings) have a decisive role in improving thermal comfort and should be carefully considered (Hami et al., 2019).



PLANT PALETTE

Species	Status	HT	THP	DT	LP	
Acanthus mollis	NNN	○	●	●	●	3
Acer negundo	INV	●	●	●	●	4
Aster lanceolatus	NN	○	●	○	●	2
Aucuba japonica	NN	●	○	●	●	3
Avena strigosa	NN	○	○	●	○	1
Bergenia cordifolia	NN	●	●	●	●	4
Castanea sativa	NA	●	○	●	●	3
Cortaderia selloana	INV	○	●	●	○	2
Dactylis glomerata	NA	●	●	●	●	4
Foeniculum vulgare	NA	○	●	●	●	3
Fraxinus angustifolia	NA	●	●	●	●	4
Galactites tomentosus	NA	○	●	●	○	2
Hedera helix	NA	●	●	●	●	4
Jacaranda mimosifolia	NN	○	○	○	●	1
Ligustrum lucidum	NN	●	○	●	●	3
Ligustrum ovalifolium	NN	●	●	●	●	4
Liriodendron tulipifera	NN	●	●	○	●	3
Pinus pinaster	NA	○	○	●	○	1
Pittosporum tobira	NNC	○	○	●	●	2
Plantago lanceolata	NA	○	●	○	○	1
Platanus hispanica	NN	●	●	●	●	4
Populus nigra	NN	○	●	○	●	2
Pteridium aquilinum	NA	○	○	○	●	1
Quercus rubra	NN	●	●	●	●	4
Rubus ulmifolius	NA	○	○	○	●	1
Veronica arvensis	NA	○	●	○	●	2
Veronica persica	NN	○	●	○	●	2
Vinca major	NN	●	●	●	●	4



STATUS
NA - Native
NN - Non-native
NNC - Casual
NNN - Naturalized
INV - Invasive

ACTION
Remove
Monitor
Keep
Add

LAYER
Herbaceous
Shrub
Tree

TARGETED ADAPTATION TRAITS
HT - Heat Tolerance
THP - Temperature Hardiness Plasticity*
DT - Drought Tolerance
LP - Light Plasticity**
● Tolerant / High plasticity (≥ 4 zones*, ≥ 2 types**)
○ Not tolerant / Low plasticity / Unknown

Figure 5.3. Illustrative sections and plant palette to address heatwaves.

The shade provided will be proportional to the intercepted light, so more mature, denser, wider, and taller trees (e.g., *Platanus hispanica*, *Castanea sativa*, *Populus nigra*) have greater shading potential (Hami et al., 2019; Windhager et al., 2011). Shade can be strategically planned for the whole year (e.g., *Pinus pinaster*) or just for the warmest season with deciduous trees (e.g., *Fraxinus angustifolia*), which is more relevant for the case of Porto (Brown, 2010; Windhager et al., 2011). Shade can also be stronger or softer depending on the planting arrangement or crown density (e.g., *Castanea sativa* forms dense canopies while *Jacaranda mimosifolia* forms sparse canopies). In the latter, there is an opportunity to combine shading and ventilation strategies (Table 5.2). When using strong shading covers it is also vital to ensure that the understory is shade-tolerant (e.g., *Aucuba japonica*, *Bergenia cordifolia*, *Hedera helix*). In this case, it can be useful to include species with higher light plasticity. For instance, some species can grow in full shade, partial shade, and full sun (e.g., *Acanthus mollis*, *Dactylis glomerata*, *Ligustrum ovalifolium*).

Table 5.2. General mitigation potential based on the vertical structure and number of layers of plant compositions (Brown, 2010; Hami et al., 2019; Santiago et al., 2019; Windhager et al., 2011).

Vertical Structure Typology	**Number of layers**	**Mitigation factor**			
		Shading	**Ventilation**	**Evapotranspiration**	**Stormwater interception**
Canopy only (dense)	1	Moderate-high	Moderate	Moderate-high	Moderate-high
Canopy only (sparse)	1	Moderate	Moderate-high	Moderate	Moderate
Canopy with low shrubs or groundcover	2	High	Low-moderate	High	Moderate-high
Canopy, shrubs, and groundcover	3	Very high	Low	Very high	Very high
Low shrubs or groundcover only	1	Low	Very high	Low-moderate	Low-moderate

Species with high evapotranspiration potential may also represent interesting solutions to decrease temperatures and improve thermal comfort (Hami et al., 2019; Zölch et al., 2016). However, in this case, the water consumption is higher, which can become a disadvantage. Species with higher leaf surfaces and no water-saving mechanisms will transpire more moisture but will be more vulnerable to dry seasons. On the other hand, higher evapotranspiration capacity can usually allow species to remove more pollutants in the smog (Windhager et al., 2011). In this case, a vertical structure with more layers will enhance evapotranspiration (Hami et al., 2019), but it will not be compatible with a strategy that intends to promote ventilation (Table 5.2), so both factors must be strategically designed or managed.

Even though increasing canopy can be highly effective to reduce temperatures, we also included an open area in our proposal so that the space is not excessively enclosed and dark which can lead to feelings of insecurity and oppressiveness (Asgarzadeh, Koga, Hirate, Farvid, & Lusk, 2014). In this case, clearings enhance ventilation (Table 5.2) and can provide recreational and contemplative opportunities. Using a woodland-edge-clearing continuum model based on Appleton's (1975) prospect-refuge theory, we ensured a diverse spatial organization through the vegetation to respond to multiple urban dwellers needs, preferences, and interests beyond thermal comfort.

In this proposal, we used heat-tolerant and, when possible, drought-tolerant species as well (e.g., *Quercus rubra*, *Platanus hispanica*). We also considered if the species had higher temperature hardiness plasticity, i.e., more than four hardiness zones covered (e.g., *Liriodendron tulipifera*, *Vinca major*), as it will determine if they are prepared to wider ranges of temperatures (Hunter, 2011).

Proposal to address pluvial flooding

To address pluvial flooding, the main goals of the second proposal (Figure 5.4) were to adjust the plant community to waterlogging, drought, and pollution (adaptation) and to manage flood risk and stormwater (mitigation). This proposal is located in Porto's central region, where there is a continuous patch with higher run-off coefficient value.

Regarding the current situation, we also removed invasive species that expand in the Portuguese territory aggressively. Besides *Cortaderia selloana*, we also removed *Acacia dealbata* (which germinates rapidly and vigorously, promotes soil alterations, and forms very dense settlements that impede the development of other species) and *Erigeron karvinskianus* (which reproduces vegetatively through rhizomes, forms continuous mats, and competes with other species for space, water, and nutrients) (Marchante et al., 2014).

We propose to keep and closely monitor casual and naturalized species that represent a risk of becoming invasive (*Oenothera glazioviana*, *Zantedeschia aethiopica*, *Buddleja davidii*). In this case, special attention should be given to species with higher ecological risks (*Reynoutria japonica*). Likewise, species that may be perceived as an indicator of dereliction (*Rubus ulmifolius*) should also be monitored and their appearance and care must be enhanced (Nassauer, 1995). We kept the existing desirable and advantageous species (e.g., *Populus nigra* 'Italica', *Ulex europaeus*, *Cerastium glomeratum*) and suggested adding 11 targeted species to achieve and maximize the established goals.

This proposal mainly focuses on improving the factors that influence human safety during flooding events: stormwater interception, infiltration and storage, and erosion control (Table 5.1). In this case, we increased the vegetation that will intercept and slow stormwater while also directing the run-off to a location where it can be stored and slowly infiltrated into the soil (Matos Silva, 2016).

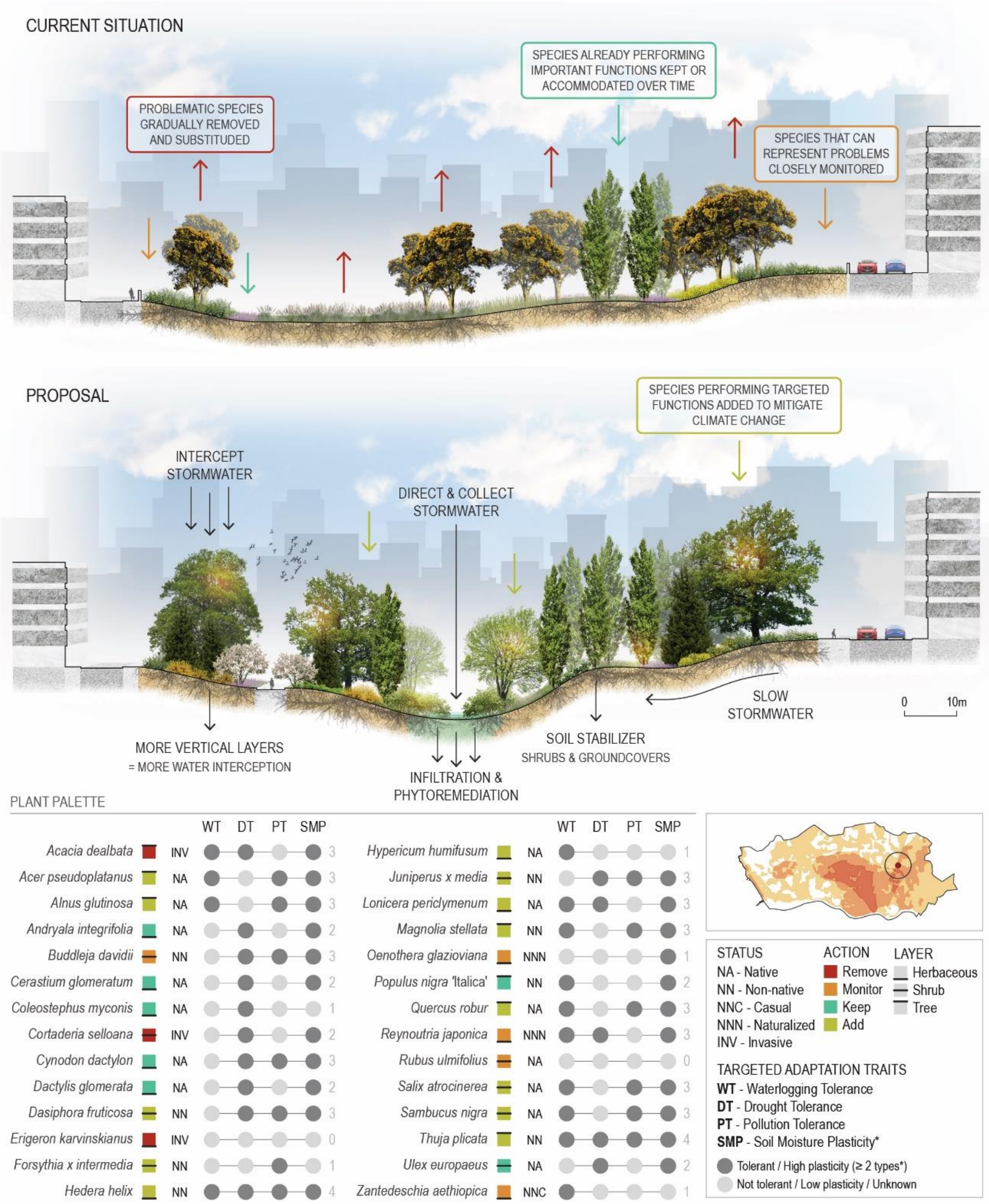


Figure 5.4. Illustrative sections and plant palette to address pluvial flooding.

Plant traits such as height, width, multi-stem development, stem flexibility, leaf area, crown surface area, and crown density (Table 5.1) play a vital role in intercepting, slowing, and absorbing stormwater, thereby reducing their impacts (Espeland & Kettenring, 2018; Hami et al., 2019; Xiao & McPherson, 2016; Yan et al., 2021). This way, species with larger and denser crowns (e.g., *Acer pseudoplatanus*) or species with multi-stems development and stem flexibility (e.g., *Salix atrocinerea*) will represent reliable options. Due to stormwater movement and storage, vegetation with erosion control potential (e.g., *Hedera helix*, *Juniperus x media*, *Rubus ulmifolius*) will also be critical to prevent the risk of landslide. In this case, the interception provided by the canopy structure will directly affect soil erosion by slowing and redistributing the stormwater (Yan et al., 2021).

We included waterlogging-tolerant species and, when possible, pollution-tolerant as well (e.g., *Alnus glutinosa*, *Salix atrocinerea*, *Thuja plicata*), since stormwater is usually very polluted. Pollution in cities associated with flooding and storm events is also strongly linked to negative impacts on human health (viral infections and contaminations), so proposals to address pluvial flooding should focus on improving the quality of water as well (Hami et al., 2019). For that reason, it is advisable to include species with phytoremediation potential (e.g., *Populus spp.*, *Pinus spp.*, *Salix spp.*, *Sambucus spp.*) (Kennen & Kirkwood, 2015).

Flooding events may be more extreme in the future but rarer, so, when possible, it is also relevant to include species that will be drought-tolerant (e.g., *Dasiphora fruticosa*, *Juniperus x media*, *Ulex europaeus*). Nevertheless, this is not easily achieved and when exposed to extreme and extended drought periods, plants that are not highly drought-tolerant can and should be watered. Therefore, it can be useful to look to the plants with higher soil moisture plasticity. For instance, some species can grow in dry, fresh, and moist soil types (e.g., *Sambucus nigra*, *Hedera helix*, *Thuja plicata*).

Overview of the proposals

The presented proposals focus separately on heatwaves and pluvial flooding based on specific adaptation and mitigation goals (Table 5.1). However, there may be situations where adaptation and mitigation of both heatwaves and pluvial flooding are necessary. In this case, it is important to set priorities and understand how the strategies can align and complement each other.

Table 5.3 shows a straightforward way of quantifying the final gains and losses resulting from the decisions made in each proposal. Compared to the current situation, the final species combinations in all the proposals increases the species richness, response diversity, and structural and functional diversity (Appendix 5B). After implementation and based on the established goals and prioritization, the proposals should be monitored according to performance metrics (Table 5.1).

Table 5.3. Number of species in each proposal (before and after) regarding overall diversity (species richness), structural diversity (layer), assemblage of native and non-native species (status), and response diversity (targeted traits). Final net gains and losses resulting from changes between the current (before) and the proposed situation (after). The species numbers refer to the complete plant palette available in Appendix 5B.

	Proposal 1			Proposal 2		
Variable	BEFORE	AFTER	GAIN/LOSS	BEFORE	AFTER	GAIN/LOSS
SPECIES RICHNESS	42	52	+10	37	47	+10
LAYER						
Herbaceous	36	37	+1	31	33	+2
Shrubs	3	5	+2	4	8	+4
Trees	3	10	+7	2	6	+4
STATUS						
Native (NA)	31	34	+3	28	35	+7
Non-native (NN)	7	15	+8	3	9	+6
Non-native casual (NNC)	1	1	0	1	1	0
Non-native naturalized (NNN)	1	1	0	2	2	0
Invasive (INV)	2	1	-1	3	0	-3
TARGETED ADAPTATION TRAITS						
Heat tolerance (HT) – heat-tolerant species	4	13	+9			
Temperature hardiness plasticity (THP) – species ranging between more than 4 hardiness zones	15	21	+6			
Light Plasticity (LP) – species ranging between more than 2 light types	21	31	+10			
Drought tolerance (DT) – drought-tolerant species	11	19	+8	10	13	+3
Waterlogging tolerance (WT) – waterlogging-tolerant species				4	13	+9
Pollution tolerance (PT) – pollution-tolerant species				2	13	+11
Soil Moisture Plasticity (SMP) – species ranging between more than 2 soil moisture types				17	26	+9

5.4. Discussion and conclusion

The proposed framework offers a more experimental and adaptable way of designing and managing plant communities in cities, which may be increasingly mandatory in the face of uncertain future climate change effects and to ensure the comfort and safety of urban dwellers. For that reason, knowledge collected from an implemented adaptive planting design and management proposal can represent a unique opportunity to learn from a complex and real-time urban environment experiment, which is impossible to replicate in a controlled setting (Felson & Pickett, 2005).

We focus on opportunities emerging from novel plant communities for climate change adaptation and mitigation, which are relevant and promising but require further research. Novel and spontaneous assemblages of species can harbor large levels of biodiversity that will influence the adaptive capacity and socio-ecological resilience of cities (Ahern et al., 2014; Light et al., 2013; Van Mechelen et al., 2015). Additionally, by focusing on preserving ecosystem functions, the Novel Urban Ecosystems concept allows an appreciation of the function and adaptability of species or combinations of species above their identity or origin (Davis et al., 2011; Del Tredici, 2020; Starzomski, 2013).

We demonstrated how the framework could be applied in Porto but believe it can also be applied to other urban contexts and regions. This research provides guidance for the design and management of small to intermediate plantings that provide localized benefits. Notwithstanding, interventions at smaller scales can still have an enduring effect across the whole city and its neighborhoods.

Through the proposed adaptive framework, it is possible to value existing formal and informal urban green spaces actively and according to specific goals (e.g., aesthetic, cultural, political, ecological, and/or social). The illustrative proposals show planting strategies in urban green spaces that aim to maintain or enhance existing ecosystem functions and to introduce new species and planting types to provide new benefits. The principles suggested in this work can also guide the development of new green spaces. Ultimately, this study offers a starting point for experimentation, a necessary step to construct valuable knowledge to address and tackle forthcoming extreme events and climate change scenarios.

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Supplementary material

Appendix 5A. Main climate changes projected for the city of Porto until the end of the 21st century. Adapted from (CMP, 2016), based on national (Soares et al., 2015), and southern Europe and global projections (IPCC, 2021).

Climate change projections	**Details**
Increase in the **temperature**	• Increase in the average annual temperature (1 to 4°C) • Sharp increase in maximum temperatures in autumn and summer (2 to 5°C) • Increase in the number of days with very high temperatures (≥ 35°C) • More frequent and intense heatwaves
Decrease in the **precipitation**	• Decrease in the average annual precipitation (3 to 25%) • Decrease in seasonal precipitation: spring (10 to 35%) and autumn (9 to 36%) • Decrease in the number of days with precipitation (12 to 29 days per year). • Increased frequency and intensity of droughts – **southern Europe projections.**
Increase in **extreme precipitation events**	• Increase in extreme events, in particular intense or very intense precipitation – **national projections**. • More intense winter storms (rain and strong winds) – **global projections**.
Increase in the **sea level**	• Increase in the average sea level (between 0,17m and 0,38m for 2050 and between 0,26m and 0,82m until the end of the century – **global projections**. • Increase in the average sea level with more severe impacts, when combined with sea level rise associated with storm surge – **global projections**.

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Appendix 5B. Detailed plant palettes from proposals 1 (heatwaves) and 2 (pluvial flooding).

Table 5B.1. Plant palette from Proposal 1 addressing heatwaves.

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							HT	THP	DT	LP	TOTAL
X	X	*Acanthus mollis**	Monitor	Herbaceous	Naturalized	Medium risk		X	X	X	3
X	X	*Acer negundo**	Monitor	Tree	Invasive	Unknown	X	X	X	X	4
X	X	*Anagallis arvensis*	Keep	Herbaceous	Native					X	1
X	X	*Andryala integrifolia*	Keep	Herbaceous	Native						0
X	X	*Aster lanceolatus**	Keep	Herbaceous	Non-native			X		X	2
	X	*Aucuba japonica**	Add	Shrub	Non-native		X		X	X	3
X	X	*Avena strigosa**	Keep	Herbaceous	Non-native				X		1
	X	*Bergenia cordifolia**	Add	Herbaceous	Non-native		X	X	X	X	4
X	X	*Bromus catharticus*	Keep	Herbaceous	Non-native						0
X	X	*Bromus diandrus*	Keep	Herbaceous	Native						0
	X	*Castanea sativa**	Add	Tree	Native		X		X	X	3
X	X	*Cerastium glomeratum*	Keep	Herbaceous	Native					X	1
X	X	*Chamaemelum fuscatum*	Keep	Herbaceous	Native						0
X		*Cortaderia selloana**	Remove	Shrub	Invasive	High gravity		X	X		2
X	X	*Cynodon dactylon*	Keep	Herbaceous	Native				X		1
X	X	*Dactylis glomerata**	Keep	Herbaceous	Native		X	X	X	X	4
X	X	*Euphorbia peplus*	Keep	Herbaceous	Native					X	1

(Continued …)

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							HT	THP	DT	LP	TOTAL
X	X	*Foeniculum vulgare**	Keep	Herbaceous	Native			X	X	X	3
	X	*Fraxinus angustifolia**	Add	Tree	Native		X	X	X	X	4
X	X	*Galactites tomentosus**	Keep	Herbaceous	Native			X	X		2
X	X	*Galactites tomentosus**	Keep	Herbaceous	Native			X	X		2
X	X	*Galium aparine*	Keep	Herbaceous	Native					X	1
X	X	*Geranium dissectum*	Keep	Herbaceous	Native						0
X	X	*Hedera helix**	Keep	Herbaceous	Non-native		X	X	X	X	4
X	X	*Hirschfeldia incana*	Keep	Herbaceous	Native					X	1
X	X	*Hordeum murinum*	Keep	Herbaceous	Native						0
	X	*Jacaranda mimosifolia**	Add	Tree	Non-native					X	1
X	X	*Ligustrum lucidum**	Keep	Tree	Non-native		X		X	X	3
	X	*Ligustrum ovalifolium**	Add	Shrub	Non-native		X	X	X	X	4
	X	*Liriodendron tulipifera**	Add	Tree	Non-native		X	X		X	3
X	X	*Medicago polymorpha*	Keep	Herbaceous	Native						0
X	X	*Mercurialis ambigua*	Keep	Herbaceous	Native						0
X	X	*Orlaya daucoides*	Keep	Herbaceous	Native						0
X	X	*Ornithopus compressus*	Keep	Herbaceous	Native						0
	X	*Pinus pinaster**	Add	Tree	Native				X		1
X	X	*Pittosporum tobira**	Monitor	Shrub	Casual	Low risk			X	X	2

(Continued …)

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							HT	**THP**	**DT**	**LP**	**TOTAL**
X	X	*Plantago lanceolata**	Keep	Herbaceous	Native			X			1
	X	*Platanus hispanica**	Add	Tree	Non-native		X	X	X	X	4
X	X	*Poa annua*	Keep	Herbaceous	Native			X			1
X	X	*Populus nigra**	Keep	Tree	Non-native			X		X	2
X	X	*Pteridium aquilinum**	Monitor	Herbaceous	Native					X	1
	X	*Quercus rubra**	Add	Tree	Non-native		X	X	X	X	4
X	X	*Ranunculus muricatus*	Keep	Herbaceous	Native					X	1
X	X	*Rubus ulmifolius**	Monitor	Shrub	Native					X	1
X	X	*Senecio vulgaris*	Keep	Herbaceous	Native			X			1
X	X	*Silene gallica*	Keep	Herbaceous	Native					X	1
X	X	*Sonchus asper*	Keep	Herbaceous	Native					X	1
X	X	*Trifolium pratense*	Keep	Herbaceous	Native			X			1
X	X	*Trifolium resupinatum*	Keep	Herbaceous	Native						0
X	X	*Veronica arvensis**	Keep	Herbaceous	Native			X		X	2
X	X	*Veronica persica**	Keep	Herbaceous	Non-native			X		X	2
X	X	*Vicia cordata*	Keep	Herbaceous	Native						0
X	X	*Vicia disperma*	Keep	Herbaceous	Native						0
	X	*Vinca major**	Add	Shrub	Non-native		X	X	X	X	4

** Present in Figure 5.3*
HT: Heat tolerance; THP: Temperature hardiness plasticity; DT: Drought tolerance; LP: Light plasticity.

Table 5B.2. Plant palette from Proposal 2 addressing pluvial floodings.

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							WT	DT	PT	SMP	TOTAL
X		*Acacia dealbata**	Remove	Tree	Invasive	High gravity	X	X		X	3
	X	*Acer pseudoplatanus**	Add	Tree	Native		X		X	X	3
	X	*Alnus glutinosa**	Add	Tree	Native		X		X	X	3
X	X	*Andryala integrifolia**	Keep	Herbaceous	Native			X		X	2
X	X	*Bromus catharticus*	Keep	Herbaceous	Non-native						0
X	X	*Bromus diandrus*	Keep	Herbaceous	Native						0
X	X	*Buddleja davidii**	Monitor	Shrub	Non-native			X	X	X	3
X	X	*Cerastium glomeratum**	Keep	Herbaceous	Native			X		X	2
X	X	*Cirsium arvense*	Keep	Herbaceous	Native						0
X	X	*Coleostephus myconis**	Keep	Herbaceous	Native			X			1
X	X	*Convolvulus arvensis*	Keep	Herbaceous	Native					X	1
X		*Cortaderia selloana**	Remove	Shrub	Invasive	High gravity		X		X	2
X	X	*Cynodon dactylon**	Keep	Herbaceous	Native			X	X	X	3
X	X	*Dactylis glomerata**	Keep	Herbaceous	Native			X		X	2
	X	*Dasiphora fruticosa**	Add	Shrub	Non-native			X	X	X	3
X	X	*Daucus carota*	Keep	Herbaceous	Native						0
X	X	*Dittrichia viscosa*	Keep	Herbaceous	Native						0
X	X	*Erigeron karvinskianus**	Remove	Herbaceous	Invasive	Medium gravity					0
	X	*Forsythia x intermedia**	Add	Shrub	Non-native				X		1

(Continued …)

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							WT	DT	PT	SMP	TOTAL
X	X	*Galium murale*	Keep	Herbaceous	Native						0
X	X	*Geranium purpureum*	Keep	Herbaceous	Native						0
	X	*Hedera helix**	Add	Herbaceous	Non-native		X	X	X	X	4
X	X	*Hirschfeldia incana*	Keep	Herbaceous	Native					X	1
	X	*Hypericum humifusum**	Add	Herbaceous	Native		X				1
	X	*Juniperus x media 'Pfitzeriana'**	Add	Shrub	Non-native			X	X	X	3
X	X	*Leontodon taraxacoides*	Keep	Herbaceous	Native						0
	X	*Lonicera periclymenum**	Add	Herbaceous	Native		X	X		X	3
	X	*Magnolia stellata**	Add	Tree	Non-native		X		X	X	3
X	X	*Medicago arabica*	Keep	Herbaceous	Native						0
X	X	*Oenothera glazioviana**	Monitor	Herbaceous	Naturalized	Low risk				X	1
X	X	*Orlaya daucoides*	Keep	Herbaceous	Native						0
X	X	*Ornithopus compressus*	Keep	Herbaceous	Native						0
X	X	*Plantago lanceolata*	Keep	Herbaceous	Native					X	1
X	X	*Populus nigra 'Italica'**	Keep	Tree	Non-native		X			X	2
	X	*Quercus robur**	Add	Tree	Native		X		X	X	3
X	X	*Reichardia intermedia*	Keep	Herbaceous	Native						0
X	X	*Reynoutria japonica**	Monitor	Herbaceous	Naturalized	High risk	X	X		X	3
X	X	*Rubus ulmifolius**	Monitor	Shrub	Native						0
X	X	*Rumex conglomeratus*	Keep	Herbaceous	Native						0

Continued …)

Current situation	Proposal	Scientific name	Action	Layer	Status	Risk/gravity analysis	Targeted Adaptive Traits				
							WT	DT	PT	SMP	TOTAL
	X	*Salix atrocinerea**	Add	Shrub	Native		X		X	X	3
	X	*Sambucus nigra**	Add	Shrub	Native		X		X	X	3
X	X	*Scrophularia scorodonia*	Keep	Herbaceous	Native						0
X	X	*Senecio vulgaris*	Keep	Herbaceous	Native					X	1
X	X	*Silene gallica*	Keep	Herbaceous	Native					X	1
X	X	*Sonchus oleraceus*	Keep	Herbaceous	Native					X	1
	X	*Thuja plicata**	Add	Tree	Non-native		X	X	X	X	4
X	X	*Trifolium pratense*	Keep	Herbaceous	Native						0
X	X	*Ulex europaeus**	Keep	Shrub	Native			X		X	2
X	X	*Vicia cordata*	Keep	Herbaceous	Native						0
X	X	*Zantedeschia aethiopica**	Monitor	Herbaceous	Casual	Medium risk	X				1

** Present in Figure 5.4*
WT: Waterlogging tolerance; DT: Drought tolerance; PT: Pollution tolerance; SMP: Soil moisture plasticity.

6

CHAPTER 6 |

PLANT TRAITS DATABASE FOR CLIMATE CHANGE ADAPTATION AND MITIGATION IN NORTHWEST PORTUGAL

“Preadaptation is a powerful idea for understanding urban plant ecology for two reasons. First, it helps answer questions about why some species are common in cities whereas others are not. Second, it replaces a static, ‘native’ definition of nature based on history and on history and geography with a dynamic, ‘cosmopolitan’ definition based on fitness and flux.” (Del Tredici, 2020, p. 6)

Chapter 6 | Plant traits database for climate change adaptation and mitigation in Northwest Portugal

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Article submitted and currently under review in *Data in Brief*

Type of article: Data article
Journal CiteScore (2020): 1.7

Citation: Teixeira, C. P., Fernandes, C. O., Ahern, J., & Farinha-Marques, P. Plant traits database for climate change adaptation and mitigation in Northwest Portugal. *Data in Brief.* *(**Under Review**)*

Abstract

The database presented in this data article is related to the article "*Adaptive planting design and management framework for urban climate change adaptation and mitigation*" (Teixeira, Fernandes, & Ahern, n.d.). It includes a list of 287 plant species presently occurring in Porto, Portugal, more precisely in urban green spaces with high urban ecological novelty levels. The plant species in this list were classified and organized according to several traits with a particular focus on plant species' adaptation, mitigation, and ornamental characteristics. Data collection resorted to articles, books, and various open access and online datasets. Data were organized in an Excel file that organizes information on more than 50 plant species traits/variables.

Keywords: Climate change adaptation; Climate change mitigation; Green infrastructure; Plant traits; Planting design; Urban Ecological Novelty; Urban green spaces; Porto, Portugal

6.1. Specifications table

Subject	Biodiversity
Specific subject area	Plant traits for climate change adaptation and mitigation in Northwest Portugal
Type of data	Table Figure Excel database
How data were acquired	Literature search of published data
Data format	Coded and filtered
Parameters for data collection	Data about the specific plant traits that will assist the design or management of plant communities in cities for climate change adaptation and mitigation, including consideration of the ornamental value of plants.
Description of data collection	Data was collected from published literature and also through open access and online plant traits datasets. Plant species were searched by scientific name. Specific traits considered climate change adaptation and mitigation, and ornamental value.
Data source location	Primary data sources: El árbol en jardinería y paisajismo: guía de aplicación para España y países de clima mediterráneo y templado, Árvores e Arbustos em Portugal, Citree, eFloras, Flora Digital de Portugal, Flora Iberica, Flora-On, Gardenia, Guia Prático para a Identificação de Plantas Invasoras em Portugal, Lorenz Von Ehren: The Nursery, Missouri Botanical Garden, Nova Flora de Portugal, Phyto: Principles and Resources for Site Remediation and Landscape Design, Plants For A Future, The Royal Horticulture Society, The Royal Horticulture Society New Encyclopedia of Plants and Flowers, TRY plant trait database, Van Den Berk Nurseries, Wild Urban Plants of the Northeast: A Field Guide
Data accessibility	With the article
Related research article	C.P. Teixeira, C.O. Fernandes, J. Ahern, Adaptive planting design and management framework for urban climate change adaptation and mitigation, *Urban Forestry & Urban Greening*. Under Review.

6.2. Value of the Data

- Compilation of data from various publications and databases about plant traits that have an active role in climate change adaptation and mitigation and ornamental value;
- The data is useful to researchers interested in studying plant traits and landscape design and management practitioners interested in applying the compiled knowledge;
- The data can assist the design and/or management of plant communities in cities for climate change adaptation and mitigation goals, and also considers plants' ornamental value;
- The data facilitates the selection of plant species for all types of urban green spaces;
- The data represent a starting point and the database can continue to be developed, so other relevant species and traits can be included over time as knowledge about climate change adaptation and mitigation increases.

6.3. Data Description

This work presents a plant traits database that will assist the design or management of plant communities in cities for climate change adaptation and mitigation, considering as well the ornamental value of plants. The database is available in an Excel file. In total, the dataset includes available trait information for 287 plant species from 75 botanical families and 206 genera. Figure 6.1 shows the locations where the plant list was retrieved. Table 6.1 lists the traits included in the database and respective data sources.

6.4. Experimental Design, Materials and Methods

6.4.1. Plant species selection

The first step in the elaboration of this database comprised the selection of a list of plant species. For that, we resorted to a previous work that assessed level of urban ecological novelty throughout 85 urban green spaces in Porto (Figure 6.1), belonging to three different urban green spaces categories: Parks and Gardens, Urban Woodlands, and Vacant Lands (Farinha-Marques et al., 2015, 2014; Teixeira, Fernandes, Ahern, Honrado, & Farinha-Marques, 2021). We selected 19 sites (out of a total of 85 urban green spaces) where the level of urban ecological novelty was higher, based on the Urban Ecological Novelty Index (UNI). The 19 sites are highlighted in Figure 6.1 and established a list of 287 plant species.

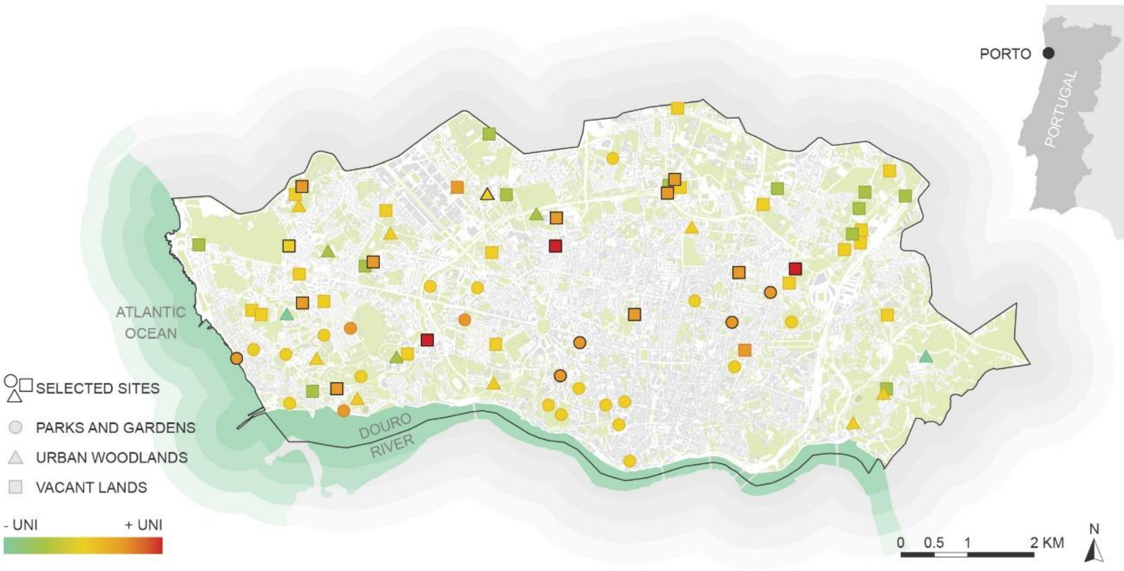

Figure 6.1. Level of urban ecological novelty throughout 85 urban green spaces in Porto, Portugal. 19 sites highlighted in the figure selected based on a higher Urban Ecological Novelty Index (UNI).

6.4.2. Traits' selection and data collection

The list of 287 plant species was the starting point for the development of this database. Following that step, we selected a list of traits based in core landscape planting publications and with a particular focus on adaptation, mitigation, and ornamental characteristics (Brown, 2010; Del Tredici, 2020; Espeland & Kettenring, 2018; Hami, Abdi, Zarehaghi, & Maulan, 2019; Hunter, 2011; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015; Vogt et al., 2017; Windhager, Simmons, & Blue, 2011; Xiao & McPherson, 2016; Yan, Wang, Liao, Xu, & Wan, 2021). Data was collected in several publications (articles and books) and also in open access and online databases.

Traits were organized in four categories:

- **Plant ID & distribution** – refers to information that supports the identification of the plant species. This group also has information about the plant origin (nativeness) and distribution range, which is very relevant information under climate change.
- **Plant fitness & tolerance** – refers to information about the species fitness, tolerance, and plasticity (ability to perform across a range of environmental conditions) to different environmental conditions (light, soil, temperature, or water).
- **Plant structure** – refers to information about the whole plant structure (life form, shape, height and width, etc.) and also about the characteristics of particular plant parts (foliage, flower, and fruit).
- **Other features** – refers to other important features of plants for climate change adaptation and mitigation, but also to improve ornamental value and human well-being and safety.

To each trait we defined a comprehensive list of classes, allowing a straightforward classification and organization of all plant species in the database. We included all the available information we were able to find, still a small portion of the plant species in the database lack information regarding some traits.

Information about the selected traits and respective classes are detailed in Table 6.1. Information about the traits source references is detailed in the Supplementary Material (Appendix 6A).

Table 6.1. List of traits selected to organize the database. Main focus: A – Adaptation, M – Mitigation, and O – Ornamental.

Trait	Classes	Main focus
PLANT ID & DISTRIBUTION		
Botanical name & authorship		
Common name (EN)		
Common name (PT)		
Family		
Genera		
Status	Native, non-native, non-native with ecological risk (casual, naturalized, or invasive)	A
Risk and gravity analysis	Low risk, medium risk, high risk (for casual and naturalized) Low gravity, medium gravity, high gravity (for invasive)	A
Geographical distribution	Cosmopolitan, Eurasia and North Africa, Europe, outside Europe, Mediterranean and Macaronesia, endemic, uncertain origin	A
PLANT FITNESS & TOLERANCE		
Light	Full sun, partial, full shade	A
Light plasticity	Number of light types covered: from 1 to 3	A
Soil substrate	Sandy, loamy, clayey	A
Soil substrate plasticity	Number of soil substrate types covered: from 1 to 3	A
Soil pH	Acid, neutral, alkaline	A
Soil pH plasticity	Number of soil pH types covered: from 1 to 3	A
Soil moisture	Dry, fresh, moist	A
Soil moisture plasticity	Number of soil moisture types covered: from 1 to 3	A
Temperature hardiness zone	Hardiness zones range	A
Temperature hardiness plasticity	Number of zones covered: from 2 to 10	A
Known tolerances and sensitivities	Drought, heat, maritime exposure, pollution, flooding, wind	A

(Continued …)

Trait	Classes	Main focus
PLANT STRUCTURE		
Habit	Tree, shrub, subshrub, herb/forb, grass/sedge, fern, climber, bamboo, palm	M, O
Life form	Hydrophyte/helophyte, geophyte, therophyte, hemicryptophyte, chamaephyte, nanophanerophyte, microphanerophyte, mesophanerophyte, megaphanerophyte	A, M, O
Growth rate	Slow, moderate, fast	M
Height and Width	Expected height and width (categories in meters)	M, O
Shape	Clumped/tufted, columnar, oval, pyramidal, round, spreading, umbrella, vase/weeping	M, O
Crown density*	High, medium, low	M, O
Multi-stem development	Yes, no	M, O
Foliage color	Green, Green-yellowish, Green-reddish, Green-purplish, Green-bluish, Green-greyish	O
Foliage fall color*	No fall color, Yellow, orange, red, purple, brown	O
Foliage persistence*	Deciduous, evergreen, semi-evergreen	M, O
Flower color	White, cream, yellow, orange, red, pink, purple, blue, green, brown, inconspicuous	O
Flower bloom time	Months range (Jan-Dec)	A, O
Flower bloom time plasticity	Number of bloom months covered: from 1 to 12	A, O
Fruit/seed color	White, cream, yellow, orange, red, pink, purple, blue, green, brown, inconspicuous	O
OTHER FEATURES		
Known functions	Erosion control, fragrant parts, phytoremediation, shading, windbreak, nitrogen fixer, wildlife resources (birds and insects)	M, O
Known hazards	Allergy or toxicity, invasive risk, odor nuisance, thorns or spikes	M, O

**Information only for trees and shrubs*

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Supplementary material

Appendix 6A. List of traits source references.

Trait	Source References
PLANT ID & DISTRIBUTION	
Botanical name & authorship	Castroviejo (1986-2015), Flora Digital de Portugal (2021), Flora-On (2021)
Common name (EN)	Brickell (1999), Del Tredici (2020), eFloras (2021), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021)
Common name (PT)	Castroviejo (1986-2015), Flora Digital de Portugal (2021), Flora-On (2021), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), Moreira (2008)
Family	Castroviejo (1986-2015), Flora Digital de Portugal (2021), Flora-On (2021)
Genera	Castroviejo (1986-2015), Flora Digital de Portugal (2021), Flora-On (2021)
Status	Flora-On (2021), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), Marchante, Morais, Freitas, & Marchante (2014)
Risk and gravity analysis	Marchante et al. (2014)
Geographical distribution	Castroviejo (1986-2015), Flora Digital de Portugal (2021), Brickell (1999), eFloras (2021), Plants For A Future (2021)
FITNESS & TOLERANCE	
Light	Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Citree (2021), Gardenia (2021)
Light plasticity	
Soil substrate	Lorenz von Ehren (2014), Plants For A Future (2021), RHS (2021), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), (Viñas, 1995)
Soil substrate plasticity	
Soil pH	Lorenz von Ehren (2014), Plants For A Future (2021), RHS (2021), Citree (2021), Gardenia (2021), Viñas (1995)
Soil pH plasticity	
Soil moisture	Lorenz von Ehren (2014), Plants For A Future (2021), RHS (2021), Citree (2021), Gardenia (2021), Viñas (1995)
Soil moisture plasticity	
Temperature hardiness zone	Missouri Botanical Garden (2021), Plants For A Future (2021), Gardenia (2021)
Temperature hardiness plasticity	
Known tolerances and sensitivities	Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)

(Continued …)

Trait	Source References
PLANT STRUCTURE	
Habit	Castroviejo (1986-2015), Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Moreira (2008), Viñas (1995)
Life form	Flora Digital de Portugal (2021), Flora-On (2021), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), TRY (Bragazza, 2009; Campetella et al., 2011; Choat et al., 2012; Ciccarelli, 2015; Dressler, Schmidt, & Zizka, 2014; Fitter & Peat, 1994; Kattge et al., 2020; Kleyer et al., 2008; Kühn, Durka, & Klotz, 2004; Moretti & Legg, 2009; Roy, Hill, & Preston, 2004)
Growth rate	Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Plants For A Future (2021), RHS (2021), Citree (2021)
Height and Width	Castroviejo (1986-2015), Brickell (1999), Del Tredici (2020), eFloras (2021), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Franco & Afonso (1994, 1998, 2003), Franco (1971, 1984), Moreira (2008), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Shape	Brickell (1999), Lorenz von Ehren (2014), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Crown density*	Citree (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Multi-stem development	Citree (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Foliage color	Castroviejo (1986-2015), Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Foliage fall color*	Brickell (1999), Lorenz von Ehren (2014), RHS (2021), Moreira (2008), Gardenia (2021), Van Den Berk Nurseries (2021)
Foliage persistence*	Brickell (1999), eFloras (2021), Lorenz von Ehren (2014), Plants For A Future (2021), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Flower color	Castroviejo (1986-2015), Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
Flower bloom time	Flora Digital de Portugal (2021), Flora-On (2021), Brickell (1999), eFloras (2021), Missouri Botanical Garden (2021), Plants For A Future (2021), Moreira (2008)
Flower bloom time plasticity	
Fruit/seed color	Castroviejo (1986-2015), Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)
OTHER FEATURES	
Known functions	Brickell (1999), Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Moreira (2008), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995), Kennen & Kirkwood (2015)
Known hazards	Del Tredici (2020), Lorenz von Ehren (2014), Missouri Botanical Garden (2021), Plants For A Future (2021), RHS (2021), Moreira (2008), Marchante et al. (2014), Citree (2021), Gardenia (2021), Van Den Berk Nurseries (2021), Viñas (1995)

**Information only for trees and shrubs*

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7

CHAPTER 7 |

ATTITUDES AND PREFERENCES TOWARDS PLANTS IN URBAN GREEN SPACES: IMPLICATIONS FOR THE DESIGN AND MANAGEMENT OF NOVEL URBAN ECOSYSTEMS

"A strength of the term ecological novelty is that (…) it is only descriptive. It simply states that ecosystems are changing and are different than they were in the past, even the recent past. It says nothing about whether this change is good or bad." (Davis, 2018, p. 6)

Chapter 7 | Attitudes and preferences towards plants in urban green spaces: implications for the design and management of Novel Urban Ecosystems

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Article submitted and currently under review in the journal *Journal of Environmental Management*

Type of article: Research article
Journal Impact Factor (2020): 6.789

Citation: Teixeira, C. P., Fernandes, C. O., Ryan, R., & Ahern, J. Attitudes and preferences towards plants in urban green spaces: Implications for the design and management of Novel Urban Ecosystems. *Journal of Environmental Management. (**Under Review**)*

Abstract

Novel Urban Ecosystems (NUE) are emerging and widespread in urban environments and may be adapted or preadapted to current and future climates and environmental stresses. In the context of the Anthropocene, these emerging ecosystems can inspire design and management guidelines for urban green spaces to contribute to climate change adaptation and mitigation in cities. As the integration of NUE in the urban green infrastructure will largely depend on the acceptance of these ecosystems, this research aimed to assess the willingness of landscape professionals to accept NUE into urban green spaces through a questionnaire. We surveyed 203 professionals involved in the design, planning, and management of green spaces regarding their attitudes and preferences towards plants' origin (native and non-native) and intentionality (cultivated and spontaneous). Our results revealed stronger acceptance for native and cultivated plants but still general acceptance towards non-native and spontaneous plants. Support for non-native and spontaneous plants increased after respondents were informed about the potential value of NUE to tackle climate change, and there were circumstances where respondents preferred combinations of native and non-native, cultivated and spontaneous plants in urban green spaces. Respondents were extremely supportive of NUE to adapt and mitigate climate change in cities and revealed major acceptance of NUE in several types of urban green spaces. Results from this investigation are promising and informative to guide the following steps on integrating the NUE concept in the design, planning, and management of the urban green infrastructure.

Keywords: Climate change; Cultivated plants; Native plants; Non-native plants; Spontaneous plants; Urban greening

7.1. Introduction

Novel Urban Ecosystems (NUE) are shaped by the combination of native and non-native plants and do not always depend on human intervention (introduction and/or management of plants) to provide ecological functions and manifest novel qualities (Hobbs et al., 2006). The emergence of these novel assemblages of plants in cities results from thousands of years of direct or indirect, accidental or deliberate human-induced activities (e.g., movement of species between regions and climate change). Since they are limited or facilitated by environmental filters, NUE thrive and are adapted or preadapted to current and future climates and environmental stresses, such as pollution, heat, or drought (Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Kowarik, 2021). Thus, is it appropriate to incorporate the NUE concept in the urban green infrastructure and, when necessary, improve these ecosystems through design and/or management according to societal expectations (Nassauer, 1995; Perring, Standish, & Hobbs, 2013; Teixeira, Fernandes, & Ahern, 2021). The relationship between NUE and the urban green infrastructure is relevant not only to support climate change adaptation and mitigation in cities but also to strengthen connectivity between urban green spaces (UGS) and create new opportunities to contact with nature (Klaus & Kiehl, 2021; Kowarik, 2018).

The successful incorporation of NUE into cities' urban green infrastructure planning and management will require that these new and emerging forms of nature become more accepted by urban dwellers. For that, two actions will be imperative: (1) raise awareness and educate practitioners, decision-makers, and the general public about the potential advantages of these ecosystems in order to deconstruct culturally established conceptions and prejudices; and (2) understand attitudes and preferences towards NUE, namely which factors (e.g., social, cultural, and professional background), barriers, and motivations will determine acceptance of NUE (Del Tredici, 2014; L. K. Fischer et al., 2020; Kowarik, 2018).

To understand these issues, the objective of this study is to assess through a questionnaire the willingness of landscape professionals to accept Novel Urban Ecosystems into urban green spaces. Since the NUE concept is complex and not easily communicated, the study was restricted to professionals involved in the design, planning and management of green spaces. Even so, as the terminology is still relatively unknown among professionals (Teixeira et al., 2021), it was also necessary to develop a questionnaire based on the deconstruction of the concept into more familiar terms that could ultimately act as a proxy for the NUE concept. Thereby, we assumed that acceptance of Novel Urban Ecosystems would be ultimately determined by attitudes and preferences towards plants' origin (native or non-native) and plants' intentionality or human agency, i.e., the way plants emerge and establish in the urban environment (cultivated or spontaneous).

Growing concern to control and limit the spread of invasive plants is shifting the way plants are perceived and selected for UGS (Hoyle, Hitchmough, & Jorgensen, 2017). Fear towards invasive plants often leads to a widespread prejudice extended to all non-native plants, even when they are needed, do not have a record of causing adverse impacts, and have existed in cities for long periods (Gaertner et al., 2017). Non-native plants are often negatively perceived or mistakenly assumed as invasive for several reasons, such as the use of ambiguous and inconsistent definitions and manipulative language, focusing only on the harmful effects of non-native species, a lack of recognition of their potential values, and the misunderstanding that only non-native plants can cause negative impacts (Davis, 2018, 2020; Davis et al., 2011; Gbedomon, Salako, & Schlaepfer, 2020; Guiaşu & Tindale, 2018; Hill & Hadly, 2018; Kueffer & Kull, 2017; Lewis, Granek, & Nielsen-Pincus, 2019; Selge, Fischer, & van der Wal, 2011). As opposed to ecological novelty, the nativism paradigm reflects this idea that non-native species can be *a priori* perceived as undesirable and a threat to (native) biodiversity (Davis, 2018; Gbedomon et al., 2020). This perspective currently dominates the scientific literature, the operationalization of biodiversity and conservation programs, and green space management policies and practices in many cities (Gbedomon et al., 2020; Hoyle et al., 2017). Recently several studies have been questioning this line of reasoning and documenting the benefits of non-native plants (Guiaşu & Tindale, 2018; Potgieter et al., 2017; Schlaepfer, 2018), which often translates into polarized views about this issue among practitioners and researchers (Gbedomon et al., 2020; Kowarik, Straka, Lehmann, Studnitzky, & Fischer, 2021; Kueffer, 2013; Van Der Wal, Fischer, Selge, & Larson, 2014).

Likewise, for a long time, spontaneous vegetation has been generally negatively perceived by urban residents, because spontaneous plants are usually associated with plants that "appear in the wrong place" as indicators of abandonment and often defined as unattractive, unhealthy, unsafe, neglected, messy, or wild (L. K. Fischer et al., 2020; Li, Fan, Kühn, Dong, & Hao, 2019; Mathey, Arndt, Banse, & Rink, 2018). Spontaneous vegetation is an essential component of cities and comprises native and non-native species that arise without being intentionally planted (Del Tredici, 2010; Kühn, 2006). Spontaneous vegetation appears in any type of UGS. Still, in formal UGS that are designed and require high maintenance levels (e.g., public parks and gardens), spontaneous plants are usually removed (Chen et al., 2021). It is mostly in informal UGS that are not regularly managed or neglected (e.g., vacant lands, abandoned industrial areas, edges of parking lots, street verges, and brownfields), where spontaneous vegetation tends to dominate (Bonthoux, Brun, Di Pietro, Greulich, & Bouché-Pillon, 2014; Brun, Di Pietro, & Bonthoux, 2018; Del Tredici, 2010, 2014). Despite often being undervalued and forgotten, areas with spontaneous vegetation can provide several ecosystem services in urban environments, which have stimulated the interest of researchers in recent years (Li et al., 2019; Mathey et al., 2018; Phillips & Lindquist, 2021; Vega, Schläpfer-Miller, & Kueffer, 2021; Włodarczyk-Marciniak, Sikorska, & Krauze, 2020).

Consequently, non-native and spontaneous plants, which are crucial components of NUE, may be rejected based on their origin and intentionality, without consideration of their adaptive capacity in the face of climate change and their underlying values (Davis et al., 2011; Hoyle et al., 2017).

Specifically, this study aims to respond to the following research questions: (1) What is the level of acceptance towards non-native and spontaneous plants in urban green spaces? (2) What are the key factors that drive rejection of non-native and spontaneous plants in urban green spaces? (3) Do respondents' attitudes towards non-native and spontaneous plants in urban green spaces change when the NUE concept is introduced (without using the term "Novel Urban Ecosystems")? (4) Do respondents prefer combinations of native and non-native plants and combinations of cultivated and spontaneous plants in urban green spaces? Under which circumstances and in which types of urban green spaces? and (5) Do the socio-demographic and professional background influence respondents' attitudes and preferences regarding plants' origin and intentionality?

7.2. Methods

7.2.1. Sample and data collection

In this study we targeted Portuguese professionals involved in the design, planning, and/or management of green spaces. Professionals were contacted through e-mail and invited to complete an online questionnaire. The Portuguese Association of Landscape Architects (APAP) helped in the dissemination of the questionnaire through relevant mailing lists. Respondents were additionally asked to share the questionnaire with peers and colleagues within the same field. Data was collected between July and early September 2021 and a total of 203 completely filled-in questionnaires were received and considered in the data analysis.

7.2.2. Questionnaire design

The online questionnaire was developed using Lime Survey (https://www.limesurvey.org/) to assess respondents' willingness to accept Novel Urban Ecosystems in cities. The questionnaire was written in Portuguese and structured in three sections.

The first section was composed of 5 questions using 5-point Likert scale and started with an introduction briefly defining five terms that were frequently used throughout the questionnaire followed by examples from Continental Portugal: "native plant species", "non-native plant species", "invasive plant species", "cultivated plants", and "spontaneous plants". This section was mainly focused on assessing the level of agreement towards all possible pairs of plant types (origin x intentionality) and the attitudes towards native, non-native, cultivated, and spontaneous plants (Q1-4). A question about respondents' level of knowledge about different aspects of plants was also included in this first section (Q5), including: species identification, habitats, geographical distribution, origin, ecological risk, capacity to adapt to and mitigate climate change effects.

The second section included 8 questions mainly using 5-point Likert scale and started with an introduction and description of NUE and its opportunities to climate change adaptation and mitigation, without using the term "Novel Urban Ecosystems". This section was mainly focused on re-assessing attitudes and assessing preferences towards plants origin (native or non-native) and intentionality (cultivated or spontaneous) after the NUE concept was introduced and explained (Q6-9). Additionally, it was important to understand whether respondents considered the NUE concept relevant (level of relevance) for climate change adaptation and mitigation (Q10) and in which types of UGS respondents would agree with presence of these types of ecosystems (Q11). Since the description provided in the beginning of the section did not include the term "Novel Urban Ecosystems", a question was included to first inform that the type of ecosystems described has been labeled "Novel Urban Ecosystems" in scientific literature and then, ask about their level of knowledge about this term (Q12). To allow respondents to make any additional comments, an open question (Q13) was also included in end of this section.

Finally, the third section encompassed 9 questions asking about socio-demographic information of the respondents (gender, age, highest education level) and professional background (field of expertise, current professional situation, work activities frequency, workplace type, context, and location, using close-ended and 5-point Likert scale questions (Q14-22).

The draft questionnaire was pre-tested on a small sample (n=8) of experts where they were specifically asked to comment on the duration, inconsistencies, ambiguities, or repetitions, as well as on the language and platform used in the questionnaire.

7.2.3. Statistical analysis

Questionnaire data were analyzed using the open-source software R 1.2.1335 (R Core Team, 2019). Means and standard deviations were calculated to analyze numerical data for the close-ended questions. T-tests (between two variables) and one-way analysis of variance (between three or more variables) with Bonferroni post-hoc tests and a confidence interval of 95% were used to compare respondents' groups based upon their: attitudes (accept, neutral, reject) towards non-native plants and spontaneous plants; and preferences for combinations of plants with different proportions of native and non-native plants and cultivated and spontaneous plants. Additionally, Fisher's Exact test was used to compare attitudes and preferences across socio-demographic (gender, age, education level) and professional groups (field of expertise, dominant workplace, dominant territorial work context, dominant geographical work context).

7.3. Results

7.3.1. Respondents' characteristics

Socio-demographic and professional profiles

Among 203 respondents, 63.5% were female, 34.0% were male, and the remaining 2.5% identified themselves as non-binary. Regarding age, most respondents were from younger age groups (53.2%), mainly between 26 and 35 years (46.3%). Almost the entire sample had a high education level (98.5%) from which most hold a master's degree (63.5%). See Appendix 7A for further details.

The majority of respondents were landscape architects (83.7%). The remaining respondents included professionals working in Architecture/Urbanism (2.0%), Engineering/Technology (7.4%), and Biological Sciences (3.0%). The most dominant workplace types in respondents' whole professional careers were: Landscape Architecture firms (27.1%), Municipal councils/agencies or governmental services (20.2%), University (16.3%), and Companies of construction, management, and/or inspection of green spaces (16.3%). The urban context was the most dominant territorial work context in respondents' professional careers (66.0%), followed by suburban (23.2%) and rural contexts (10.8%). Respondents have mainly worked in Portugal (89.9%) and just a small fraction have spent most of their professional careers working outside Portugal (10.1%), for instance in Switzerland or England. For those that mainly worked in Portugal, the majority worked in the northern region of the country (47.8%), followed by the central (24.1%) and southern (10.3%) regions, with just a small portion working in Madeira or Azores (1.0%). See Appendix 7B for further details.

Level of knowledge about plants

Asked to self-rate their level of knowledge about different aspects of plants (Figure 7.1), respondents revealed an overall intermediate to high knowledge (on a 5-point scale of level of knowledge with 1 = none at all and 5 = a high level of expertise), as expected from an expert sample. Particularly, respondents had more knowledge about "plant species identification" (mean = 3.842) and less knowledge about "plant species capacity to adapt/survive to climate change" (mean = 3.182).

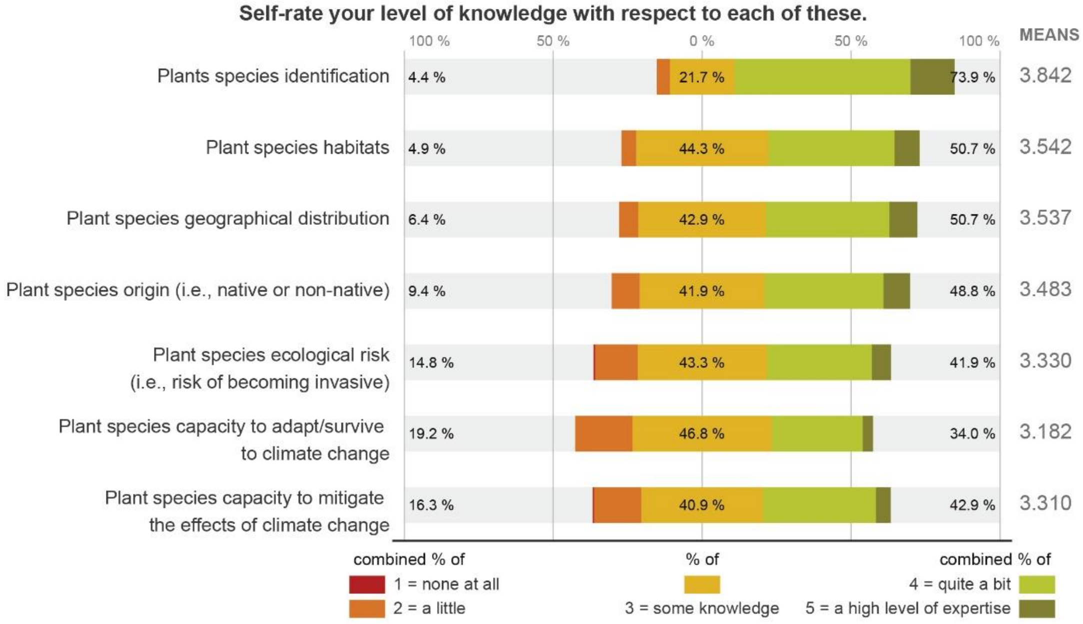

Figure 7.1. Respondents' level of knowledge about plants.

7.3.2. What is the level of acceptance towards non-native and spontaneous plants in urban green spaces?

Generally, respondents agreed accepting (on a 5-point scale of level of agreement with 1 = strongly disagree and 5 = strongly agree) both non-native and spontaneous plants in UGS (Figure 7.2). The level of agreement was higher regarding "cultivated native" plants (97.6% either agreed or strongly agreed) and lower regarding "spontaneous non-native" plants (41.4% either agreed or strongly agreed).

Responses regarding each of the assessed pairs of plant types (origin x intentionality) were associated to define attitudes (accept, neutral, reject). For instance, attitudes towards "non-native" plants were determined by the mean responses regarding both "cultivated non-native" plants and "spontaneous non-native" plants. Respondents clearly revealed a much stronger acceptance level for "native" and "cultivated" plants (98.5% and 95.6% acceptance, respectively), when compared to "non-native" and "spontaneous" plants (63.1% and 73.9% acceptance, respectively). About a quarter of the respondents expressed a neutral opinion towards "spontaneous" and "non-native" plants (21.7% and 25.1%, respectively).

Figure 7.2. Respondents' level of agreement (bar plots) towards pairs of plant types (origin x intentionality) and attitudes (donut charts) towards native, non-native, cultivated, and spontaneous plants.

7.3.3. What are the key factors that drive rejection towards non-native and spontaneous plants in urban green spaces?

To understand which factors could be driving rejection towards non-native and spontaneous plants, respondents were asked about their level of agreement (on a 5-point scale of agreement with 1 = strongly disagree and 5 = strongly agree) regarding statements comparing native to non-native plants (Figure 7.3) and areas with cultivated vegetation to areas with spontaneous vegetation (Figure 7.4). The responses were further compared between attitudes towards non-native and spontaneous plants (accept, neutral, reject), as shown in Figure 7.2.

When asked to compare native with non-native plants, respondents revealed a tendency to disagree with most of the statements, especially that non-native plants "are less ornamental" than native plants (overall mean = 1.995). Respondents who were more likely to reject non-native plants were also significantly more likely to agree with most of the statements (Figure 7.3). Significant differences were only not observed among attitudes towards non-native plants regarding their adaptation to the environmental conditions of mainland Portugal.

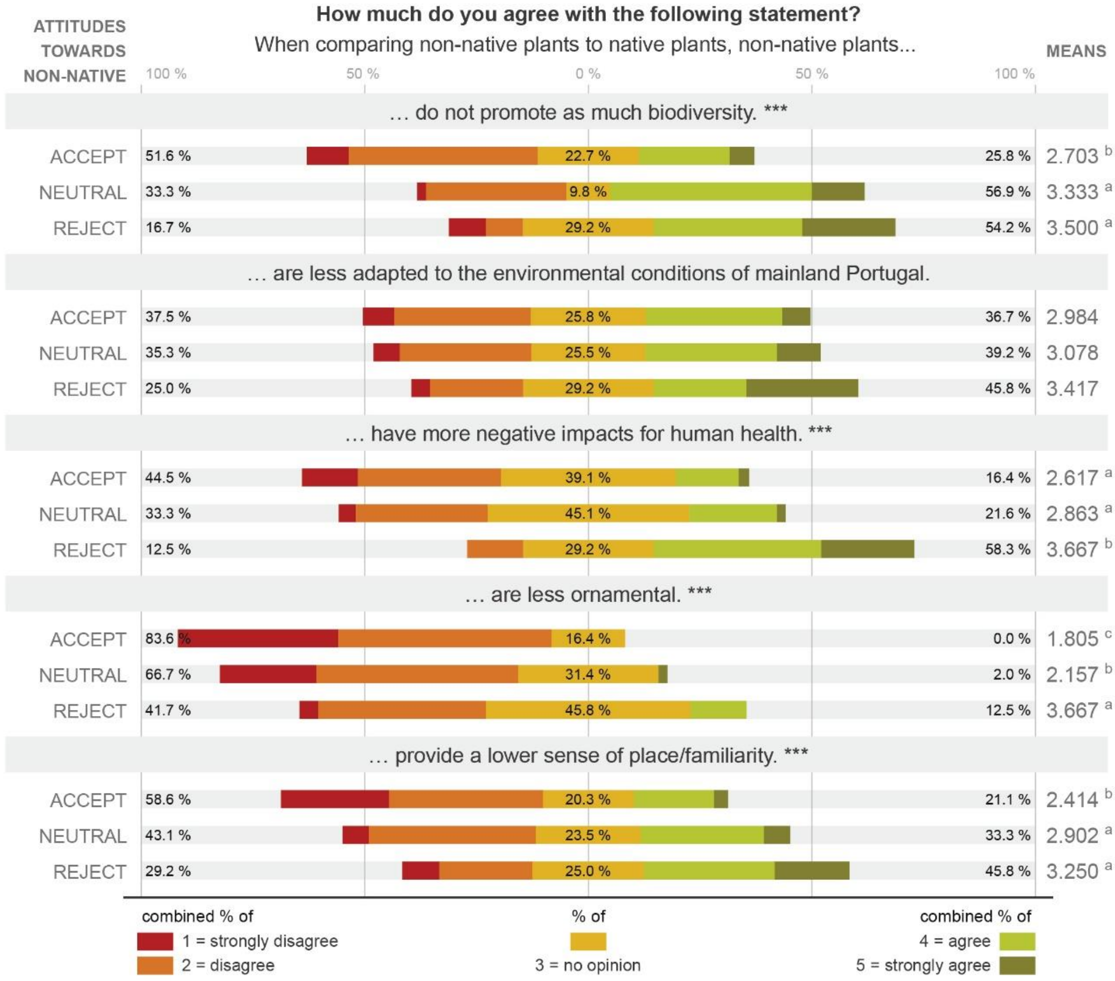

Figure 7.3. Respondents' opinions comparing non-native to native plants and the effect on attitudes towards non-native plants. Significant differences (*** $p<0.001$) across attitudes towards non-native plants (accept, neutral, reject). Different subscripts ($^{a, b, c}$) mark which means in each factor are significantly different from each other.

When asked to compare areas with cultivated vegetation to areas with spontaneous vegetation, respondents revealed a tendency to disagree with most of the statements, particularly that areas with spontaneous vegetation "look less resilient to climate change" (overall mean = 2.010, SD =

0.865) and "look less rich in biodiversity (flora and fauna)" (overall mean = 2.128, SD = 0.938) than areas with cultivated vegetation. Nevertheless, respondents were more inclined to agree that areas with spontaneous vegetation "look less cared for" (mean = 3.148, SD = 0.996). No significant differences were observed between respondents who were more willing to accept spontaneous plants and respondents who were more willing to reject spontaneous plants (Figure 7.4).

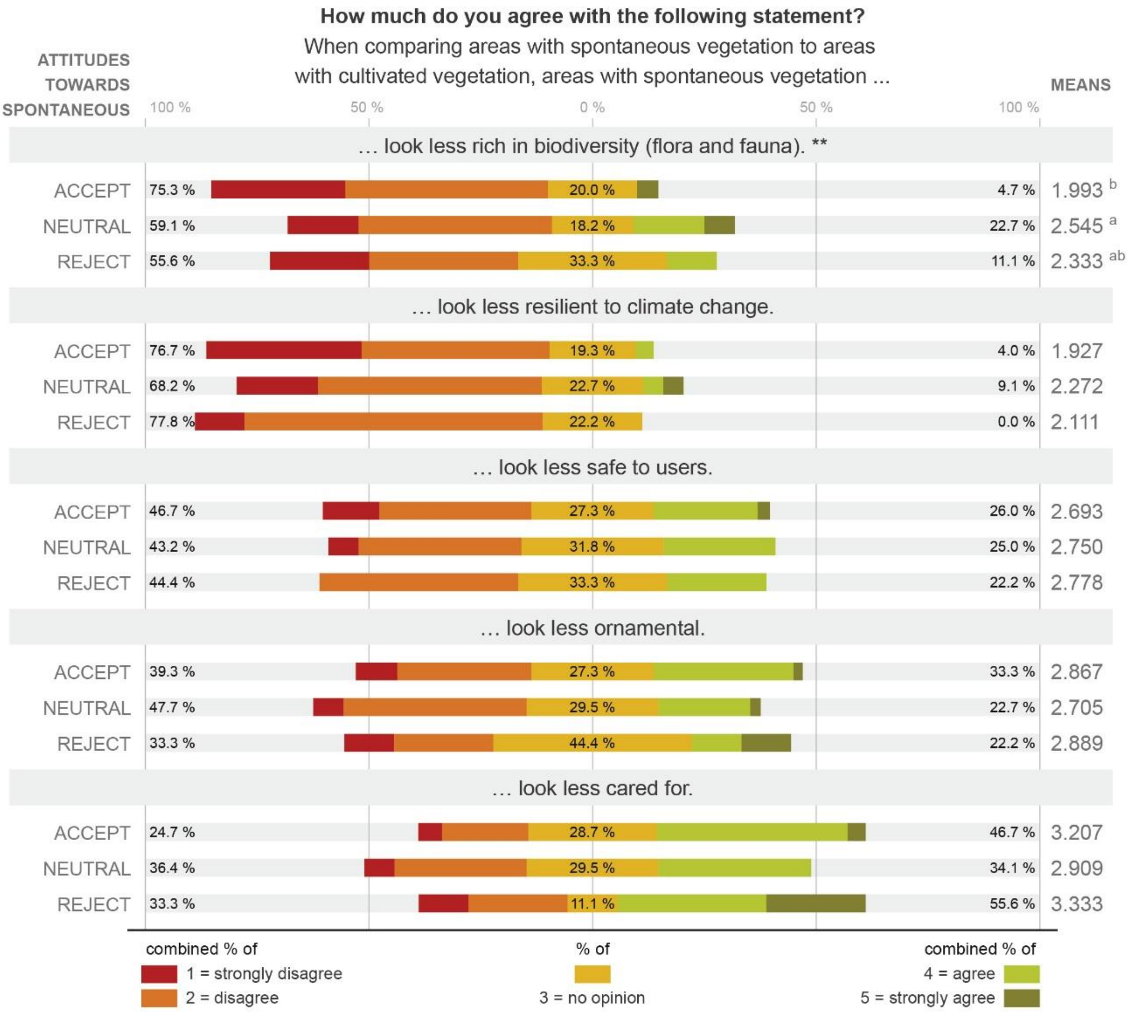

Figure 7.4. Respondents' opinions comparing areas with spontaneous vegetation to areas with cultivated vegetation and the effect on attitudes towards spontaneous plants. Significant differences (** p<0.01) across attitudes towards non-native plants (accept, neutral, reject). Different subscripts ([a, b]) mark which means in each factor are significantly different from each other.

We expected that less level of knowledge about plants could also be a key factor driving rejection towards non-native plants and spontaneous plants, but we found no support in this regard (Appendix 7C).

7.3.4. Do respondents' attitudes towards non-native and spontaneous plants in urban green spaces change when the NUE concept is introduced (without using the term "Novel Urban Ecosystems")?

To assess if attitudes towards non-native and spontaneous plants would change, respondents were asked to read a short paragraph about the NUE concept (without using the term "Novel Urban Ecosystems") and NUE's opportunities to climate change adaptation and mitigation. Then, respondents were asked again to rate their level of agreement (on a 5-point scale of agreement with 1 = strongly disagree and 5 = strongly agree) regarding the presence of pairs of plant types (origin x intentionality).

When asked after reading information about the NUE concept, respondents gave significantly higher ratings to "spontaneous non-native", "non-native", and "spontaneous" plants. However, there were no significant changes in their ratings for "cultivated" and "native" plants in any combination (Table 7.1).

Table 7.1. Comparing attitudes toward plants origin (native or non-native) and intentionality (cultivated or spontaneous) before and after the NUE concept is introduced (without using the term "Novel Urban Ecosystems").

Variables	BEFORE	AFTER	t	df	p-value	Sig
	Mean	Mean				
ORIGIN X INTENTIONALITY						
Cultivated native	4.793	4.724	1.384	403	0.167	n.s.
Cultivated non-native	3.892	3.995	-1.334	399	0.183	n.s.
Spontaneous native	4.404	4.438	-0.503	400	0.615	n.s.
Spontaneous non-native	3.167	3.517	-3.546	404	0.000	***
ORIGIN						
Native	4.599	4.581	0.352	403	0.725	n.s.
Non-native	3.530	3.756	-3.049	404	0.002	**
INTENTIONALITY						
Cultivated	4.342	4.360	-0.345	402	0.730	n.s.
Spontaneous	3.786	3.978	-2.860	402	0.004	**

Significance levels (Sig): n.s. p>0.05; * p<0.05; ** p<0.01; *** p<0.001.

7.3.5. Do respondents prefer combinations of native and non-native plants and combinations of cultivated and spontaneous plants in urban green spaces? Under which circumstances and in which types of urban green spaces?

After providing a short paragraph about NUE (without using the term "Novel Urban Ecosystems"), respondents were asked to select, for a list of actions, which combination of plants they would prefer regarding different proportions of native and non-native plants (Figure 7.5) and cultivated and spontaneous plants (Figure 7.6).

Respondents mainly preferred combinations of native and non-native plants in the following circumstances: to “mitigate climate change” (54.7%), to “promote sense of place/familiarity” (55.7%), to “adapt to scenarios of climate change” (56.2%), and, mostly, to “increase ornamental value of urban green spaces” (68.0%) (Figure 7.5).

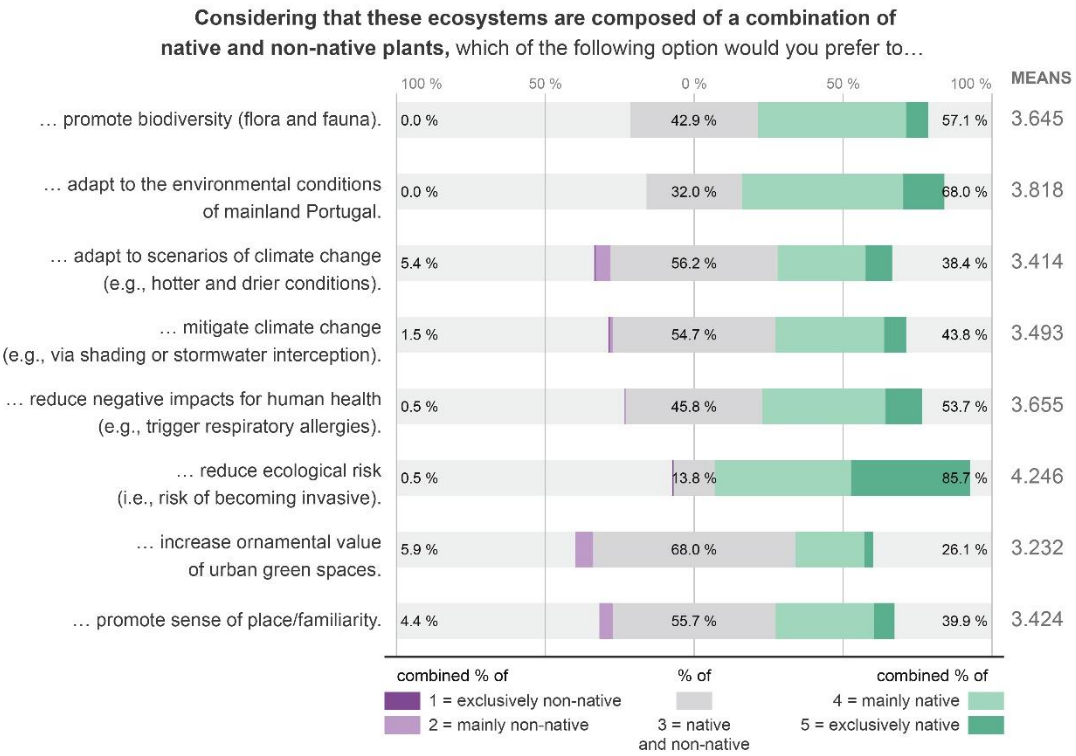

Figure 7.5. Respondents’ preferences of combinations of plants with different proportions of native and non-native plants.

In another survey question about the lack of dependence on human intervention, preference for combinations of cultivated and spontaneous plants prevailed to “increase ornamental value of urban green spaces” (49.8%), to “promote biodiversity” (51.2%), and, mostly, to “increase the availability of habitat and resources for pollinators” (55.2%) and to “promote climate change resilience” (55.2%) (Figure 7.6).

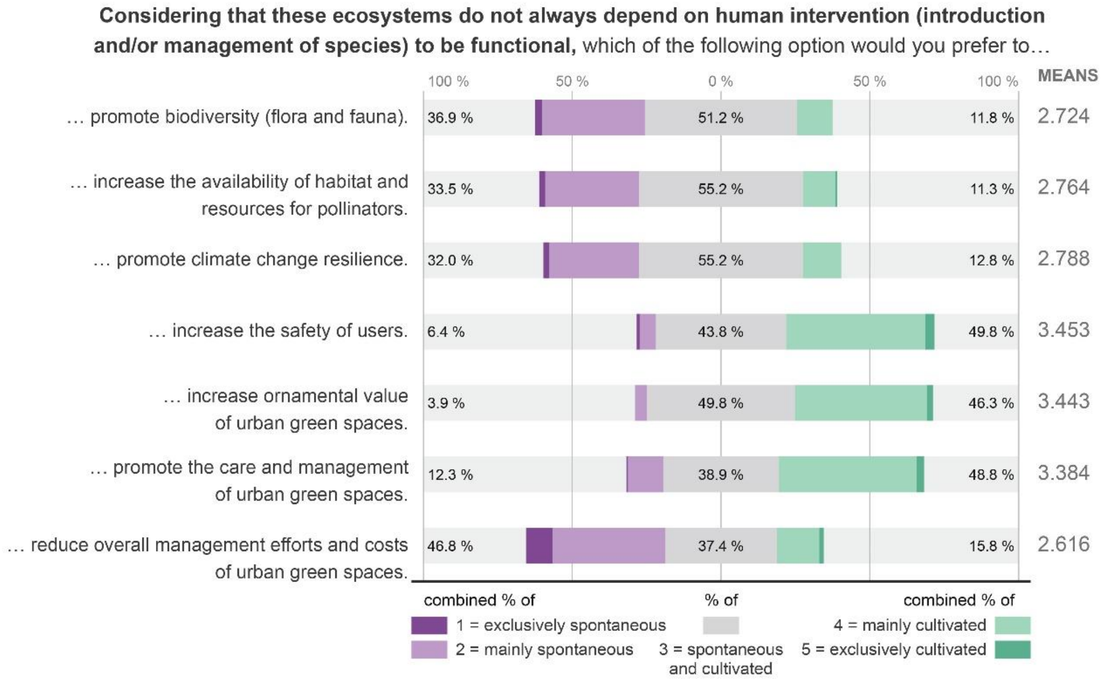

Figure 7.6. Respondents' preferences of combinations of plants with different proportions of cultivated and spontaneous plants.

Respondents were additionally asked about the likelihood of accepting the described ecosystems in different types of UGS (on a 5-point scale of likelihood with 1 = very unlikely and 5 = very likely) (Figure 7.7). The majority of respondents were either likely or very likely to accept the presence of the described ecosystems (NUE) in all the surveyed types of UGS, including public parks and gardens (mean = 4.291), green roofs (mean = 4.197), and urban woodlands (mean = 4.163), but slightly less likely to accept them "along urban streams or rivers" (mean = 3.946).

When asked about the likelihood of being influenced to prefer native plants instead of non-native plants in UGS, the majority of respondents were either very likely or likely to be influenced by all the surveyed factors (on a 5-point scale of likelihood with 1 = very unlikely and 5 = very likely). Respondents were also asked about their level of agreement (on a 5-point scale of agreement with 1 = strongly disagree and 5 = strongly agree) regarding the statement "plants that were previously considered the most adapted (e.g., native) may no longer be the most adapted to current and future local environmental conditions". The majority either strongly agreed or agreed (56.7%) with that statement.

Preference for combinations of native and non-native plants was significantly higher in respondents that were less likely to be influenced by measures that promote the use of native plants instead of non-native plants in UGS (except regarding "social media groups informing about the benefits of native plants") (Figure 7.8a), and in respondents that agreed more with the statement “plants that were previously considered the most adapted (e.g., native) may no longer be the most adapted to current and future local environmental conditions” (Figure 7.8b).

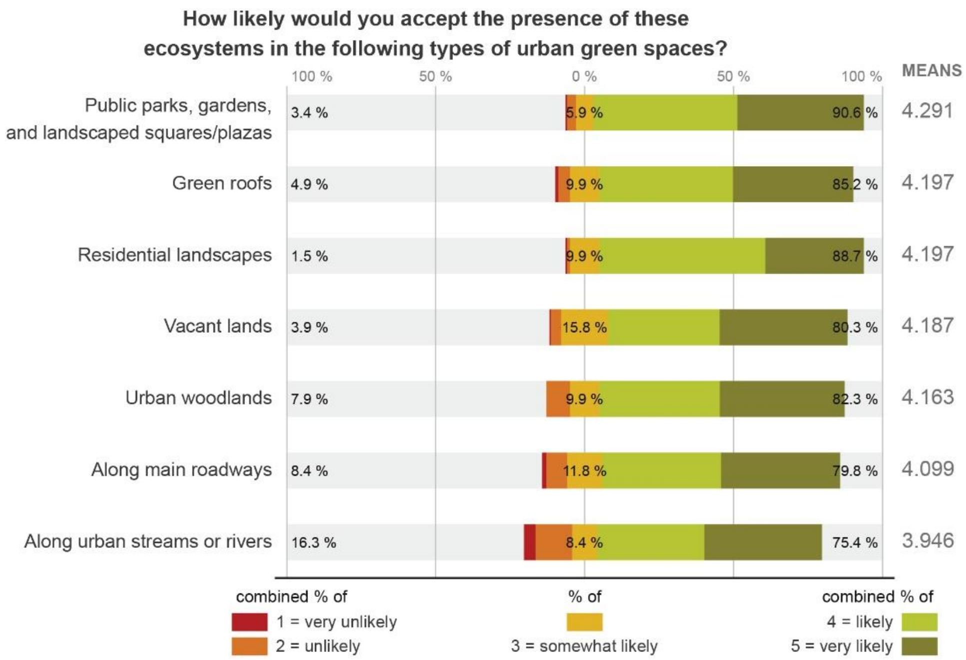

Figure 7.7. Respondents’ likelihood of accepting the described ecosystems in different types of UGS.

Finally, we asked about the level of relevance the described ecosystems may have for climate change adaptation and mitigation (on a 5-point scale of relevance with 1 = not relevant and 5 = extremely relevant). The majority of the respondents considered them either extremely relevant or relevant (96.1%). In the end of the questionnaire, we informed respondents that the types of ecosystems described have been labeled as “Novel Urban Ecosystems” and then asked about their level of knowledge about the term “Novel Urban Ecosystems”. Respondents revealed an overall low to intermediate knowledge (mean = 2.581 on a 5-point scale of level of knowledge with 1 = none at all and 5 = a high level of expertise). Only 12.8% of the respondents revealed a higher level of knowledge about the term.

We expected that respondents would prefer combinations with native and non-native plants as well as combinations with cultivated and spontaneous plants if they considered the described ecosystems more relevant for climate change adaptation and mitigation (Figure 7.9). Instead, we found widespread support for NUE that can adapt and mitigate climate change in cities.

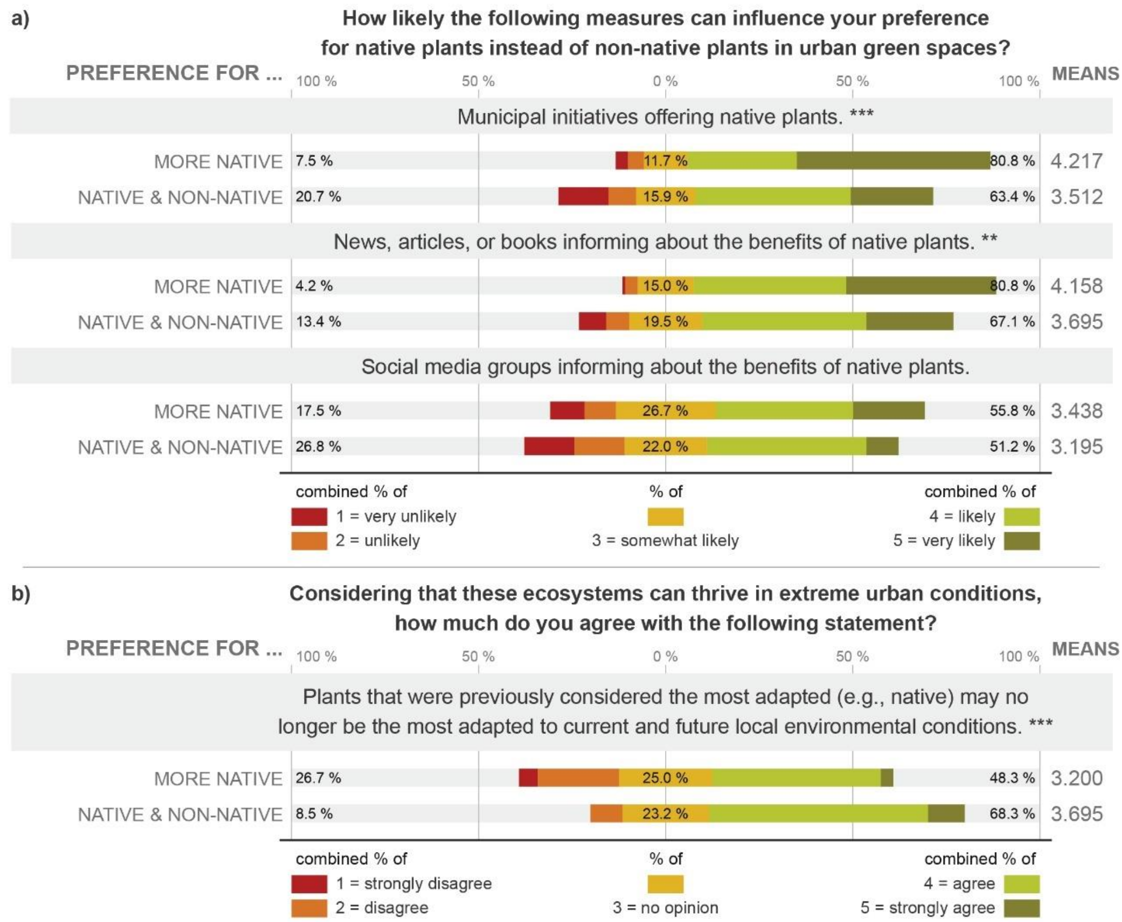

Figure 7.8. (**a**) Respondents' likelihood of being influenced by measures that promote the use of native plants instead of non-native plants in UGS and the effect on preferences regarding plants' origin; (**b**) Respondents' level of agreement regarding the statement "Plants that were previously considered the most adapted (e.g., native) may no longer be the most adapted to current and future local environmental conditions" and the effect on preferences regarding plants' origin. Significant differences (** p<0.01, *** p<0.001) across preferences.

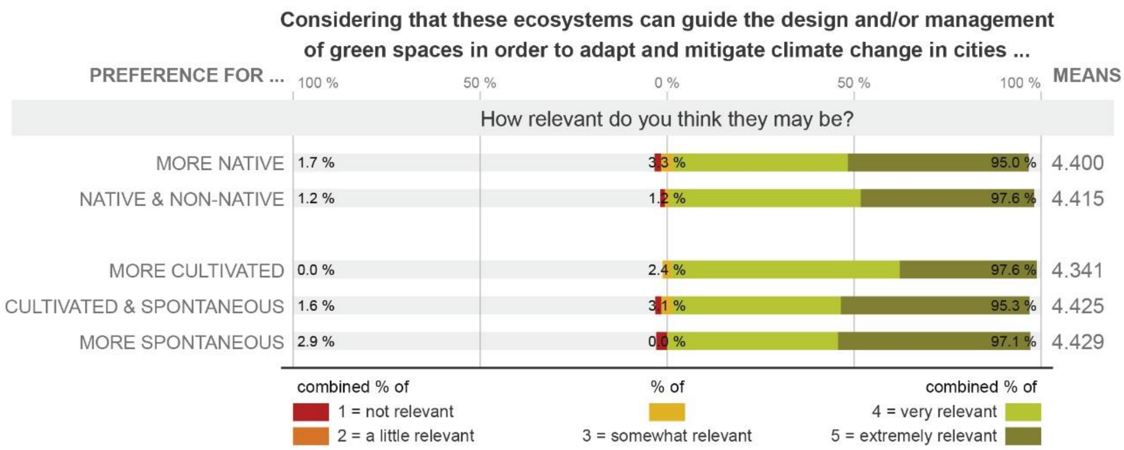

Figure 7.9. Respondents' opinion regarding the level of relevance of the described ecosystems and the effect on preferences regarding plants' origin and intentionality.

7.3.6. Do the socio-demographic and professional background influence respondents' attitudes and preferences regarding plants' origin and intentionality?

Attitudes and preferences regarding plants' origin and intentionality were mostly consistent when compared between socio-demographic and professional groups of respondents, with a few exceptions. Attitudes towards non-native plants were significantly different among fields of expertise. While landscape architects mainly accepted non-native plants, other professionals mostly expressed a neutral opinion (Appendix 7D). Additionally, preferences for combinations of plants with different proportions of cultivated and spontaneous plants were significantly different among respondents' dominant workplaces and dominant work geographical contexts. While most respondents preferred combinations of cultivated and spontaneous plants in UGS, respondents working in governmental workplaces and respondents working in the northern region of Portugal have mainly preferred combinations with more cultivated plants (Appendix 7E).

7.4. Discussion

Even though support was clearly stronger for native and cultivated plants, insights from this study suggest that landscape professionals generally accept non-native and spontaneous plants in UGS. And in some circumstances preferred combinations of native/non-native and cultivated/spontaneous plants in UGS. Results also revealed that acceptance towards non-native and spontaneous plants significantly increased after respondents were provided with information about NUE. Support for NUE was overwhelmingly positive as there was a major acceptance of these ecosystems in several types of UGS and virtually all respondents considered NUE either relevant or extremely relevant for climate change adaptation and mitigation.

7.4.1. Attitudes towards plant origin and intentionality

Attitudes towards non-native plants

Previous studies verified that the general population has a tendency to have negative attitudes towards non-native plants (A. Fischer & Young, 2007; Lewis et al., 2019), but our results pointed in a different direction. Although we were concerned that the widespread devaluation of non-native species would influence non-native plants' acceptance, most respondents accepted the presence of non-native plants in UGS (63.1%, Figure 7.2), especially if they were cultivated. These results suggest that professionals do not reject the presence of non-native plants in UGS based on their origin and, on the contrary, they identify a role for non-native plants in cities (Hoyle et al., 2017). Research developed by Van Der Wal et al., (2014) and Gbedomon et al., (2020) found that both the public and experts judge species primarily in terms of factors and net impacts rather than based on origin. Still, a small portion of the respondents (11.8%, Figure 7.2) rejected the presence of non-native plants in UGS without context or species information, which suggests that they may have rejected them based on their origin, probably following a view aligned with the nativism paradigm in which it is better to assume that all non-native species pose threats and are presumed “guilty until proven innocent” (Guiaşu & Tindale, 2018; Kueffer, 2013).

Our findings also suggest that respondents who rejected non-native plants in UGS had strong opposing opinions to respondents who accepted them, reinforcing the idea that there are polarized perspectives about the origin of plants. Respondents who rejected non-native plants consistently had a greater tendency to agree that native plants were better than non-native plants in several situations. On the other hand, respondents who accepted non-native plants in UGS were more likely to disagree with the comparisons drawn between native and non-native plants in UGS.

Overall, respondents mainly agreed that non-native plants “are less adapted to the environmental conditions of mainland Portugal” than native plants. More than a third of respondents accepting non-native plants also showed a tendency to agree with this sentence (36.7% agreement, Figure 7.3), suggesting that the idea that native plants are better adapted to local conditions persists among professionals. In the face of rapid global changes and new dynamics imposed by the Anthropocene, determining the adaptation of plants to a particular location based on their origin is far from guaranteed as all plants will respond to the changing context in which they are inserted (Davis, 2018; Hill & Hadly, 2018).

The statement “when comparing non-native plants to native plants, non-native plants have more negative impacts for human health” received most agreement from respondents rejecting non-native plants in UGS (58.3% agreement, Figure 7.3), suggesting that this may have been one of the main factors for rejecting non-native plants in UGS. These results are probably justified because negative impacts to human well-being (e.g., vectors of diseases, toxicity, and allergic reactions) have been associated with invasive species (Gaertner et al., 2017). Nevertheless, these findings contrast with the results from the study conducted by Gbedomon et al., (2020), which verified that members of the scientific community mainly disagreed that non-native species pose a threat to human well-being.

Overall, there was more disagreement regarding the statement “when comparing non-native plants to native plants, non-native plants are less ornamental” including from respondents rejecting non-native plants (41.7% disagreement, Figure 7.3). In line with this, Hoyle et al. (2017) observed that people in the UK considered non-native plants more attractive than native plants in urban environments. These findings are not surprising, as many non-native plants were introduced to new locations because of desirable aesthetic characteristics (Kueffer & Kull, 2017; van Kleunen et al., 2018).

Our respondents also mainly disagreed that, compared to native plants, non-native plants "do not promote as much biodiversity" and "provide a lower sense of place/familiarity". Biodiversity conservation strategies primarily focus on preserving native biodiversity and do not consider that non-native species can contribute to biodiversity (Kowarik, 2011; Schlaepfer, 2018). Although the respondents who rejected non-native plants may be aligned with this vision, our results suggest that most respondents believe that non-native plants can also promote biodiversity. Regarding the sense of place, the vegetation that people grow up with and have known for the longest time will be the vegetation they are emotionally connected with (Kueffer & Kull, 2017; Lewis et al., 2019). Many non-native plants have been part of our cities for many years (Özgüner, Kendle, & Bisgrove, 2007). Moreover, in the past, many non-native plants were brought to certain locations by settlers to recreate landscapes that were more familiar to them (Kueffer & Kull, 2017; Shackleton et al., 2019). Thereby, the sense of place should not be determined by origin (Gaertner et al., 2017), and our findings suggest that most of the professionals share this perspective.

We believe that our respondents' general acceptance of non-native plants may also be justified because our sample comprises experts with higher levels of knowledge and experience about plants. This may also explain why attitudes towards non-native plants were not significantly different regarding plant knowledge, even though respondents with more general plant knowledge were slightly more likely to accept non-native plants (Appendix 7C). Likewise, we did not find significant differences in attitudes towards non-native plants regarding socio-demographic and professional variables, except that landscape architects were significantly more likely to accept non-native plants in UGS. Non-native plants are often used for their aesthetic qualities in projects, which may explain these results. Although results were not significant, professionals who mainly worked in an urban context were slightly more likely to accept non-native plants in UGS. This is relevant because it is primarily in an urban environment that makes sense to use non-native plants, as addressed in a comment by one respondent: "The use of native species in an urban environment can bring economic, environmental, and social advantages, but it should not be a justification to stop planting Jacaranda or Agapanthus".

Attitudes towards spontaneous plants

In our study, 73.9% of respondents accepted spontaneous plants in UGS, and only 4.4% rejected them (Figure 7.2), thus revealing a clearly more positive tendency to welcome these elements in cities. These results are consistent with studies that have verified acceptance towards areas with spontaneous plants (L. K. Fischer et al., 2018; Li et al., 2019; Muratet, Pellegrini, Dufour, Arrif, & Chiron, 2015). But contrast with other previous studies that reported a tendency to perceive areas with spontaneous plants negatively (Brun et al., 2018; Mathey et al., 2018) or in a contradictory way (Chen et al., 2021; Vega et al., 2021; Włodarczyk-Marciniak et al., 2020).

Overall, respondents tended to disagree that spontaneous vegetation "look less resilient to climate change" and "look less rich in biodiversity (flora and fauna)". These findings suggest that respondents are aware of the advantages of spontaneous vegetation in UGS. In addition to being automatically adapted to the environmental conditions where they arise and have the ability to persist without continued maintenance and artificial inputs, spontaneous vegetation can adapt to and mitigate climate change effects and support a wide diversity of animal and plant species (Bonthoux et al., 2014; Brun et al., 2018; Del Tredici, 2010, 2014; Filibeck, Petrella, & Cornelini, 2016; Kowarik, 2018, 2021; Kühn, 2006; Robinson & Lundholm, 2012).

In a not-so-expressive way, respondents also tended to disagree that areas with spontaneous vegetation "look less safe to users" and "look less ornamental" than areas with cultivated vegetation. Areas with spontaneous vegetation are often perceived as dangerous, abandoned, and unattractive, with links to human health risks (e.g., allergies and ticks) (Chen et al., 2021; Filibeck et al., 2016; L. K. Fischer et al., 2020; Hofmann, Westermann, Kowarik, & Van der Meer, 2012; Li et al., 2019; Özgüner et al., 2007; Włodarczyk-Marciniak et al., 2020), which may explain why disagreement was not so dominant among respondents. Still, the aesthetic potential of spontaneous vegetation was already documented in the literature, namely due to brightly colored flowers with more extended flowering periods, which are very relevant for increasing attractiveness and can be improved by targeted interventions (Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019).

Overall, there was more agreement regarding the statement "when comparing areas with spontaneous vegetation to areas with cultivated vegetation, areas with spontaneous vegetation look less cared for", which suggests that this may have been the main factor to reject spontaneous plants in UGS. This result is consistent with a multitude of studies that observed that people generally identify areas with spontaneous vegetation as chaotic, messy, untidy, and neglected, proving the need for recognizing human intention and control (Brun et al., 2018; Chen et al., 2021; Filibeck et al., 2016; Kowarik et al., 2021; Mathey et al., 2018), the so-called "cues to care" (Nassauer, 1995).

Again, we did not find significant differences in attitudes towards spontaneous plants regarding plant knowledge and socio-demographic and professional variables (Appendix 7E). Similar to our results regarding attitudes towards non-native plants, we believe that a general acceptance of spontaneous plants may also be explained by our experts' sample. This is in line with earlier studies that have found that professionals are more likely to have positive views towards spontaneous plants (Chen et al., 2021; Hofmann et al., 2012; Li et al., 2019; Phillips & Lindquist, 2021), also because professionals with experience can more easily recognize ecological function (Filibeck et al., 2016; Nassauer, 1995).

7.4.2. Effect of knowledge about NUE on attitudes

We opted to deconstruct the NUE concept and present it without labels to prevent the term "Novel Urban Ecosystems" from influencing respondents' attitudes. Interestingly, we verified that respondents revealed significantly more acceptance towards "spontaneous non-native", "non-native", and "spontaneous" plants after reading a short paragraph about the NUE concept (Table 7.1). This suggests that information about the NUE concept increased respondents' support and acceptance of both "non-native" and "spontaneous" plants in UGS. Since the NUE concept was presented as an opportunity for climate change adaptation and mitigation in urban contexts, climate change may have been a determining factor in accepting both non-native and spontaneous plants, as also previously observed by Hoyle et al. (2017) regarding non-native plants. Despite the significant changes observed, acceptance of native and cultivated plants was consistently higher before and after the informative paragraph, likely because respondents already had positive attitudes towards "native" and "cultivated" plants. Additionally, plants' origin seemed to have been more determinant in respondents' attitudes than plants' intentionality, as native plants were the most accepted and non-native plants the least. Likewise, there was overall less acceptance for "spontaneous non-native" plants in both moments, which can be explained by a possible link to the invasiveness risk.

Lastly, we verified that a considerable portion of the respondents revealed a neutral opinion regarding non-native plants and spontaneous plants (Figure 7.2). This may be due to the complex and controversial nature of this topic, or it may even be an indicator of a process of transition of opinions as suggested in a research carried out by Gbedomon et al., (2020), even though it is not clear in which direction.

7.4.3. Preferences towards plant origin and intentionality

Preferences for combinations of native and non-native plants

In general, the majority of the respondents (59.1 %) preferred combinations with more native plants, which suggests that even though most respondents accepted non-native plants, it does not necessarily mean that they prefer them in UGS. Preference for combinations with more native plants was exceptionally high to “reduce ecological risk (i.e., risk of becoming invasive)” (85.7%, Figure 7.5). Similarly, in a study conducted in the UK on the general public, Hoyle et al. (2017) observed that some participants showed reservations about using non-native plants due to their possible invasiveness. The same study also verified that, despite this concern, many respondents revealed a sophisticated understanding of the differences between non-native and invasive plants. Professionals with experience in dealing with invasive problems are generally more aware of the risks of invasion (Kowarik et al., 2021), so it is understandable that the fear of non-native plants becoming invasive was a determining factor in preferences. It is reasonable that in situations of ecological risk, one would want to reduce the proportion of non-native. It is only problematic when one generalizes this concern to all non-native plants (Davis, 2018).

Respondents also preferred combinations with more native plants in other situations, namely to “promote biodiversity (flora and fauna)”, “adapt to the environmental conditions of mainland Portugal”, and “reduce negative impacts for human health (e.g., trigger respiratory allergies)” (Figure 7.5). This suggests that for these circumstances, they believe that the dominance of native plants is more beneficial. In Portugal, there have been recent campaigns and initiatives that seem to align with the nativism paradigm. These movements may indirectly alienate society to fear non-native plants, even when they have no negative impacts (Davis, 2018; Hoyle et al., 2017; Selge et al., 2011). The fact that respondents who preferred combinations with more native plants were more likely to be influenced by governmental, academic, and social pressures (Figure 7.8a) suggests that this nativism narrative may somehow also influence professionals involved in the design, planning, and management of green spaces.

Nevertheless, a large percentage of respondents (40.4%) preferred combinations of native and non-native plants and were less likely to be influenced by measures promoting native plants, which suggests that they were probably more motivated by internal and personal values than external forces such as governmental, academic, and social pressures (Figure 7.8a). Preference for combinations of native and non-native plants will largely depend on context, soil, functionality, and several other factors. In this case, respondents preferred combinations of native and non-native plants to “increase ornamental value of urban green spaces” and “promote sense of place/familiarity” (Figure 7.5). These findings are supported by literature stating that non-native plants are usually introduced for aesthetic reasons and sense of place (Davis, 2018; Gaertner et al., 2017; Kueffer & Kull, 2017; Shackleton et al., 2019).

Interestingly, most respondents also revealed a preference for combinations of native and non-native plants to “adapt to scenarios of climate change (e.g., hotter and drier conditions)” and “mitigate climate change (e.g., via shading or stormwater interception)” (Figure 7.5). Additionally, we also observed that respondents that preferred combinations of native and non-native plants were significantly more likely to agree with the statement “plants that were previously considered the most adapted (e.g., native) may no longer be the most adapted to current and future local environmental conditions" (Figure 7.8b), which suggests that respondents believe that non-native plants will play an important future role in cities and would prefer them combined with native plants to enhance adaptation (Ahern, 2016; Kowarik, 2011). This was also illustrated by the comment from one respondent: "I believe that there is an increasing need to adapt to change (…). In order for there to be a balance and for us all to coexist with the climate changes that we are witnessing, we must, in my opinion, adapt concepts. Combining well-adapted non-native species with native species in the public green space seems to me one of the ways to go."

Preferences for combinations of cultivated and spontaneous plants

Most of our respondents (62.6%) preferred combinations of cultivated and spontaneous plants. The study developed by Muratet et al., (2015) also found that most park users in Paris preferred combinations of cultivated and spontaneous plants rather than removing spontaneous plants. As previously noted, spontaneous vegetation has many benefits for biodiversity, pollination, resilience, and ornamental value (Bonthoux et al., 2014; Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019; Robinson & Lundholm, 2012) and, in these circumstances, respondents preferred a combination of cultivated and spontaneous (Figure 7.6). This suggests that they are aware of the benefits of spontaneous plants and, at the same time, there will always be a desire for some level of control and maintenance of UGS (Muratet et al., 2015). Previous investigations observed that the relationship between biodiversity and preference for areas with spontaneous vegetation is quite complex. People prefer intermediate levels of biodiversity rather than early and advanced levels of ecological succession where vegetation is either non-existent or overgrown (translating insecurity or neglect) (Brun et al., 2018; Mathey et al., 2018; Phillips & Lindquist, 2021).

This may also explain the fact that respondents mostly preferred combinations with more cultivated plants to "increase the safety of users" and "promote the care and management of urban green spaces" (Figure 7.6). We have previously noted that spontaneous vegetation is often associated with unsafety, mess, and neglect (Chen et al., 2021; Filibeck et al., 2016; L. K. Fischer et al., 2020; Li et al., 2019). In that sense, multiple studies verified a tendency to prefer more organized and manicured UGS, where human design and control can be easily recognized (Hofmann et al., 2012; Hoyle, 2021; Kowarik et al., 2021; Mathey et al., 2018; Nassauer, 1995; Włodarczyk-Marciniak et al., 2020), which may ultimately justify our respondents' preference for cultivated plants in these circumstances. On the other hand, when the goal is to "reduce overall management efforts and costs of urban green spaces", our respondents mainly preferred combinations with more spontaneous plants, suggesting that the fact that spontaneous vegetation requires less maintenance and costs may be the determining reason for professionals use them in UGS (Özgüner et al., 2007).

Higher preference for combinations of cultivated and spontaneous plants can be explained by our expert sample, as earlier studies have found that, compared to laypeople, professionals are more likely to value and identify structure and beauty in areas dominated by spontaneous vegetation (L. K. Fischer et al., 2018; Hofmann et al., 2012; Hoyle, 2021). Besides, professionals can recognize spontaneous plants better than laypeople (Muratet et al., 2015). Furthermore, the study presented by Li et al., (2019) in China also found that professionals preferred spontaneous vegetation and innovative combinations of cultivated and spontaneous plants.

7.5. Conclusion

7.5.1. Implications for the design and management of NUE

Our findings revealed that the majority of our respondents would accept NUE in multiple UGS types and virtually all respondents considered them relevant for climate change adaptation and mitigation. These results are very promising and a significant finding of this study as they reflect not only general acceptance towards NUE but also support for their future integration in cities' green structures through design and management. This research also suggests that education about the potential role of NUE in climate change adaptation and mitigation has a positive effect on professionals' acceptance of non-native and spontaneous plants. These were also exciting findings in this study, as they point to clear future pathways: (1) bridge gaps in knowledge by providing useful information on what NUE are, how they emerged, their potential benefits and challenges; (2) demystify prejudices and broad perspectives about non-native and spontaneous plants by adopting a less biased language and approach (Davis, 2018); (3) motivate further research and disseminate gained knowledge by testing ways to integrate NUE in the urban green structure and monitoring their progress and ecosystem services and disservices trade-offs. This is also pertinent since knowledge about the term "Novel Urban Ecosystems" was relatively low among professionals, indicating an opportunity to raise awareness and spread understanding about the concept. However, we note that increasing knowledge is not a guaranteed solution that can completely change the value systems of professionals (Selge et al., 2011); not least because there will probably always be more acceptance towards NUE by people who perceive nature as something dynamic and constantly changing (Kowarik et al., 2021; Kueffer & Kull, 2017).

By investigating attitudes and preferences regarding the origin and intentionality of plants in UGS, we were also able to identify under which circumstances NUE can be more welcomed and in which circumstances there will be potential conflicts. These insights will inform NUE design and management and help prioritize actions to enhance NUE advantages and resolve disadvantages. We identified concerns that persist among some professionals regarding non-native plants (e.g., inadequate adaptation to the local conditions, negative impacts to human well-being, and risk of becoming invasive) and spontaneous plants (e.g., unattractiveness, lack of safety, and lack of "cues to care"). These and other conflicts can be resolved through target interventions in which the underlying values of NUE are maximized, while harmful components can be minimized or eliminated (Bakshi & Gallagher, 2020; Del Tredici, 2020; Klaus & Kiehl, 2021). For instance, areas with NUE can be adapted to welcome new uses and functions, or organized so that design and some level of human control can be recognized – "cues to care" (Nassauer, 1995). Likewise, harmful plants can be removed depending on the species, context, or social values (e.g., plants that are invasive, aggressive, damaged, unhealthy or dangerous for people) (Del Tredici, 2014, 2020; Phillips & Lindquist, 2021). In the same line, new plants can be added to increase ornamental value and provide desired ecosystem services (Ahern, 2016; Kühn, 2006). Additionally, areas with NUE can become more welcoming and safer to people through precise interventions in the vegetation (e.g., change the spatial arrangement of elements or trim dense vegetation that restricts views) (Włodarczyk-Marciniak et al., 2020).

7.5.2. Limitations and future research recommendations

Even though the questionnaire was restricted to professionals, it may have been quite demanding because of the complex possible interactions between species origin and intentionality. Previous investigations have studied attitudes and preferences towards non-native (Gbedomon et al., 2020; Hoyle et al., 2017; Lewis et al., 2019) and spontaneous plants (Li et al., 2019; Mathey et al., 2018; Phillips & Lindquist, 2021) with relevant findings, but rarely together. Moreover, the way we evaluated preference regarding origin and intentionality may have some challenges since most preference studies use photographs or simulations that help to contextualize options (Kowarik et al., 2021; Li et al., 2019; Mathey et al., 2018).

Considering that we have only examined the attitudes and preferences of professionals, our sample was homogeneous. The vast majority were landscape architects who can easily have socially-shared experiences and a common understanding regarding plants' origin and intentionality. This may explain why we did not identify major differences in terms of knowledge, socio-demographic, and professional background variables, while several studies have pointed that these variables are relevant regarding both non-native (Kowarik et al., 2021; Potgieter, Gaertner, O'Farrell, & Richardson, 2019) and spontaneous plants (Li et al., 2019; Włodarczyk-Marciniak et al., 2020).

Experts' opinions and points of view are usually very different from laypeople (L. K. Fischer et al., 2018; Hofmann et al., 2012; Hoyle, 2021; Kowarik et al., 2021; Li et al., 2019; Özgüner et al., 2007). Thus, it would be interesting to expand this research in the future to the general population, stakeholders, or UGS users, possibly using presential questionnaires in different urban settings or resorting to photographing stimuli. And also, to conduct this survey in other countries. Nevertheless, it is still pertinent to understand where professionals stand regarding this very complex topic that will most likely be a part of decisions on the fate of future urban green spaces. Since they are widespread in the urban environment, where human influence prevails, NUE increasingly become a reality difficult to avoid in the new Era of the Anthropocene. And the new kind of nature that we will most likely have to embrace as climate change requires new approaches to creating sustainable urban ecosystems.

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Supplementary material

Appendix 7A. Respondents' socio-demographic profiles (gender, age, and education level).

SOCIO-DEMOGRAPHIC VARIABLES	N (%)
GENDER	
Female	129 (63.5%)
Male	69 (34.0%)
Other (non-binary)	5 (2.5%)
AGE	
≤ 35 years	108 (53.2%)
< 26 years	14 (6.9%)
26 to 35 years	94 (46.3%)
36 to 55 years	70 (34.5%)
36 to 45 years	40 (19.7%)
46 to 55 years	30 (14.8%)
≥ 56 years	25 (12.3%)
56 to 65	22 (10.8%)
> 65 years	3 (1.5%)
EDUCATION LEVEL	
PhD	17 (8.4%)
Master's degree	129 (63.5%)
Bachelor's degree	54 (26.6%)
High school	1 (0.5%)
Other	2 (1.0%)

Note: Underrepresented respondents' groups (i.e., below 10 responses) were excluded from statistical procedures and are marked in red. Respondents' sub-groups are marked in blue.

Appendix 7B. Respondents' professional profiles (field of expertise, dominant workplace, dominant territorial work context, and dominant geographical work context).

PROFESSIONAL VARIABLES	N (%)
FIELD OF EXPERTISE	
Landscape Architecture	170 (83.7%)
Other	33 (16.3%)
Architecture/Urbanism	4 (2.0%)
Engineering/Technology	15 (7.4%)
Biological Sciences	6 (3.0%)
Horticulture/Landscaping	2 (1.0%)
Other	6 (3.0%)
DOMINANT WORKPLACE	
Firms and Companies	93 (45.8%)
Landscape Architecture firm	55 (27.1%)
Regional planning firm	5 (2.5%)
Companies of construction, management, and/or inspection of green spaces	33 (16.3%)
Governmental workplaces (Municipal councils/agencies or governmental services)	41 (20.2%)
Non-governmental workplaces	14 (6.9%)
Non-governmental organizations	9 (4.4%)
Institutions that own or manage landscapes	5 (2.5%)
University	33 (16.3%)
Other	22 (10.8%)
DOMINANT TERRITORIAL WORK CONTEXT	
Urban	134 (66.0%)
Suburban	47 (23.2%)
Rural	22 (10.8%)
DOMINANT GEOGRAPHICAL WORK CONTEXT *	
Outside Portugal	19 (9.4%)
North	97 (47.8%)
Center	49 (24.1%)
South	21 (10.3%)
Islands (Azores and Madeira)	2 (1.0%)

* 15 missing responses.

Note: Underrepresented respondents' groups (i.e., below 10 responses) were excluded from statistical procedures and are marked in red. Respondents' sub-groups are marked in blue.

Appendix 7C. Effect of level of knowledge about plants on attitudes towards non-native and spontaneous plants.

Variables	NON-NATIVE PLANTS				SPONTANEOUS PLANTS			
	Reject ≤ 2,600 (n = 24)	Neutral 2.600 – 3.400 (n = 51)	Accept ≥ 3.400 (n = 128)	Sig.	Reject ≤ 2,600 (n = 9)	Neutral 2.600 – 3.400 (n = 44)	Accept ≥ 3.400 (n = 150)	Sig.
OVERALL LEVEL OF KNOWLEDGE ABOUT PLANTS	3.423	3.431	3.480	ns	3.492	3.513	3.444	ns
Plants identification	3.708	3.863	3.859	ns	3.889	3.932	3.813	ns
Plants habitats	3.375	3.471	3.602	ns	3.333	3.523	3.560	ns
Plants geographical distribution	3.500	3.510	3.555	ns	3.444	3.636	3.513	ns
Plants origin (i.e., native or non-native)	3.375	3.510	3.492	ns	3.556	3.545	3.460	ns
Plants ecological risk (i.e., risk of becoming invasive)	3.458	3.333	3.305	ns	3.444	3.341	3.320	ns
Plants capacity to adapt/survive to climate change	3.208	3.039	3.234	ns	3.000	3.341	3.147	ns
Plants capacity to mitigate the effects of climate change	3.333	3.294	3.313	ns	3.778	3.273	3.293	ns

Significance levels (Sig): ns p>0.05; * p<0.05; ** p<0.01; *** p<0.001.

Appendix 7D. Effects of socio-demographic and professional background on attitudes towards non-native plants and spontaneous plants. Fisher's Exact test (F) was used for statistical comparison between attitudes towards non-native plants and spontaneous plants (accept, neutral, reject).

VARIABLES	ATTITUDES TOWARDS NON-NATIVE PLANTS				ATTITUDES TOWARDS SPONTANEOUS			
	REJECT	NEUTRAL	ACCEPT	F	REJECT	NEUTRAL	ACCEPT	F
GENDER, N (%)				ns				ns
Female	13 (10.1)	35 (27.1)	81 (62.8)		5 (3.9)	31 (24.0)	93 (72.1)	
Male	10 (14.5)	16 (23.2)	43 (62.3)		4 (5.8)	12 (17.4)	53 (76.8)	
AGE, N (%)				ns				ns
≤ 35 years	12 (11.1)	26 (24.1)	70 (64.8)		4 (3.7)	22 (20.4)	82 (75.9)	
36 - 55 years	7 (10.0)	17 (24.3)	46 (65.7)		3 (4.3)	16 (22.9)	51 (72.9)	
≥ 56 years	5 (20.0)	8 (32.0)	12 (48.0)		2 (8.0)	6 (24.0)	17 (68.0)	
EDUCATION, N (%)				ns				ns
Bachelor's degree	8 (14.8)	16 (29.6)	30 (55.6)		5 (9.3)	16 (29.6)	33 (61.1)	
Master's degree	13 (10.1)	31 (24.0)	85 (65.9)		4 (3.1)	24 (18.6)	101 (78.3)	
PhD	3 (17.6)	3 (17.6)	11 (64.7)		0 (0.0)	4 (23.5)	13 (76.5)	
FIELD OF EXPERTISE, N (%)				**				ns
Landscape Architecture	19 (11.2)	35 (20.6)	**116 (68.2)**		8 (4.7)	37 (21.8)	125 (73.5)	
Other	5 (15.2)	**16 (48.5)**	12 (36.4)		1 (3.0)	7 (21.2)	25 (75.8)	

(Continued …)

VARIABLES	ATTITUDES TOWARDS NON-NATIVE PLANTS				ATTITUDES TOWARDS SPONTANEOUS			
	REJECT	NEUTRAL	ACCEPT	F	REJECT	NEUTRAL	ACCEPT	F
DOMINANT WORKPLACE, N (%)				ns				ns
Firms and Companies	11 (11.8)	22 (23.7)	60 (64.5)		4 (4.3)	25 (26.9)	64 (68.8)	
Governmental	4 (9.8)	10 (24.4)	27 (65.9)		3 (7.3)	5 (12.2)	33 (80.5)	
Non-governmental	2 (14.3)	6 (42.9)	6 (42.9)		1 (7.1)	2 (14.3)	11 (78.6)	
University	3 (9.1)	8 (24.2)	22 (66.7)		1 (3.0)	5 (15.2)	27 (81.8)	
Other	4 (18.2)	5 (22.7)	13 (59.1)		0 (0.0)	7 (31.8)	15 (68.2)	
DOMINANT WORK TERRITORIAL CONTEXT, N (%)				ns				ns
Urban	13 (9.7)	30 (22.4)	91 (67.9)		4 (3.0)	33 (24.6)	97 (72.4)	
Suburban	6 (12.8)	16 (34.0)	25 (53.2)		4 (8.5)	7 (14.9)	36 (76.6)	
Rural	5 (22.7)	5 (22.7)	12 (54.5)		1 (4.5)	4 (18.2)	17 (77.3)	
DOMINANT WORK GEOGRAPHICAL CONTEXT, N (%)				ns				ns
Outside Portugal	0 (0.0)	4 (21.1)	15 (78.9)		0 (0.0)	4 (21.1)	15 (78.9)	
North of Portugal	12 (12.4)	23 (23.7)	62 (63.9)		5 (5.2)	19 (19.6)	73 (75.3)	
Center of Portugal	7 (14.3)	15 (30.6)	27 (55.1)		2 (4.1)	13 (26.5)	34 (69.4)	
South of Portugal	2 (9.5)	5 (23.8)	14 (66.7)		1 (4.8)	4 (19.0)	16 (76.2)	

Significance levels (Sig): ns p>0.05; * p<0.05; ** p<0.01; *** p<0.001.

Appendix 7E. Effects of socio-demographic and professional background on preferences regarding combinations with different proportions of native and non-native plants and cultivated and spontaneous plants. Fisher's Exact test (F) was used for statistical comparison between preferences regarding different proportions of native and non-native plants (more native, native and non-native) and between preferences regarding different proportions of cultivated and spontaneous plants (more cultivated, cultivated and spontaneous, more spontaneous).

VARIABLES	PREFERENCES ON ORIGIN			PREFERENCES ON INTENTIONALITY			
	Native and Non-native	More Native	F	More Spontaneous	Cultivated / Spontaneous	More Cultivated	F
GENDER, N (%)			ns				ns
Female	54 (41.9)	75 (58.1)		26 (20.2)	81 (62.8)	22 (17.1)	
Male	26 (37.7)	42 (60.9)		8 (11.6)	43 (62.3)	18 (26.1)	
AGE, N (%)			ns				ns
≤ 35 years	43 (39.8)	64 (59.3)		14 (13.0)	70 (64.8)	24 (22.2)	
36 - 55 years	31 (44.3)	39 (55.7)		13 (18.6)	46 (65.7)	11 (15.7)	
≥ 56 years	8 (32.0)	17 (68.0)		8 (32.0)	11 (44.0)	6 (24.0)	
EDUCATION, N (%)			ns				ns
Bachelor's degree	26 (48.1)	28 (51.9)		10 (18.5)	33 (61.1)	11 (20.4)	
Master's degree	50 (38.8)	78 (60.5)		20 (15.5)	81 (62.8)	28 (21.7)	
PhD	6 (35.3)	11 (64.7)		5 (29.4)	10 (58.8)	2 (11.8)	
FIELD OF EXPERTISE, N (%)			ns				ns
Landscape Architecture	70 (41.2)	99 (58.2)		27 (15.9)	109 (64.1)	34 (20.0)	
Other	12 (36.4)	21 (63.6)		8 (24.2)	18 (54.5)	7 (21.2)	

(Continued …)

VARIABLES	PREFERENCES ON ORIGIN			PREFERENCES ON INTENTIONALITY			
	Native and Non-native	More Native	F	More Spontaneous	Cultivated / Spontaneous	More Cultivated	F
DOMINANT WORKPLACE, N (%)			ns				**
Firms and Companies	37 (39.8)	56 (60.2)		13 (14.0)	**62 (66.7)**	18 (19.4)	
Governmental	15 (36.6)	26 (63.4)		10 (24.4)	14 (34.1)	**17 (41.5)**	
Non-governmental	5 (35.7)	9 (64.3)		4 (28.6)	**7 (50.0)**	3 (21.4)	
University	17 (51.5)	16 (48.5)		4 (12.1)	**25 (75.8)**	4 (12.1)	
Other	8 (36.4)	13 (59.1)		4 (18.2)	**16 (72.7)**	2 (9.1)	
DOMINANT WORK TERRITORIAL CONTEXT, N (%)			ns				ns
Urban	59 (44.0)	75 (56.0)		21 (15.7)	84 (62.7)	29 (21.6)	
Suburban	14 (29.8)	32 (68.1)		7 (14.9)	31 (66.0)	9 (19.1)	
Rural	9 (40.9)	13 (59.1)		7 (31.8)	12 (54.5)	3 (13.6)	
DOMINANT WORK GEOGRAPHICAL CONTEXT, N (%)			ns				***
Outside Portugal	5 (26.3)	14 (73.7)		3 (15.8)	**13 (68.4)**	3 (15.8)	
North of Portugal	42 (43.3)	54 (55.7)		10 (10.3)	18 (18.6)	**69 (71.1)**	
Center of Portugal	22 (44.9)	27 (55.1)		10 (20.4)	**28 (57.1)**	11 (22.4)	
South of Portugal	9 (42.9)	12 (57.1)		6 (28.6)	**12 (57.1)**	3 (14.3)	

Significance levels (Sig): ns p>0.05; * p<0.05; ** p<0.01; *** p<0.001.

8

CHAPTER 8 |

GENERAL DISCUSSION AND CONCLUSIONS

"The issues around novel ecosystems are part of a broader dialog about humanity's changing relationship with nature. All ecosystems – including novel ones – will continue to change into the future, perhaps at unprecedented rates. The challenge is to find a path through the complex and pervasive issues that need to be tackled in the quest to nurture and maintain human populations and the world's ecosystems and species." (Hobbs, Higgs, & Hall, 2013c, p. 359)

Chapter 8 | General discussion and conclusions

Capítulo 8 | Discussão geral e conclusões

8.1. Thesis overview: Main findings and contributions

As mentioned throughout this thesis, several evidences point out the possibility that the planet has entered a new geological epoch, designated Anthropocene (Crutzen, 2006; Steffen, Crutzen, Mcneill, & Events, 2007; Steffen, Grinevald, Crutzen, & Mcneill, 2011; Waters, Zalasiewicz, Williams, Ellis, & Snelling, 2014; Zalasiewicz, Williams, Haywood, & Ellis, 2011). For the first time, humans replace nature as the dominant force on Earth, contributing decisively to the reconfiguration of ecosystem processes and patterns (Ellis, 2015; Seastedt, Hobbs, & Suding, 2008; Vitousek, Mooney, Lubchenco, & Melillo, 1997; Williams & Jackson, 2007). Novel Urban Ecosystems result from these complex changes imposed in the Anthropocene (Collier & Devitt, 2016; Hobbs et al., 2006; Morse et al., 2014), so they may contain responses to the challenges that this changing context represents. This way, this research aimed to contribute to understanding the opportunities and challenges of Novel Urban Ecosystems, specifically within the scope of Landscape Architecture and its potential contribution to the design, planning, and management of the urban green structure.

This chapter discusses the main findings and contributions of this research in response to

8.1. Visão geral da tese: Principais descobertas e contributos

Tal como foi referido ao longo desta tese, diversas evidências apontam para a possibilidade de o planeta ter entrado numa nova época geológica, denominada Antropocénico (Crutzen, 2006; Steffen, Crutzen, Mcneill, & Events, 2007; Steffen, Grinevald, Crutzen, & Mcneill, 2011; Waters, Zalasiewicz, Williams, Ellis, & Snelling, 2014; Zalasiewicz, Williams, Haywood, & Ellis, 2011). Pela primeira vez, o Homem substitui a natureza como a força dominante na Terra, contribuindo decisivamente para a reconfiguração dos processos e padrões dos ecossistemas (Ellis, 2015; Seastedt, Hobbs, & Suding, 2008; Vitousek, Mooney, Lubchenco, & Melillo, 1997; Williams & Jackson, 2007). Os Novos Ecossistemas Urbanos surgem em resultado destas complexas mudanças impostas no quadro do Antropocénico (Collier & Devitt, 2016; Hobbs et al., 2006; Morse et al., 2014) podendo, por isso, conter respostas para os desafios que este contexto de alteração acarreta. Como tal, esta investigação propôs-se a contribuir para a compreensão das oportunidades e dos desafios associados ao conceito de Novos Ecossistemas Urbanos, concretamente no âmbito da Arquitetura Paisagista e do seu potencial contributo para o desenho, planeamento e gestão da estrutura verde urbana.

the problems identified in the introduction chapter (chapter 1), namely:

- The need to clarify and stabilize the concept of Novel Urban Ecosystems and demonstrate its usefulness and relevance to the disciplinary area of Landscape Architecture;
- The relevance of developing tools for studying Novel Urban Ecosystems, particularly to measure the ecological novelty in urban green spaces, allowing the application and integration of the concept in Landscape Architecture practice;
- The importance of understanding the attitudes and preferences towards Novel Urban Ecosystems, which will determine their acceptance, application, and integration in the design, planning, and management of the urban green structure.

Neste capítulo discutem-se, assim, os principais resultados obtidos durante esta investigação em resposta às problemáticas identificadas no capítulo de introdução (capítulo 1), nomeadamente:

- A necessidade de esclarecer e estabilizar o conceito de Novos Ecossistemas Urbanos e demonstrar a sua utilidade e relevância para a área disciplinar da Arquitetura Paisagista;
- A pertinência de desenvolver ferramentas para o estudo de Novos Ecossistemas Urbanos, particularmente para medir a novidade ecológica nos espaços verdes urbanos, permitindo a aplicação e integração do conceito nas áreas de atuação da Arquitetura Paisagista;
- A importância de compreender as atitudes e as preferências em relação a Novos Ecossistemas Urbanos, determinantes para a sua aceitação, aplicação e integração no desenho, planeamento e gestão da estrutura verde urbana.

8.1.1. Novel Urban Ecosystems: An evolving concept with utility for Landscape Architecture

The research initiated with a state-of-the-art update (**chapter 2** – *Novel Ecosystems: A review of the concept in non-urban and urban contexts*), which allowed us to understand the origin, history, and evolution of the Novel Ecosystems and Novel Urban Ecosystems concepts. The publications collected in the systematic literature review allowed us to verify that, although the use of the terms "Novel Ecosystems" and "Novel Urban Ecosystems" is relatively recent (Chapin III & Starfield, 1997; Hobbs et al., 2006), **there is**

8.1.1. Novos Ecossistemas Urbanos: Um conceito em evolução com utilidade para a Arquitetura Paisagista

A investigação iniciou com uma atualização do estado da arte (**capítulo 2** – *Novel Ecosystems: A review of the concept in non-urban and urban contexts*), que possibilitou compreender a origem, a história e a evolução dos conceitos de Novos Ecossistemas e Novos Ecossistemas Urbanos. As publicações recolhidas no âmbito da revisão sistemática de literatura permitiram verificar que, apesar de o uso dos termos "Novos Ecossistemas" e "Novos Ecossistemas Urbanos" ser relativamente recente (Chapin III & Starfield, 1997; Hobbs et al., 2006), **já está disponível um**

already a consistent body of literature available that proves the relevance and topicality of the subject. **A growing trend and interest in researching the concept in urban environments (Novel Urban Ecosystems) was also identified**, which follows the attention given to other related topics, such as urban biodiversity and ecosystem services (Collier, 2014; Klaus, 2013; Knapp et al., 2012; Kowarik, 2011; Lugo, Winchell, & Carlo, 2018; Perring, Manning, et al., 2013). This trend was corroborated in the years after the literature review was conducted (2019 to 2021) since numerous articles strictly focused on Novel Urban Ecosystems emerged (Andrade et al., 2021; Klaus & Kiehl, 2021; Lewis, Granek, & Nielsen-Pincus, 2019; Moreno-Contreras, de Silva, Andrade-Gonzalez, Vital-Garcia, & Ortiz-Ramirez, 2019; Planchuelo, Kowarik, & von der Lippe, 2020; Planchuelo, von Der Lippe, & Kowarik, 2019). In this way, the bibliography on the topic was continuously updated throughout the investigation and used in the various chapters that constitute the thesis.

From the analyzed body of literature, special attention was given to publications that sought to define Novel Ecosystems (Higgs, 2017; Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013a; Hobbs, Higgs, & Harris, 2009; Milton, 2003; Morse et al., 2014; Radeloff et al., 2015; Truitt et al., 2015) and Novel Urban Ecosystems (Ahern, 2016; Kowarik, 2011, 2018; Kowarik & von der Lippe, 2018). It was possible to observe that these ecosystems are essentially characterized based on four

consistente corpo de literatura que comprova a relevância e atualidade do tema. Identificou-se também uma **tendência e interesse crescentes pela investigação do conceito em ambiente urbano (Novos Ecossistemas Urbanos)**, o que, de algum modo, acompanha a atenção dada a outros temas relacionados, como por exemplo, a biodiversidade urbana e os serviços de ecossistema (Collier, 2014; Klaus, 2013; Knapp et al., 2012; Kowarik, 2011; Lugo, Winchell, & Carlo, 2018; Perring, Manning, et al., 2013). Esta tendência foi corroborada nos anos posteriores à realização da revisão de literatura (2019 a 2021), durante os quais surgiram inúmeros artigos estritamente focados em Novos Ecossistemas Urbanos (Andrade et al., 2021; Klaus & Kiehl, 2021; Lewis, Granek, & Nielsen-Pincus, 2019; Moreno-Contreras, de Silva, Andrade-Gonzalez, Vital-Garcia, & Ortiz-Ramirez, 2019; Planchuelo, Kowarik, & von der Lippe, 2020; Planchuelo, von Der Lippe, & Kowarik, 2019). Desta forma, a bibliografia sobre o tema foi sendo continuamente atualizada ao longo do trabalho e utilizada nos vários capítulos que compõem a tese.

Partindo da literatura analisada, deu-se especial atenção às publicações que procuraram definir Novos Ecossistemas (Higgs, 2017; Hobbs et al., 2006; Hobbs, Higgs, & Hall, 2013a; Hobbs, Higgs, & Harris, 2009; Milton, 2003; Morse et al., 2014; Radeloff et al., 2015; Truitt et al., 2015) e Novos Ecossistemas Urbanos (Ahern, 2016; Kowarik, 2011, 2018; Kowarik & von der Lippe, 2018), sendo essencialmente caracterizados com base em quatro critérios: i) atividades antrópicas; ii) novas combinações de espécies;

criteria: i) human-induced; ii) species assemblages; iii) thresholds; and iv) self-sustaining (chapter 2, Table 2.3). It was also verified that **rarely all criteria are used simultaneously to characterize Novel Ecosystems or Novel Urban Ecosystems**. **Only the human and biotic dimensions of the concepts (criteria "human-induced" and "species assemblages", respectively) appear in all the analyzed definitions**. Additionally, two proposals for the classification of Novel Ecosystems and Novel Urban Ecosystems were identified: one based on categories, i.e., whether an ecosystem is "novel" or not (Hallett et al., 2013; Hobbs et al., 2009), and another based on degrees of ecological novelty, i.e., whether an ecosystem has more or less novelty (Corlett, 2014; Radeloff et al., 2015).

These findings were fundamental for developing the methodology presented in chapter 4. On the one hand, it became increasingly evident that a dichotomous categorization of Novel Urban Ecosystems ignored key elements such as the constant disturbance dynamics observed in an urban environment (Ahern, 2016; Del Tredici, 2010; Kowarik, 2011, 2018; Lugo et al., 2018), validating the hypothesis that it would be **more appropriate to assess Novel Urban Ecosystems based on a continuum of ecological novelty**. On the other hand, identifying the criteria was essential for the quantification of ecological novelty, even though these criteria impose distinct challenges in that process (Hallett et al., 2013; Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Truitt et al., 2015). For

iii) limiares; e iv) estabilidade (capítulo 2, Tabela 2.3). Verificou-se que **raramente todos os critérios são utilizados em simultâneo para caracterizar Novos Ecossistemas ou Novos Ecossistemas Urbanos. Apenas as dimensões humana e biótica dos conceitos (critérios "atividades antrópicas" e "novas combinações de espécies", respetivamente) surgem em todas as definições analisadas**. Adicionalmente, identificaram-se duas propostas para a classificação de Novos Ecossistemas e Novos Ecossistemas Urbanos: uma com base em categorias, ou seja, se um ecossistema é "novo" ou não (Hallett et al., 2013; Hobbs et al., 2009) e outra com base em graus de novidade ecológica, ou seja, se um ecossistema tem mais ou menos novidade (Corlett, 2014; Radeloff et al., 2015).

Estas descobertas foram fundamentais para o desenvolvimento da metodologia apresentada no capítulo 4. Por um lado, tornou-se cada vez mais evidente que uma categorização dicotómica dos Novos Ecossistemas Urbanos ignorava elementos fundamentais como as dinâmicas de perturbação constantes observadas em ambiente urbano (Ahern, 2016; Del Tredici, 2010; Kowarik, 2011, 2018; Lugo et al., 2018), validando a hipótese de que seria **mais apropriado avaliar Novos Ecossistemas Urbanos com base num *continuum* de novidade ecológica**. Por outro lado, a identificação dos critérios foi essencial para a quantificação da novidade ecológica, ainda que estes critérios imponham desafios distintos nesse processo (Hallett et al., 2013; Harris, Murphy, Nelson, Perring, & Tognetti, 2013; Truitt et al., 2015). Por exemplo, os critérios "limiares" e "estabilidade" são difíceis de analisar (Hobbs et example, the criteria "thresholds" and "self-sustaining" are difficult to analyze (Hobbs et al., 2013a; Morse et al., 2014; Radeloff et al., 2015), so it is not surprising that the available methodologies focused on the easiest criterion to quantify, i.e., the biotic dimension (L K Fischer, Von der Lippe, & Kowarik, 2013; Knapp et al., 2012; Perring et al., 2012; Schittko et al., 2020; Tognetti, 2013; Trueman, Standish, & Hobbs, 2014; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018; Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009). However, **the criterion assessing the contribution of the human dimension to Novel Urban Ecosystems was also not yet quantified**. Therefore, the methodology developed in this research makes an important contribution by combining, for the first time, the human and biotic dimensions.

The literature review also allowed the development of a conceptual framework where approaches that identify the most relevant types of urban green spaces for a Novel Urban Ecosystems research are gathered and analyzed (chapter 1.2; Figure 1.5) (Ahern, 2016; Del Tredici, 2010; Kowarik, 2005, 2011, 2018).

This stage of the work, carried out at an early phase, allowed to consolidate and organize concepts, demonstrate the originality and topicality of the subject, and identify research perspectives and gaps. On the one hand, **the relevance of applying the concept in urban areas was proven in this study**

al., 2013a; Morse et al., 2014; Radeloff et al., 2015). Assim, não surpreende que as metodologias disponíveis se concentrassem no critério de mais fácil quantificação, ou seja, a dimensão biótica (L K Fischer, Von der Lippe, & Kowarik, 2013; Knapp et al., 2012; Perring et al., 2012; Schittko et al., 2020; Tognetti, 2013; Trueman, Standish, & Hobbs, 2014; Van Mechelen, Van Meerbeek, Dutoit, & Hermy, 2015; Vanstockem, Ceusters, Van Dyck, Somers, & Hermy, 2018; Wilsey, Teaschner, Daneshgar, Isbell, & Polley, 2009). Contudo, o **critério que avalia o contributo da dimensão humana para os Novos Ecossistemas Urbanos também não era ainda ponderado**. A metodologia desenvolvida no âmbito desta investigação dá, por isso, um importante contributo ao combinar, pela primeira vez, as dimensões humana e biótica.

A revisão de literatura permitiu também elaborar um quadro conceptual onde se reúnem e analisam abordagens que identificam os tipos de espaços verdes urbanos mais relevantes para uma investigação sobre Novos Ecossistemas Urbanos (capítulo 1.2; Figura 1.4) (Ahern, 2016; Del Tredici, 2010; Kowarik, 2005, 2011, 2018).

Esta etapa do trabalho, levada a cabo numa fase inicial da investigação, permitiu consolidar e organizar conceitos, demonstrar a originalidade e a atualidade da temática e identificar perspetivas e lacunas de investigação. Por um lado, **a pertinência de aplicar o conceito em áreas urbanas ficou comprovada neste estudo, uma vez que é nas cidades que as oportunidades do conceito adquirem uma maior relevância** (por exemplo, em relação ao desenho e ao

since it is in cities that the opportunities of the concept acquire greater relevance (for instance, regarding urban design and planning). On the other hand, it was proved that in order to explore the opportunities of Novel Urban Ecosystems, it would be necessary to reflect further on the practical dimension of the concept for Landscape Architecture (chapter 3) and to clarify how these ecosystems can be quantified in the green structure of cities (chapter 4).

The relationship of the Novel Urban Ecosystems concept with Landscape Architecture had already been suggested in the scientific literature by some authors (Ahern, 2016; Del Tredici, 2014; Grose, 2014; Sack, 2013) but was, in general, largely unexplored. Thus, in **chapter 3** – *Novel Urban Ecosystems: Opportunities from and to Landscape Architecture*, we reflected i) on the extent to which Landscape Architecture methodologies, tools, and principles can contribute concretely to the debate, application, and understanding of the Novel Urban Ecosystems concept, and ii) on the usefulness and relevance of the concept for Landscape Architecture, positioning the discipline in a current discussion.

The way recognized Landscape Architecture projects have been implemented and how they have been managed has allowed for collecting fundamental knowledge for understanding the Novel Urban Ecosystems concept. These projects took advantage of the adaptive capacity of novel plant communities that emerge and thrive in extreme urban conditions (e.g., extreme heat

planeamento urbano). Por outro lado, constatou-se que, para explorar as oportunidades dos Novos Ecossistemas Urbanos, seria necessário refletir mais aprofundadamente na dimensão prática do conceito na Arquitetura Paisagista (capítulo 3) e esclarecer de que forma estes ecossistemas podem ser quantificados na estrutura verde das cidades (capítulo 4).

A relação do conceito de Novos Ecossistemas Urbanos com a Arquitetura Paisagista já tinha sido sugerida na literatura científica por alguns autores (Ahern, 2016; Del Tredici, 2014; Grose, 2014; Sack, 2013), mas encontrava-se, no geral, extensamente inexplorada. Deste modo, no **capítulo 3** – *Novel Urban Ecosystems: Opportunities from and to Landscape Architecture,* refletiu-se i) em que medida as metodologias, as ferramentas e os princípios da Arquitetura Paisagista podem contribuir concretamente para o debate, aplicação e compreensão do conceito de Novos Ecossistemas Urbanos, e ii) sobre a utilidade e relevância do conceito para a Arquitetura Paisagista, posicionando a disciplina numa discussão atual.

A forma como reconhecidos projetos de Arquitetura Paisagista foram implementados e como têm sido geridos, permitiu construir conhecimento fundamental para a estabilização e melhor compreensão do conceito de Novos Ecossistemas Urbanos. Estes projetos tiraram partido da capacidade de adaptação das novas comunidades de plantas que surgem e sobrevivem em condições urbanas extremas (por exemplo, em condições de calor e seca extrema ou em solos contaminados e perturbados) and drought conditions or in contaminated and disturbed soils) (Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Gallagher et al., 2018; Light, Thompson, & Higgs, 2013). Simultaneously, they have introduced into the Novel Urban Ecosystems concept aesthetic dimensions that contribute to the visual recognition of their distinct functional capacities (Del Tredici, 2014; Felson & Pickett, 2005; Gobster, Nassauer, Daniel, & Fry, 2007; Nassauer, 1995; Nassauer & Opdam, 2008).

The project for the *Landscape Park Duisburg-Nord*, 1990-2002, (Latz+Partner, 2021), in Germany, has been a source of inspiration for many reclamation projects in degraded post-industrial areas. This proposal provides an example of how novel plant combinations emerging in neglected conditions can be intervened and managed to support ecological processes and promote aesthetic and cultural improvement (Bakshi & Gallagher, 2020; Kowarik, 2018, 2021; Kühn, 2006; Sack, 2013). The development of baseline studies prior to the project implementation highlighted the presence of communities with a high diversity of native and non-native species, some dominated by invasive species. Besides being adapted to the difficult existing conditions (e.g., disturbed, contaminated, and nutrient-poor substrates), these communities were already performing ecological functions that were important to preserve, such as the support for rare and threatened species and habitat and resources for wildlife (Keil, 2019). These findings emphasize the **relevance that some**

(Ahern, 2016; Bakshi & Gallagher, 2020; Del Tredici, 2020; Gallagher et al., 2018; Light, Thompson, & Higgs, 2013). Simultaneamente, introduziram no conceito de Novos Ecossistemas Urbanos, dimensões estéticas que contribuem para o reconhecimento visual das distintas competências funcionais destas comunidades (Del Tredici, 2014; Felson & Pickett, 2005; Gobster, Nassauer, Daniel, & Fry, 2007; Nassauer, 1995; Nassauer & Opdam, 2008).

O projeto para o *Landscape Park Duisburg-Nord, 1990-2002,* (Latz+Partner, 2021), na Alemanha, tem sido uma fonte de inspiração para muitos projetos de recuperação de áreas industriais degradadas. Esta proposta constitui um exemplo de como novas combinações de plantas que surgem em condições negligenciadas podem ser intervencionadas e geridas para suportar processos ecológicos e para promover uma valorização estética e cultural (Bakshi & Gallagher, 2020; Kowarik, 2018, 2021; Kühn, 2006; Sack, 2013). A realização de estudos de base, prévios à implementação do projeto, sinalizou a presença de comunidades com elevada diversidade de espécies nativas e exóticas, algumas dominadas por espécies invasoras. Estas comunidades, para além de estarem adaptadas às difíceis condições existentes (por exemplo, substratos perturbados, contaminados, com vestígios antropogénicos e pobres em nutrientes), desempenhavam já funções ecológicas que importavam preservar, como o suporte de espécies raras e ameaçadas, habitat e recursos para a vida selvagem (Keil, 2019). Estas descobertas salientam **a relevância que algumas comunidades espontâneas podem ter na reabilitação de locais**

spontaneous communities can have in the rehabilitation of degraded sites and the role of non-native species in maximizing vegetation performance. This knowledge is opposed to current narratives that advocate the dominance or exclusivity of native species (nativism paradigm) (Davis, 2018; Gbedomon, Salako, & Schlaepfer, 2020; Hoyle, Hitchmough, & Jorgensen, 2017).

Applying the Novel Urban Ecosystems concept in Landscape Architecture practice depends on awareness about these matters and how these ecosystems are perceived. Therefore, the results of this discussion were essential for applying the Novel Urban Ecosystems concept to urban green structure design, planning, and management (chapters 4, 5, and 6) and for investigating professionals' opinions about Novel Urban Ecosystems (chapter 7).

8.1.2. Novel Urban Ecosystems: Application in urban green structure design, planning, and management

As already mentioned, **the practical application of the Novel Ecosystems and Novel Urban Ecosystems concepts depends on tools that enable their identification and quantification**. However, measuring ecological novelty is a difficult task since most of the criteria that characterize these ecosystems are not readily observable and measurable (Hallett et al., 2013; Harris et al., 2013; Hobbs et al., 2013a; Morse et al., 2014; Radeloff et al., 2015; Truitt et al., 2015). Furthermore, it was verified an increased

degradados, mas também o papel das espécies exóticas para maximizar o desempenho da vegetação. Este conhecimento opõe-se, assim, a correntes atuais que defendem o domínio ou exclusividade de espécies nativas (paradigma do nativismo) (Davis, 2018; Gbedomon, Salako, & Schlaepfer, 2020; Hoyle, Hitchmough, & Jorgensen, 2017).

A aplicação do conceito de Novos Ecossistemas Urbanos nas áreas de atuação da Arquitetura Paisagista depende de uma consciencialização acerca destas matérias e da forma como estes ecossistemas são percecionados. Os resultados desta discussão foram, por isso, essenciais para a aplicação do conceito de Novos Ecossistemas Urbanos no desenho, planeamento e gestão da estrutura verde urbana (capítulos 4, 5 e 6) e para investigar a opinião de profissionais sobre Novos Ecossistemas Urbanos (capítulo 7).

8.1.2. Novos Ecossistemas Urbanos: Aplicação no desenho, planeamento e gestão da estrutura verde urbana

Como já mencionado, **a aplicação prática dos conceitos de Novos Ecossistemas e Novos Ecossistemas Urbanos depende da disponibilidade de ferramentas que possibilitem a sua identificação e quantificação**. No entanto, medir a novidade ecológica revelou-se uma tarefa difícil, uma vez que a maioria dos critérios que caracterizam estes ecossistemas não são facilmente observáveis e mensuráveis (Hallett et al., 2013; Harris et al., 2013; Hobbs et al., 2013a; Morse et al., 2014; Radeloff et al., 2015; Truitt et al., 2015).

investment in the development of methodologies for the assessment of ecological novelty in non-urban contexts (Kueffer, Schumacher, Dietz, Fleischmann, & Edwards, 2010; Mascaro, Becklund, Hughes, & Schnitzer, 2008; Oliveira-Neto, Nascimento, & Carvalho, 2017; Perring et al., 2012; Tognetti, 2013; Trueman et al., 2014; Wilsey et al., 2009), i.e., this assessment regarding Novel Urban Ecosystems is less explored in the literature.

These problems were addressed in **chapter 4** – *Urban ecological novelty assessment: Implications for urban green infrastructure planning and management*, in which a methodology developed to assess urban ecological novelty is presented in the expectation that, if a tool was available, the inclusion of ecological novelty in the urban green structure planning and management would be possible. The proposed methodology is based on two pillars: i) the human dimension should be explicitly considered a key component in the measurement of urban ecological novelty, alongside the biotic dimension of the concept, and ii) urban ecological novelty is present in all types of urban green spaces, but in different degrees, i.e., in a continuum of ecological novelty.

Unlike other proposed methodologies, which only quantify differences in biotic (Schittko et al., 2020; Vanstockem et al., 2018; Wilsey et al., 2009) and/or abiotic conditions (Lugo & Helmer, 2004; Martinuzzi, Lugo, Brandeis, & Helmer, 2013; Radeloff et al., 2015), the

Além disso, constatou-se, ainda, um maior investimento no desenvolvimento de metodologias para a avaliação da novidade ecológica em contexto não-urbano (Kueffer, Schumacher, Dietz, Fleischmann, & Edwards, 2010; Mascaro, Becklund, Hughes, & Schnitzer, 2008; Oliveira-Neto, Nascimento, & Carvalho, 2017; Perring et al., 2012; Tognetti, 2013; Trueman et al., 2014; Wilsey et al., 2009), ou seja, esta avaliação em relação a Novos Ecossistemas Urbanos encontra-se menos explorada na literatura.

Estes problemas foram abordados no **capítulo 4** – *Urban ecological novelty assessment: Implications for urban green infrastructure planning and management*, no qual se apresenta uma metodologia desenvolvida para avaliar novidade ecológica urbana, na expectativa de que, estando disponível uma ferramenta de avaliação, fosse possível a inclusão da novidade ecológica no planeamento e gestão da estrutura verde das cidades. A metodologia proposta assenta em dois pilares: i) a dimensão humana deve ser explicitamente considerada uma componente fundamental na medição da novidade ecológica urbana, a par da dimensão biótica do conceito, e ii) a novidade ecológica urbana está presente em todos os tipos de espaços verdes urbanos, mas em diferentes graus, isto é, num *continuum* de novidade ecológica.

Ao contrário de outras metodologias propostas, que apenas quantificam diferenças de condições bióticas (Schittko et al., 2020; Vanstockem et al., 2018; Wilsey et al., 2009) e/ou abióticas (Lugo & Helmer, 2004; Martinuzzi, Lugo, Brandeis, &

approach developed within this thesis also quantified the human dimension. In this way, **it did not consider this dimension only as a driver of change but also as an integral part of urban ecosystems**. The human dimension was also considered at various points in time, namely regarding: i) transformations that occur at a specific point in time (e.g., genesis and a specific disturbance); ii) incremental transformations that occur over a certain period (e.g., land-use history); and iii) transformations that result from a constant human presence (e.g., human management and use, urbanization intensity). Novel Urban Ecosystems are, above all, social-ecological systems in which Humanity and Nature are seen in an equated, interdependent, and interactive way (Mori, Spies, Sudmeier-Rieux, & Andrade, 2013). Thus, the proposed assessment established a clear relationship with the anthropogenic genesis of the Novel Urban Ecosystems concept and with the intervening character of the urban green structure planning and management.

The assessment of Novel Urban Ecosystems through gradients proved to be the most appropriate for the urban context, since the different types of urban green spaces may present high internal heterogeneity (i.e., differences between green spaces of the same type) and external heterogeneity (i.e., differences between types of green spaces), both regarding species combinations (e.g., proportions of native and non-native species) and regarding human influence (e.g., level of maintenance and degrees of land-use change). Thus, a

Helmer, 2013; Radeloff et al., 2015), **a abordagem desenvolvida no âmbito desta tese também quantificou a dimensão humana**. Desta forma, **não considerou esta dimensão apenas como um motor de mudança, mas também como parte integrante dos ecossistemas urbanos**. A dimensão humana foi também considerada em vários momentos, nomeadamente em relação a: i) transformações que ocorrem num momento específico (por exemplo, uma perturbação específica); ii) transformações incrementais que ocorrem ao longo de um determinado período (por exemplo, história de uso do solo); e iii) transformações que resultam de uma presença humana constante (por exemplo, gestão humana, utilização, intensidade de urbanização). Os Novos Ecossistemas Urbanos são, acima de tudo, sistemas socioecológicos em que a Humanidade e a Natureza são vistos de forma equiparada, interdependente e interativa (Mori, Spies, Sudmeier-Rieux, & Andrade, 2013). O procedimento proposto permitiu, assim, estabelecer uma relação clara com a génese antropogénica do conceito de Novos Ecossistemas Urbanos e com o caráter interventivo do planeamento e gestão da estrutura verde urbana.

A avaliação de Novos Ecossistemas Urbanos através de gradientes revelou-se a mais adequada ao contexto urbano, uma vez que os diferentes tipos de espaços verdes urbanos podem apresentar uma grande heterogeneidade interna (isto é, diferenças entre espaços verdes do mesmo tipo) e externa (isto é, diferenças entre tipos de espaços verdes), não só no que concerne a combinação de espécies (por exemplo, proporções de espécies nativas e simplistic classification of ecosystems as “novel” or “not novel” neglects the level of complexity of different green spaces and the heterogeneity of factors involved in the genesis of Novel Urban Ecosystems. Assessing urban ecological novelty in a continuum also has the advantage of being more straightforward since it does not require the identification of thresholds (Heger et al., 2019).

In that sense, the developed methodology consisted of creating an Urban Ecological Novelty Index (UNI) that, by combining human influence variables with biotic variables, allows positioning urban green spaces in a continuum of ecological novelty (Chapter 4, Figure 4.6). This methodology was tested in the green structure of the city of Porto using data about urban woodlands, parks and gardens, and vacant lands. These were the three types of urban green spaces identified in the literature review (chapter 2) as the most likely to present different degrees of urban ecological novelty (Ahern, 2016; Kowarik, 2005, 2011, 2018). The application of the UNI made it possible to draw very relevant conclusions for the debate on how ecological novelty manifests in urban green spaces. In general, **vacant lands showed higher urban ecological novelty, parks and gardens occupied intermediate positions, and urban woodlands revealed lower urban ecological novelty**. However, it was also possible to verify that **the degree of novelty does not always depend on the type of urban green space under evaluation** since, for instance, some vacant

exóticas), como também no que diz respeito à influência humana (por exemplo, nível de manutenção e graus de alteração do uso do solo). Desta forma, uma classificação simplista dos ecossistemas em “novos” ou “não novos” negligencia o nível de complexidade dos diferentes espaços verdes e a heterogeneidade de fatores envolvidos na génese de Novos Ecossistemas Urbanos. A avaliação da novidade ecológica urbana num *continuum* apresenta também a vantagem de ser mais expedita, na medida em que deixa de ser necessária a identificação de limiares (Heger et al., 2019).

Neste seguimento, a metodologia desenvolvida consistiu na criação de um Índice de Novidade Ecológica Urbana (UNI) que, ao combinar variáveis de influência humana com variáveis bióticas, permite posicionar os espaços verdes urbanos num *continuum* de novidade ecológica (capítulo 4, Figura 4.6). Esta metodologia foi testada na estrutura verde da cidade do Porto recorrendo especificamente a dados relativos a matas urbanas, parques e jardins, e espaços verdes expectantes. Estes foram os três tipos de espaços verdes urbanos identificados na revisão de literatura (capítulo 2) como os mais passíveis de apresentarem diferentes graus de novidade ecológica urbana (Ahern, 2016; Kowarik, 2005, 2011, 2018). A aplicação do UNI possibilitou extrair conclusões muito relevantes para o debate sobre o modo como a novidade ecológica se manifesta nos espaços verdes urbanos. De uma forma geral, **os espaços verdes expectantes apresentaram maior novidade ecológica urbana, os parques e jardins ocuparam posições mais intermédias e as matas urbanas revelaram menor novidade** lands presented a lower ecological novelty than some urban woodlands.

Urban ecological novelty in intentionally designed and continuously maintained spaces (in this case, parks and gardens) is contested by some authors (Higgs, 2017; Hobbs et al., 2014; Morse et al., 2014). The results obtained in this research provided a fundamental contribution to this discussion since it is demonstrated that these types of green spaces, usually very diverse in native and non-native species, can present new dynamics and functions, spontaneity, and uncontrollable interactions between species (Lundholm, 2015; Perring, Manning, et al., 2013). Thus, **parks and gardens can exhibit high urban ecological novelty** and even higher novelty than spaces where continued human influence is absent (e.g., vacant lands).

The proposed methodology also determined which dimension of the concept (the human dimension or the biotic dimension) contributed more to the obtained result. This was possible by positioning the green spaces in four quadrants of urban ecological novelty determined by the variable contribution of each dimension (Chapter 4, Figure 4.5b). Thus, it was verified, for example, that **in vacant lands, the contribution of the human dimension is generally higher than the contribution of the biotic dimension**. **Exactly opposite tendencies were found regarding parks and gardens**. The following reasons explain these seemingly paradoxical results: i) vacant lands have a genesis often linked to abandonment, which is a

ecológica urbana. No entanto, foi também possível verificar que **nem sempre o grau de novidade depende do tipo de espaço verde urbano em avaliação** uma vez que, por exemplo, alguns espaços expectantes revelaram uma menor novidade ecológica do que algumas matas urbanas.

A novidade ecológica urbana em espaços intencionalmente desenhados e com manutenção continuada (neste caso, parques e jardins) é contestada por alguns autores (Higgs, 2017; Hobbs et al., 2014; Morse et al., 2014). Os resultados obtidos neste trabalho dão um contributo fundamental para esta discussão na medida em que se demonstra que este tipo de espaços, geralmente muito diversificados em espécies nativas e exóticas, podem apresentar novas dinâmicas e funções, espontaneidade e interações incontroláveis entre espécies (Lundholm, 2015; Perring, Manning, et al., 2013). Desta forma, verificou-se que **os parques e jardins também podem apresentar elevada novidade ecológica urbana**, e até mesmo superior a espaços onde a influência humana continuada é menosprezável (por exemplo, espaços verdes expectantes).

A metodologia proposta permitiu ainda determinar qual a dimensão do conceito (a dimensão humana ou a dimensão biótica) que mais contribuiu para o resultado obtido. Isto foi possível através do posicionamento dos espaços verdes em quatro quadrantes de novidade ecológica urbana determinados pelo contributo variável de cada dimensão (capítulo 4, Figura 4.5b). Assim, averiguou-se, por exemplo, que **nos espaços verdes expectantes o contributo da dimensão humana é geralmente maior do** determining factor for the increase of ecological novelty (Hallett et al., 2013; Higgs, 2017; Lugo & Helmer, 2004; Morse et al., 2014); ii) parks and gardens have high native and non-native species diversity, so the new functions and interactions that non-native species bring to the ecosystem determine the increase in ecological novelty (Hobbs et al., 2006; Schittko et al., 2020; Tognetti, 2013).

Information on the degree of urban ecological novelty is not considered in the process of planning and managing the green structure of cities (Buijs et al., 2019; Hansen, Olafsson, van der Jagt, Rall, & Pauleit, 2019; Hansen & Pauleit, 2014; Pauleit et al., 2019; Pauleit, Liu, Ahern, & Kazmierczak, 2011). Nevertheless, the obtained results **supported the idea that this information can (and should) inform planning and management decisions**. **The presence of urban green spaces with different degrees of ecological novelty contributes to the diversity, multifunctionality, and resilience of the urban green structure**. Furthermore, **spaces with different degrees of urban ecological novelty can contribute to the urban green structure in distinct ways**, facilitating the prioritization of interventions based on available resources (e.g., labor and monetary costs) (Clement & Standish, 2018; Hobbs et al., 2014; Morse et al., 2014; Perring, Standish, & Hobbs, 2013; Truitt et al., 2015). For example, spaces with lower urban ecological novelty are essential in the green structure of cities as they may constitute spaces with less transformation and reservoirs of native species (Perring,

que o contributo da dimensão biótica. **Nos parques e jardins públicos verificaram-se tendências exatamente opostas**. Estes resultados, aparentemente paradoxais, são explicados pelas seguintes razões: i) os espaços verdes expectantes têm uma génese frequentemente ligada ao abandono, que é um fator determinante para o aumento da novidade ecológica (Hallett et al., 2013; Higgs, 2017; Lugo & Helmer, 2004; Morse et al., 2014); ii) os parques e jardins apresentam uma elevada diversidade florística nativa e exótica, pelo que as novas funções e interações que as espécies exóticas trazem para o ecossistema impulsionam o aumento da novidade ecológica (Hobbs et al., 2006; Schittko et al., 2020; Tognetti, 2013).

A informação sobre o grau de novidade ecológica urbana não é considerada no processo de planeamento e gestão da estrutura verde das cidades (Buijs et al., 2019; Hansen, Olafsson, van der Jagt, Rall, & Pauleit, 2019; Hansen & Pauleit, 2014; Pauleit et al., 2019; Pauleit, Liu, Ahern, & Kazmierczak, 2011). Todavia, os resultados obtidos **suportaram a ideia de que esta informação pode (e deve) informar decisões de planeamento e gestão**. **A presença de espaços verdes urbanos com diferentes graus de novidade ecológica contribui para a diversidade, multifuncionalidade e resiliência da estrutura verde urbana**. Além disso, **espaços com diferentes graus de novidade ecológica urbana podem contribuir para a estrutura verde urbana de forma distinta**, facilitando a priorização de intervenções com base nos recursos disponíveis (por exemplo, mão-de-obra e custos monetários) (Clement & Standish, 2018;

Standish, et al., 2013; Trueman et al., 2014). Spaces with higher urban ecological novelty are also crucial in the urban green structure as they have already undergone an intense transformation and present novel combinations of native and non-native species adapted to extreme conditions and performing critical ecological functions (Ahern, 2016; Collier, 2014; Del Tredici, 2010; Lugo et al., 2018; Perring, Manning, et al., 2013). Thus, restoring these spaces to previous conditions, besides being a challenging task, may also be undesirable (Perring, Standish, et al., 2013).

The research developed in chapter 4 allowed the collection of very detailed information about the structure and floristic composition of the spaces with higher ecological novelty, namely regarding the combinations of native and non-native species that constitute them. This information was fundamental for the elaboration of the adaptive methodology presented in **chapter 5** – *Adaptive planting design and management framework for urban climate change adaptation and mitigation*, which positions the research on Novel Urban Ecosystems at the scale of the urban green space, reflecting on its design and management concerning the effects of climate change in cities.

The effects of climate change are more intense in the urban context, so cities also present the ideal conditions to test and implement solutions to this problem (Carter, Handley, Butlin, & Gill, 2017; Hami, Abdi, Zarehaghi, & Maulan, 2019; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010; van

Hobbs et al., 2014; Morse et al., 2014; Perring, Standish, & Hobbs, 2013; Truitt et al., 2015). Por exemplo, espaços com baixa novidade ecológica urbana são importantes na estrutura verde das cidades, uma vez que podem constituir espaços com pouca transformação e reservatórios de espécies nativas (Perring, Standish, et al., 2013; Trueman et al., 2014). Os espaços com elevada novidade ecológica urbana também são importantes na estrutura verde urbana pois já foram submetidos a transformações intensas e apresentam novas composições de espécies nativas e exóticas adaptadas a condições extremas e a desempenhar funções ecológicas críticas (Ahern, 2016; Collier, 2014; Del Tredici, 2010; Lugo et al., 2018; Perring, Manning, et al., 2013). Desta forma, a restauração destes espaços para condições anteriores, para além de não ser fácil, pode também não ser desejável (Perring, Standish, et al., 2013).

A investigação desenvolvida no âmbito do capítulo 4 permitiu recolher informação muito detalhada sobre a estrutura e a composição florística dos espaços com maior novidade ecológica, nomeadamente sobre as combinações de espécies nativas e exóticas que os constituem. Esta informação foi fundamental para a elaboração da metodologia adaptativa apresentada no **capítulo 5** – *Adaptive planting design and management framework for urban climate change adaptation and mitigation*, que posiciona a investigação sobre Novos Ecossistemas Urbanos à escala do espaço verde urbano, refletindo no seu desenho e manutenção em relação aos efeitos das alterações climáticas nas cidades.

Staden, 2014). Based on the above, **the proposed methodology adopted an adaptive strategy, which is based on an experimental and dynamic approach as a way to overcome the uncertainty associated with climate change**. In this sense, the feasibility and success of the proposals are regularly evaluated and monitored, enabling adjustments as more knowledge is acquired and tested (learning loop), which optimizes the long-term resilience of the proposals (Felson & Pickett, 2005; Kato & Ahern, 2008; Lister, 2007; Pickett, Cadenasso, & Grove, 2004). This strategy may also consider design and management decisions as hypotheses rather than proven solutions, where the risks of failure are *a priori* understood and accepted – "safe-to-fail" (Ahern, 2011).

The presented methodology was developed based on the city of Porto and involved: (i) the identification of the current and future most concerning climate risks for Porto (CMP, 2016; Monteiro, Madureira, Fonseca, & Velho, 2018) and the areas of the city most vulnerable to those risks; ii) the selection of plants present in green spaces with higher ecological novelty (chapter 4) and the collection and systematization of the traits that give them greater adaptation to extreme conditions (e.g., tolerance to prolonged periods of heat and drought, flooding, pollution) and greater efficiency in mitigating the effects of climate change, namely in improving climatic comfort (e.g., production of "cool shadows", evapotranspiration), and in managing stormwater during extreme events

Os efeitos das alterações climáticas são mais intensos em contexto urbano pelo que são também as cidades que reúnem as condições ideais para testar e implementar soluções para este problema (Carter, Handley, Butlin, & Gill, 2017; Hami, Abdi, Zarehaghi, & Maulan, 2019; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010; van Staden, 2014). Com base no exposto, a metodologia proposta adotou **uma estratégia adaptativa, que se baseia numa abordagem experimental e dinâmica como forma de ultrapassar a incerteza associada às alterações climáticas.** Neste sentido, a viabilidade e o sucesso das propostas são regularmente avaliados e monitorizados, possibilitando ajustes à medida que mais conhecimento vai sendo adquirido e testado (*learning loop*), o que otimiza a resiliência das propostas a longo prazo (Felson & Pickett, 2005; Kato & Ahern, 2008; Lister, 2007; Pickett, Cadenasso, & Grove, 2004). Esta estratégia pode ainda considerar as decisões de projeto e manutenção como hipóteses ao invés de soluções comprovadas, onde os riscos de insucesso são *a priori* compreendido e aceites – "*safe-to-fail*" (Ahern, 2011).

A metodologia apresentada foi desenvolvida tendo por base o contexto do Porto e envolveu: i) a identificação dos riscos climáticos atuais e futuros mais preocupantes para a cidade (CMP, 2016; Monteiro, Madureira, Fonseca, & Velho, 2018) e das áreas mais vulneráveis a esses riscos; ii) a seleção das plantas presentes nos espaços verdes com maior novidade ecológica (capítulo 4) e a recolha e sistematização dos atributos que lhes conferem maior adaptação a condições extremas (por exemplo, tolerância a (e.g., intersection capacity and reduction of water velocity); iii) the identification of green spaces with higher ecological novelty located in the areas of the city most vulnerable to climate risks and the evaluation of these sites for their multifunctional performance (ecological quality, aesthetics, accessibility, etc.); and, finally, iv) the elaboration of proposals for managing the vegetation cover (management and planting design) in order to maximize the potential of these green spaces.

The developed methodology offers a new perspective for interventions in urban green spaces, integrating spontaneous communities and evaluating the plants based on the functions they are performing and the specific context in which they appear (Davis et al., 2011; Del Tredici, 2020; Harris, Hobbs, Higgs, & Aronson, 2006; Starzomski, 2013). In this way, **it takes into account the adaptive potential of all species in the community** (non-native and native, spontaneous and cultivated) and **proposes to flag and monitor species that under common circumstances would be excluded** (e.g., species that have ecological risk). This measure does not compromise the creative and experimental process of the methodology because it allows regularly evaluating the behavior and interactions between species.

The intervention proposals in the vegetation cover aim to include or maximize absent or poorly represented functions (Dunnett & Hitchmough, 2004; Hunter, 2011; Sack, 2013). For example, vacant lands with high

períodos prolongados de calor e seca, inundações, poluição) e maior eficiência na mitigação dos efeitos das alterações climáticas, nomeadamente na melhoria do conforto climático (por exemplo, produção de "sombras frescas", evapotranspiração), e na gestão das águas pluviais durante eventos extremos (por exemplo, capacidade de intersecção e redução da velocidade da água); iii) a identificação dos espaços verdes com maior novidade ecológica localizados nas áreas da cidade mais vulneráveis a riscos climáticos e a avaliação desses locais quanto ao seu desempenho multifuncional (qualidade ecológica, estética, acessibilidade, etc.); e, por fim, iv) a elaboração de propostas para a gestão do coberto vegetal (manutenção e plantação) com vista a maximizar o potencial destes espaços verdes.

A metodologia desenvolvida oferece uma nova perspetiva para as intervenções nos espaços verdes urbanos, integrando comunidades espontâneas e avaliando as plantas presentes com base nas funções que desempenham no contexto específico em que surgem (Davis et al., 2011; Del Tredici, 2020; Harris, Hobbs, Higgs, & Aronson, 2006; Starzomski, 2013). Desta forma, **tem em consideração o potencial adaptativo de todas as espécies presentes na comunidade** (exóticas e nativas, espontâneas e cultivadas) e **propõe sinalizar e monitorizar espécies que, em circunstâncias comuns, seriam excluídas** (por exemplo, espécies que comportam risco ecológico). Esta medida não compromete o processo criativo e experimental da metodologia porque possibilita avaliar regularmente o comportamento e as interações entre espécies.

ecological novelty and where it is intended to include public utility and interest may be already adapted to extreme heat conditions but not be prepared to regulate temperature and promote users' climatic comfort (if the tree cover is scarce or non-existent). In this way, interventions can grant the space this vital function, very pertinent for climate change effects mitigation. Furthermore, if necessary, interventions at these sites can also improve the ornamental quality of communities and public safety (Collier, 2014; Ignatieva & Hedblom, 2018; Köppler, Kowarik, Kühn, & von der Lippe, 2014; Kowarik, 2018, 2021; Kühn, 2006).

The matters discussed in this chapter are probably those of greatest sensitivity and debate regarding the Novel Urban Ecosystems concept. While there is literature advocating the removal of all invasive species or species that may carry ecological risk (Simberloff, 2015; Simberloff, Parker, & Windle, 2005; Simberloff & Vitule, 2014), the research conducted throughout this thesis has shown that **there is still much unexplored about the functions these species are performing in ecosystems**. Excluding species based on their origin reduces the proposal's potential. In this regard, the article "*Don't judge species on their origins*" by Davis et al. (2011) represents an important step in highlighting that, in a changing world, the benefits of non-native species should not be ignored or underestimated.

As propostas de intervenção no coberto vegetal têm como objetivo incluir ou maximizar funções ausentes ou pouco representadas (Dunnett & Hitchmough, 2004; Hunter, 2011; Sack, 2013). Por exemplo, espaços verdes expectantes com elevada novidade ecológica e onde se pretenda conferir utilidade e interesse público, podem estar adaptados a condições extremas de calor, apesar de não estarem preparados para regular a temperatura e promover o conforto climático dos utilizadores (caso o coberto arbóreo seja escasso ou inexistente). Desta forma, as intervenções podem conceder ao espaço esta importante competência, muito pertinente para a mitigação dos efeitos das alterações climáticas. Além disso, se necessário, as intervenções nestes locais podem também melhorar a qualidade ornamental das comunidades e a segurança do público (Collier, 2014; Ignatieva & Hedblom, 2018; Köppler, Kowarik, Kühn, & von der Lippe, 2014; Kowarik, 2018, 2021; Kühn, 2006).

As matérias discutidas neste capítulo são, provavelmente, as de maior sensibilidade e debate em relação ao conceito de Novos Ecossistemas Urbanos. Embora exista literatura que advoga a remoção de todas as espécies invasoras ou de espécies que possam comportar risco ecológico (Simberloff, 2015; Simberloff et al., 2005; Simberloff & Vitule, 2014), a investigação desenvolvida ao longo desta tese tem vindo a demonstrar que **há ainda muito por investigar sobre as funções que estas espécies desempenham nos ecossistemas.** Excluir espécies com base na sua origem diminui o potencial das propostas. A este respeito o artigo "*Don't judge species on their origins*" de

This reflection did not intend to minimize the relevance of native species in ecosystem processes and dynamics (particularly concerning fauna interactions), just point out that practitioners with responsibility regarding urban green spaces, particularly **landscape architects, cannot position themselves in a narrative that excludes non-native species from the start**. In urban green spaces, a diverse combination of native and non-native species, cultivated and spontaneous, promotes the performance of essential functions and ensures a wide range of responses to very diverse problems, including climate change, which will reflect positively on the well-being and quality of life of the population (Alizadeh & Hitchmough, 2019; Collier, 2014; Light et al., 2013; Starzomski, 2013; Van Mechelen et al., 2015).

During the preparation of the proposals that illustrated the application of the adaptive methodology, it became evident the usefulness of the information collected and systematized about the species that integrate the database, both from a research and an applied point of view, for designers and managers who intervene in urban green spaces, in the city of Porto or similar urban contexts. For this reason, it was important to make this information available in open access, which demanded a detailed description of the structure and composition of the database in **chapter 6** – *Plant traits database for climate change adaptation and mitigation in Northwest Portugal*.

Davis et al. (2011), foi um importante passo para salientar que, num mundo em contante alteração, os benefícios das espécies exóticas não devem ser ignorados ou subestimados.

Não se pretende com esta reflexão minimizar a relevância das espécies nativas nos processos e nas dinâmicas dos ecossistemas (nomeadamente em relação a interações com a fauna), mas apenas salientar que os diversos intervenientes nos espaços verdes urbanos e, em particular, **os arquitetos paisagistas, não se podem posicionar numa narrativa que exclua, à partida, as espécies exóticas**. Nos espaços verdes urbanos uma combinação diversificada de espécies nativas e exóticas, cultivadas e espontâneas, promove o desempenho de importantes funções e garante uma vasta gama de respostas a problemas muito diversos, incluindo a alterações climáticas, refletindo-se positivamente no bem-estar e na qualidade de vida da população (Alizadeh & Hitchmough, 2019; Collier, 2014; Light et al., 2013; Starzomski, 2013; Van Mechelen et al., 2015).

Durante a elaboração das propostas que exemplificam a aplicação da metodologia adaptativa tornou-se evidente a utilidade da informação recolhida e sistematizada sobre as espécies que integram a base de dados, tanto num contexto de investigação como num contexto mais aplicado (para projetistas e gestores que intervêm nos espaços verdes urbanos da cidade do Porto ou em contextos urbanos semelhantes). Por isso, foi tão importante disponibilizar esta informação em acesso aberto, o que implicou uma descrição detalhada da estrutura e composição da base de

The species list in this database resulted from the floristic surveys carried out in the urban green spaces with the highest degree of urban ecological novelty, identified in chapter 4 (green spaces positioned in quadrant 3 – Figure 4.5b). The species' traits included in the database were selected according to the species capacity for climate change adaptation and mitigation. Some of the considered traits concerned tolerance to extreme conditions (e.g., drought, heat, pollution), canopy density and leaf persistence (related to the ability to produce shade), multi-stem development and stem flexibility (related to the ability to reduce stormwater velocity) (Brown, 2010; Del Tredici, 2020; Espeland & Kettenring, 2018; Hami et al., 2019; Hunter, 2011; Van Mechelen et al., 2015; Vogt et al., 2017; Windhager, Simmons, & Blue, 2011; Xiao & McPherson, 2016; Yan, Wang, Liao, Xu, & Wan, 2021).

Other traits considered relevant were also recorded, such as the performance of specific functions (erosion control, availability of shelter and/or food for fauna), associated risks (toxicity, allergies, biological invasion), and ornamental quality (plant's architecture and leaf and flower color). This way, the database included species with different habits, life cycles, functions, origins, potential distribution areas, among other traits, which facilitates the selection and combination of species during the development of intervention proposals in urban green spaces (Hunter, 2011; Vogt et al., 2017).

dados no **capítulo 6** – *Plant traits database for climate change adaptation and mitigation in Northwest Portugal*.

A lista de espécies desta base de dados resultou dos inventários florísticos realizados nos espaços verdes urbanos com maior grau de novidade ecológica urbana, identificados no capítulo 4 (espaços verdes posicionados no quadrante 3 – Figura 4.5b). Os atributos das espécies a incluir na base de dados foram selecionados de acordo com a capacidade de adaptação e mitigação em relação às alterações climáticas. Alguns dos atributos considerados dizem respeito à tolerância a condições extremas (por exemplo, seca, calor, poluição), à densidade da copa e à persistência das folhas (relacionadas com a capacidade de produzir sombra), ao desenvolvimento multicaule e à flexibilidade do caule (relacionados com a capacidade de reduzir a velocidade de águas torrenciais) (Brown, 2010; Del Tredici, 2020; Espeland & Kettenring, 2018; Hami et al., 2019; Hunter, 2011; Van Mechelen et al., 2015; Vogt et al., 2017; Windhager, Simmons, & Blue, 2011; Xiao & McPherson, 2016; Yan, Wang, Liao, Xu, & Wan, 2021).

Também foram registados outros atributos considerados importantes, como o desempenho de funções específicas (controlo de erosão, disponibilidade de abrigo e/ou alimento para a fauna), os riscos associados (toxicidade, alergias, invasão biológica) e a qualidade ornamental (a arquitetura da planta, a cor da folha e flor). A base de dados incluiu, assim, espécies com diferentes hábitos, ciclos de vida, funções, origens, áreas de distribuição potencial, entre outros atributos, o que facilita a seleção e a

The urban green spaces that supported the construction of this database show a higher proportion of native species (62%) and herbaceous vegetation (75%). In addition, they are mostly vacant lands and, therefore, dominated by spontaneous, unmanaged communities developing and thriving under high disturbance conditions. Although the proportion of non-native species is lower (38%), it was found, for example, that **the species in the database identified as tolerant to heat and pollution are mostly non-native species** (70% and 64%, respectively). The list of non-native species also includes some invasive species (14%) and species with ecological risk (11%), some of which have traits that may also reveal a greater adaptation ability (e.g., rapid growth or tolerance to prolonged periods of drought).

It was verified that, **compared to adaptation traits, mitigation traits for climate change effects are more complex to analyze since the plants' mitigating capacity may depend on the presence of several traits simultaneously**. For instance, the ability to produce shade and the type of shade produced depends, simultaneously, on plant height, width, and architecture, canopy density and shape, and also on leaf persistence (Brown, 2010; Duursma et al., 2012; Gill, Handley, Ennos, & Pauleit, 2007; Hami et al., 2019; Windhager et al., 2011; Zölch, Maderspacher, Wamsler, & Pauleit, 2016). **This type of knowledge is not systematized and is not easily accessible. Information on species traits of different layers is not uniform, and there is generally more information available**

combinação das espécies durante o desenvolvimento de propostas de intervenção nos espaços verdes (Hunter, 2011; Vogt et al., 2017).

Os espaços que suportaram a construção desta base de dados apresentam uma maior proporção de espécies nativas (62%) e de vegetação herbácea (75%). Além disso, são maioritariamente espaços verdes expectantes e, por isso, dominados por comunidades espontâneas, sem manutenção e que se desenvolvem em condições de elevada perturbação. Apesar de a proporção de espécies exóticas ser inferior (38%), constatou-se, por exemplo, que **as espécies da base de dados identificadas como tolerantes ao calor e à poluição são, na sua maioria, espécies exóticas** (70% e 64%, respetivamente). A lista de espécies exóticas inclui, ainda, algumas espécies invasoras (14%) e espécies com risco ecológico (11%), algumas das quais com atributos que podem também revelar uma maior capacidade de adaptação (por exemplo, crescimento rápido ou tolerância a períodos prolongados de seca).

Verificou-se que, **em comparação com atributos relacionados com a adaptação, os atributos relacionados com a mitigação dos efeitos das alterações climáticas são mais complexos de analisar, uma vez que a capacidade mitigadora de uma planta pode depender da presença de vários atributos em simultâneo.** Por exemplo, a capacidade de produzir sombra e o tipo de sombra produzida dependem, simultaneamente, da altura, largura e arquitetura da planta, da densidade e forma da copa e, ainda, da persistência da folha (Brown,

about trees and shrubs (which only make up 25% of the species in the database). In this sense, the database also represents a starting point in the adaptive process explored within this research (Ahern, Cilliers, & Niemelä, 2014; Felson & Pickett, 2005; Kato & Ahern, 2008), since as more knowledge is gathered, the database can be strengthened, filling in information that was missing, and providing more options for responding to climate change.

The methodologies developed within this research for the city of Porto (chapters 4 and 5) can be replicated and adjusted to other urban contexts. Alongside the database (chapter 6), **these tools can be useful for Landscape Architecture practice**, thus promoting environmentally sustainable and socially resilient cities. **The true potential and weaknesses of these tools can only be proved through their implementation and use in the real context**, so it is essential that professionals with responsibility regarding urban green spaces know Novel Urban Ecosystems and are receptive to applying this concept in cities (Chapter 7). Although there is still a way to go in this respect, **this thesis represents a starting point that can facilitate experimentation and the collection of vital information to instruct the design, planning, and management of the urban green structure**.

2010; Duursma et al., 2012; Gill, Handley, Ennos, & Pauleit, 2007; Hami et al., 2019; Windhager et al., 2011; Zölch, Maderspacher, Wamsler, & Pauleit, 2016). **Este tipo de conhecimento não se encontra sistematizado, não é facilmente acessível e a informação sobre os atributos de espécies de diferentes estratos não é uniforme, havendo geralmente mais informação disponível sobre árvores e arbustos** (que apenas constituem 25% das espécies da base de dados). Neste sentido, a base de dados representa também um ponto de partida no processo adaptativo explorado no âmbito desta investigação (Ahern, Cilliers, & Niemelä, 2014; Felson & Pickett, 2005; Kato & Ahern, 2008), uma vez que à medida que mais conhecimento é recolhido, a base de dados pode ser robustecida, colmatando informações que estavam em falta e fornecendo mais opções de resposta às alterações climáticas.

As metodologias desenvolvidas no âmbito desta investigação para o contexto da cidade do Porto (capítulo 4 e 5) podem ser replicadas e ajustadas a outros contextos urbanos. Juntamente com a base de dados (capítulo 6), **estas ferramentas podem ser úteis para a Arquitetura Paisagista, no âmbito da sua atuação na estrutura verde urbana**, de modo a promover cidades ambientalmente sustentáveis e socialmente resilientes. **O verdadeiro potencial e as fragilidades destes instrumentos só poderão ser averiguados através da sua implementação e utilização em contexto real**, pelo que é fundamental que os principais intervenientes no espaço verde urbano conheçam os Novos Ecossistemas Urbanos e estejam recetivos à aplicação deste conceito (capítulo 7). Apesar de ainda haver um longo caminho a percorrer a esse respeito, esta **tese constitui um ponto de partida que pode facilitar a experimentação e a recolha de informação importante para instruir o desenho, o planeamento e a gestão da estrutura verde urbana**.

8.1.3. Novel Urban Ecosystems: Attitudes and preferences determinant for the successful application of the concept

Throughout the research it became clear that how Novel Urban Ecosystems are perceived can determine how they are received and the willingness to integrate this concept into professional practice (Del Tredici, 2014; Kowarik, 2018). Thus, in **chapter 7** – *Attitudes and preferences towards plants in urban green spaces: implications for the design and management of Novel Urban Ecosystems*, the attitudes and preferences of professionals involved in the design, planning, and management of green spaces towards Novel Urban Ecosystems were assessed through an online questionnaire. The complexity of the concept required the use of more familiar and easily communicated terms. Thus, the two essential dimensions of Novel Urban Ecosystems, i.e., the human and the biotic dimensions (deducted from the literature review presented in chapter 2 and explored in chapter 4) were respectively analyzed through the intentionality with which plants appear in green spaces (cultivated or spontaneous) and the geographic origin of those plants (native or non-native).

8.1.3. Novos Ecossistemas Urbanos: Atitudes e preferências determinantes para o sucesso da aplicação do conceito

Ao longo da investigação foi ficando claro que o modo como os Novos Ecossistemas Urbanos são percecionados pode determinar a forma como são acolhidos e a predisposição para integrar este conceito na prática profissional (Del Tredici, 2014; Kowarik, 2018). Desta forma, no **capítulo 7** – *Attitudes and preferences towards plants in urban green spaces: implications for the design and management of Novel Urban Ecosystems*, avaliaram-se, através de um questionário administrado online, as atitudes e preferências de profissionais envolvidos no desenho, planeamento e gestão de espaços verdes em relação a Novos Ecossistemas Urbanos. A complexidade do conceito obrigou à utilização de termos mais familiares e facilmente comunicáveis. Assim, as duas dimensões essenciais dos Novos Ecossistemas Urbanos, ou seja, a dimensão humana e a dimensão biótica (deduzidas a partir da revisão de literatura apresentada no capítulo 2 e exploradas no capítulo 4) foram, respetivamente, analisadas através da intencionalidade com que as plantas surgem nos espaços verdes (cultivadas ou espontâneas) e da origem geográfica dessas plantas (nativas ou exóticas).

Previous studies have verified a tendency to perceive negatively non-native plants (Davis, 2018; Davis et al., 2011; Gbedomon et al., 2020; Guiaşu & Tindale, 2018; Hill & Hadly, 2018; Lewis et al., 2019) and spontaneous vegetation (Leonie K. Fischer et al., 2020; Li, Fan, Kühn, Dong, & Hao, 2019; Mathey, Arndt, Banse, & Rink, 2018). The questionnaire results revealed that, **while there is clearly greater acceptance of native and cultivated plants, the inquired professionals also generally accept non-native and spontaneous plants in urban green spaces**. These results can be explained by the fact that expert opinions can be quite distinct from the general public (Leonie K Fischer & Kowarik, 2018; Hofmann, Westermann, Kowarik, & Van der Meer, 2012; Hoyle, 2021; Kowarik, Straka, Lehmann, Studnitzky, & Fischer, 2021; Li et al., 2019; Özgüner, Kendle, & Bisgrove, 2007), as professionals have higher knowledge and can more easily recognize species ecological functions (Filibeck, Petrella, & Cornelini, 2016; Nassauer, 1995).

Estudos anteriores demonstraram que há uma tendência para percecionar de forma negativa as plantas exóticas (Davis, 2018; Davis et al., 2011; Gbedomon et al., 2020; Guiaşu & Tindale, 2018; Hill & Hadly, 2018; Lewis et al., 2019) e a vegetação espontânea (Leonie K. Fischer et al., 2020; Li, Fan, Kühn, Dong, & Hao, 2019; Mathey, Arndt, Banse, & Rink, 2018). Os resultados do questionário permitiram verificar que, **embora haja claramente uma maior aceitação de plantas nativas e cultivadas, os profissionais inquiridos também aceitam, no geral, plantas exóticas e espontâneas em espaços verdes urbanos**. Estes resultados podem ser explicados pelo facto de a opinião de especialistas poder ser bastante distinta do público em geral (Leonie K Fischer & Kowarik, 2018; Hofmann, Westermann, Kowarik, & Van der Meer, 2012; Hoyle, 2021; Kowarik, Straka, Lehmann, Studnitzky, & Fischer, 2021; Li et al., 2019; Özgüner, Kendle, & Bisgrove, 2007), uma vez que os profissionais têm maior conhecimento e conseguem reconhecer mais facilmente as funções ecológicas das espécies (Filibeck, Petrella, & Cornelini, 2016; Nassauer, 1995).

The danger that non-native species can pose to human well-being was one of the aspects that mostly limited the acceptance of these species. This concern is generally associated with invasive species (Gaertner et al., 2017) and was not verified in other studies that found that most members of the scientific community disagree that alien species pose a threat to human well-being (Gbedomon et al., 2020). On the other hand, **the association with unsafe, unattractive, and poorly maintained sites were the**

O perigo que as espécies exóticas podem representar para o bem-estar foi um dos aspetos que mais limitou a aceitação destas espécies. Esta preocupação associa-se geralmente a espécies invasoras (Gaertner et al., 2017) e não foi verificada em outros estudos que descobriram que a maioria dos membros da comunidade científica discorda que as espécies exóticas representam uma ameaça para o bem-estar humano (Gbedomon et al., 2020). Por outro lado, **a associação com locais inseguros, pouco atraentes e com uma manutenção**

factors that most determined the rejection of spontaneous plants in urban green spaces. The same findings were also reported by several studies (Chundi Chen et al., 2021; Filibeck et al., 2016; Leonie K. Fischer et al., 2020; Hofmann et al., 2012; Özgüner et al., 2007; Włodarczyk-Marciniak, Sikorska, & Krauze, 2020), although the aesthetic potential of spontaneous vegetation (vegetation with brightly colored flowers and longer flowering periods) has already been documented in the literature (Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019).

Despite these initial results, **making information available about the potential of the Novel Urban Ecosystems concept, particularly regarding climate change, had a significantly positive effect on the acceptance of non-native and spontaneous plants**. The study developed by Hoyle et al. (2017) found that the role of non-native species for climate change is a determining factor in their acceptance in urban green spaces. The obtained results suggest that **this may also be a determining factor in the acceptance of Novel Urban Ecosystems**, although this acceptance is probably always higher by people who tend to perceive nature as something dynamic and constantly changing (Kowarik et al., 2021; Kueffer & Kull, 2017).

There was also a **greater preference for combinations composed mostly of native plants** after information about Novel Urban Ecosystems was provided. These results suggest that, **although most respondents accept non-native plants, this does not**

deficiente, foram os fatores que mais determinaram a rejeição de plantas espontâneas nos espaços verdes urbanos. As mesmas conclusões foram também referidas por vários estudos (Chundi Chen et al., 2021; Filibeck et al., 2016; Leonie K. Fischer et al., 2020; Hofmann et al., 2012; Özgüner et al., 2007; Włodarczyk-Marciniak, Sikorska, & Krauze, 2020), apesar de o potencial estético da vegetação espontânea (vegetação com flores de cores vivas e com períodos de floração mais prolongados) ter sido já documentado na literatura (Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019).

Apesar destes resultados iniciais, constatou-se que **disponibilizar informação sobre o potencial do conceito de Novos Ecossistemas Urbanos, nomeadamente em relação às alterações climáticas, tem um efeito significativamente positivo na aceitação de plantas exóticas e espontâneas**. O estudo desenvolvido por Hoyle et al. (2017) verificou que o papel das espécies exóticas para as alterações climáticas é um fator determinante na sua aceitação em espaços verdes urbanos. Os resultados obtidos sugerem que **este pode também ser um fator determinante na aceitação de Novos Ecossistemas Urbanos**, ainda que esta aceitação seja provavelmente sempre superior por pessoas que tendem a percecionar a natureza como algo dinâmico e em constante mudança (Kowarik et al., 2021; Kueffer & Kull, 2017).

Verificou-se também **uma maior preferência por combinações maioritariamente compostas por plantas nativas** após a informação sobre Novos Ecossistemas Urbanos

necessarily mean that they prefer them in urban green spaces. **The preference for combinations mostly composed of native plants was exceptionally high for reducing ecological risk**, i.e., the risk of plants become invasive. These results are consistent with other studies that observed a reserve about using non-native plants for the same reasons (Hoyle et al., 2017), demonstrating that the surveyed professionals are somewhat influenced by the “nativism paradigm” (Davis, 2018; Selge, Fischer, & van der Wal, 2011). However, **when the goal was to improve response to climate change effects, most respondents preferred combinations composed of native and non-native plants in equal proportion**. Thus, it proved that most professionals understand the potential of combining native and non-native plants to increase the resilience of cities to climate change effects (Ahern, 2016; Kowarik, 2011) and that plants’ origin does not guarantee their ability to adapt, as species respond to the changing context in which they are embedded (Davis, 2018; Hill & Hadly, 2018).

On the other hand, it was verified **a greater preference for combinations composed of cultivated and spontaneous plants, particularly when the goal was to increase biodiversity, ornamental quality, and climate change resilience**. These findings suggest that, while they are aware of spontaneous vegetation benefits (Bonthoux, Brun, Di Pietro, Greulich, & Bouché-Pillon, 2014; Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019; Robinson & Lundholm,

ter sido disponibilizada. Estes resultados sugerem que, **embora a maioria dos inquiridos aceite plantas exóticas, isso não significa necessariamente que as preferem em espaços verdes urbanos**. **A preferência por combinações maioritariamente compostas por plantas nativas foi excecionalmente elevada para reduzir o risco ecológico**, ou seja, o risco das plantas se tornarem invasoras. Estes resultados são consistentes com outros estudos que observaram uma reserva quanto à utilização de plantas exóticas pelos mesmos motivos (Hoyle et al., 2017), demonstrando que os profissionais inquiridos são de alguma forma influenciados pelo “paradigma do nativismo” (Davis, 2018; Selge, Fischer, & van der Wal, 2011). No entanto, **quando o objetivo era melhorar a resposta aos efeitos das alterações climáticas, a maioria dos respondentes preferiu combinações compostas por plantas nativas e exóticas em igual proporção**. Deste modo, comprovou-se que a maioria dos profissionais compreende o potencial de combinar plantas nativas e exóticas para aumentar a resiliência das cidades aos efeitos das alterações climáticas (Ahern, 2016; Kowarik, 2011) e que a origem das plantas não garante a sua capacidade de adaptação, uma vez que estas respondem ao contexto de mudança em que estão inseridas (Davis, 2018; Hill & Hadly, 2018).

Por outro lado, assistiu-se a **uma maior preferência por combinações compostas por plantas cultivadas e espontâneas, nomeadamente quando o objetivo era aumentar a biodiversidade, a qualidade ornamental e a resiliência às alterações**

2012), professionals recognize the need to ensure some control and maintenance of vegetation in urban green spaces (Muratet, Pellegrini, Dufour, Arrif, & Chiron, 2015; Nassauer, 1995). In that sense, **when the goal was to increase users' safety and promote the care and management of urban green spaces, respondents mainly preferred combinations mostly composed of cultivated plants**. Similarly, these results are consistent with previous studies that observed a tendency to prefer more organized and cared-for green spaces, where human intention and control (cues to care) can be easily recognized (Hofmann et al., 2012; Hoyle, 2021; Kowarik, 2021; Mathey et al., 2018; Nassauer, 1995; Włodarczyk-Marciniak et al., 2020).

The findings achieved in this stage of the research reinforce some ideas discussed throughout the thesis, namely the relevance of the proposals developed in chapter 5 and the usefulness of the database presented in chapter 6 for climate change. These results necessarily have implications in the way urban green spaces should be intervened at the level of planting design and management strategies, and in the way urban green structure should be planned and managed (chapter 4). For example, **the concern verified in the questionnaire regarding the ecological risk of some species demonstrates the need to regularly monitor their behavior and dispersion**. Furthermore, it was proven that **the potentially negative effect of spontaneous species on the perception of safety, appearance, and ornamental quality of**

climáticas. Estas descobertas sugerem que, embora estejam a par dos benefícios da vegetação espontânea (Bonthoux, Brun, Di Pietro, Greulich, & Bouché-Pillon, 2014; Ignatieva & Hedblom, 2018; Kühn, 2006; Li et al., 2019; Robinson & Lundholm, 2012), os profissionais reconhecem a necessidade de garantir algum controlo e manutenção da vegetação dos espaços verdes urbanos (Muratet, Pellegrini, Dufour, Arrif, & Chiron, 2015; Nassauer, 1995). Nesse seguimento, **quando o objetivo era aumentar a segurança dos utilizadores e promover o cuidado e a gestão dos espaços verdes urbanos, os inquiridos preferiram principalmente combinações maioritariamente compostas por plantas cultivadas**. Da mesma forma, estes resultados são consistentes com estudos anteriores que observaram uma tendência para preferir espaços verdes mais organizados e cuidados, onde a intenção e o controlo humano (*cues to care*) podem ser facilmente reconhecidos (Hofmann et al., 2012; Hoyle, 2021; Kowarik, 2021; Mathey et al., 2018; Nassauer, 1995; Włodarczyk-Marciniak et al., 2020).

Os resultados alcançados nesta etapa da investigação reforçam algumas ideias abordadas ao longo da tese, nomeadamente a relevância das propostas desenvolvidas no capítulo 5 e a utilidade da base de dados apresentada no capítulo 6 no contexto das alterações climáticas. Estes resultados têm necessariamente implicações na forma como os espaços verdes urbanos devem ser intervencionados ao nível das plantações e estratégias de manutenção, e na forma como a estrutura verde urbana deve ser planeada e gerida (capítulo 4). Por exemplo, **a preocupação verificada no questionário em**

green spaces, can be mitigated by the presence or addition of cultivated species with more recognized cultural references and aesthetic functions.

Overall, this study allowed understanding that **professionals involved in the design, planning, and management of green spaces demonstrate willingness to apply and integrate the Novel Urban Ecosystems concept** (chapter 4 and 5), especially because **the vast majority considered these ecosystems relevant to tackle climate change effects in cities**. Since disseminating information about the Novel Urban Ecosystems concept can increase its acceptance, the information compiled throughout this research represents an important contribution in this sense, although there are still many variables to explore regarding this concept.

relação ao risco ecológico de algumas espécies demonstra a necessidade de monitorizar com regularidade o seu comportamento e dispersão. Além disso, comprovou-se que **o efeito potencialmente negativo de espécies espontâneas na perceção sobre a segurança, aparência e qualidade ornamental dos espaços verdes, pode ser atenuado pela presença ou adição de espécies cultivadas com referências culturais e funções estéticas mais reconhecidas**.

De uma forma geral, este estudo permitiu compreender que **os principais intervenientes no espaço verde demonstram recetividade à aplicação e integração do conceito de Novos Ecossistemas Urbanos** (capítulo 4 e 5), especialmente porque a **grande maioria considerou estes ecossistemas relevantes para combater os efeitos das alterações climáticas nas cidades.** Uma vez que divulgar informação sobre o conceito de Novos Ecossistemas Urbanos pode aumentar a sua aceitação, a informação compilada ao longo desta investigação constitui um importante contributo neste sentido, apesar de haver ainda muitas variáveis por explorar em relação a este conceito.

8.2. Limitations and future research recommendations

Novel Urban Ecosystems, the focus of this research, have elicited growing interest in the scientific community. A solid body of literature is already available covering several

8.2. Limitações e recomendações de investigação futura

Os Novos Ecossistemas Urbanos, tema central desta investigação, têm vindo a ser alvo de um interesse crescente pela comunidade científica, estando já disponível um corpo de literatura dimensions of the concept. However, and as has been identified several times throughout this investigation, several questions remain open.

The fact that the research is focused on a complex concept, which is still not stabilized, but is evolving, was one of the difficulties of this thesis. Although the term "Novel" was widely adopted after publishing a seminal article by Hobbs et al. (2006), some literature on this type of ecosystem that does not use this terminology may not have been captured in the literature review carried out in chapter 2. For example, concerning Landscape Architecture projects, some of which are presented in chapter 3, it was verified that the authors often do not adopt or acknowledge the terminologies "Novel Ecosystems" or "Novel Urban Ecosystems". However, the ecosystems that are the subject of their studies fall under this designation. While several works and/or projects have probably remained unexplored, it is also important to mention that the literature collected, analyzed, and cited in this thesis is vast and diverse.

Additionally, these concepts have generated some controversy in the literature, with groups being very enthusiastic about their potential (Hobbs, Higgs, & Hall, 2013b; Lugo et al., 2018; Mascaro et al., 2013; Perring, Manning, et al., 2013; Standish, Thompson, Higgs, & Murphy, 2013), and other groups that mostly emphasize risks that may be associated with them (Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016; Murcia et al., 2014; Simberloff, 2015). While these

bastante sólido e que cobre várias dimensões do conceito. Contudo, e tal como foi sendo identificado ao longo deste trabalho, várias questões permanecem em aberto.

O facto de a investigação se focar num conceito complexo, ainda pouco estabilizado, mas em franca evolução, constituiu uma das dificuldades desta tese. Apesar de a designação "*Novel*" ter sido amplamente adotada após a publicação de um artigo seminal de Hobbs et al. (2006), alguma literatura sobre este tipo de ecossistemas que não utiliza esta terminologia pode não ter sido captada na revisão de literatura efetuada no capítulo 2. Por exemplo, em relação a projetos de Arquitetura Paisagista, alguns dos quais apresentados no capítulo 3, constatou-se que muitas vezes os autores não adotam ou reconhecem as terminologias "Novos Ecossistemas" ou "Novos Ecossistemas Urbanos". No entanto, os ecossistemas que são objeto dos seus estudos enquadram-se nessa designação. Embora tenham ficado por explorar provavelmente vários trabalhos e/ou projetos, importa também referir que a literatura recolhida, analisada e citada no âmbito desta tese é vasta e muito diversificada.

Por outro lado, estes conceitos têm gerado alguma controvérsia, havendo grupos muito entusiastas quanto ao seu potencial (Hobbs, Higgs, & Hall, 2013b; Lugo et al., 2018; Mascaro et al., 2013; Perring, Manning, et al., 2013; Standish, Thompson, Higgs, & Murphy, 2013), e grupos que dão sobretudo ênfase aos riscos que lhes possam estar associados (Aronson et al., 2014; Kattan, Aronson, & Murcia, 2016; Murcia et al., 2014; Simberloff, 2015). Apesar destas visões opostas originarem um debate opposing views give rise to an interesting and stimulating debate, they can also be a source of constraints since the publication on this topic is often challenging. Ariel Lugo's (1992) work on "novel" forests in Puerto Rico is probably the most well-known example, not only for its pioneering approach to this topic but also because it took almost a decade to be published[1] (Marris, 2009). Despite these obstacles, researchers such as Ahern (2016), Hobbs, Higgs, & Hall (2013b), and Kowarik (2011), were able to highlight the relevance and usefulness of the concept, pointing new research perspectives, namely those that guided this thesis.

The development of some steps of the work, such as the evaluation of the urban ecological novelty (chapter 4), was also constrained by the lack of historical floristic data for the city of Porto. Unlike in cities with a long tradition of research in urban ecology (as is the case of Berlin), most Portuguese cities (Porto included) do not have available historical floristic data, i.e., floristic data prior to periods of major urban transformation. For example, these data would have allowed analyzing biotic novelty over longer periods (Morse et al., 2014), which would have been useful for an even more robust determination of urban ecological novelty (chapter 4). However, this

interessante e estimulante, podem também ser uma fonte de constrangimentos na medida em que a publicação sobre este tema é, não raramente, dificultada. O trabalho de Ariel Lugo (1992) sobre "novas" florestas em Porto Rico é, provavelmente, o exemplo mais reconhecido não só pelo seu pioneirismo na abordagem a este tema, mas também por ter demorado quase uma década a ser publicado[2] (Marris, 2009). Apesar destes entraves, investigadores como Ahern (2016), Hobbs, Higgs, & Hall (2013b) e Kowarik (2011), têm evidenciado a relevância e utilidade do conceito, apontando novos caminhos para a investigação, nomeadamente os que conduziram à elaboração desta tese.

O desenvolvimento de algumas etapas do trabalho, como, por exemplo, a avaliação da novidade ecológica urbana (capítulo 4), foi também dificultado pela indisponibilidade de dados florísticos históricos para a cidade do Porto. Ao contrário do que acontece em cidades com uma longa tradição de investigação em ecologia urbana (como é o caso de Berlim), a maioria das cidades portuguesas (a cidade do Porto incluída), não têm disponíveis dados florísticos históricos, isto é, dados florísticos anteriores a períodos de grande transformação urbana. Estes dados teriam permitido, por exemplo, analisar a novidade biótica em períodos de tempo mais longos (Morse et al.,

[1] The results of Lugo's work (1992) found that the understory of the "novel" forests of Puerto Rico had more aboveground biomass and used nutrients more efficiently than the understory of native forests.

[2] Os resultados do trabalho de Lugo (1992), verificavam que o subcoberto das florestas "novas" de Porto Rico tinha mais biomassa acima do solo e usavam mais eficientemente os nutrientes do que o subcoberto das florestas nativas.

constraint was overcome with the methodology proposed by Schittko et al. (2020), which considers the different coexistence periods of native and non-native species by determining the residence time of non-native species. In any case, cities that wish to integrate ecological quality indicators in the planning and management of their green structure should perceive the systematic collection of this type of data as a priority measure.

Despite the limitation in accessing historical floristic data, this research benefited from other types of data collected and made available by previous research projects and in public databases, namely data about the urban green structure of the city of Porto (Farinha-Marques, Alves, Fernandes, Guilherme, & Gonçalves, 2018; Farinha-Marques et al., 2014) and about climate change scenarios projected for this city (ClimAdaPT.Local, 2016; CMP, 2016; Monteiro et al., 2018). During the work, important documents were published, such as the revision of the Municipal Master Plan (CMP, 2021), which assumes the municipal ecological structure as a structuring axis for the city's sustainable development and as a response to climate change. Thus, the development of this work was facilitated by the fact that the municipality of Porto proved to be aligned with the sustainability goals and policies of the European Union (Aguiar et al., 2018) and attentive to global environmental issues.

During the construction of the database presented in chapter 6, it was more

2014), o que teria sido útil para uma determinação ainda mais robusta da novidade ecológica urbana (capítulo 4). Este constrangimento foi, no entanto, ultrapassado com a adoção da metodologia proposta por Schittko et al. (2020), que considera os diferentes períodos de coexistência de espécies nativas e exóticas através da determinação do tempo de residência de espécies exóticas. De qualquer forma, as cidades que pretendam integrar indicadores de qualidade ecológica no planeamento e gestão da sua estrutura verde devem encarar a recolha sistemática deste tipo de dados como uma medida prioritária.

Apesar da limitação no acesso a dados florísticos históricos, esta investigação beneficiou de outro tipo de dados recolhidos e disponibilizados por projetos de investigação anteriores e em bases de dados públicas, nomeadamente dados sobre a estrutura verde urbana da cidade do Porto (Farinha-Marques, Alves, Fernandes, Guilherme, & Gonçalves, 2018; Farinha-Marques et al., 2014) e sobre os cenários de alterações climáticas projetados para esta cidade (ClimAdaPT.Local, 2016; CMP, 2016; Monteiro et al., 2018). Durante o decorrer do trabalho foram publicados documentos importantes como a revisão do Plano Diretor Municipal (CMP, 2021), que assume a estrutura ecológica municipal como um eixo estruturante para o desenvolvimento sustentável da cidade e como resposta aos cenários de alterações climáticas. Assim, o desenvolvimento deste trabalho foi facilitado pelo facto do município do Porto se ter revelado muito alinhado com os objetivos e políticas de sustentabilidade da União Europeia (Aguiar et al., 2018) e atento a questões ambientais globais.

problematic to obtain information on herbaceous plants (e.g., growth rate, temperature resistance, suitability for light and soil conditions) than information about trees and shrubs. In general, there is also little literature about species traits related to particular abilities to mitigate the effects of climate change (e.g., tree species with wider and denser canopies contribute more to an increase in the shade and, consequently, regulate the temperature in cities). Implementing the adaptive methodology proposed in chapter 5 can be a valuable tool since it includes monitoring species' behavior in a real context, thus ensuring data collection and theoretical information validation. In this sense, it would be necessary for future work to investigate in greater detail how this monitoring should be conducted, for how long, and based on which indicators.

Regarding the assessment of attitudes and preferences towards Novel Urban Ecosystems (chapter 7), adopting a face-to-face or mixed methodology would have also allowed assessing the perspective of green space users (i.e., non-experts). In this way, concepts that may hold some complexity (native, non-native, cultivated, or spontaneous plants) would not necessarily have to be mastered by respondents if they were assessed through real-life situations (C Chen, Wang, & Jia, 2018; Hoyle et al., 2017; Lewis et al., 2019; Muratet et al., 2015). However, the pandemic context, during which this research component took place, precluded conducting the questionnaire along these lines. Still, conducting the

Durante a construção da base de dados apresentada no capítulo 6 foi mais difícil obter informação sobre plantas herbáceas (por exemplo, ritmo de crescimento, resistência à temperatura, adequação a condições de luz e solo), em comparação com a informação sobre árvores e arbustos. Em geral, há também pouca literatura disponível referente aos atributos das espécies relacionados com competências particulares para mitigar os efeitos das alterações climáticas (por exemplo, espécies arbóreas com copas mais largas e densas contribuem mais para um aumento de sombra e, consequentemente, para regular a temperatura nas cidades). A implementação da metodologia adaptativa proposta no capítulo 5, pode ser uma ferramenta de grande utilidade, na medida em que pressupõe a monitorização do comportamento das espécies num contexto real, garantindo, desse modo, a recolha de dados e a validação de informação teórica. Nesse sentido, seria importante que, em trabalhos futuros, se averiguasse com maior detalhe de que forma esta monitorização deve decorrer, por quanto tempo e com base em que indicadores.

No que respeita à avaliação de atitudes e preferências em relação aos Novos Ecossistemas Urbanos (capítulo 7), a adoção de uma metodologia presencial ou mista teria permitido avaliar também a perspetiva de utilizadores de espaços verdes (ou seja, não especialistas). Desta forma, os conceitos do questionário que podem encerrar alguma complexidade (plantas nativas, exóticas, cultivadas, ou espontâneas) não teriam necessariamente de ser dominados pelos questionnaire online allowed for a considerable amount of responses to be collected, enabling statistical comparisons to be drawn and robust results to be obtained.

The pioneering character of this research in a complex theme highlights the importance of continuing the work started in this thesis, exploring some of the issues that were raised in this chapter. It would be, for instance, of the utmost importance to be able to implement in real urban environments the strategies and proposals presented in chapter 4 (application of the urban ecological novelty assessment in the process of planning and management of the urban green structure) and chapter 5 (management of plant cover based on the potential of novel combinations of species that may be adapted to urban conditions) in order to prove, experimentally, the potential of Novel Urban Ecosystems. The continuation of this research would enable to strengthen the argument for integrating the concept of Novel Urban Ecosystems into urban policy agendas. Thus, it is hoped that this work will pave the way for further research that would benefit from more time and resources.

respondentes se fossem avaliados através de situações reais (C Chen, Wang, & Jia, 2018; Hoyle et al., 2017; Lewis et al., 2019; Muratet et al., 2015). Porém, o contexto pandémico, durante o qual se desenrolou esta componente da investigação, impediu a realização do questionário nestes moldes. Ainda assim, a realização do questionário online permitiu recolher uma quantidade considerável de respostas, permitindo traçar comparações estatísticas e obter resultados robustos.

O carácter pioneiro desta investigação num tema complexo e em consolidação põe em evidência a importância de se dar continuidade ao trabalho iniciado nesta tese, explorando algumas das questões que foram levantadas. Seria, por exemplo, importante poder implementar em ambientes urbanos reais as estratégias e propostas apresentadas no capítulo 4 (aplicação da avaliação de novidade ecológica urbana no processo de planeamento e gestão da estrutura verde urbana) e no capítulo 5 (gestão do coberto vegetal com base no potencial de novas combinações de espécies que surgem adaptadas a condições urbanas) de modo a comprovar, experimentalmente, o potencial de Novos Ecossistemas Urbanos. A continuidade desta investigação permitiria robustecer o argumento da integração do conceito de Novos Ecossistemas Urbanos nas agendas políticas urbanas. Assim, deseja-se que este trabalho seja igualmente proveitoso para outras investigações que beneficiem de mais tempo e recursos.

8.3. Conclusions: Towards a new nature in cities

The findings, practical contributions, and tools originated within this thesis (methodology to assess the urban ecological novelty, adaptive framework for planting design and management of urban green spaces, plant species database) may have practical implications in the long term and at various scales in the way urban green spaces are intervened and perceived. Moreover, the strategies and response options explored in this work may positively impact the quality of life of the population, as well as the development and sustainability of cities.

Thus, it is considered that this research has achieved the proposed objectives through six original publications that constitute the body of this work (chapters 2 to 7). Individually and as a whole, these works contribute to the construction of knowledge about the Novel Urban Ecosystems concept, paving the way to pursue this task through the lenses of Landscape Architecture. This final chapter presents an overview of the thesis, reflecting on the research's main findings and contributions, limitations, and future recommendations, supporting an overall evaluation of the research process. The obtained results and reflections conceived throughout the chapters proved the relevance and innovation of investigating the Novel Urban Ecosystems concept within the disciplinary area of Landscape Architecture, demonstrating its usefulness and potential.

8.3. Conclusões: Rumo a uma nova natureza nas cidades

As descobertas, os contributos práticos e as ferramentas originadas no âmbito desta tese (metodologia para avaliar novidade ecológica urbana, metodologia adaptativa para desenhar e manter os espaços verdes urbanos, base de dados de plantas) podem ter implicações práticas, a longo prazo e a várias escalas, na forma como intervimos e percecionamos os espaços verdes urbanos. Além disso, as estratégias e opções de resposta exploradas neste trabalho podem repercutir-se positivamente na qualidade de vida da população, assim como no desenvolvimento e sustentabilidade das cidades.

Considera-se, assim, que esta investigação alcançou os objetivos propostos através de seis publicações originais que compõem o corpo deste trabalho (capítulos 2 a 7). Isoladamente e no seu conjunto, estes trabalhos contribuem para a construção de conhecimento sobre o conceito de Novos Ecossistemas Urbanos, permitindo prosseguir esta tarefa através da Arquitetura Paisagista. Neste capítulo final apresentou-se uma visão geral da tese, refletindo acerca das principais descobertas e contributos do trabalho, assim como das limitações e recomendações futuras, suportando uma avaliação geral do processo de investigação. Os resultados obtidos e reflexões concebidas ao longo dos capítulos comprovaram a pertinência e inovação de investigar o conceito de Novos Ecossistemas Urbanos no âmbito da área disciplinar da Arquitetura Paisagista, demostrando a sua utilidade e potencial.

Although the most important findings of this research have been highlighted in this chapter (chapter 8), it was also considered relevant to gather the main conclusions of the work into a few topics:

- There is a growing interest in investigating the concept in the urban context (Novel Urban Ecosystems). In cities, the opportunities of the concept are more relevant, particularly regarding urban design and planning.

- The four criteria that characterize Novel Ecosystems and Novel Urban Ecosystems (human-induced, species assemblages, thresholds, and self-sustaining) are rarely used simultaneously. Only the human and biotic dimensions appear in all the definitions analyzed.

- The practical application of the Novel Urban Ecosystems concept in Landscape Architecture practice depends on i) the availability of tools that allow its identification and quantification in the green structure of cities and ii) the way these ecosystems are perceived.

- It is more appropriate to assess Novel Urban Ecosystems based on a continuum of urban ecological novelty since the disturbance dynamics associated with anthropogenic activities are constant in the urban environment, and the different types of urban green spaces may present great heterogeneity (different levels of maintenance and degrees of land-use change, different proportions of native and

Embora as conclusões mais importantes desta investigação tenham vindo a ser destacadas no presente capítulo (capítulo 8), considerou-se igualmente relevante reunir as principais conclusões do trabalho em alguns tópicos:

- Existe um interesse crescente em investigar o conceito no contexto urbano (Novos Ecossistemas Urbanos) e é nas cidades que as oportunidades do conceito adquirem uma maior relevância, nomeadamente em relação ao desenho e ao planeamento urbano.

- Os quatro critérios que caracterizam os Novos Ecossistemas e os Novos Ecossistemas Urbanos (atividades antrópicas, novas combinações de espécies, limiares e estabilidade) raramente são utilizados em simultâneo e apenas a dimensão humana e a dimensão biótica surgem em todas as definições analisadas.

- A aplicação prática do conceito de Novos Ecossistemas Urbanos nas áreas de atuação da Arquitetura Paisagista depende i) da disponibilidade de ferramentas que possibilitem a sua identificação e quantificação na estrutura verde das cidades e ii) da forma como estes ecossistemas são percecionados.

- É mais apropriado avaliar Novos Ecossistemas Urbanos com base num *continuum* de novidade ecológica, uma vez que as dinâmicas de perturbação associadas às atividades antrópicas são constantes em ambiente urbano e os diferentes tipos de espaços verdes urbanos podem apresentar uma grande heterogeneidade (distintos níveis de non-native species, etc.). Therefore, this assessment should include the quantification of the human dimension, considering the influence of human activities as a fundamental component in the measurement of urban ecological novelty.

- The degree of urban ecological novelty does not depend on the type of green space under evaluation. The urban ecological novelty assessment can (and should) inform urban green structure planning and management decisions since spaces with different degrees of urban ecological novelty can contribute to the urban green structure differently. Additionally, the presence of urban green spaces with different degrees of ecological novelty contributes to the diversity, multifunctionality, and resilience of the urban green structure.

- The Novel Urban Ecosystems concept allows an appreciation of the function and adaptive capacity of species or combinations of species above their identity or origin. In this way, proposals for intervention in Novel Urban Ecosystems can consider the potential of all species present in the community (non-native and native, spontaneous and cultivated) and monitor species that would be excluded under common circumstances (e.g., species with ecological risk).

- The methodologies and tools developed in this research may be useful for Landscape Architecture. However, their true potential and weaknesses can only be ascertained

manutenção e graus de alteração do uso do solo, diferentes proporções de espécies nativas e exóticas, etc.). Esta avaliação deve, por isso, incluir a quantificação da dimensão humana, considerando a influência das atividades antrópicas uma componente fundamental na medição da novidade ecológica urbana.

- O grau de novidade ecológica urbana não depende do tipo de espaço verde em avaliação. A avaliação de novidade ecológica urbana pode e deve informar decisões de planeamento e gestão da estrutura verde urbana, uma vez que espaços com diferentes graus de novidade ecológica urbana podem contribuir para a estrutura verde urbana de forma distinta. Além disso, a presença de espaços verdes urbanos com diferentes graus de novidade ecológica contribui para a diversidade, multifuncionalidade e resiliência da estrutura verde urbana.

- O conceito de Novos Ecossistemas Urbanos permite uma valorização da função e capacidade adaptativa das espécies ou combinações de espécies acima da sua identidade ou origem. Desta forma, as propostas de intervenção em Novos Ecossistemas Urbanos podem ter em consideração o potencial de todas as espécies presentes na comunidade (exóticas e nativas, espontâneas e cultivadas) e sinalizar e monitorizar espécies que em circunstâncias comuns seriam excluídas (por exemplo, espécies que comportam risco ecológico).

- As metodologias e ferramentas desenvolvidas nesta investigação podem ser úteis para a Arquitetura Paisagista, mas o seu verdadeiro potencial e fragilidades só poderão through implementation and use in a real-world context.

- Although there is clearly a greater acceptance of native and cultivated plants, professionals surveyed in this research also generally accept non-native and spontaneous plants in urban green spaces. Furthermore, providing information about the potential of the Novel Urban Ecosystems concept, particularly regarding climate change, has a significantly positive effect on the acceptance of non-native and spontaneous plants.

- The vast majority of surveyed professionals in the scope of this thesis were receptive to the application and integration of the Novel Urban Ecosystems concept in cities and considered these ecosystems relevant to tackle climate change effects.

ser averiguados através da sua implementação e utilização em contexto real.

- Embora haja claramente uma maior aceitação de plantas nativas e cultivadas, os profissionais inquiridos no âmbito desta investigação também aceitam, no geral, plantas exóticas e espontâneas em espaços verdes urbanos. Além disso, disponibilizar informação sobre o potencial do conceito de Novos Ecossistemas Urbanos, nomeadamente em relação às alterações climáticas, tem um efeito significativamente positivo na aceitação de plantas exóticas e espontâneas.

- A grande maioria dos profissionais inquiridos no âmbito desta tese mostrou-se recetivo à aplicação e integração do conceito de Novos Ecossistemas Urbanos nas cidades e considerou estes ecossistemas relevantes para combater os efeitos das alterações climáticas.

In conclusion, the Novel Urban Ecosystems concept represents the rapid changes continuously operated in cities. Removing humanity from the equation to restore ecosystems to historic or pristine conditions seems an unlikely solution. New challenges require new measures. Therefore, the Novel Urban Ecosystems concept allows adopting a new narrative and perspective regarding urban green spaces in the context of the Anthropocene, admitting the need to expand response options to environmental problems based on the likelihood of success of different interventions. It is thus urgent to reflect critically about the inevitable change of ecosystems, building new paradigms that allow creating a more sustainable and harmonious future for both Humanity and Nature.

Em suma, o conceito de Novos Ecossistemas Urbanos representa as mudanças céleres que são operadas continuamente nas cidades. Remover a Humanidade da equação, tendo como objetivo restaurar os ecossistemas para condições históricas ou pristinas parece, cada vez mais, uma solução improvável. Desafios novos necessitam de novas medidas. Por conseguinte, o conceito de Novos Ecossistemas Urbanos permite adotar uma nova narrativa e perspetiva em relação aos espaços verdes urbanos no contexto do Antropocénico, admitindo a necessidade de expandir opções de resposta aos problemas ambientais com base na probabilidade de sucesso de diferentes intervenções. Urge, assim, refletir criticamente a respeito da mudança incontornável dos ecossistemas, construindo novos paradigmas que permitam criar um futuro mais sustentável e harmonioso para a Humanidade e a Natureza.

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GENERAL APPENDICES

Appendix I | List of publications

List of publications, published or under consideration for publication, developed within the scope of this thesis as first author or as co-author. These include contributions in international and peer reviewed journals and conferences (as abstract, full paper, or poster).

INTERNATIONAL AND PEER REVIEWED JOURNALS

Teixeira, C. P., Fernandes, C. O., Ryan, R., & Ahern, J. Attitudes and preferences towards plants in urban green spaces: Implications for the design and management of Novel Urban Ecosystems. Journal of Environmental Management, 314, 115103. https://doi.org/10.1016/j.jenvman.2022.115103

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Teixeira, C. P., Fernandes, C. O., & Ahern, J. Adaptive planting design and management framework for urban climate change adaptation and mitigation. Urban Forestry & Urban Greening, 70, 127548. https://doi.org/10.1016/j.ufug.2022.127548

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Appendix II | Fieldwork sheets from the 85 study sites in the city of Porto

STUDY SITE 1

ID: UW_AFN01

UGS category: Urban Woodland

Location: Rua de Martim Moniz

Area: 3 392.67 m^2

Number of surveys: 1

Dominant species: *Eucalyptus globulus*

Species richness: 11

	Species richness	Species cover
Native	54.55%	31.28%
Non-native	9.09%	22.03%
Non-native casual	18.18%	9.25%
Non-native naturalized	0.00%	0.00%
Non-native invasive	18.18%	37.44%

STUDY SITE 2

ID: UW_AFN02

UGS category: Urban Woodland

Location: Rua Cidade da Beira

Area: 10 209.36 m^2

Number of surveys: 1

Dominant species: *Pinus pinaster*

Species richness: 35

	Species richness	Species cover
Native	94.29%	97.45%
Non-native	5.71%	2.55%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%

STUDY SITE 3

ID: UW_AFN03

UGS category: Urban Woodland

Location: Rua de Afonso Baldaia

Area: 8 181.61 m^2

Number of surveys: 1

Dominant species: *Pinus pinaster*

Species richness: 24

	Species richness	Species cover
Native	95.83%	99.60%
Non-native	4.17%	0.40%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%

STUDY SITE 4

ID: UW_AFN04

UGS category: Urban Woodland

Location: Rua Pintor César Abbot

Area: 2 619.96 m^2

Number of surveys: 4

Dominant species: *Metrosideros excelsa*

Species richness: 39

	Species richness	Species cover
Native	58.97%	28.55%
Non-native	30.77%	55.11%
Non-native casual	0.00%	16.18%
Non-native naturalized	2.56%	0.15%
Non-native invasive	7.69%	0.00%

STUDY SITE 5

ID: UW_LOM03

UGS category: Urban Woodland

Location: Rua de Paulo da Gama

Area: 2 680.26 m^2

Number of surveys: 1

Dominant species: *Fagus sylvatica*

Species richness: 27

	Species richness	Species cover
Native	81.48%	47.43%
Non-native	11.11%	34.86%
Non-native casual	3.70%	17.14%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.70%	0.57%

STUDY SITE 6

ID: UW_LOM01

UGS category: Urban Woodland

Location: Via Panorâmica

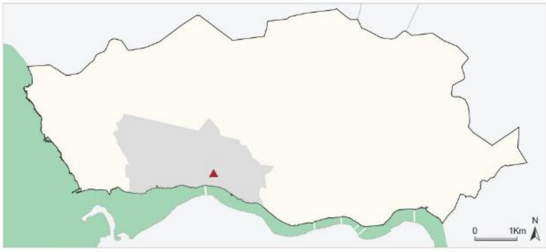
Area: 5 107.24 m^2

Number of surveys: 2

Dominant species: *Thuja plicata*

Species richness: 32

	Species richness	Species cover
Native	71.88%	32.26%
Non-native	15.63%	61.61%
Non-native casual	0.00%	0.00%
Non-native naturalized	6.25%	0.97%
Non-native invasive	6.25%	5.16%



STUDY SITE 7

ID: UW_LOM02

UGS category: Urban Woodland

Location: Rua da Pasteleira

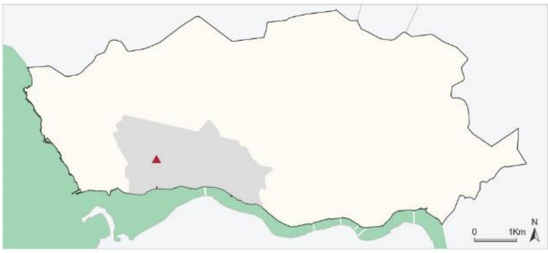
Area: 4 160.95 m^2

Number of surveys: 1

Dominant species: *Festuca arundinacea*

Species richness: 15

	Species richness	Species cover
Native	88.67%	86.92%
Non-native	6.67%	0.42%
Non-native casual	6.67%	12.66%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 8

ID: UW_RAM01

UGS category: Urban Woodland

Location: Avenida Vasco da Gama

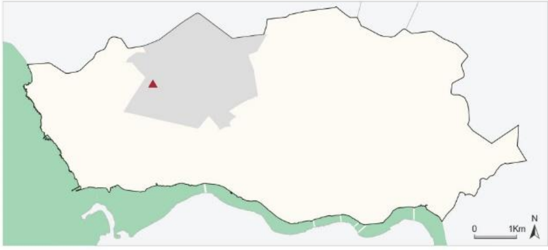
Area: 2 488.17 m^2

Number of surveys: 1

Dominant species: *Populus nigra*

Species richness: 21

	Species richness	Species cover
Native	61.90%	30.31%
Non-native	23.81%	49.61%
Non-native casual	4.76%	15.75%
Non-native naturalized	0.00%	0.00%
Non-native invasive	9.52%	4.33%



STUDY SITE 9

ID: UW_RAM02

UGS category: Urban Woodland

Location: Rua Professor Rocha Pereira

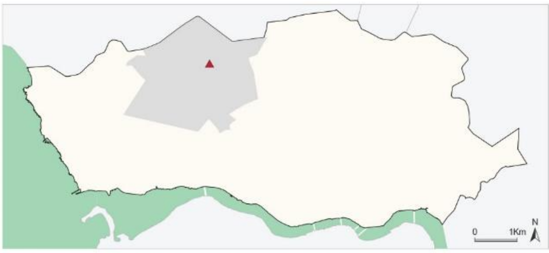
Area: 3 783.27 m²

Number of surveys: 1

Dominant species: *Populus nigra*

Species richness: 34

	Species richness	Species cover
Native	70.59%	45.65%
Non-native	14.71%	40.94%
Non-native casual	0.00%	0.00%
Non-native naturalized	8.82%	4.35%
Non-native invasive	5.88%	9.06%



STUDY SITE 10

ID: UW_RAM03

UGS category: Urban Woodland

Location: Hospital da Prelada

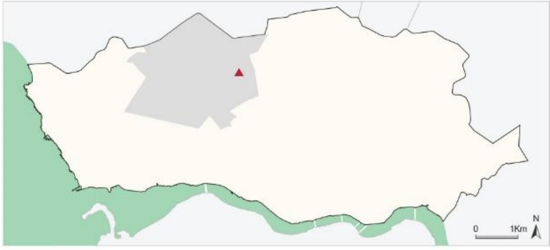
Area: 6 961.62 m²

Number of surveys: 1

Dominant species: *Acer pseudoplatanus*

Species richness: 19

	Species richness	Species cover
Native	78.95%	83.21%
Non-native	10.53%	14.60%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	10.53%	2.19%



STUDY SITE 11

ID: UW_PAR01

UGS category: Urban Woodland

Location: Rua de Faria Guimarães

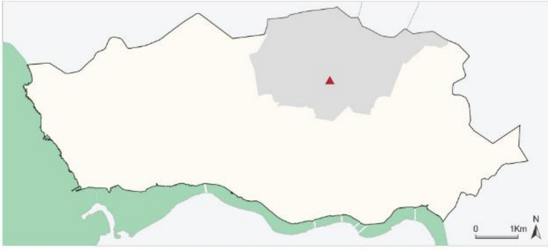
Area: 2 257.79 m^2

Number of surveys: 1

Dominant species: *Liquidambar styraciflua*

Species richness: 23

	Species richness	Species cover
Native	78.26%	69.23%
Non-native	13.04%	29.49%
Non-native casual	4.35%	0.64%
Non-native naturalized	4.35%	0.64%
Non-native invasive	0.00%	0.00%



STUDY SITE 12

ID: UW_CAM01

UGS category: Urban Woodland

Location: Avenida Francisco Xavier Esteves

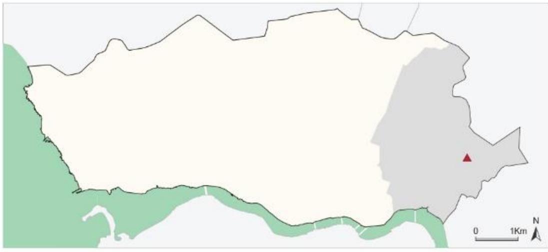
Area: 3 967.44 m^2

Number of surveys: 2

Dominant species: *Quercus robur*

Species richness: 31

	Species richness	Species cover
Native	90.32%	95.06%
Non-native	3.23%	3.80%
Non-native casual	0.00%	0.00%
Non-native naturalized	3.23%	0.19%
Non-native invasive	3.23%	0.95%



STUDY SITE 13

ID: UW_CAM02

UGS category: Urban Woodland

Location: Rua Rio da Vila

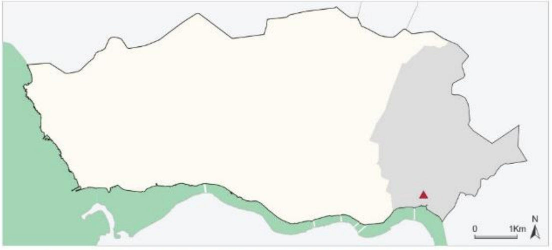
Area: 5 205.7 m^2

Number of surveys: 1

Dominant species: *Quercus robur*

Species richness: 23

	Species richness	Species cover
Native	82.61%	59.52%
Non-native	0.00%	0.00%
Non-native casual	4.35%	0.40%
Non-native naturalized	0.00%	0.00%
Non-native invasive	13.04%	40.08%



STUDY SITE 14

ID: UW_CAM03

UGS category: Urban Woodland

Location: Rua do Freixo

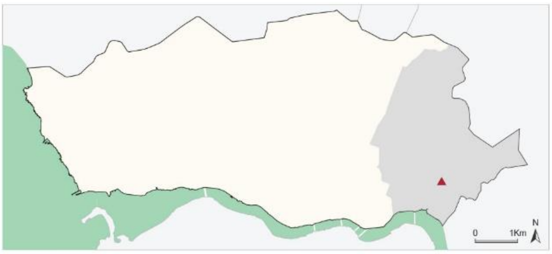
Area: 1 895.16 m^2

Number of surveys: 1

Dominant species: *Quercus coccinea*

Species richness: 32

	Species richness	Species cover
Native	87.50%	61.37%
Non-native	9.38%	38.27%
Non-native casual	3.13%	0.36%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 15

ID: PG_AFN01

UGS category: Parks and Gardens

Location: Jardim da Praia da Luz

Area: 7 918.81 m^2

Number of surveys: 6

Dominant species: *Stenotaphrum secundatum*

Species richness: 38

	Species richness	Species cover
Native	65.79%	27.59%
Non-native	21.05%	28.83%
Non-native casual	7.89%	16.55%
Non-native naturalized	2.63%	26.90%
Non-native invasive	2.63%	0.14%

STUDY SITE 16

ID: PG_AFN02

UGS category: Parks and Gardens

Location: Jardim da Praça de Liége

Area: 4 483.59 m^2

Number of surveys: 7

Dominant species: *Juniperus x media*

Species richness: 43

	Species richness	Species cover
Native	60.47%	55.22%
Non-native	30.23%	40.48%
Non-native casual	2.33%	0.57%
Non-native naturalized	4.65%	3.63%
Non-native invasive	2.33%	0.11%

STUDY SITE 17

ID: PG_AFN03

UGS category: Parks and Gardens

Location: Jardim José Roquete

Area: 4 966.48 m²

Number of surveys: 7

Dominant species: *Juniperus x media*

Species richness: 47

	Species richness	Species cover
Native	78.72%	46.60%
Non-native	14.89%	46.46%
Casual	2.13%	0.13%
Naturalized	2.13%	5.34%
Invasive	2.13%	1.47%

STUDY SITE 18

ID: PG_AFN04

UGS category: Parks and Gardens

Location: Jardim na rua Alfredo Keil

Area: 3 592.22 m²

Number of surveys: 4

Dominant species: *Pittosporum crassifolium*

Species richness: 29

	Species richness	Species cover
Native	89.66%	61.75%
Non-native	6.90%	38.02%
Casual	0.00%	0.00%
Naturalized	0.00%	0.00%
Invasive	3.45%	0.23%

STUDY SITE 19

ID: PG_AFN05

UGS category: Parks and Gardens

Location: Jardim do Passeio Alegre

Area: 32 606.05 m^2

Number of surveys: 13

Dominant species: *Pittosporum tobira*

Species richness: 64

	Species richness	Species cover
Native	57.81%	32.60%
Non-native	28.13%	40.77%
Casual	3.13%	14.58%
Naturalized	4.69%	3.50%
Invasive	6.25%	8.55%

STUDY SITE 20

ID: PG_AFN06

UGS category: Parks and Gardens

Location: Marginal da Cantareira

Area: 21 425.36 m^2

Number of surveys: 6

Dominant species: *Coprosma repens*

Species richness: 30

	Species richness	Species cover
Native	76.67%	45.38%
Non-native	16.67%	40.31%
Casual	3.33%	14.00%
Naturalized	0.00%	0.00%
Invasive	3.33%	0.31%

STUDY SITE 21

ID: PG_LOM01

UGS category: Parks and Gardens

Location: Jardim do Largo Dom João III

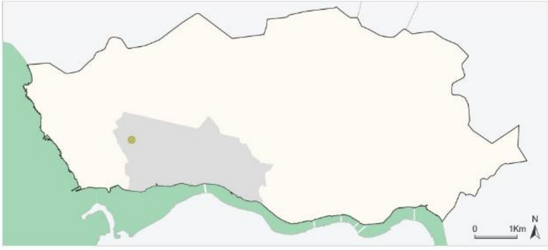
Area: 3 650.17 m^2

Number of surveys: 5

Dominant species: *Lolium perenne*

Species richness: 45

	Species richness	Species cover
Native	62.22%	47.66%
Non-native	28.89%	35.16%
Non-native casual	4.44%	4.04%
Non-native naturalized	2.22%	13.02%
Non-native invasive	2.22%	0.13%



STUDY SITE 22

ID: PG_LOM02

UGS category: Parks and Gardens

Location: Parque da Pasteleira

Area: 71 887.42 m^2

Number of surveys: 25

Dominant species: *Paspalum dilatatum*

Species richness: 120

	Species richness	Species cover
Native	68.33%	46.18%
Non-native	27.50%	43.81%
Non-native casual	0.83%	2.59%
Non-native naturalized	2.50%	6.35%
Non-native invasive	1.67%	1.07%

STUDY SITE 23

ID: PG_LOM04

UGS category: Parks and Gardens

Location: Jardim na Rua Manuel Bandeira

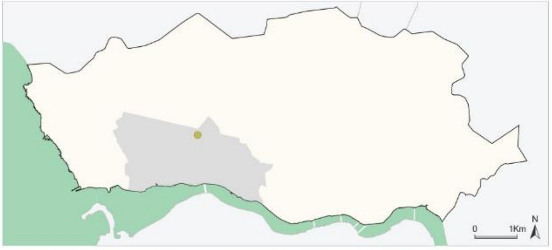
Area: 6 217.65 m^2

Number of surveys: 3

Dominant species: *Acer negundo* 'Variegata'

Species richness: 41

	Species richness	Species cover
Native	65.85%	46.90%
Non-native	29.27%	29.66%
Non-native casual	2.44%	22.99%
Non-native naturalized	0.00%	0.00%
Non-native invasive	2.44%	0.46%



STUDY SITE 24

ID: PG_LOM05

UGS category: Parks and Gardens

Location: Jardim de Sophia e Praça da Galiza

Area: 8 216.22 m^2

Number of surveys: 15

Dominant species: *Poa supina*

Species richness: 88

	Species richness	Species cover
Native	69.32%	43.17%
Non-native	27.27%	55.58%
Non-native casual	0.00%	0.00%
Non-native naturalized	1.14%	1.00%
Non-native invasive	2.27%	0.25%

STUDY SITE 25

ID: PG_LOM06

UGS category: Parks and Gardens

Location: Largo da Maternidade Júlio Dinis

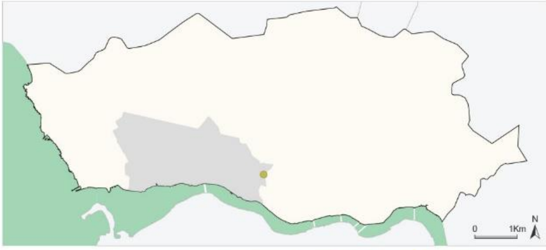
Area: 1 770.79 m^2

Number of surveys: 5

Dominant species: *Tilia tomentosa*

Species richness: 29

	Species richness	Species cover
Native	51.72%	23.30%
Non-native	41.38%	75.83%
Non-native casual	3.45%	0.72%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.45%	0.14%



STUDY SITE 26

ID: PG_LOM07

UGS category: Parks and Gardens

Location: Jardim da Casa Tait

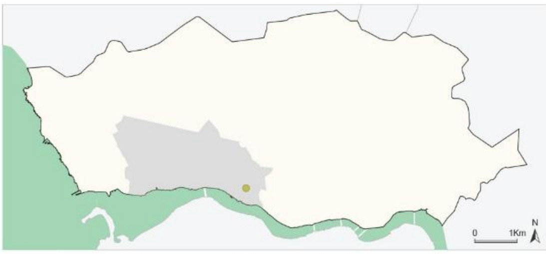
Area: 12 258.12 m^2

Number of surveys: 13

Dominant species: *Digitaria sanguinalis*

Species richness: 95

	Species richness	Species cover
Native	60.00%	35.70%
Non-native	29.47%	52.00%
Non-native casual	1.05%	0.07%
Non-native naturalized	4.21%	4.56%
Non-native invasive	5.26%	7.67%



STUDY SITE 27

ID: PG_LOM08

UGS category: Parks and Gardens

Location: Jardins do Palácio de Cristal

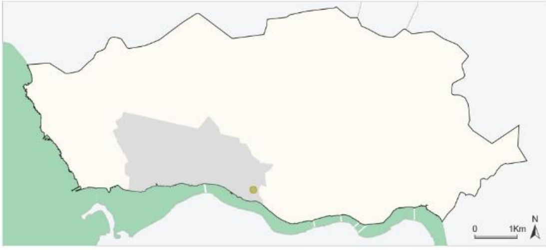
Area: 81 985.84 m²

Number of surveys: 33

Dominant species: *Agapanthus africanus*

Species richness: 134

	Species richness	Species cover
Native	51.49%	31.14%
Non-native	35.82%	61.38%
Non-native casual	1.49%	0.06%
Non-native naturalized	4.48%	4.40%
Non-native invasive	5.97%	3.03%



STUDY SITE 28

ID: PG_RAM01

UGS category: Parks and Gardens

Location: Jardim Machado de Assis

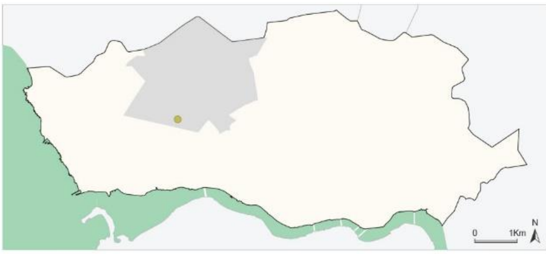
Area: 7 854.20 m²

Number of surveys: 5

Dominant species: *Ligustrum lucidum*

Species richness: 39

	Species richness	Species cover
Native	61.54%	19.92%
Non-native	28.21%	65.09%
Non-native casual	2.56%	14.37%
Non-native naturalized	5.13%	0.41%
Non-native invasive	2.56%	0.21%



STUDY SITE 29

ID: PG_RAM02

UGS category: Parks and Gardens

Location: Jardins da Fundação EAA

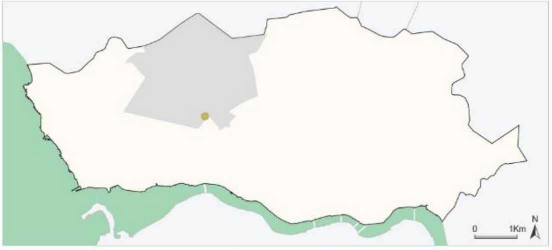
Area: 13 900.31 m²

Number of surveys: 21

Dominant species: *Pittosporum tobira* 'Nana'

Species richness: 62

	Species richness	Species cover
Native	32.26%	25.35%
Non-native	58.06%	58.80%
Non-native casual	1.61%	7.88%
Non-native naturalized	6.45%	7.74%
Non-native invasive	1.61%	0.23%



STUDY SITE 30

ID: PG_CED01

UGS category: Parks and Gardens

Location: Jardim da Praça de Pedro Nunes

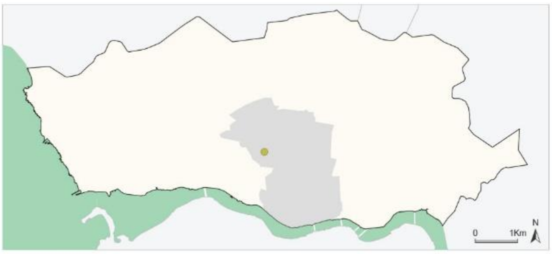
Area: 1 269.42 m²

Number of surveys: 6

Dominant species: *Liriodendron tulipifera*

Species richness: 32

	Species richness	Species cover
Native	68.75%	25.37%
Non-native	25.00%	65.58%
Non-native casual	0.00%	0.00%
Non-native naturalized	3.13%	8.90%
Non-native invasive	3.13%	0.15%



STUDY SITE 31

ID: PG_CED02

UGS category: Parks and Gardens

Location: Jardim do Carregal

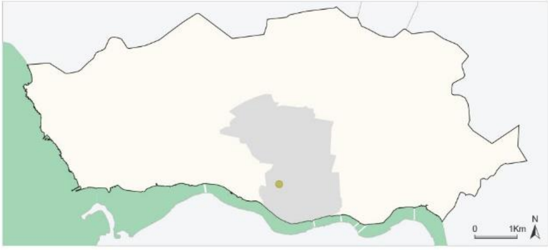
Area: 6 260.90 m^2

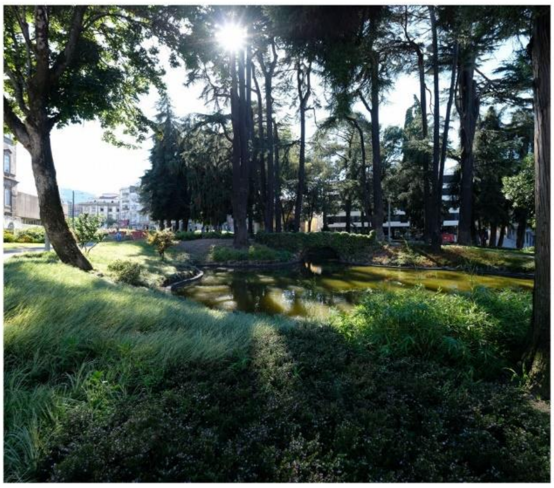
Number of surveys: 3

Dominant species: *Ruscus hypophyllum*

Species richness: 34

	Species richness	Species cover
Native	55.88%	13.38%
Non-native	38.24%	77.63%
Non-native casual	5.88%	8.99%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%





STUDY SITE 32

ID: PG_CED03

UGS category: Parks and Gardens

Location: Praça de Carlos Alberto

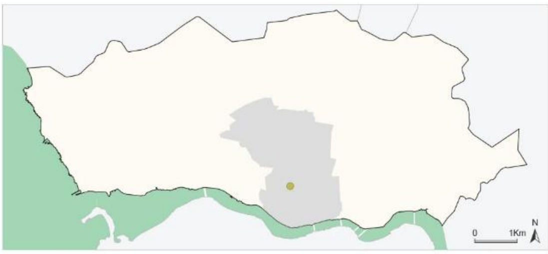
Area: 2 012.62 m^2

Number of surveys: 4

Dominant species: *Acorus gramineus*

Species richness: 20

	Species richness	Species cover
Native	50.00%	17.38%
Non-native	45.00%	82.35%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	5.00%	0.27%



STUDY SITE 33

ID: PG_CED04

UGS category: Parks and Gardens

Location: Jardim da Cordoaria

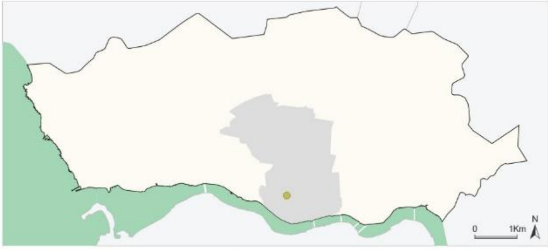
Area: 20 750.02 m^2

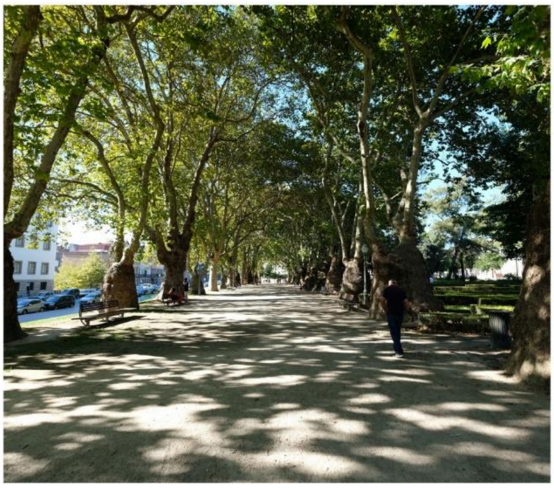
Number of surveys: 8

Dominant species: *Quercus rubra*

Species richness: 51

	Species richness	Species cover
Native	56.86%	42.73%
Non-native	35.29%	56.77%
Non-native casual	0.00%	0.00%
Non-native naturalized	3.92%	0.20%
Non-native invasive	3.92%	0.30%





STUDY SITE 34

ID: PG_CED05

UGS category: Parks and Gardens

Location: Jardim da Praça Infante D. Henrique

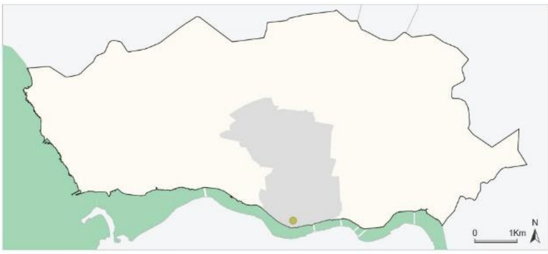
Area: 3 840.81 m^2

Number of surveys: 6

Dominant species: *Washingtonia robusta*

Species richness: 49

	Species richness	Species cover
Native	59.18%	34.09%
Non-native	32.65%	62.90%
Non-native casual	2.04%	1.88%
Non-native naturalized	2.04%	0.38%
Non-native invasive	4.08%	0.75%



STUDY SITE 35

ID: PG_CED06

UGS category: Parks and Gardens

Location: Jardim da Praça Marquês de Pombal

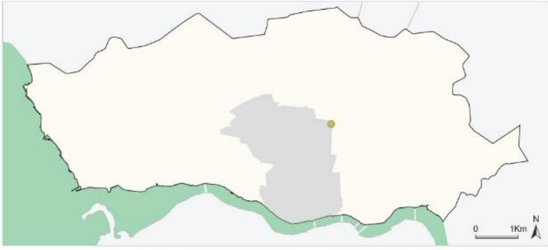
Area: 6 721.07 m²

Number of surveys: 7

Dominant species: *Ophiopogon japonicus*

Species richness: 26

	Species richness	Species cover
Native	50.00%	13.32%
Non-native	42.31%	86.38%
Non-native casual	0.00%	0.00%
Non-native naturalized	3.85%	0.15%
Non-native invasive	3.85%	0.15%



STUDY SITE 36

ID: PG_BON01

UGS category: Parks and Gardens

Location: Jardim Paulo Vallada

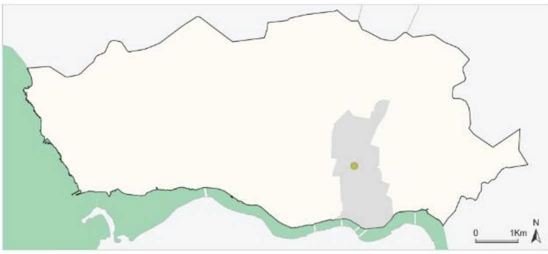
Area: 16 048.96 m²

Number of surveys: 7

Dominant species: *Lolium perenne*

Species richness: 50

	Species richness	Species cover
Native	62.00%	55.32%
Non-native	26.00%	31.60%
Non-native casual	8.00%	12.85%
Non-native naturalized	2.00%	0.12%
Non-native invasive	2.00%	0.12%



STUDY SITE 37

ID: PG_BON02

UGS category: Parks and Gardens

Location: Jardim da Praça Rainha D. Amélia

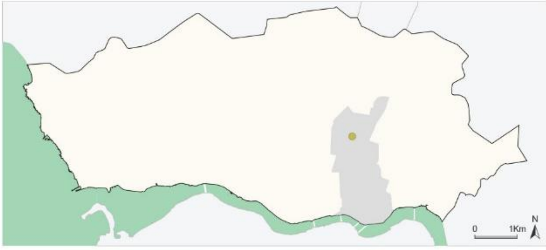
Area: 7 121.46 m^2

Number of surveys: 13

Dominant species: *Stenotaphrum secundatum*

Species richness: 73

	Species richness	Species cover
Native	54.79%	34.17%
Non-native	39.73%	51.52%
Non-native casual	0.00%	0.00%
Non-native naturalized	1.37%	13.93%
Non-native invasive	4.11%	0.39%



STUDY SITE 38

ID: PG_BON03

UGS category: Parks and Gardens

Location: Praça Velásquez

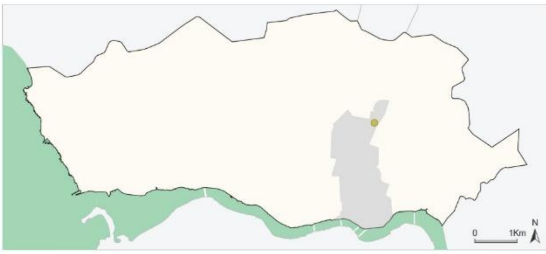
Area: 16 526.69 m^2

Number of surveys: 5

Dominant species: *Cynodon dactylon*

Species richness: 29

	Species richness	Species cover
Native	62.07%	53.47%
Non-native	31.03%	39.12%
Non-native casual	0.00%	0.00%
Non-native naturalized	3.45%	7.10%
Non-native invasive	3.45%	0.32%



STUDY SITE 39

ID: PG_PAR01

UGS category: Parks and Gardens

Location: Jardim no Largo Palmira Milheiro

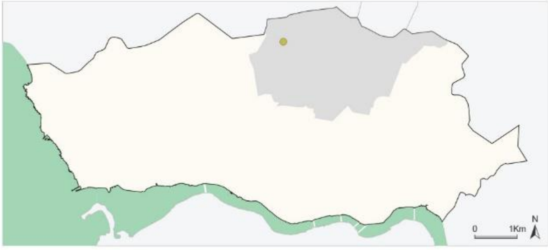
Area: 3 619.61 m^2

Number of surveys: 2

Dominant species: *Quercus rubra*

Species richness: 25

	Species richness	Species cover
Native	76.00%	16.42%
Non-native	20.00%	83.21%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	4.00%	0.37%



STUDY SITE 40

ID: PG_CAM01

UGS category: Parks and Gardens

Location: Parque de S. Roque

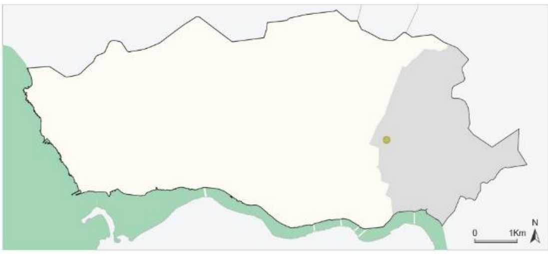
Area: 41 931.79 m^2

Number of surveys: 21

Dominant species: *Agapanthus africanus*

Species richness: 84

	Species richness	Species cover
Native	51.19%	32.55%
Non-native	30.95%	48.75%
Non-native casual	2.38%	4.39%
Non-native naturalized	4.76%	3.28%
Non-native invasive	10.71%	11.04%



STUDY SITE 41

ID: VL_AFN01

UGS category: Vacant Lands

Location: Rua de Vila Nova

Area: 923.39 m^2

Number of surveys: 2

Dominant species: *Metrosideros excelsa*

Species richness: 52

	Species richness	Species cover
Native	67.31%	35.79%
Non-native	19.23%	44.67%
Non-native casual	0.00%	0.00%
Non-native naturalized	5.77%	8.12%
Non-native invasive	7.69%	11.42%

STUDY SITE 42

ID: VL_AFN02

UGS category: Vacant Lands

Location: Avenida do Parque

Area: 4 300.26 m^2

Number of surveys: 3

Dominant species: *Trifolium pratense*

Species richness: 61

	Species richness	Species cover
Native	80.33%	75.10%
Non-native	6.56%	9.00%
Non-native casual	4.92%	0.63%
Non-native naturalized	0.00%	0.00%
Non-native invasive	8.20%	15.27%

STUDY SITE 43

ID: VL_AFN03

UGS category: Vacant Lands

Location: Avenida da Boavista

Area: 2 366.69 m^2

Number of surveys: 1

Dominant species: *Crassula tillaea*

Species richness: 31

	Species richness	Species cover
Native	83.87%	95.19%
Non-native	9.68%	2.88%
Non-native casual	3.23%	0.96%
Non-native naturalized	3.23%	0.96%
Non-native invasive	0.00%	0.00%

STUDY SITE 44

ID: VL_AFN04

UGS category: Vacant Lands

Location: Rua de Vila Nova

Area: 1 393.69 m^2

Number of surveys: 1

Dominant species: *Rubus ulmifolius*

Species richness: 15

	Species richness	Species cover
Native	86.67%	84.44%
Non-native	6.67%	0.74%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	6.67%	14.81%

STUDY SITE 45

ID: VL_AFN05

UGS category: Vacant Lands

Location: Avenida da Boavista

Area: 3 793.96 m^2

Number of surveys: 2

Dominant species: *Carex muricata subsp. pairae*

Species richness: 37

	Species richness	Species cover
Native	86.49%	92.36%
Non-native	10.81%	7.32%
Non-native casual	0.00%	0.00%
Non-native naturalized	2.70%	0.32%
Non-native invasive	0.00%	0.00%

STUDY SITE 46

ID: VL_AFN08

UGS category: Vacant Lands

Location: Rua de Fez

Area: 800.61 m^2

Number of surveys: 2

Dominant species: *Salix atrocinerea*

Species richness: 40

	Species richness	Species cover
Native	80.00%	60.00%
Non-native	10.00%	9.82%
Non-native casual	2.50%	8.77%
Non-native naturalized	5.00%	3.86%
Non-native invasive	2.50%	17.54%

STUDY SITE 47

ID: VL_AFN09

UGS category: Vacant Lands

Location: Rua Dom Francisco de Almeida

Area: 1 513.30 m^2

Number of surveys: 2

Dominant species: *Quercus robur*

Species richness: 41

	Species richness	Species cover
Native	82.93%	86.37%
Non-native	7.32%	12.65%
Non-native casual	7.32%	0.24%
Non-native naturalized	0.00%	0.00%
Non-native invasive	2.44%	0.73%

STUDY SITE 48

ID: VL_AFN11

UGS category: Vacant Lands

Location: Rua da Beneditina

Area: 350.75 m^2

Number of surveys: 1

Dominant species: *Pteridium aquilinum*

Species richness: 17

	Species richness	Species cover
Native	76.47%	97.59%
Non-native	11.76%	1.20%
Non-native casual	11.76%	1.20%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%

STUDY SITE 49

ID: VL_AFN12

UGS category: Vacant Lands

Location: Rua da Quinta

Area: 2 348.54 m^2

Number of surveys: 4

Dominant species: *Pteridium aquilinum*

Species richness: 66

	Species richness	Species cover
Native	77.27%	64.62%
Non-native	7.58%	1.38%
Non-native casual	4.55%	1.38%
Non-native naturalized	1.52%	0.46%
Non-native invasive	9.09%	32.16%

STUDY SITE 50

ID: VL_AFN13

UGS category: Vacant Lands

Location: Rua do Crasto

Area: 4 181.02 m^2

Number of surveys: 1

Dominant species: *Robinia pseudoacacia*

Species richness: 26

	Species richness	Species cover
Native	88.46%	75.93%
Non-native	7.69%	0.93%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.85%	23.15%

STUDY SITE 51

ID: VL_AFN14

UGS category: Vacant Lands

Location: Rua do Crasto

Area: 1 271.00 m^2

Number of surveys: 1

Dominant species: *Avena strigosa*

Species richness: 26

	Species richness	Species cover
Native	88.46%	70.52%
Non-native	11.54%	29.48%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%

STUDY SITE 52

ID: VL_LOM01

UGS category: Vacant Lands

Location: Rua Mouteira

Area: 4 596.70 m^2

Number of surveys: 1

Dominant species: *Bromus diandrus*

Species richness: 19

	Species richness	Species cover
Native	94.74%	95.87%
Non-native	0.00%	0.00%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	5.26%	4.13%

STUDY SITE 53

ID: VL_LOM03

UGS category: Vacant Lands

Location: Rua Grijó

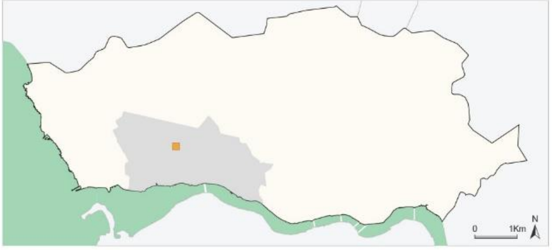
Area: 1 901.31 m^2

Number of surveys: 3

Dominant species: *Thuja plicata*

Species richness: 32

	Species richness	Species cover
Native	81.25%	44.54%
Non-native	15.63%	55.19%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.13%	0.27%



STUDY SITE 54

ID: VL_LOM04

UGS category: Vacant Lands

Location: Rua de Guerra Junqueiro

Area: 1 675.90 m^2

Number of surveys: 5

Dominant species: *Rubus ulmifolius*

Species richness: 57

	Species richness	Species cover
Native	87.72%	85.35%
Non-native	5.26%	0.75%
Non-native casual	0.00%	0.00%
Non-native naturalized	1.75%	1.64%
Non-native invasive	5.26%	12.26%

STUDY SITE 55

ID: VL_RAM01

UGS category: Vacant Lands

Location: Rua Dr. Vasco Valente

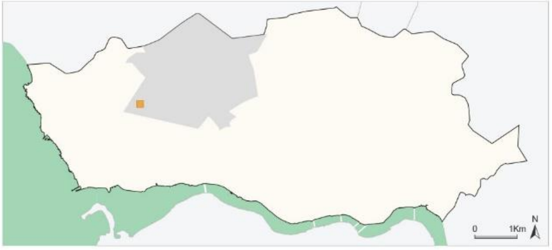
Area: 1 461.54 m^2

Number of surveys: 1

Dominant species: *Vicia cordata*

Species richness: 18

	Species richness	Species cover
Native	100.00%	100.00%
Non-native	0.00%	0.00%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 56

ID: VL_RAM02

UGS category: Vacant Lands

Location: Rua Rocha Peixoto

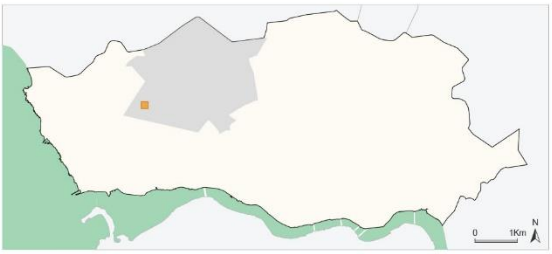
Area: 1 516.35 m^2

Number of surveys: 1

Dominant species: *Cortaderia selloana*

Species richness: 23

	Species richness	Species cover
Native	82.61%	52.29%
Non-native	8.70%	1.31%
Non-native casual	4.35%	0.65%
Non-native naturalized	0.00%	0.00%
Non-native invasive	4.35%	45.75%



STUDY SITE 57

ID: VL_RAM03

UGS category: Vacant Lands

Location: Rua Lopo Soares de Albergaria

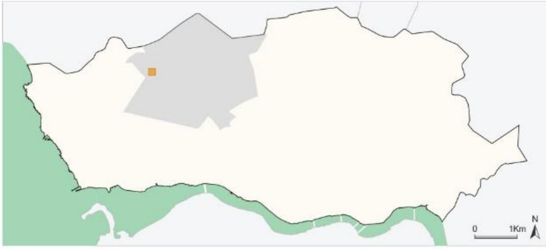
Area: 1 968.19 m^2

Number of surveys: 1

Dominant species: *Vicia benghalensis*

Species richness: 23

	Species richness	Species cover
Native	91.30%	90.16%
Non-native	8.70%	9.84%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 58

ID: VL_RAM04

UGS category: Vacant Lands

Location: Rua Dom João Coutinho

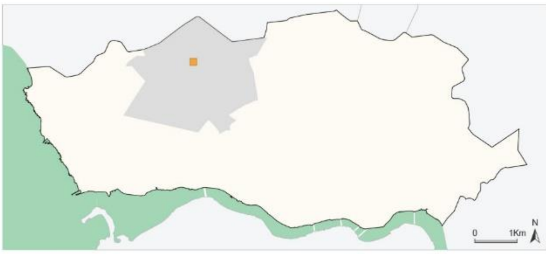
Area: 3 062.69 m^2

Number of surveys: 3

Dominant species: *Oenanthe crocata*

Species richness: 54

	Species richness	Species cover
Native	88.89%	85.19 %
Non-native	7.41%	13.35%
Non-native casual	0.00%	0.00%
Non-native naturalized	1.85%	0.24%
Non-native invasive	1.85%	1.21%



STUDY SITE 59

ID: VL_RAM06

UGS category: Vacant Lands

Location: Rua Padre Diamantino Gomes

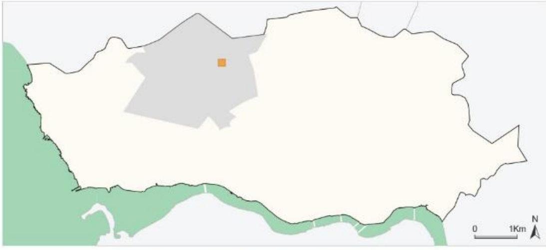
Area: 1 543.12 m^2

Number of surveys: 2

Dominant species: *Quercus robur*

Species richness: 42

	Species richness	Species cover
Native	78.57%	91.82%
Non-native	11.90%	5.45%
Non-native casual	2.38%	1.52%
Non-native naturalized	0.00%	0.00%
Non-native invasive	7.14%	1.21%



STUDY SITE 60

ID: VL_RAM07

UGS category: Vacant Lands

Location: Estrada da Circunvalação

Area: 4 477.74 m^2

Number of surveys: 1

Dominant species: *Bromus diandrus*

Species richness: 26

	Species richness	Species cover
Native	100.00%	100.00%
Non-native	0.00%	0.00%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%

STUDY SITE 61

ID: VL_RAM09

UGS category: Vacant Lands

Location: Rua Arquitecto João Andresen

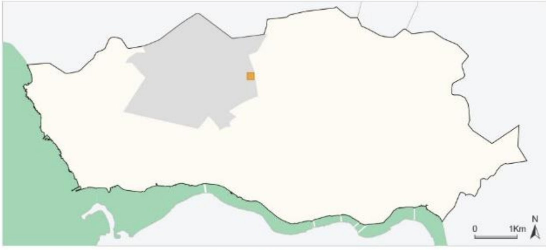
Area: 1 153.74 m^2

Number of surveys: 2

Dominant species: *Thuja plicata*

Species richness: 25

	Species richness	Species cover
Native	80.00%	53.02%
Non-native	16.00%	46.62%
Non-native casual	4.00%	0.36%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 62

ID: VL_RAM10

UGS category: Vacant Lands

Location: Rua Particular de Francos

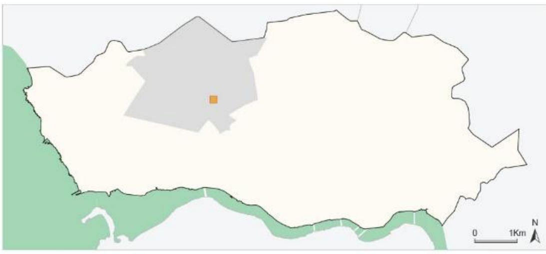
Area: 727.32 m^2

Number of surveys: 1

Dominant species: *Trifolium repens*

Species richness: 35

	Species richness	Species cover
Native	82.86%	80.34%
Non-native	11.43%	17.95%
Non-native casual	0.00%	0.00%
Non-native naturalized	2.86%	0.85%
Non-native invasive	2.86%	0.85%



STUDY SITE 63

ID: VL_RAM11

UGS category: Vacant Lands

Location: Avenida Conselho da Europa

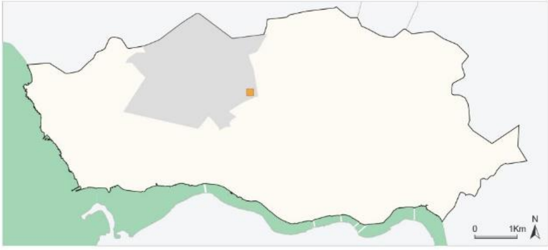
Area: 2 730.31 m^2

Number of surveys: 2

Dominant species: *Hedera hibernica*

Species richness: 26

	Species richness	Species cover
Native	84.62%	58.33%
Non-native	7.69%	18.23%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	7.69%	23.44%



STUDY SITE 64

ID: VL_CED01

UGS category: Vacant Lands

Location: Rua de Alves Redol

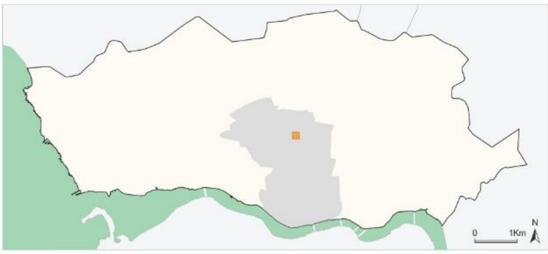
Area: 1 008.93 m^2

Number of surveys: 1

Dominant species: *Cortaderia selloana*

Species richness: 36

	Species richness	Species cover
Native	83.33%	71.54%
Non-native	13.89%	4.07%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	2.78%	24.39%



STUDY SITE 65

ID: VL_BON02

UGS category: Vacant Lands

Location: Travessa da Póvoa

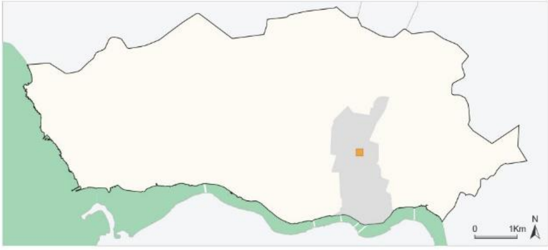
Area: 2 041.54 m^2

Number of surveys: 1

Dominant species: *Geranium purpureum*

Species richness: 14

	Species richness	Species cover
Native	92.86%	87.50%
Non-native	0.00%	0.00%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	7.14%	12.50%



STUDY SITE 66

ID: VL_PAR01

UGS category: Vacant Lands

Location: Rua do Conde de Campo Bello

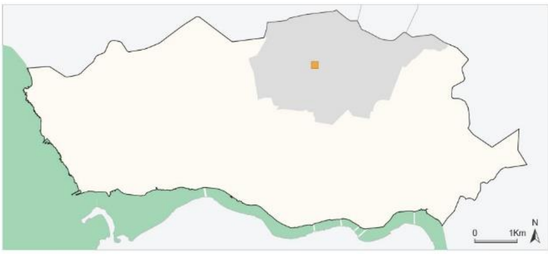
Area: 600.38 m^2

Number of surveys: 3

Dominant species: *Bidens aurea*

Species richness: 45

	Species richness	Species cover
Native	77.78%	65.71%
Non-native	11.11%	21.27%
Non-native casual	2.22%	1.59%
Non-native naturalized	0.00%	0.00%
Non-native invasive	8.89%	11.43%



STUDY SITE 67

ID: VL_PAR03

UGS category: Vacant Lands

Location: Rua Dr. António Bernardino de Almeida

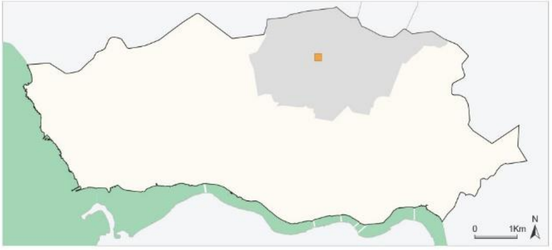
Area: 1 252.82 m^2

Number of surveys: 2

Dominant species: *Hedera hibernica*

Species richness: 42

	Species richness	Species cover
Native	88.10%	95.25%
Non-native	7.14%	1.02%
Non-native casual	0.00%	0.00%
Non-native naturalized	2.38%	0.34%
Non-native invasive	2.38%	3.39%



STUDY SITE 68

ID: VL_PAR04

UGS category: Vacant Lands

Location: Rua Dionísio dos Santos Silva

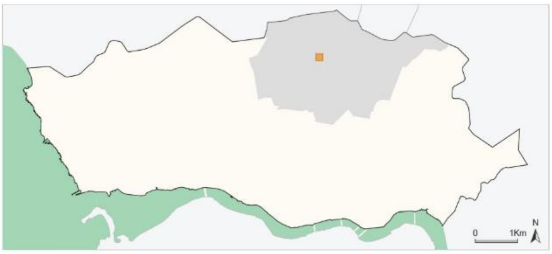
Area: 1 367.04 m^2

Number of surveys: 4

Dominant species: *Tradescantia fluminensis*

Species richness: 66

	Species richness	Species cover
Native	80.30%	63.80%
Non-native	7.58%	15.64%
Non-native casual	3.03%	1.93%
Non-native naturalized	3.03%	0.70%
Non-native invasive	6.06%	17.93%



STUDY SITE 69

ID: VL_PAR05

UGS category: Vacant Lands

Location: Rua Coronel Almeida Valente

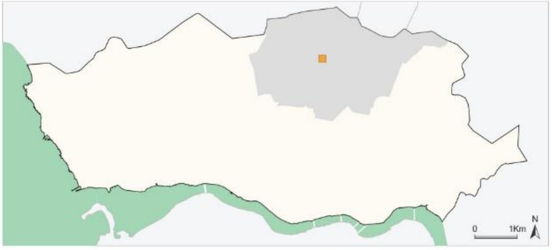
Area: 2 748.56 m^2

Number of surveys: 3

Dominant species: *Bromus diandrus*

Species richness: 50

	Species richness	Species cover
Native	84.00%	80.29%
Non-native	8.00%	6.38%
Non-native casual	0.00%	0.00%
Non-native naturalized	2.00%	2.90%
Non-native invasive	4.00%	10.43%




STUDY SITE 70

ID: VL_PAR06

UGS category: Vacant Lands

Location: Estrada da Circunvalação

Area: 2 343.48 m^2

Number of surveys: 1

Dominant species: *Cortaderia selloana*

Species richness: 14

	Species richness	Species cover
Native	71.43%	25.90%
Non-native	7.14%	0.72%
Non-native casual	7.14%	0.72%
Non-native naturalized	0.00%	0.00%
Non-native invasive	14.29%	72.66%


STUDY SITE 71

ID: VL_PAR07

UGS category: Vacant Lands

Location: Rua do Salgueiral

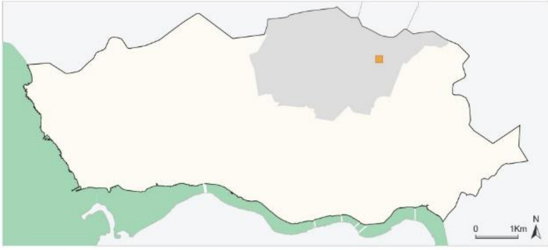
Area: 790.26 m^2

Number of surveys: 1

Dominant species: *Foeniculum vulgare*

Species richness: 28

	Species richness	Species cover
Native	85.71%	98.08%
Non-native	10.71%	1.44%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.57%	0.48%



STUDY SITE 72

ID: VL_PAR08

UGS category: Vacant Lands

Location: Rua Professor Bento de Jesus Caraça

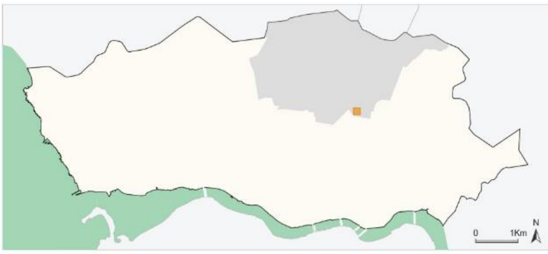
Area: 815.49 m^2

Number of surveys: 2

Dominant species: *Galium aparine*

Species richness: 25

	Species richness	Species cover
Native	76.00%	73.16%
Non-native	8.00%	20.46%
Non-native casual	8.00%	1.23%
Non-native naturalized	4.00%	1.02%
Non-native invasive	4.00%	4.10%



STUDY SITE 73

ID: VL_PAR10

UGS category: Vacant Lands

Location: Rua da Fonte do Outeiro

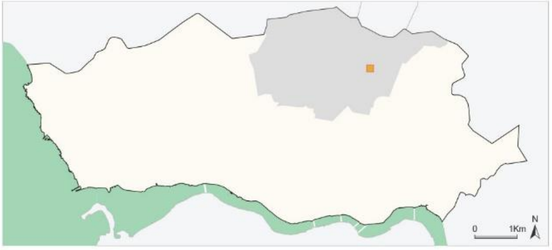
Area: 1 831.69 m²

Number of surveys: 3

Dominant species: *Hedera hibernica*

Species richness: 37

	Species richness	Species cover
Native	78.38%	78.13%
Non-native	8.11%	13.75%
Non-native casual	2.70%	1.04%
Non-native naturalized	5.41%	0.83%
Non-native invasive	5.41%	6.25%



STUDY SITE 74

ID: VL_CAM01

UGS category: Vacant Lands

Location: Calçada Ranha

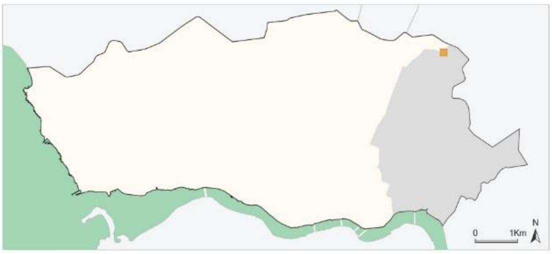
Area: 1 302.18 m²

Number of surveys: 2

Dominant species: *Celtis australis*

Species richness: 57

	Species richness	Species cover
Native	92.98%	90.73%
Non-native	0.00%	0.00%
Non-native casual	1.75%	1.25%
Non-native naturalized	1.75%	5.01%
Non-native invasive	3.51%	3.01%



STUDY SITE 75

ID: VL_CAM02

UGS category: Vacant Lands

Location: Travessa da Ranha

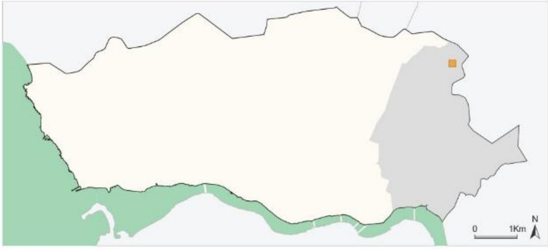
Area: 950.75 m^2

Number of surveys: 1

Dominant species: *Galium aparine*

Species richness: 31

	Species richness	Species cover
Native	93.55%	93.04%
Non-native	3.23%	0.63%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.23%	6.33%



STUDY SITE 76

ID: VL_CAM03

UGS category: Vacant Lands

Location: Rua da Nau Vitória

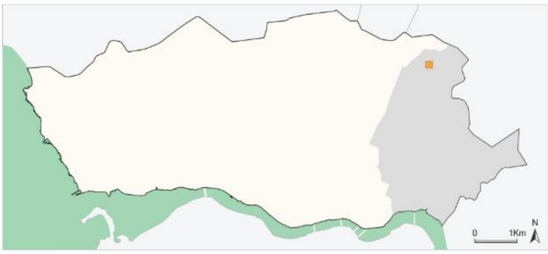
Area: 3 837.87 m^2

Number of surveys: 1

Dominant species: *Trifolium cernuum*

Species richness: 23

	Species richness	Species cover
Native	100.00%	100.00%
Non-native	0.00%	0.00%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 77

ID: VL_CAM04

UGS category: Vacant Lands

Location: Rua Dr. Corino de Andrade

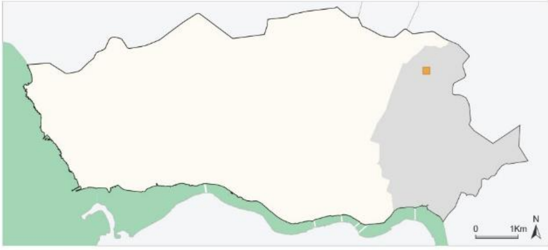
Area: 1 951.97 m^2

Number of surveys: 2

Dominant species: *Ipomoea indica*

Species richness: 37

	Species richness	Species cover
Native	91.89%	83.49%
Non-native	2.70%	0.32%
Non-native casual	0.00%	0.00%
Non-native naturalized	2.70%	0.32%
Non-native invasive	2.70%	15.87%



STUDY SITE 78

ID: VL_CAM05

UGS category: Vacant Lands

Location: Alameda de Cartes

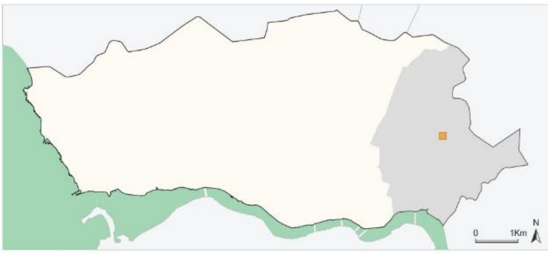
Area: 1 336.21 m^2

Number of surveys: 2

Dominant species: *Salix atrocinerea*

Species richness: 32

	Species richness	Species cover
Native	87.50%	89.12%
Non-native	9.38%	5.57%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.13%	5.31%



STUDY SITE 79

ID: VL_CAM06

UGS category: Vacant Lands

Location: Rotunda Orfeão Universitário do Porto

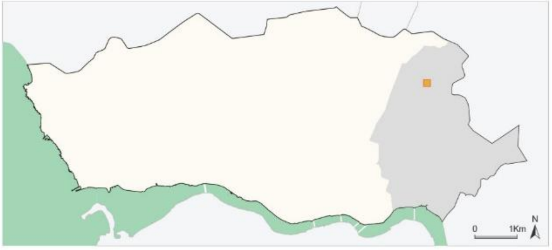
Area: 1 710.51 m^2

Number of surveys: 3

Dominant species: *Cortaderia selloana*

Species richness: 36

	Species richness	Species cover
Native	91.67%	78.23%
Non-native	0.00%	0.00%
Non-native casual	2.78%	0.24%
Non-native naturalized	2.78%	7.18%
Non-native invasive	2.78%	14.35%



STUDY SITE 80

ID: VL_CAM07

UGS category: Vacant Lands

Location: Rua João Paulo Seara Cardoso

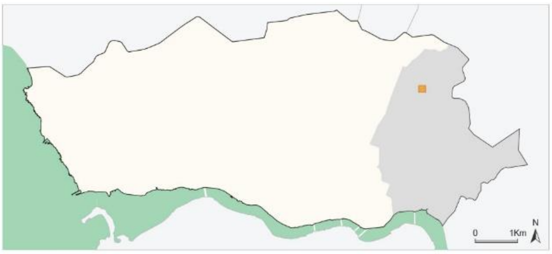
Area: 1 176.59 m^2

Number of surveys: 2

Dominant species: *Pteridium aquilinum*

Species richness: 36

	Species richness	Species cover
Native	88.89%	96.76%
Non-native	8.33%	2.83%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	2.78%	0.40%



STUDY SITE 81

ID: VL_CAM08

UGS category: Vacant Lands

Location: Rua Avelino Ribeiro

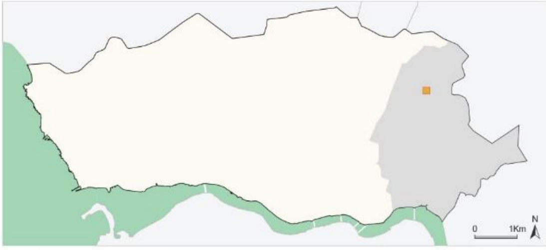
Area: 3 256.66 m^2

Number of surveys: 1

Dominant species: *Daucus carota*

Species richness: 22

	Species richness	Species cover
Native	81.82%	84.97%
Non-native	18.18%	15.03%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	0.00%	0.00%



STUDY SITE 82

ID: VL_CAM09

UGS category: Vacant Lands

Location: Rua do Giestal

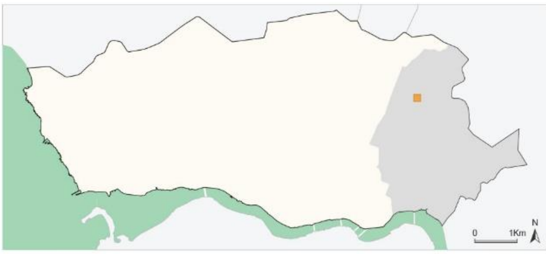
Area: 744.94 m^2

Number of surveys: 1

Dominant species: *Dittrichia viscosa*

Species richness: 25

	Species richness	Species cover
Native	84.00%	88.89%
Non-native	8.00%	6.94%
Non-native casual	0.00%	0.00%
Non-native naturalized	4.00%	0.69%
Non-native invasive	4.00%	3.47%



STUDY SITE 83

ID: VL_CAM10

UGS category: Vacant Lands

Location: Rua Maria Adelaide Freitas Gonçalves

Area: 2 727.97 m^2

Number of surveys: 2

Dominant species: *Cortaderia selloana*

Species richness: 35

	Species richness	Species cover
Native	80.00%	44.71%
Non-native	8.57%	19.41%
Non-native casual	2.86%	35.59%
Non-native naturalized	0.00%	0.00%
Non-native invasive	8.57%	0.29%

STUDY SITE 84

ID: VL_CAM11

UGS category: Vacant Lands

Location: Alameda das Antas

Area: 1 405.24 m^2

Number of surveys: 2

Dominant species: *Rubus ulmifolius*

Species richness: 38

	Species richness	Species cover
Native	89.47%	92.20%
Non-native	5.26%	3.90%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	5.26%	3.90%

STUDY SITE 85

ID: VL_CAM12

UGS category: Vacant Lands

Location: Rua Rio da Vila

Area: 1 077.95 m^2

Number of surveys: 1

Dominant species: *Geranium purpureum*

Species richness: 32

	Species richness	Species cover
Native	93.75%	93.29%
Non-native	3.13%	0.61%
Non-native casual	0.00%	0.00%
Non-native naturalized	0.00%	0.00%
Non-native invasive	3.13%	6.10%