Assessing the Impacts of Invasive Alien Plants on Urban Ecosystem Services

by

Luke Potgieter

Dissertation presented for the degree of Doctor of Philosophy

at

Stellenbosch University

Department of Botany and Zoology

Faculty of Science

Principal supervisor: Prof. David M. Richardson

Co-supervisors:

Dr Patrick J. O'Farrell

Dr Mirijam Gaertner

April 2019

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

April 2019

Abstract

The sustainable provision of ecosystem services (ES) is a critical issue in the ongoing and evolving urbanization process that is placing enormous pressures on natural resources within and around urban landscapes. Urban ecosystems provide multiple ES for human well-being, but they can also generate functions, processes and attributes that result in perceived or actual negative impacts on human well-being, termed ecosystem disservices (EDS). Understanding the ES-EDS dichotomy within the context of the urban landscape is important for promoting the development of resilient and sustainable cities.

Many alien plants introduced to urban areas around the world specifically to create, augment or restore key ES, are now firmly embedded in urban landscapes and have complex social and economic ties. Urban areas are particularly susceptible to invasion by alien plant species and some have subsequently spread beyond original plantings and have become invasive, causing negative effects on existing ES or creating novel ES or EDS. Complex interactions between humans and alien plants allow these impacts to manifest in many ways. Managing urban plant invasions is particularly challenging given the complex interactions between ecological, economic and social elements that exist in the urban milieu. Management decisions need to give explicit and transparent consideration to divergent stakeholder perceptions to mitigate potential conflicts of interest around alien and invasive plants and their management. Additionally, practical approaches for integrating ES and EDS in the decision-making process are needed to guide urban managers and planners. Given the limited resources available for managing invasive alien plants (IAPs), efficient prioritization of areas for IAP control is crucial for effective land management and ecological restoration.

A literature review was conducted to determine the role of alien plants in providing urban ES and EDS globally (Chapter 2). The city of Cape Town was then used as a study system to elucidate the complex interactions between urban residents and managers, and alien and invasive plants in a unique ecological, political and social setting. Questionnaire-based surveys were conducted across the city to determine the perceptions of urban residents regarding IAPs and the capacity of IAPs to provide ES and EDS (Chapter 3). A multi-criterion decision-making analysis (using the Analytic Hierarchy Process approach) was then performed for the city to develop a prioritisation framework for managing areas invaded by alien plants at the city/landscape and at local scales (Chapter 4). The impact of IAPs on safety and security was assessed by exploring the link between urban vegetation and criminal activity through questionnaire-based surveys, analysing criminal court cases, and searching the grey literature (Chapter 5). Finally, an approach, merging several available tools and techniques (such as remote sensing), was developed to assess the role of urban vegetation (including alien and invasive plants) in providing ES and EDS at a local-scale urban context (Chapter 6).

A small number of alien plant taxa were recorded as providing multiple ES in many urban ecosystems around the world. Some of these species also generate significant EDS (Chapter 2). IAPs and their management are perceived both negatively and positively by urban residents - these perceptions were shaped by socio-demographic characteristics of individuals (Chapter 3). Factors related to safety and security (such as fire risk to infrastructure) emerged as key features for setting spatially-explicit priorities for IAP management (Chapter 4). The association between vegetation and criminal activity may not always be determined by the biogeographical status of dominant plants (i.e. whether vegetation is dominated by native, alien, or invasive alien species), but rather on the structure they provide. A stronger link between crime and vegetation is likely to occur in areas where plant invasions have drastically altered vegetation structure, as is the case in the Cape Floristic Region (Chapter 5). At the local scale, nodes of high ES provision such as residential gardens and urban green spaces are characterized by the presence of large trees. However, many of these areas also experience numerous EDS due to invasions of alien trees and shrubs – particularly along rivers, in wetlands, and along the urban edge where tall alien trees have established and spread into natural vegetation. This suggests significant trade-offs regarding the management of species and the ES and EDS they provide (Chapter 6).

Using and developing new approaches across disciplines and spatial scales, this thesis provides new insights on the role of alien and invasive plants in providing ES and EDS in urban areas. It highlights the need to integrate public perceptions into the planning and management of IAPs in urban areas to alleviate potential conflicts of interest; it also emphasises the importance of including ES assessments in the decision-making process. The findings will be useful for managers in all urban settings to guide the selection and prioritization of land parcels for IAP management at multiple spatial scales to maximise the provision of ES.

Opsomming

Die volhoubare voorsiening van ekosisteemdienste (ED) is 'n kritieke kwessie in die voortgaande en ontwikkelende verstedelikingsproses wat geweldige druk op natuurlike hulpbronne in en rondom die stedelike omgewing plaas. Stedelike ekosisteme voorsien meervoudige ED vir menslike welstand. Hulle kan egter ook funksies, prosesse of eienskappe genereer wat lei tot voorgestelde of werklike negatiewe impakte op menslike welstand, genaamd ekosisteemwandienste (EWD). Vir die ontwikkeling van aanpasbare en volhoubare stede, is dit belangrik om die ED-EWD-kontras binne die konteks van die stedelike omgewing te verstaan.

Baie uitheemse plante wat in stedelike gebiede regoor die wêreld ingebring is, wat spesifiek sleutel ED skep, versterk of herstel, is nou stewig ingewortel in die stedelike landskap en het komplekse sosiale en ekonomiese implikasies. Stedelike gebiede is veral geteister deur uitheemse indringerspesies, wat negatiewe impakte op bestaande ED veroorsaak of nuwe ED of EWD skep. As gevolg van die komplekse aard van interaksies tussen mense en uitheemse plante, manifesteer hierdie impakte op baie maniere. Indringerbestuur in stedelike gebiede is besonder uitdagend weens die komplekse interaksies tussen ekologiese, ekonomiese en sosiale elemente in die stedelike opset. Die persepsies van die uiteenlopende belanghebbendes met potensiële belangebotsings rondom indringerbestuur moet in ag geneem word met duidelike en deursigtige bestuursbesluite. ED en EWD moet met praktiese benaderings geintegreer word in die besluitnemingsprosesse wat nodig is om stedelike bestuurders en beplanners riglyne te gee. Met die beperkte hulpbronne vir inderingerbeheer, is doeltreffende priotisering noodsaaklik vir effektiewe grondbestuur en ekologiese herstel.

In hoofstuk 2 is ‘n uitgebreide literatuuroorsig uitgevoer om die rol van uitheemse plante in die voorsiening van stedelike ED en EWD op wêreldwye skaal te bepaal. Hoofstuk 3 het die stad Kaapstad gebruik as 'n studie stelsel om lig te werp op die komplekse interaksies tussen stedelike inwoners en bestuurders, en uitheemse en indringerplante in 'n unieke ekologiese, politieke en sosiale omgewing. Om die persepsies van stedelike inwoners rakende die indringerplante te bepaal en die kapasiteit van die indringerplante om ED en EWD te lewer, is ‘n opname met vraelyste gedoen. In hoofstuk 4 is ‘n multikriteria-besluitnemingsanalise (met behulp van Analytic Hierarchy Process) uitgevoer om vir die stad 'n prioriteitsraamwerk te ontwikkel vir die bestuur van gebiede met indringerplante op ‘n stedelike en plaaslike skaal. Hoofstuk 5 beoordeel die impak van die indringerplante op veiligheid en sekuriteit deur die verband tussen stedelike plantegroei en kriminele aktiwiteit deur middel van vraelys-opnames te ondersoek, kriminele hofsake te ontleed en deur die grys literatuur te soek. Ten slotte in hoofstuk 6 is 'n benadering ontwikkel om verskeie beskikbare metodes en tegnieke (soos

'Remote Sensing') saam te voeg, om die rol van stedelike plantegroei (insluitende uitheemse en indringerplante) te assesseer in die verskaffing van ED en EWD op 'n plaaslike skaal in 'n stedelike konteks.

In stedelike ekosisteme regoor die wêreld is daar slegs 'n klein aantal uitheemse plant spesies aangeteken wat verskeie ED verskaf. Sommige van hierdie spesies verskaf egter ook beduidende EWD (Hoofstuk 2). Indringerplante en die bestuur daarvan word sowel negatief as positief deur stedelike inwoners beskou, en hierdie persepsies is gevorm deur individue se sosio-demografiese eienskappe (Hoofstuk 3). Faktore wat verband hou met veiligheid en sekuriteit (soos brandrisiko vir infrastruktuur) het as sleutelkenmerk uitgekom, om duidelike ruimtelike prioriteite vir indringerbestuur te stel (Hoofstuk 4). Die verband tussen plantegroei en kriminele aktiwiteite kan nie altyd bepaal word deur die biogeografiese status van dominante plante nie (dit wil sê of plantegroei oorheers word deur inheemse, uitheemse of uitheemse indringers spesies), maar eerder op die struktuur wat hulle verskaf. Alhoewel 'n sterker verband tussen misdaad en plantegroei waarskynlik sal voorkom in gebiede waar plantindringing 'n drasties verandering van oorspronklike plantegroei struktuur veroorsaak het (Hoofstuk 5). Op die plaaslike skaal word gebiede wat 'n hoë ED voorsien, soos residensiële tuine en stedelike parke, gekenmerk deur die teenwoordigheid van groot bome. Baie van hierdie gebiede lewer egter ook talle EWD as gevolg van uitheemse bome en struike wat indring - veral langs riviere, in vleilande en langs die stadsgrense waar uitheemse bome vestig en versprei in die natuurlike plantegroei. Dit dui op beduidende teenstellings rakende die bestuur van spesies en die ED en EWD wat hulle verskaf (Hoofstuk 6).

Met die gebruik van en ontwikkeling van nuwe benaderings oor verskeie dissiplines en ruimtelike skale, bied hierdie proefskrif belangrike insigte oor die rol van uitheemse en indringerplante in die verskaffing van ED en EWD in stedelike gebiede. Dit beklemtoon die noodsaaklikheid om publieke persepsies in die beplanning en bestuur van indringerplante in stedelike gebiede te integreer om potensiële konflik te verlig. Ook beklemtoon dit die belangrikheid om ED-assesserings in die besluitnemingsproses in te sluit. Die bevindinge is bruikbaar vir bestuurders van alle stedelike opsette vir leiding in die keuse en prioritisering van gebiede vir indringerbestuur op verskeie ruimtelike skale, sodat die maksimum ED voorsien kan word.

Acknowledgements

A huge thank you to my supervisor and mentor Prof. Dave Richardson for his support and encouragement over the past years. Thanks to my co-supervisors Patrick O'Farrell and Mirijam Gaertner for their consistent enthusiasm and endless support throughout this work.

I would also like to thank Louise Stafford for her early guidance and support and the Invasive Species Unit (especially Mfundo Wotsitsa) for access to data.

Thanks to Suzaan Kritzinger-Klopper for assisting with the Abstract Afrikaans translation.

I am deeply thankful to my beautiful wife, Genevieve, for always listening to me droning on about invasive species and always being interested. Your help, support and love are very much appreciated.

Thanks to my family and friends whom gave me support throughout the project.

A special shout-out to the almighty coffee bean. Without you, this work would not have been accomplished.

For further details see the acknowledgements section in chapters two to six.

The studies in this thesis were financially supported by the DST-NRF Centre of Excellence for Invasion Biology, the Working for Water Programme and the National Research Foundation of South Africa (through grant 85417 to Dave Richardson).

Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1. Introduction

Urbanisation is rapidly increasing globally, altering ecosystem functioning and affecting the capacity of ecosystems to provide services on which human well-being depend (Elmqvist et al. 2015; Luederitz et al. 2015). In the face of this global trend, many countries are struggling to find an appropriate balance between the demands of economic development and ensuring the delivery of ecosystem services to urban dwellers (Le Maitre et al. 2011).

Ecosystem services (ES) are the benefits that humans derive from ecosystem functions and processes and are an important basis for the well-being of society (MA 2005). ES include provisioning services such as food, water and timber; regulating services that affect climate, floods and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. Urban ecosystems are those where the built infrastructure covers a large proportion of the land surface, or those in which people live at high densities (Pickett et al. 2001). In an urban context, the ES concept describes the dependence of urban populations on the goods and services appropriated from ecosystems (Gómez-Baggethun and Barton 2013). Urban ecosystems also generate functions, processes and attributes that result in perceived or actual negative impacts on human well-being (such as environmental, social, economic, health, visual and aesthetic problems) – these are termed ecosystem disservices (EDS) (Shackleton et al. 2016; Vaz et al. 2017).

With increasing urbanization, the importance of conservation within cities grows too. Conserving and enhancing urban biodiversity have unique implications for human well-being, public health, and biodiversity conservation awareness (Kowarik 2011). Future population growth and expansion of human settlements provides escalating challenges for conservation, particularly in species-rich regions (Luck 2007). For custodians and managers of biodiversity, understanding the challenges that cities and urban areas need to cope with is critical if the planning and design of sustainability interventions are to be successful.

Urban environments are characterized by high levels of habitat heterogeneity, an abundance of disturbance-generated establishment opportunities, and modified climatic conditions. Urban areas are hubs of human-mediated introductions and are foci for the dissemination of alien species (Alston and Richardson 2006; Kowarik 2011). Many alien species introduced specifically to supply, augment or restore ES, have spread beyond original containment/plantings to become invasive. Some of these invasive species can alter ecosystem functions, reduce native biodiversity, and negatively impact on ES and human well-being (Levine et al. 2003; Pejchar and Mooney 2009; Shackleton et al. 2016). As urban populations grow, and the sustainability of different land-use practices continues to be strained, evaluating the ES and EDS provided by alien species becomes increasingly important.

Although research on invasive species has primarily been ecological in nature (García-Llorente et al. 2009; Hui and Richardson 2017), the ways in which social dimensions mediate responses to biological invasions are emerging as crucial considerations (Kull et al. 2011; Shackleton et al. 2018a). Species that provide both ES and EDS often generate conflicts of interest around their use and management (van Wilgen and Richardson 2014; Gaertner et al. 2016). Effective management strategies for such "conflict species" depend largely on cooperation and support from all stakeholders - those who support the use of these species and those who support their control. Indeed, management to optimise specific ES exclusively may exacerbate associated EDS, and interventions aiming only at reducing EDS may reduce ES (Shackleton et al. 2016). Stakeholder involvement is a fundamental element of the research agenda for invasive alien plants (IAPs) and ES (de Groot et al. 2010; Seppelt et al. 2011; Novoa et al. 2018; Shackleton et al. 2018a). Engaging with stakeholders has the potential to advance the understanding of land-use impacts, trade-offs and possible management options, thereby paving the way for more effective decision making (MA 2005). Understanding how people perceive IAPs is also essential for environmental decision-making because it can alleviate potential management conflicts and indicate where management interventions should be focused, either by identifying high-priority areas for control or determining the scale at which IAPs need to be managed.

Various strategies have been adopted around the world for managing invasive species, invaded areas, and pathways for their introduction and movement within regions. However, many problems and challenges emerge when implementing such strategies in urban contexts. Such challenges are often closely linked to the availability of funding and city-planning priorities. For example, some cities may prioritise the management of urban green space, whereas others are mandated to channel limited funding to other departments which typically receive higher priority (Irlich et al. 2017). Prioritising land parcels for IAP control helps to ensure that limited resources are appropriately allocated, resulting in the best return on investment. It also assists municipalities in addressing competing issues characteristic of dynamic urban environments.

This thesis uses interdisciplinary, multi-scale approaches that draw on socio-ecological processes and techniques to explore the links between alien plants and human well-being in urban areas. This is done in five research chapters, each of which is presented as a stand-alone paper (some of which are published, some have been submitted for publication) (Figure 1.1).

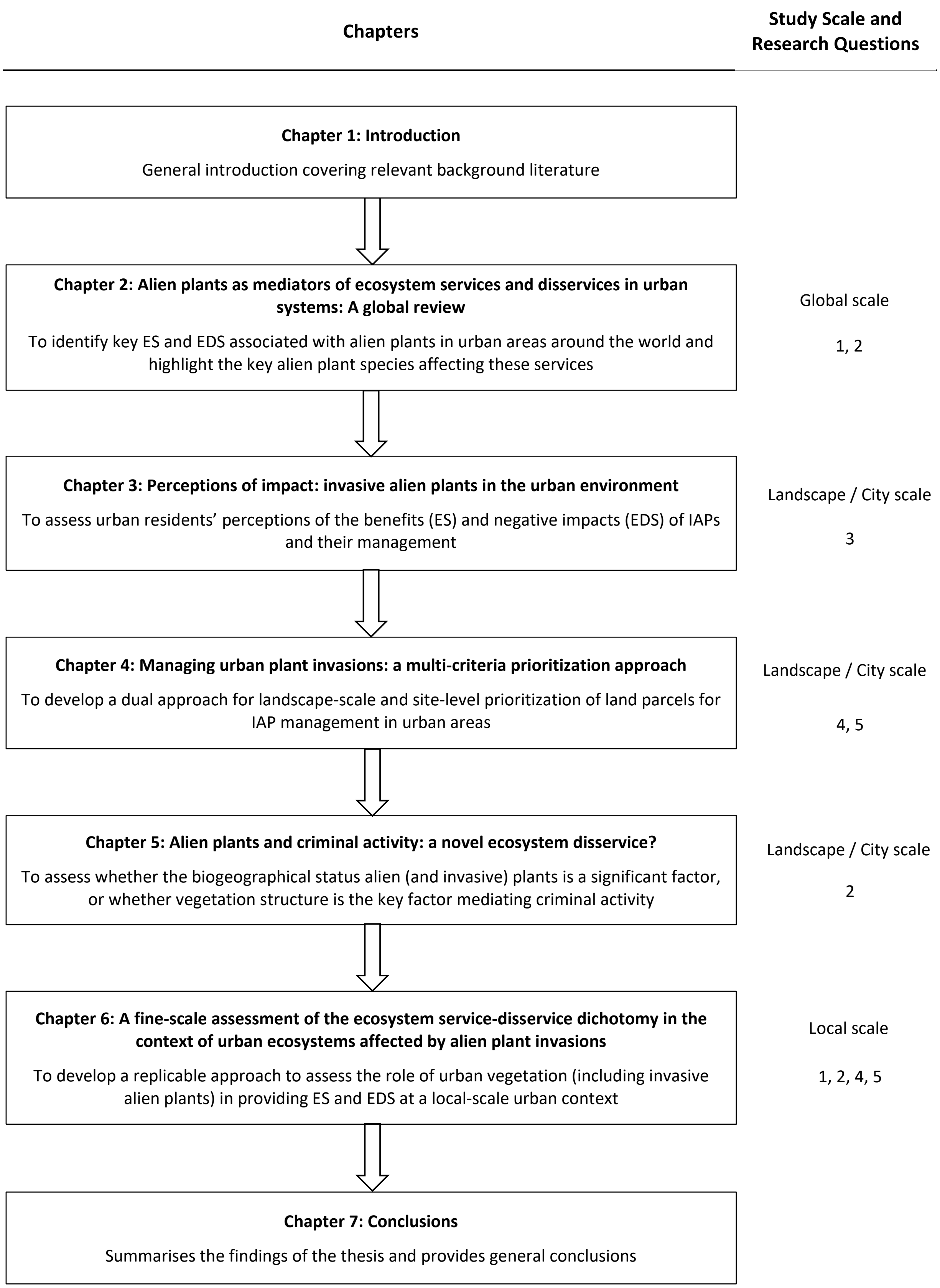


Figure 1.1. Diagram illustrating the hierarchical structure of the thesis, chapter titles, aims, and research questions.

As is common for PhD theses, the work reported in this dissertation demanded the assistance and collaboration with many people, some of whom are listed as co-authors on the published and submitted papers. In all cases, I was primarily responsible (with input from my supervisors) for the design of the research approach and formulation of the research questions. I undertook all data collection, field work and analyses and wrote the first drafts of all chapters. All co-authors assisted with interpretation of results and writing. The contributions of authors for each chapter are detailed below:

Chapter 2 – LJP conducted the literature review and analyses and wrote the first draft; all authors contributed critically to successive drafts and gave final approval for publication.

Chapter 3 – LJP conducted questionnaire surveys and interviews and wrote the first draft; all authors contributed critically to successive drafts and gave final approval for publication.

Chapter 4 – LJP, MG and LS held the workshop. LJP undertook data collection and analysis and wrote the first draft; all authors contributed critically to successive drafts and gave final approval for publication.

Chapter 5 – LJP and DMR conceived the study. LJP conducted the literature surveys, interviews, and questionnaire surveys and wrote the first draft; all authors contributed critically to successive drafts and gave final approval for publication.

Chapter 6 – LJP conceived the study. LJP conducted the analysis and wrote the first draft; all authors contributed critically to successive drafts and gave final approval for publication.

1.1 Chapter synopses

Alien and invasive plants are firmly embedded in urban areas around the world where they impact directly and indirectly on ES and human well-being in many ways. To explore this, I identified the following broad set of research questions:

1. What role do alien plants play in providing ecosystem services in urban areas?
2. How do alien and invasive plants negatively impact on ecosystem services and human well-being, and do these impacts manifest in novel ways?
3. How do urban residents perceive invasive alien plants and which factors drive these perceptions?
4. What approaches can be used to streamline decision-making and management regarding invasive alien plants in urban areas?
5. What are the major barriers to effective management of alien and invasive plants in urban areas and how can these be overcome?

Below, I briefly summarise the approaches taken in each chapter to answer the questions outlined above.

Chapter 2: Alien plants as mediators of ecosystem services and disservices in urban systems: A global review.

Citation: Potgieter LJ, Kueffer C, Larson BMH, Livingston S, O'Farrell P, Gaertner M, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588

Questions: *What role do alien plants play in providing ecosystem services in urban areas? How do alien and invasive plants negatively impact on ecosystem services and human well-being?*

Chapter 2 provides a global review of the ways in which alien plants mediate ES and EDS in urban areas around the world; the aim of this chapter was to highlight knowledge gaps and identify areas for further research. It also identifies the main ES and EDS associated with alien plants, and highlights the key species involved. This chapter shows that current knowledge about the ES and EDS provided by alien plant species in urban areas is still relatively limited and is biased in several ways. Considerable research has been done in developed countries, but much more work is needed to elucidate the link between alien plants and ES and EDS in developing countries. The review shows that urban planners and managers need to be mindful of both the positive and negative effects of alien plant species.

In subsequent studies, the city of Cape Town was used as a study system to elucidate the complex interactions between urban residents and managers, and alien and invasive plants in a unique ecological, political and social setting.

Chapter 3: Perceptions of impact: Invasive alien plants in the urban environment.

Citation: Potgieter LJ, Gaertner M, O'Farrell PJ, Richardson DM (2018) Perceptions of impact: Invasive alien plants in the urban environment. J Environ Manage. doi:10.1016/j.jenvman.2018.05.080

Question: *How do urban residents perceive invasive alien plants and which factors drive these perceptions?*

Although the level of understanding of the social aspects of biological invasions is generally poor (García-Llorente et al. 2008), there is increasing recognition of the crucial role of social issues in invasion science and management (Shackleton et al. 2018a). This chapter explores urban residents' perceptions of IAPs and their capacity to provide ES and EDS. The results show that socio-demographic variables such as age, education, environmental awareness, and ethnicity shape these perceptions and that potential conflicts of interest are likely to arise when attempting to control and eradicate IAPs. It highlights the need to integrate public perceptions into the planning and management of IAPs and emphasises the importance of including ES assessments into the decision-making process, particularly in urban areas.

Chapter 4: Managing urban plant invasions: a multi-criteria prioritization approach.

Citation: Potgieter LJ, Gaertner M, Irlich UM, O'Farrell PJ, Stafford L, Vogt H, Richardson DM (2018) Managing urban plant invasions: a multi-criteria prioritization approach. Environ Manage doi:10.1007/s00267-018-1088-4

Questions: *What approaches can be used to streamline decision-making and management regarding invasive alien plants in urban areas? What are the major barriers to effective management of alien and invasive plants in urban areas and how can these be overcome?*

Effective and efficient prioritization of areas for IAP control is crucial for effective land management and ecological restoration, as the number and distribution of invasive species increase, and budgets decrease (Hohmann et al. 2013). To guide the selection and prioritization of land parcels for IAP management, Chapter 4 develops a dual-prioritisation approach for managing IAPs in urban areas at landscape and local scales using multi-criteria decision analyses. The results show that factors related to human safety and security are most important when prioritising land parcels for IAP management across the Cape Town metro (followed by factors relating to biodiversity and ecosystem services). A strategic landscape-scale prioritisation map was developed based on the selected, weighted criteria, and a tactical (site-level) prioritisation scheme was developed for guiding on-the-ground control operations. The overall approach resulted in an intuitive framework for dealing with the complexities involved in decision-making processes in urban environments and can be useful for managers in all urban settings to guide the selection and prioritization of land parcels for IAP management.

Chapter 5: Alien plants and criminal activity: a novel ecosystem disservice?

This chapter has been submitted to the journal *Forest Ecosystems*.

Question: *How do alien and invasive plants negatively impact on ecosystem services and human well-being and do these impacts manifest in novel ways?*

Dense vegetation, especially thickets of trees or shrubs, has been associated with actual and perceived crime risk in several parts of the world (Fisher and Nasar 1992). Drawing attention to a novel interaction between humans and vegetation in a complex socio-political landscape, Chapter 5 examines the link between vegetation and criminal activity using questionnaire-based surveys, and analyses of criminal court cases and the grey literature. Using insights from multiple case studies, this chapter shows that the incidence of crime is not determined by the origin and biogeographic status of vegetation, but rather on the structure that dominant plants provide. It also shows that a stronger association between crime and vegetation is likely to occur in areas (such as the Cape Floristic Region) where plant invasions have drastically altered vegetation structure. This chapter highlights the need for context-specific approaches when managing urban plant invasions. The findings will be useful for guiding the selection and prioritization of areas for vegetation management.

Chapter 6: A fine-scale assessment of the ecosystem service-disservice dichotomy in the context of urban ecosystems affected by alien plant invasions

This chapter has been submitted to the journal *Cities*.

Questions: *What role do alien plants have in providing ecosystem services in urban areas? How do alien and invasive plants negatively impact on ecosystem services and human well-being and do these impacts manifest in novel ways? What approaches can be used to streamline decision-making and management regarding invasive alien plants in urban areas? What are the major barriers to effective management of alien and invasive plants in urban areas and how can these be overcome?*

Drawing on insights from the previous chapters, the last chapter explores the many facets of the ES-EDS dichotomy using a local-scale case study.

Given the limited resources available for assessing ES in many cities, practical approaches for integrating ES and EDS in the decision-making process are needed. Using a local-scale case study in the city of Cape Town, Chapter 6 applies remote sensing techniques and supplementary spatial data to develop a practical approach for assessing the role of urban vegetation (including invasive alien plants) in providing ES and EDS at a local-scale and identify areas denoting potential management trade-offs based on the spatial distribution of ES and EDS. The results show that areas of high ES provision (characterised predominantly by tall trees) are also associated with many EDS resulting from the presence of invasive alien trees and shrubs. This suggests significant trade-offs regarding the management of species and the ES and EDS they provide. The approach applied in this chapter can be used to provide recommendations and to guide city planners and managers to fine-tune management interventions at local scales.

This thesis provides important insights on the role of alien and invasive plants in providing ES and EDS in urban areas. It stresses the need for urban planners and managers to be mindful of both the positive and negative effects of alien plant species. It highlights the need to integrate stakeholder perceptions into the planning and management of IAPs in urban areas to alleviate potential conflicts of interest and emphasises the importance of including ES assessments into the decision-making process.

1.2 References

Alston KP, Richardson DM (2006) The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol Conserv 132:183–198

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol Complex 7:260–272

Elmqvist T, Setälä H, Handel SN, van der Ploeg S, Aronson J, Blignaut JN, Gómez-Baggethun E, Nowak DJ, Kronenberg, de Groot R (2015) Benefits of restoring ecosystem services in urban areas. Curr Opin Environ Sustain 14:101-108

Fisher BS, Nasar JL (1992) Fear of crime in relation to three exterior site features: Prospect, refuge, and escape. Environ Behav 24:35-65

Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape Urban Plan 151: 1–9. https://doi.org/10.1016/j.landurbplan.2016.03.010

García-Llorente M, Martín-López B, González JA, Alcorlo P, Montes C (2008) Social perceptions of the impacts and benefits of invasive alien species: Implications for management. Biol Conserv 141:2969-2983

Gomez-Baggethun E, Barton N (2013) Classifying and valuing ecosystem services for urban planning. Ecol Econ 83:235–245.

Hohmann MG, Just MG, Frank PJ, Wall WA, Gray JB (2013) Prioritizing invasive plant management with multi-criteria decision analysis. Invasive Plant Sci Manage 6:339–351. https://doi.org/10.1614/IPSM-D-11-00080.1

Hui C, Richardson DM (2017) Invasion Dynamics. Oxford University Press, Oxford.

Irlich UM, Potgieter LJ, Stafford L, Gaertner M (2017) Recommendations for municipalities to become compliant with national legislation on biological invasions. Bothalia 47:1–11. https://doi.org/10.4102/abc.v47i2.2156

Kowarik I (2011) Novel urban ecosystems, biodiversity, and conservation. Environ Pollut 159:1974–83.

Kull CA, Shackleton CM, Cunningham PJ, Ducatillon C, et al. (2011) Adoption, use and perception of Australian acacias around the world. Divers Distrib 17:822-836

Le Maitre DC, Gaertner M, Marchante E, Ens EJ, Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J, Richardson DM (2011) Impacts of invasive Australian acacias: implications for management and restoration. Divers Distrib 17:1015-1029

Levine JM, Vila M, D'Antonio CM, Dukes JS, Grigulis K, Lavorel S (2003) Mechanisms underlying the impacts of exotic plant invasions. Proc Roy Soc B 270:775–781

Luck GW (2007) A review of the relationships between human population density and biodiversity. Biol Reviews 82:607-645

Luederitz C, Brink E, Gralla F, et al. (2015) A review of urban ecosystem services: six key challenges for future research. Ecosyst Serv 14:98–112. doi:10.1016/j.ecoser.2015.05.001

Millennium Ecosystem Assessment (MA) (2005) Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press

Novoa A, Shackleton RT, Canavan S, Cybèle C, Davies SJ, Dehnen-Schmutz K, Fried J, Gaertner M, Geerts S, Griffiths C, Kaplan H, Kumschick S, Le Maitre DC, Measey GJ, Nunes AL, Richardson DM, Robinson TB, Touza J, Wilson JRU (2018) A framework for engaging stakeholders on the management of alien species. J Environm Manage 205:286-297

Pejchar L, Mooney HA (2009) Invasive species, ecosystem services and human wellbeing. Trends Ecol Evol 24:497–504

Pickett STA, Cadenasso ML, Grove MJ, Nilon CH, Pouyat CV, Zipperer WC, Costanza R (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu Rev Ecol Syst 32:127-157. http://dx.doi.org/10.1146/annurev.ecolsys.32.081501.114012

Seppelt R, Dormann CF, Eppink FV, Lautenbach S, Schmidt S (2011) A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J Appl Ecol 48:630–636

Shackleton CM, Ruwanza S, Sinasson Sanni GK et al. (2016) Unpacking Pandora's box: understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19:587–600. doi: 10.1007/ s10021-015-9952-z

Shackleton RT, Adriaens T, Brundu G, Dehnen-Schmutz K, Estévez R, Fried J, Larson BMH, Liu S, Marchante E, Marchante H, Moshobane C, Novoa A, Reed M, Richardson DM (2018b) Stakeholder engagement in the study and management of invasive alien species. J Environ Manage (in press) https://doi.org/10.1016/j.jenvman.2018.04.044

Shackleton RT, Larson BMH, Novoa A, Richardson DM, Kull CA (2018a) The human and social dimensions of invasion science and management. J Environm Manage (in press) https://doi.org/10.1016/j.jenvman.2018.08.04

Shackleton RT, Richardson DM, Shackleton CM, Bennett B, Crowley S, Dehnen-Schmutz K, Estévez R, Fischer A, Kueffer C, Kull C, Marchante E, Novoa A, Potgieter LJ, Vaas J, Vaz AS, Larson BHM (2018b) Explaining people's perceptions of invasive alien species: A conceptual framework. J Environ Manage (in press) https://doi.org/10.1016/j.jenvman.2018.04.045

van Wilgen BW, Richardson DM (2014) Challenges and trade-offs in the management of invasive alien trees. Biol Invasions 16:721–734. https://doi.org/10.1007/s10530-013-0615-8

Vaz AS, Kueffer C, Kull CA et al. (2017) Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst Serv 23:94–107. doi:10.1016/j.ecoser.2016.11.017

Chapter 2. Alien plants as mediators of ecosystem services and disservices in urban systems: A global review

This chapter has been published.

Citation: Potgieter LJ, Kueffer C, Larson BMH, Livingston S, O'Farrell P, Gaertner M, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588

Luke J. Potgieter[1], Mirijam Gaertner[1,2], Christoph Kueffer[1,3], Brendon M.H. Larson[4], Stuart Livingstone[5], Patrick O'Farrell[6,7], David M. Richardson[1]

[1]Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa.

[2]Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

[3]Institute of Integrative Biology, Department of Environmental Systems Science, ETH Zurich, Universitätsstrasse 16, CH-8092 Zürich, Switzerland.

[4]School of Environment, Resources and Sustainability, University of Waterloo, 200 University Avenue West, N2L3G1 Waterloo, ON, Canada.

[5]Department of Physical Environmental Sciences, University of Toronto-Scarborough, 1265 Military Trail, SW542, Toronto, ON, Canada.

[6]Natural Resources and Environment CSIR, P.O. Box 320, Stellenbosch, 7599, South Africa.

[7]Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa.

2.1 Abstract

Urban areas have unique assemblages of species, the establishment and growth of which are influenced by novel ecological processes. People living in these environments have specific needs and demands in terms of ecosystem services (ES). Urban ecosystems are transformed in many ways by human activities and their floras comprise a high proportion of alien plant species, many of which were intentionally introduced to provide, augment or restore ES. Urban environments also have novel disturbance regimes and provide colonization sites for the establishment, dispersal and proliferation of alien plant species; such conditions often generate biological invasions which may cause marked changes to ES. We review the roles that alien plants play in providing urban ES and ecosystem disservices (EDS) globally. We identify the main ES and EDS associated with alien plants, and highlight the key species involved.

A literature search revealed 335 papers, representing studies in 58 cities or urban areas in 27 countries. These studies recorded 337 alien plant species, contributing to 39 different ES and 27 EDS - 310 species were recorded as contributing to ES and 53 species to EDS. A small number of alien plant taxa were frequently recorded as providing multiple ES in many urban ecosystems; the 10 most recorded species accounted for 21% of the ES recorded. Some of these species also result in significant EDS; three species accounted for 30% of the EDS recorded. Cultural services (notably aesthetics) are the most reported ES provided by alien plants in urban areas of developed countries, while provisioning services (notably food production) are most reported in developing countries. The most commonly studied EDS provided by alien plants is the impact on human health (notably allergic reactions). Eighty percent of studies on alien plants and ES and EDS have been done in developed countries. To elucidate the full range of effects of alien plants, more work is needed in developing countries. Urban planners and managers need to be mindful of both the positive and negative impacts of alien plant species to maximise the provision of ES.

Keywords • *Ailanthus altissima* • Biological invasions • Developed and developing countries • Human health • Planning and management • Plant invasions • Tree Invasions • Urbanisation • Urban ecosystems

2.2 Introduction

Urbanization is influencing the functioning of ecosystems and the services they provide in many ways worldwide. This adds complexity to management activities that are aimed at enhancing the well-being of urban residents by preventing the loss of biodiversity and ecosystem degradation, and maintaining flows of ecosystem services (ES) into and within urban areas (Elmqvist et al. 2015; Luederitz et al. 2015). Acknowledging this global trend, local government leaders and city managers face the challenge of seeking an appropriate balance between the demands of economic development, the provision of ES, and the conservation of biodiversity (Gaston et al. 2013).

Assessments at regional and global scales indicate that human-accelerated environmental changes, including altered land use and escalating biological invasions, are compromising the provision of a range of ES and making them more prone to sudden collapse (MA 2005). Furthermore, the non-sustainable use of ES has caused widespread degradation which now threatens human health and livelihoods in many parts of the world (MA 2005). This is of particular concern in urban areas where ES are in high demand.

2.2.1 Ecosystem services and disservices in an urban context

The benefits that humans derive from ecosystem functions and processes (i.e. ES) are an important basis for the well-being of society. In this context, well-being is defined as access to secure livelihoods, health, good social relations, security and freedom (Mooney 2005). The concept of ES has been criticized for only considering the beneficial outputs of ecosystems while overlooking the unwanted or harmful effects (termed ecosystem disservices; EDS) (Vaz et al. 2017a). This is partly because different people may perceive the same ecosystem function in different ways (Gaertner et al. 2016; Kueffer and Kull 2017). For example, one person may find a tree to be aesthetically pleasing and comforting whereas another person may find it to be a source of allergens, unwanted leaf litter, and obstructed views. Such divergent views vary spatially, temporally and between individuals or societal groups (Chan et al. 2012; Shackleton et al. 2016; Kueffer and Kull 2017), thus complicating management efforts. Management to optimise specific ES exclusively may exacerbate associated EDS, and interventions aiming only at reducing EDS may reduce ES (Shackleton et al. 2016). For example, planting Black Locust (*Robinia pseudoacacia* L., Fabaceae) in urban areas provides many benefits such as aesthetic enhancement (Noe et al. 2008), shade (Moser et al. 2015), and provides resources for honey producing bees (Haussman et al. 2015), but also provides EDS such as altered soil fertility and reduced species richness (Marozas et al. 2015). Integrating ES and EDS in decision making for management may yield better outcomes for human well-being.

Urban ecosystems are those where humans live at high densities and where the built infrastructure covers a large proportion of the land surface (Pickett et al. 2001). The definition of ES in an urban context remains contested due to the spatial and temporal disparities between the physical boundaries of urban areas and the resources drawn into and used within them (Borgström et al. 2006; Luederitz et al. 2015). For example, most of the total annual water supply for the city of Cape Town, South Africa is supplied from outside the municipal boundaries of the city (Anderson and O'Farrell 2012). Valuable services from ecosystems in a city include air filtration, noise reduction, flood prevention, microclimatic regulation, and many cultural services, including recreation (Bolund and Hunhammar 1999; Costanza et al. 2007). Such ES are generated by a diverse set of green spaces (as reviewed by Haase et al. 2014).

Developing countries are now urbanising faster than any group of countries in the past (OECD 2015), while the developed world has already experienced an urban transition, with 80% of people residing in towns and cities (UNFPA 2007). Developing countries face particularly complex challenges as inefficient resource- and land-use directly results in negative environmental consequences and socioeconomic impacts (Piracha and Marcotullio 2003). The per capita resources in developing countries are significantly lower than for developed countries, and growth in developing regions is still concentrated around urban cores rather than in surrounding suburban areas (Pauchard et al. 2006). This unprecedented demographic shift is concentrating pressure on ES in and around urbanizing regions; such higher-density development presents challenges and opportunities for managing ES (Tratalos et al. 2007).

2.2.2 Importance and consequences of alien plants in urban systems

Urban floras are typically characterized by greater species richness than adjoining natural areas (Kühn et al. 2004; Wania et al. 2006), replacement of native species with alien species (Godefroid 2001; Millard 2008; Cadotte et al. 2017), and increasingly fragmented populations (McKinney 2002). Since alien plant species make up a large proportion of urban floras (Pyšek 1998; Kühn and Klotz 2006), it is important to weigh the detrimental effects of alien species against the ways they enhance local diversity and maintain important functional roles (Elmqvist et al. 2008).

Many alien plants were introduced specifically to create, augment or restore key ES (Pimentel et al. 2001), for example, to provide shade and visual amenity, provide resources for honey producing bees, provide timber and fuel wood, sequester carbon, fix nitrogen, stabilize sands and control erosion (Foster and Sandberg 2004; De Wit et al. 2009; Cilliers and Siebert 2012; Pyšek et al. 2012; Dickie et al. 2014). Yet, some alien plant species introduced for such purposes subsequently spread beyond original plantings and have become invasive, causing negative effects on existing ES (Pysek and Richardson 2010) or creating novel ES or EDS (Hobbs et al. 2013; Shackleton et al. 2014; Vaz et al. 2017a).

Trade-offs arise when the ES provided by alien plants are weighed against the EDS provided by the same species, often creating conflicts over whether to manage for the former or the latter (Gaertner et al. 2016). For example, *Rhus typhina* L. (Anacardiaceae) shows strong invasive behaviour and is cited as a source of allergy-producing pollen (Mao et al. 2013), but this species is also valued for its aesthetics (Dyderski et al. 2015). *Acer platanoides* L. (Sapindaceae) has contrasting effects on the chemical composition of the air: it removes CO_2 (thereby contributing to climate change mitigation) but contributes to the emission of biogenic volatile organic compounds (BVOCs) (Millward and Sabir 2011). BVOCs have a significant influence on air quality by increasing the concentration levels of secondary air pollutants such as ground-level ozone and secondary organic aerosols, which negatively impacts human health (Bogacki and Sygula 2013).

Urban areas are particularly susceptible to invasion by alien plant species as they are important points of entry for the introduction (intentional and inadvertent) and further spread of alien plant species into surrounding areas (Kowarik 1995; Pyšek 1998; Gaertner et al. 2016). Trade, traffic, and horticulture are the most prominent dispersal pathways (Von Der Lippe and Kowarik 2007; Padayachee et al. 2017). Altered disturbance regimes and increased resource availability associated with human activities often differentially improves the performance of alien over native plant species, leading to invasions (Daehler 2003; Cadotte et al. 2017). Furthermore, climatic conditions, hydrology, and soils that have been profoundly altered by human activity play a significant role in urban plant invasion patterns and processes (Klotz and Kühn 2010). Management of invasive alien plants (IAPs) follows very different approaches in different parts of the world, which affects the number and distribution of IAPs within cities. This is often closely linked to the availability of funding and city-planning priorities. For example, some cities may prioritise management of urban green space, while others are mandated to channel limited funding to other departments which are given higher priority (Irlich et al. 2017).

The composition of biotic communities in urban ecosystems affects ES (Kremen 2005; Bennett et al. 2009; Luck et al. 2009) and IAPs are becoming increasingly dominant in many cities around the world. This leads to concerns over the capacity and type of ES that these environments can produce and therefore the potential effects of IAPs on human well-being (Eviner et al. 2012). To respond, managers need a better understanding of the drivers of establishment of the species, how they impact local biodiversity, and their effect on ES and/or EDS. It is therefore imperative to further our understanding of the links between IAPs and ES/EDS so that we can better manage their delivery and to ensure their ability to withstand and recover from disturbances and diverse facets of environmental change (Carpenter et al. 2001).

This paper identifies key ES and EDS associated with alien plants in urban areas around the world and highlights the key alien plant species affecting these services. We also contrast the role of alien plants in providing ES and EDS in developing and developed country contexts and identify potential research gaps. This study provides important insights on the links between alien plants and ES and EDS in urban areas and may help guide urban managers in prioritizing alien plant species for management and developing appropriate strategies for enhancing ES provision.

2.3 Methods

2.3.1 Data collection

We reviewed the literature, using ISI Web of Science, Scopus and Google Scholar, to identify key ES around the world and the most important alien plant species that affect such services. As the term 'ecosystem service' is not always used in the literature, we searched the whole document for keywords related to the ES categorisation of the Millennium Ecosystem Assessment (MA) (2005) and refined the search to include literature from only urban areas. Examples of keywords used for the search included: "urban*" OR "city" OR "cities" OR "town" OR "metropolitan" OR "built-up" AND "ecosystem service*" OR "environment* service*" OR "landscape service*" OR "ecologic* service*" AND "food" OR "fibre" OR "fuel" (see Appendix A for a full list of keywords searched). Our literature search criteria did yield several non-English publications (with abstracts in English) and these were included in the analysis.

EDS were categorised according to the typology proposed by Vaz et al. (2017a) (namely health, material, safety and security, cultural and aesthetic, and leisure and recreation), but two additional categories (economic and environmental problems) were included based on the categorisation of Roy et al. (2012). Because the concept of EDS (particularly in urban settings) is new, we searched for keywords related to urban areas and the aforementioned EDS categories, and not only to explicit reference to "disservices". Examples of keywords used for the search included: "urban*" OR "city" OR "cities" OR "town" OR "metropolitan" OR "built-up" AND "ecosystem disservice*" OR "environment* disservice*" OR "landscape disservice*" OR "ecologic* disservice*" OR "ecosystem dis-service*" AND "health" OR "safety" OR "security" OR "aesthetic" (see Appendix A for a full list of keywords searched). Additional papers were identified from the reference lists of papers found through the formal literature search (i.e. snowballing).

We acknowledge that our search did not locate all the literature on ES and EDS, but we are confident that the collection of publications that were included in our analysis provides an appropriate sample for a broad overview of the most significant literature and to draw reliable conclusions on recent approaches to urban invasions and ES and EDS research. Importantly, several biases exist in the literature. For example, the invasive species literature is biased in favour of studies that address the negative impacts of a limited number of taxa or plant groups. On the other hand, the literature on landscape architecture, gardening, and urban design is biased towards studies that emphasize the positive roles of alien plants. Similarly, the literature on ES and EDS provided by urban vegetation rarely distinguishes between native and alien species and for the latter seldom address their introduction status (i.e. whether the species is just alien, naturalized or invasive). The literature on invasive alien species heavily underrepresents social and cultural aspects (Vaz et al. 2017b), which may have led to a strong underrepresentation of cultural ES and EDS, and especially of non-economic and informal ones. There is also a biased towards few intensively and many little studied species in the invasive species literature (Kueffer et al. 2013).

2.3.2 Analysis

The following information was recorded for each publication retrieved in our search: (i) ecosystem service category (categorised according to the MA 2005); (ii) ecosystem service; (iii) ecosystem disservice category (categorised according to Vaz et al. 2017a); (iv) ecosystem disservice; (v) urban area (city, town, etc.); (vii) country; (viii) world region; (ix) species name; and (x) literature source. The countries in which the research took place were further categorised into developed or developing countries based on the classification of the United Nations (2017). Only studies which referred to alien taxa at the species level were included in the analysis. Where studies did not differentiate between alien and native plant species, we identified the native range of each recorded species using peer-reviewed literature and noted whether it was native or alien at the respective study sites (a list of all publications appears in Appendix B). Where possible, we noted from the literature whether the alien plant species was classified as invasive at the study site (following the criteria proposed by Richardson et al. 2011).

2.4 Results

The literature search revealed 335 papers, representing studies in 58 cities or urban areas in 27 countries. These studies recorded 337 alien plant species, contributing to 39 different ES and 27 EDS; 307 species were recorded as contributing to the provision of ES and 53 species to EDS. A small number of alien plant taxa were frequently recorded as providing multiple ES and the 10 most recorded species accounted for 21% of the ES recorded. Some of these species also result in significant EDS and three species accounted for 30% of the EDS recorded. There was a clear bias towards studies in Europe (41% of studies from 33 cities in 14 countries) and North America (28% of studies from 17 cities in USA and Canada).

2.4.1 Alien plants and ecosystem services and disservices

Regarding ES, the role of alien plants is most significant in the delivery of provisioning services, with 172 species contributing to the provision of services such as food production (Fig. 2.1). Next most important were cultural services with 137 species found to be important in delivering services such as aesthetic enhancement. Regulating services have received relatively little attention in the literature and 33 species were found to be important in delivering services such as CO_2 sequestration and improving air quality. The role of alien plants in the delivery of supporting services (e.g. nutrient cycling and soil formation) has received the least attention and only 16 species were identified as being important in this regard.

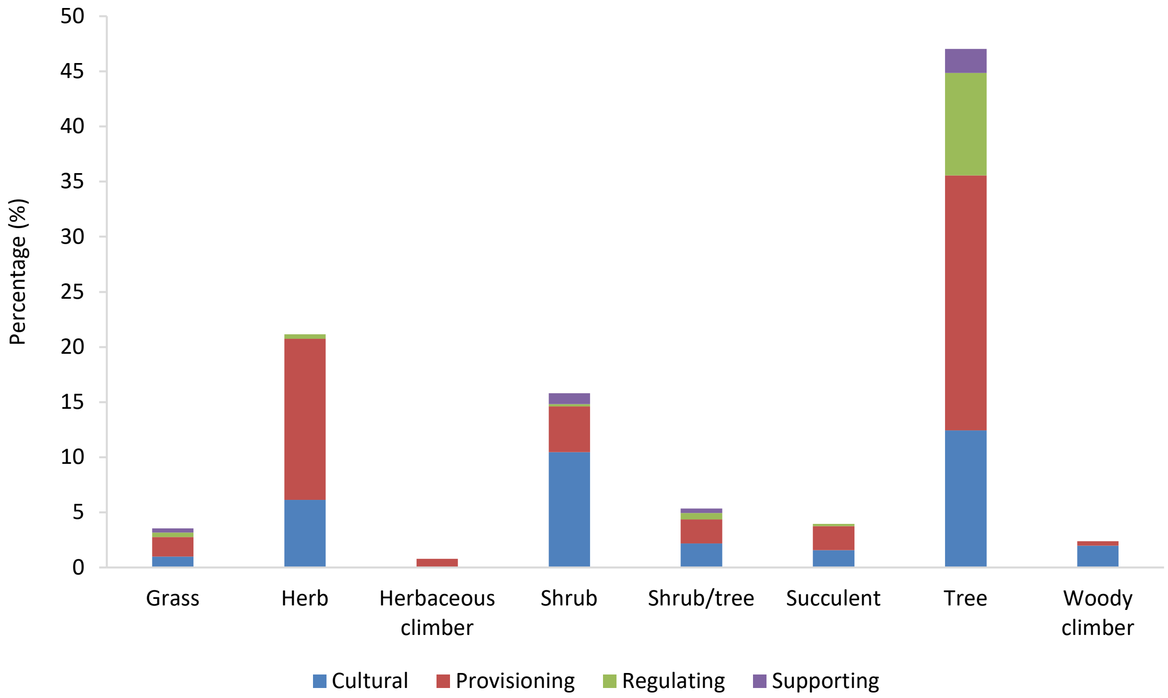


Figure 2.1. Percentage of alien plant species recorded as providing urban ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005), classified according to growth form.

Our analysis shows that 67% of studies focussed on woody alien plant species, with trees and shrubs providing ES across all service categories (Fig. 2.1). Herbaceous alien plant species have received less attention in the literature. Of the woody alien plants, the role of *Ailanthus altissima* (Mill.) Swingle (Simaroubaceae) contributing to ES was the most prevalent in the literature, followed by *Platanus* x *acerifolia* (Aiton) Willd. (Platanaceae), while *Carica papaya* L. (Caricaceae) was the most studied herbaceous plant (Table 2.1; although this species exhibits a tree-like growth form, it is categorised as herbaceous; Ming et al. 2008).

Table 2.1. Number of records in the literature of urban ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005) provided by the ten most recorded alien plant species (see Appendix C for the full list of records).

Species	**Family**	**Growth Form**	**Ecosystem Service Category**				**Total**
			Cultural	Provisioning	Regulating	Supporting	
Acer platanoides L.	Sapindaceae	Deciduous tree	1	2	4	0	7
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	4	15	6	7	32
Carica papaya L.	Caricaceae	Evergreen herbaceous tree	0	9	0	0	9
Jacaranda mimosifolia D.Don	Bignoniaceae	Deciduous tree	3	1	1	0	5
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	1	0	4	5
Morus alba L.	Moraceae	Deciduous tree	2	4	1	0	7
Opuntia ficus-indica Mill.	Cactaceae	Succulent shrub/tree	3	2	0	0	5
Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	3	2	5	0	10
Psidium guajava L.	Myrtaceae	Evergreen shrub/tree	1	4	1	0	6
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	2	1	3	0	6

The most commonly studied EDS provided by alien plants was the impact on human health (Fig. 2.2), with 53 species contributing to EDS such as allergic reactions or the emission of BVOCs, followed by the creation of environmental problems, with 21 species providing EDS such as the alteration of soil fertility and reducing species diversity. Other EDS included infrastructural damage, reduction in property value, and threats to safety. Woody alien plant species resulted in the greatest proportion of EDS with 78% of the most harmful species being woody and only 19% being herbaceous (Fig. 2.2).

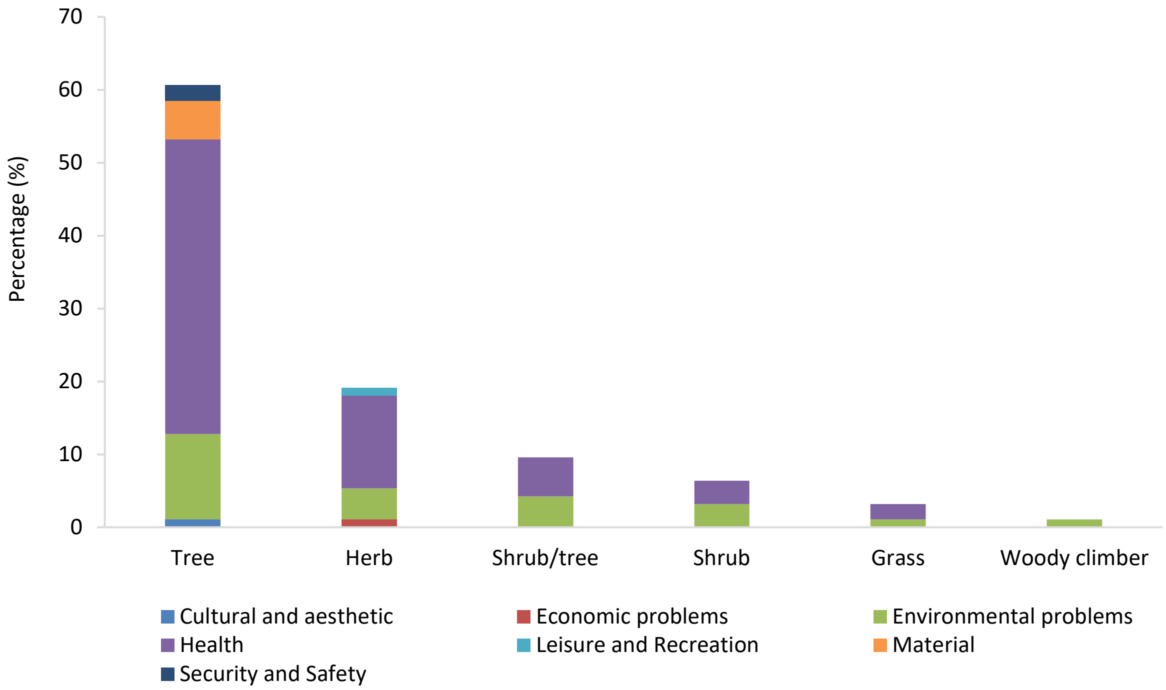


Figure 2.2. Percentage of alien plant species recorded as providing ecosystem disservices (categorised according to the Vaz et al. 2017a and Roy et al. 2012), classified according to growth form.

There is a strong connection between the species that are important for the provision of ES and those that result in EDS – 27% of all recorded species provided both ES and EDS. *Ailanthus altissima*, although important for the provision of ES (see Box 1), results in several EDS such as infrastructural damage, pollen allergies, and loss of biodiversity (Casella and Vurro 2013; Table 2.2). Similarly, *Platanus x acerifolia* contributes to the provision of ES such as CO_2 sequestration, but also generates EDS such as the emission of BVOCs. The allergenic *Ambrosia artemisiifolia* L. (Asteraceae) was most harmful of the herbaceous species given its impacts on human health in many European cities (Table 2.2).

Table 2.2. Number of records in the literature of urban ecosystem disservices (categorised according to Vaz et al. 2017a and Roy et al. 2012) provided by the ten most recorded alien plant species (see Appendix C for the full list of records).

Species	**Family**	**Growth Form**	**Ecosystem Disservice Category**							**Total**
			Cultural and aesthetic	Economic problems	Environmental problems	Health	Leisure and recreation	Material	Security and safety	
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	1	0	5	6	0	5	2	19
Ambrosia artemisiifolia L.	Asteraceae	Annual herb	0	0	0	9	0	0	0	9
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	0	0	3	2	0	0	0	5
Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	0	0	0	4	0	0	0	4
Rhamnus cathartica L.	Rhamnaceae	Deciduous shrub/tree	0	0	3	0	0	0	0	3
Vincetoxicum rossicum (Kleopow) Barbar.	Asclepiadaceae	Perennial herbaceous vine	0	0	3	0	0	0	0	3
Cedrus deodara (Roxb. ex D.Don) G.Don	Pinaceae	Evergreen tree	0	0	0	2	0	0	0	2
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	0	2	0	0	0	0	2
Myriophyllum spicatum L.	Haloragaceae	Aquatic perennial herb	0	1	0	0	1	0	0	2
Rhus typhina L.	Anacardiaceae	Deciduous shrub	0	0	0	2	0	0	0	2

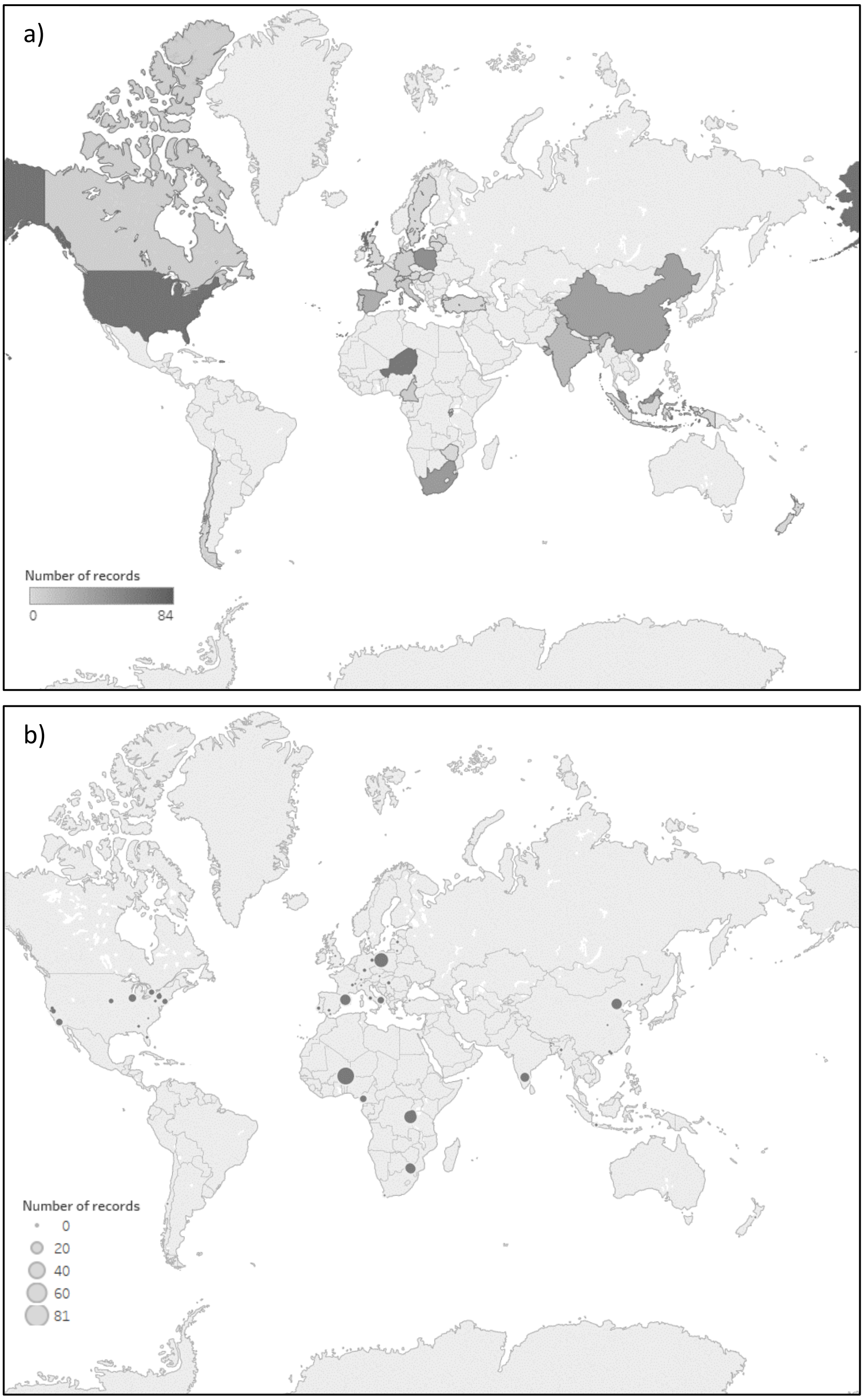


Figure 2.3. Geographic distribution of literature records included in the analysis for a) countries and b) urban areas around the world.

2.4.2 Alien plants in the developing world

Research on the roles that alien plants play in providing ES is largely confined to urban areas in developed countries (Fig. 2.3a). Of the 310 species recorded in the literature, 60% occurred in urban areas of developing countries and 40% in developed countries. The cities with the greatest number of records were Niamey (Niger) and Poznań (Poland) (Fig. 2.3b), though high numbers in these cities as well as some others (e.g. Bujumbura, Burundi, and Seshego, South Africa) resulted from one publication for each city that compiled comprehensive species lists and corresponding uses.

Table 2.3 shows that cultural services provided by alien plants are most recorded in urban areas of developed countries while provisioning services are most often recorded in developing countries. Alien plants used for aesthetic/ornamental purposes are most significant in developed countries, while food production is the most important ES in developing countries (Fig. 2.4).

Table 2.3. Percentage of records (of a sample of 335 papers) linking alien plants with ecosystems services (categorised according to the Millennium Ecosystem Assessment 2005) and ecosystem disservices (categorised according to Vaz et al. 2017a and Roy et al. 2012) in urban ecosystems in developed and developing countries around the world.

	Developed	**Developing**
Ecosystem Service Category		
Cultural	18.6	17.2
Provisioning	12.1	37.2
Regulating	9.1	2.0
Supporting	4.0	0
Ecosystem Disservice Category		
Cultural and aesthetic	1.1	0
Economic problems	1.1	0
Environmental problems	24.5	1.1
Health	63.9	0
Leisure and Recreation	1.1	0
Material	5.3	0
Security and Safety	2.1	0

There is a dearth of literature on the role of alien plants in providing EDS in urban areas of developing countries (Table 2.3). Of the 95 studies recording EDS provided by alien plants in urban areas, only one was from a developing country – an increase in density of *Acacia saligna* H.L.Wendl. (Fabaceae) was found to reduce avian species richness in urban and peri-urban areas of Cape Town, South Africa (Dures and Cumming 2010).

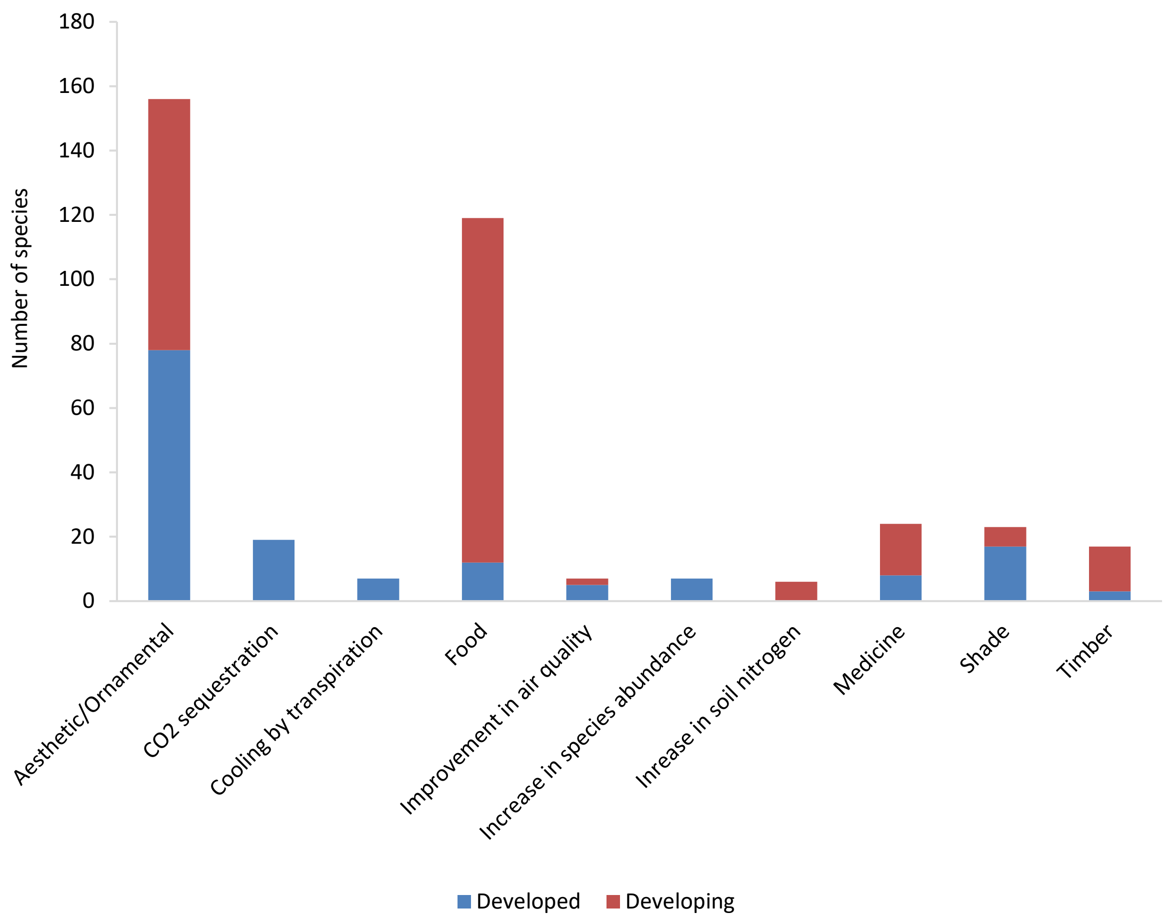


Figure 2.4. The ten most recorded urban ecosystem services provided by alien plant species for developed and developing countries.

2.5 Discussion

2.5.1 The role of alien plants in urban ecosystem service provision

Alien plant species have been introduced to urban centres around the world where they play an important role in providing ES. A select number of alien plant taxa are widely recorded as providing multiple ES (Table 2.1). Cultural and provisioning services have received the most research attention, while few studies have addressed how alien plants affect regulating and supporting services, either positively or negatively (Fig. 2.1) – a trend also observed by Charles and Dukes (2007). This may be due to the relative insignificance of their impact on these functions in urban areas. Provisioning services are the easiest to assess, since their effects occur over shorter time scales and are often felt more acutely, at least initially, than for other ES (Charles and Dukes 2007). Moreover, good data are available on provisioning services and such information is often highly relevant for decision-makers (van Wilgen et al. 2008). Regulating services are the benefits obtained through the natural regulation of habitats and ecosystem processes (MA 2005). Such ES may be characterized as being of indirect use because they provide the conditions that allow other directly used ES (e.g. provision of food) to exist (Abson and Termansen 2011). Similarly, supporting services do not directly benefit people, but are essential to the functioning of ecosystems and are therefore indirectly responsible for all other services (Haines-Young and Potschin 2010). Consequently, these services are more difficult to quantify (Rodriguez et al. 2006), particularly in urban settings, though it is also noteworthy that many IAPs may be significant providers of regulating and supporting services.

Cultural services such as ornamentation or aesthetics are significant in urban areas in both developed and developing countries (Table 2.3). Some alien plants are an important source of food in urban areas, particularly in developing countries where many alien plant species (e.g. *Carica papaya*, *Ipomoea batatas* (L.) Lam; Convolvulaceae) are cultivated in domestic gardens to produce fruits and vegetables for household consumption or for selling (e.g. Andersson et al. 2007; Hynes and Howe 2004; Bigirimana et al. 2012; Guitart et al. 2012). While the importance of utilising alien plant species in allotment and garden food production in developed countries has received little attention in the literature, studies in developing countries, where alien plants are utilized more extensively for urban food production, suggest that urban agriculture can provide additional food and nutrition security for households (Maxwell et al. 1998; Drescher 2004).

Although important for the provision of ES in cities, the flora of public and domestic urban gardens are an important source of potentially IAPs (Smith et al. 2006; McLean et al. 2017), as many alien plant species grown in gardens have escaped cultivation and become invasive within urban areas and surrounds (Williamson and Fitter 1996; Alpert et al. 2000; Alston and Richardson 2006; Guo et al. 2006). For example, *Catharanthus roseus* regia (L.) G.Don (Apocynaceae) is a common garden ornamental in Bujumbura, Burundi, but has consequently spread and is now listed as invasive (Bigirimana et al. 2012). Although the introduction of new plant species for aesthetic reasons is still an important pathway worldwide (Hulme et al. 2017), the major contribution by which ornamental horticulture facilitates plant invasions may be through repeated local introduction of alien plants, and the selective breeding of traits which increase the likelihood of successful establishment (Kowarik 2003).

While propagule pressure affects the range of introduction and the success of certain introduced species (e.g. Castro-Diez et al. 2011; Potgieter et al. 2014), the ability of species to escape cultivation and establish new populations relies largely on their life-history characteristics (Aronson et al. 2007); although the relevant life-history traits may differ between natural and man-made landscapes such as urbanised areas (Kueffer et al. 2013). Life-history characteristics associated with human importation, such as large showy flowers, colourful fruits and adaptation to disturbed areas can also be associated with reproductive success and efficient dispersal, thus allowing species to establish and spread into new environments (Aronson et al. 2007; Moodley et al. 2013). This trend in human preference for particular plant traits has led to an increase in the proportion of alien trees and shrubs in many urban areas due to escaped woody ornamentals (see Fig. 2.1, 2.2) and has been reported for cities in Italy (Celesti-Grapow and Blasi 1998), Germany (Kowarik 2005) and the Czech Republic (Chocholoušková and Pyšek 2003).

Box 1. *Ailanthus altissima* – an urban invader

Urbanization can result in 'biotic homogenization' (McKinney 2006). One reason for this is the intentional planting of a relatively small number of alien plant species and cultivars in gardens and landscaping schemes (McKinney and Lockwood 1999; Reichard and White 2001; Sullivan et al. 2005). Species adapted to highly modified built habitats at the urban core are ''global homogenizers'' and are found in cities worldwide (McKinney 2006). As cities expand across the world, biotic homogenization increases as the same ''urban-adaptable'' species become more widespread and locally abundant (McKinney 2006).

Ailanthus altissima (tree of heaven) is native to Southeast Asia but has been introduced to urban centres around the world, primarily for ornamental purposes (Kowarik and Säumel 2007; Walker et al. 2017). Sladonja et al. (2015) review the impacts of *A. altissima* on ecosystems and ecosystem services (ES). They highlight the trade-offs associated with this species as positive influences on some ES are weighed against the negative effects on the environment and human health.

Urban populations of *A. altissima* can cause significant damage to infrastructure and archaeological sites with its roots, and cause allergic reactions, respiratory problems, and skin rashes (Derrick and Darley 1994; Ballero et al. 2003; Celesti-Grapow and Blasi 2004; Luz-Lezcano Caceres and Gerold 2009; Burrows and Tyrl 2013). Although the species clearly has significant negative impacts, it also provides key cultural, provisioning, regulatory and supporting services, particularly as a source of active compounds and environmental restoration. Its tolerance of a broad range of site conditions and of most pollutants enables further functional uses as an ornamental, shelterbelts, and for erosion control (Kowarik and Säumel 2007). However, such traits enable this species to thrive in urban environments, and ineffective management approaches coupled with high levels of propagule pressure have allowed *A. altissima* to spread rapidly, resulting in significant impacts on the environment and human health (Sladonja et al. 2015).

Sladonja et al. (2015) suggest that in environments altered by human activities, *A. altissima* does not present any major threats and its invasive properties are outweighed by its potential ES. In areas where it has spread into natural ecosystems, it compromises ecological stability, and must be controlled. However, they also suggest that all the potentially positive effects of *A. altissima* presence may be outweighed by the significant costs associated with controlling the species should it continue to spread and densify.

2.5.2 Alien plants and urban ecosystem disservices

As found by Shackleton et al. (2016), our analysis showed that very little is known about the role of alien plants in providing EDS in urban environments, specifically in developing countries (Table 2.3). Von Döhren and Haase (2015) also note that most studies on EDS focus on Western Europe or the USA. Given the trend of urbanisation in developing countries and the ever-increasing dependence on the provision of ES for human well-being, the degradation of these services is a growing concern for city managers. Improved understanding of the drivers of these EDS is thus crucial.

The emphasis in the literature on certain alien plant taxa and the EDS they provide may have been initiated in response to their abundance in urban landscapes due to high levels of widespread plantings and/or invasion. Certainly, there is evidence of spatial clustering of IAPs in urban environments that leads to concentrations of EDS in certain urban landscape types (Štajerová et al. 2017). Thus, the EDS associated with more 'benign' alien species may be overlooked. Moreover, the role of woody plant species in providing both ES and EDS may be more obvious than that of the less conspicuous herbaceous species (Fig. 2.1, 2.2), and this trend may continue given the increasing shift in the distribution of trees and shrubs resulting from human preference for particular plant traits (see Williams et al. 2015).

2.5.3 Disparity between developed and developing countries

Developed countries were much better represented than developing countries in publications located in our literature search. This is probably partly because there are many more publications on issues relating to ES and EDS from developed countries overall (Luederitz et al. 2015; Grêt-Regamey et al. 2016). We recognize that our review has almost certainly missed some important contributions and insights from more obscure journals and from the grey literature, especially such publications in languages other than English.

The trend of urbanisation in developing countries has resulted in an increased demand for planning and the provision of basic services (such as water, waste disposal, regulation of climate and air quality, and food production), many of which are provided by ecosystems (Elmqvist et al. 2013). This demand is particularly high in the peri-urban poor communities of developing countries. This is partly due to the provision of such basic services being significantly lower in peri-urban zones than in urban centres. Therefore, planting species which can provide such services can relieve some of these pressures in these less economically stable areas.

A greater number of low- to middle-income people live in urban areas in developing countries, and this disparity in urban versus nonurban populations is growing (Cohen 2004). Owing to a reduction in income differentiation, urban areas of developing countries may be more homogenous than urban areas of developed countries, but native habitats continue to be transformed as the urban core expands (Huebner et al. 2012). This means that fewer remnants of native habitats are likely to persist in urban areas in developing countries, and fewer new alien (and potentially invasive) plant species are likely to be introduced (Huebner et al. 2012). This may ultimately result in urban areas with relatively low plant-species diversity, which may contain already established IAPs, but not act as a source of IAPs. The implications of this trend for the provisioning of ES and EDS requires further research, as the links between urban biodiversity (e.g. native versus alien plant taxa) and ES/EDS provisioning are still emerging (Dearborn and Kark 2010).

Scaling down to the city level, wealthier neighbourhoods tend to have increased numbers of perennial plant species, due to the higher disposable income of landowners (Hope et al. 2006). In their study of the developed city of Beijing, Clarke et al. (2014) found that species diversity and abundance shifts according to a hierarchy of need from ornamental species (cultural ES) to edible species (provisioning ES) with increasing distance from the city centre. Gardens in cities of developing countries contain species that are selected based on their food or medicinal value (Blanckaert et al. 2004; Winklerprins and de Souze 2005). Cilliers et al. (2013) found that plant species providing provisioning services such as food and medicine, and regulating services such as shade were more common in the gardens of lower income residents than in those of more affluent areas. Gavier-Pizarro et al. (2010) found that richness of alien plants was positively correlated to mean income and low-density residential areas. These studies suggest that income may function as a proxy measure of socio-economic activities that favour alien plant introductions and potential invasions, although importance of other socio-economic factors such as lifestyle behaviour and housing age (Grove et al. 2006) should not be discounted.

Indeed, this geographical disparity in research may be more idiosyncratic as some developing nation cities are well represented (albeit from single studies) and little from the UK or Australia. Therefore, supporting standardized analyses globally may be more prudent than overcoming a developed/developing nation dichotomy.

2.6 Knowledge gaps

While the composition of urban floras and the associated spatial and temporal changes have been well studied, there is a dearth of information on the role of alien plants in providing and mediating ES and EDS. Another gap is that many impacts (both positive or negative) are described qualitatively rather than measured, making it difficult to determine 'net' outcomes, and complicating synthetic analyses that seek to determine benefit: i.e. cost ratios. Indeed, researchers have struggled to develop a general approach for the quantification of invasion impact in urban areas (Kumschick et al. 2014). A diverse range of terminology describing ES in urban areas exists in the literature. For example, ES provided by urban green space (urban floras) are increasingly discussed in the context of “green infrastructure” or “nature-based solutions” in “sustainable cities” (Kabish et al. 2016; Scott et al. 2016; Hui et al. 2017). A unified lexicon within an ES context would be useful.

There has been a strong research focus on certain ES (e.g. air quality), but the species affecting such services are seldom mentioned. Moreover, the literature on ES or EDS provided by urban vegetation rarely distinguishes between native and alien species (and the introduction status for the latter is seldom clearly stated). For example, Barau (2015) presents comprehensive lists of common urban household plants used for ornamental purposes in Malaysia but does not specify whether the species are native or alien. There is also a clear disparity in the ES and EDS literature between urban areas in developed and developing countries, with a strong focus on the former. There is a need to further our understanding of the role of alien plants on ES in urban areas in developing nations, especially given the importance of effective ES delivery.

Several species are repeatedly mentioned in studies of urban plant invasions around the world, but little mention is made of their role in ES or EDS. For example, although *Robinia pseudoacacia* (25 hits in our literature search) is referred to in many studies of urban floras (e.g. Song et al. 2005; Cierjacks et al. 2013; Kowarik et al. 2013), the role of this species in mediating ES and EDS is seldom addressed. Such species often have high levels of propagule pressure, long residence time, and life-history traits suited to proliferation in urban environments. Further research is required to elucidate the impact of such species on ES and EDS.

Another important question is whether native plant species can provide the same (or more) ES than are currently provided by urban alien plant taxa and if so, whether there are associated EDS. Johnston et al. (2012) argue that a preference for native plants species may lead to urban landscapes with limited environmental, economic and social benefits. Dickie et al. (2014) describe several examples where attempts to remove alien trees were delayed or halted due to their perceived importance in providing ES such as food or habitat for charismatic or endangered native fauna. From a biodiversity conservation perspective, alien tree species can provide ES in support of other biodiversity (Johnston et al. 2012; Chalker-Scott 2015). For example, Gariola et al. (2013) found that the alien tree species *Melia azedarach* L. (Meliaceae) was a common host for native mistletoes in urban parks in Durban, South Africa. Alien plants are culturally embedded in urban landscapes around the world and have strong ties to ES provision. Much more work is needed to compare the role of native and alien plant species and the ES and EDS they provide in urban environments. Such research might become more pertinent in the context of the adaptation of cities to climate change (Sjöman et al. 2016).

2.7 Conclusions

Our review indicates that knowledge about ES and EDS provided by alien plant species to urban areas is still relatively limited and is biased in several ways. Overall, few alien species have been comprehensively studied in terms of ES and EDS provision, and for many species only data on either ES or EDS is available. Most research on the role of alien plants in ES provision has been done in developed countries, and more work is needed to elucidate the importance of alien plants in developing countries. There is also an imbalance in the study of different ES/EDS. While provisioning services are well studied there is little information on regulating services. Among cultural services, mostly aesthetics has been studied with a lack of studies on other cultural services such as psychological, social, symbolic, and religious roles that are known to be important for the perception of alien species (Kueffer and Kull 2017). Among EDS, many studies focused on few mechanisms such as pollen allergies affecting human health and emissions of BVOCs reducing air quality.

This review however shows clearly that alien plants can provide key ES and EDS in urban landscapes. Consequently, urban planners and managers need to be mindful of both the positive and negative impacts of alien plant species to maximise the provision of ES. Our findings suggest that alien plants are firmly embedded in urban landscapes and have complex social and economic ties. In the face of rapid urbanization and changing climates, the role and importance of these in delivering ES will change. Elucidating the role of alien plants in providing ES and EDS in urban areas can guide management prioritization and facilitate communication with various stakeholders.

2.8 Acknowledgements

We acknowledge financial support from the DST-NRF Centre of Excellence for Invasion Biology (C·I·B) and the National Research Foundation of South Africa (grant 85417 to DMR). An early version of this paper was presented at a workshop on “Non-native species in urban environments: Patterns, processes, impacts and challenges” that was hosted by the C·I·B in Stellenbosch in November 2016. Many participants at the workshop provided useful comments and suggestions that improved the paper.

2.9 References

Abson DJ, Termansen M (2011) Valuing ecosystem services in terms of ecological risks and returns. Conserv Biol 25:250-258

Alpert P, Bone E, Holzapfel C (2000) Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. Perspect Plant Ecol Evol Syst 3:52–66

Alston KP, Richardson DM (2006) The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol Conserv 132:183-198

Anderson PML, O'Farrell PJ (2012) An ecological view of the history of the establishment of the City of Cape Town. Ecol Soc 17(3):28

Andersson E, Barthel S, Ahrné K (2007) Measuring social–ecological dynamics behind the generation of ecosystem services. Ecol Appl 17:1267–1278. doi: 10.1890/06-1116.1

Aronson MFJ, Handel SN, Clemants SE (2007) Fruit type, life form and origin determine the success of woody plant invaders in an urban landscape. Biol Invasions 9:465–475. doi: 10.1007/s10530-006-9053-1

Ballero M, Ariu A, Falagiani P (2003) Allergy to *Ailanthus altissima* (tree of heaven) pollen. Allergy 58:532–533. doi: 10.1034/j.1398-9995.2003.00172.x

Barau AS (2015) Perception and contributions of households towards sustainable urban green infrastructure in Malaysia. Habitat Int 47:285–297

Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. Ecol Lett 12:1394–1404. doi: 10.1111/j.1461-0248.2009.01387.x

Bigirimana J, Bogaert J, De Cannière C, et al. (2012) Domestic garden plant diversity in Bujumbura, Burundi: role of the socio-economical status of the neighborhood and alien species invasion risk. Landsc Urban Plan 107:118–126. doi: 10.1016/j.landurbplan.2012.05.008

Blanckaert I, Swennen RL, Paredes Flores M, et al. (2004) Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlan, Valley of Tehuacan-Cuicatlan, Mexico. J Arid Environ 57:179–202. doi: 10.1016/S0140-1963(03)00100-9

Bogacki M, Syguła P (2013) The impact of biogenic volatile organic compounds emission on photochemical processes occurring in the troposphere. Geom Environ Engin 7(1):37–46

Bolund P, Hunhammar S (1999) Ecosystem services in urban areas. Ecol Econ 29:293–301. doi: 10.1016/S0921-8009(99)00013-0

Borgström ST, Elmqvist T, Angelstam P, Alfsen-norodom C (2006) Scale mismatches in management of urban landscapes. Ecol Soc 11:16. doi: 10.1097/MCC.0b013e32807f2aa5

Burrows GE, Tyrl RJ (2013) Toxic plants of North America, 2nd edn. Wiley-Blackwell, Hoboken

Cadotte et al. (2017) Are urban systems beneficial, detrimental, or indifferent to species invasion. Biol Invasions. doi:10.1007/s10530-017-1586-y

Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? Ecosystems 4:765–781. doi: 10.1007/si0021-001-0045-9

Casella F, Vurro M (2013) *Ailanthus altissima* (tree of heaven): Spread and harmfulness in a case- study urban area. Arboric J Int J Urban For 35:172–181. doi: 10.1080/03071375.2013.852352

Castro-Diez P, Godoy O, Saldana A, Richardson DM (2011) Predicting invasiveness of Australian acacias on the basis of the native climatic affinities, life history traits and human use. Divers Distrib 17:934–945. doi: 10.1111/j.1472-4642.2011.00778.x

Celesti-Grapow L, Blasi C (2004) The role of alien and native weeds in the deterioration of archaeological remains in Italy. Weed Technol 18:1508–1513. doi: 10.1614/0890-037X(2004)018[1508:TROAAN]2.0.CO;2

Celesti-Grapow L, Blasi C (1998) A comparison of the urban flora of different phytoclimatic regions in Italy. Glob Ecol Biogeogr Lett 7:367–378. doi: 10.1046/j.1466-822X.1998.00304.x

Chalker-Scott L (2015) Nonnative, noninvasive woody species can enhance landscape biodiversity. Arboric Urban For 41:173–186

Chan KMA, Guerry AD, Balvanera P, et al. (2012) Where are *cultural* and *social* in ecosystem services? A Framework for constructive engagement. BioScience 62:744–756. doi: 10.1525/bio.2012.62.8.7

Charles H, Dukes JS (2007) Impacts of invasive species on ecosystem services. In: Nentwig W (ed) Biological Invasions. Berlin: Springer, pp. 217–38

Chocholoušková Z, Pyšek P (2003) Changes in composition and structure of urban flora over 120 years: a case study of the city of Plzeň. Flora - Morphol Distrib Funct Ecol Plants 198:366–376. doi: 10.1078/0367-2530-00109

Cierjacks A, Kowarik I, Joshi J, et al. (2013) Biological flora of the British Isles: *Robinia pseudoacacia*. J Ecol 101:1623–1640. doi: 10.1111/1365-2745.12162

Cilliers S, Cilliers J, Lubbe R, Siebert S (2013) Ecosystem services of urban green spaces in African countries-perspectives and challenges. Urban Ecosyst 16:681–702. doi: 10.1007/s11252-012-0254-3

Cilliers SS, Siebert S (2012) Urban ecology in Cape Town. Ecol Soc 17(3):33. doi: 10.5751/ES-05146-170333

Clarke LW, Li L, Jenerette GD, Yu Z (2014) Drivers of plant biodiversity and ecosystem service production in home gardens across the Beijing Municipality of China. Urban Ecosyst 17(3):741–

760. doi: 10.1007/s11252-014-0351-6

Cohen B (2004) Urban growth in developing countries: A review of current trends and a caution regarding existing forecasts. World Dev 32(1):23–51. doi:10.1016/j.worlddev.2003.04.008

Costanza R, Wilson M, Troy A, Voinov A, Liu S, D'Agostino J (2007) The value of New Jersey's ecosystem services and natural capital. Project report to the New Jersey Department of Environmental Protection

Daehler CC (2003) Performance comparisons of co-occurring native and alien invasive plants: Implications for conservation and restoration. Annu Rev Ecol Evol Syst 34:183–211. doi: 10.1146/132403

de Wit M, van Zyl H, Crookes D, Blignaut J, Jayiya T, Goiset V, Mahumani B (2009) Investing in Natural Assets: A Business Case for the Environment in the City of Cape Town. Report prepared for the City of Cape Town, Natural Value Joint Venture, Brackenfell, South Africa. Available: https://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/EnvResEconomics-Final_Report_2009-08-18.pdf. Accessed 21 Feb 2016

Dearborn DC, Kark S (2010) Motivations for conserving urban biodiversity. Conserv Biolo24:432–440

Derrick EK, Darley C (1994) Contact reaction to the tree of heaven. Contact Dermat 30(3):178. doi: 10.1111/j.1600-0536.1994.tb00706.x

Dickie IA, Bennett BM, Burrows LE, et al. (2014) Conflicting values: ecosystem services and invasive tree management. Biol Invasions 16:705–719. doi: 10.1007/s10530-013-0609-6

Drescher AW (2004) Food for the cities: urban agriculture in developing countries. Acta Hort 643:227–231

Dures SG, Cumming GS (2010) The confounding influence of homogenising invasive species in a globally endangered and largely urban biome: Does habitat quality dominate avian biodiversity? Biol Conserv 143:768–777. doi: 10.1016/j.biocon.2009.12.019

Dyderski MK, Gdula AK, Jagodziński AM (2015) "The rich get richer" concept in riparian woody species – a case study of the Warta River Valley (Poznań, Poland). Urban For Urban Green 14:107–114. doi: 10.1016/j.ufug.2014.12.003

Elmqvist T, Alfsen-Norodom C, Colding J (2008) Urban systems. In: Jørgensen SE, Fath BD (eds) Ecosystems Vol. [5] of encyclopedia of ecology. Oxford: Elsevier, pp. 3665–3672

Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC, Wilkinson C (2013) Urbanisation, Biodiversity and Ecosystem Services:

Challenges and Opportunities. Europe: Springer

Elmqvist T, Setala H, Handel SN, et al. (2015) Benefits of restoring ecosystem services in urban areas. Curr Opin Environ Sustain 14:101–108. doi: 10.1016/j.cosust.2015.05.001

Eviner VT, Garbach K, Baty JH, Hoskinson SA (2012) Measuring the effects of invasive plants on ecosystem services: challenges and prospects. Invasive Plant Sci Manage 5:125–136. doi: 10.1614/IPSM-D-11-00095.1

Foster J, Sandberg LA (2004) Friends of foe? Invasive species and public green space in Toronto. Geogr Rev 94:178–198

Gaertner M, Larson BMH, Irlich UM, et al. (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landsc Urban Plan 151:1–9. doi: 10.1016/j.landurbplan.2016.03.010

Gairola S, Bhatt A, Govender Y, et al. (2013) Incidence and intensity of tree infestation by the mistletoe *Erianthemum dregei* (Eckl. & Zeyh.) V. Tieghem in Durban, South Africa. Urban For Urban Green 12:315–322

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) REVIEW: Managing urban ecosystems for goods and services. J Appl Ecol 50:830–840. doi:10.1111/1365-2664.12087

Gavier-pizarro AGI, Radeloff VC, Stewart SI, et al. (2010) Housing is positively associated with invasive exotic plant species richness in New England, USA. Ecol Appl 20:1913–1925. doi: 10.1890/09-2168.1

Godefroid S (2001) Temporal analysis of the Brussels flora as indicator for changing environmental quality. Landsc Urban Plan 52:203–224. doi: 10.1016/S0169-2046(00)00117-1

Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. Ecol Econ 86:235–245. doi: 10.1016/j.ecolecon.2012.08.019

Grêt-Regamey A, Sirén E, Brunner SH, Weibel B (2016) Review of decision support tools to operationalize the ecosystem services concept. Ecosyst Serv 0-1. http:// dx.doi.org/10.1016/j.ecoser.2016.10.012.

Grove JM, Troy AR, O'Neil-Dunne JPM, Burch WR, Cadenasso ML Jr, Pickett STA (2006) Characterization of households and its implications for the vegetation of urban ecosystems. Ecosystems 9:578–597. doi:10.1007/ s10021-006-0116-z

Guitart D, Pickering C, Byrne J (2012) Past results and future directions in urban community gardens research. Urban For Urban Green 11:364–373. doi: 10.1016/j.ufug.2012.06.007

Guo Q, Qian H, Ricklefs R, Xi W (2006) Distributions of exotic plants in eastern Asia and North America. Ecol Lett 9:827–834. doi: 10.1111/j.1461-0248.2006.00938.x

Haase D, Frantzeskaki N, Elmqvist T (2014) Ecosystem services in urban landscapes: practical applications and governance implications. Ambio 43:407–412. doi: 10.1007/s13280-014-0503-1

Haines-Young R, Potschin M (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelii DG, Frid CLJ (eds) Ecosystem Ecology: a new synthesis. Cambridge University Press, pp 110–139

Hobbs RJ, Higgs ES, Hall CM (2013) Defining novel ecosystems. In: Hobbs RJ, Higgs ES, Hall CM (eds) Novel Ecosystems: Intervening in the New Ecological World Order. Chichester: John Wiley & Sons Ltd, pp. 58–60

Hope D, Gries C, Casagrande D, et al. (2006) Drivers of spatial variation in plant diversity across the central Arizona-Phoenix ecosystem. Soc Nat Resour 19:101–116. doi: 10.1080/08941920500394469

Huebner CD, Nowak DJ, Pouyat R V, Bodine AR (2012) Nonnative invasive plants: maintaining biotic and soceioeconomic integrity along the urban-rural-natural gradient. In: Laband DN, Lockaby BG, Zipperer W (eds) Urban-rural interfaces: linking people and nature. Madison, WI: American Society of Agronomy, Soil Science Society of America: 71-98. doi: 10.2136/2012.urban-rural.c5

Hui C, Richardson DM, Visser V (2017) Ranking of invasive spread through urban green areas in the world's 100 most populous cities. Biol Invasions. doi:10.1007/s10530-017-1584-0

Hulme PE, Brundu G, Carboni M, et al. (2017) Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. J Appl Ecol 00:1–7. https://doi.org/10.1111/1365-2664.12953

Hynes P, Howe G (2004) Urban horticulture in the contemporary united states: personal and community benefits. Acta Hortic 643:171–181. doi: 10.17660/ActaHortic.2004.643.21

Irlich UM, Potgieter LJ, Stafford L, Gaertner M (2017) Recommendations for municipalities to become compliant with national legislation on biological invasions. Bothalia 47(2):a2156. doi: https://doi.org/10.4102/abc.v47i2.2156

Johnston M, Nail S, James S (2012) 'Natives versus aliens': The relevance of the debate to urban forest management in Britain. In: Johnston M., Percival G, (eds) Trees, People and the Built Environment. Proceedings of the Urban Trees Research Conference, Birmingham, UK, pp. 181–191

Kabisch N, Frantzeskaki N, Pauleit S, Naumann S, Davis M, Artmann M, Haase D, Knapp S, Korn H, Stadler J, Zaunberger K, Bonn A (2016) Nature-based solutions to climate change mitigation and adaptation in urban areas – perspectives on indicators, knowledge gaps, barriers and opportunities for action. Ecol Soc 21(2):39. http://doi.org/ 10.5751/ES-08373-210239

Klotz S, Kühn I (2010) Urbanisation and alien invasion. In: Gaston KJ (ed.) Urban ecology. Cambridge University Press, Cambridge, pp. 120–133

Kowarik I (1995) On the role of alien species in urban flora and vegetation. In: Pyšek P, Prach K, Rejmánek M, Wade M (eds) Plant invasions–General Aspects and Special Problems. Amsterdam: SPB Academic Publishing, pp. 85–103

Kowarik I (2003) Human agency in biological invasions: secondary releases foster naturalisation and population expansion of alien plant species. Biol Invasions 5:293–312. doi: 10.1023/B:BINV.0000005574.15074.66

Kowarik I (2005) Urban ornamentals escaped from cultivation. In Gressel J (ed.) Crop ferality and volunteerism. Boca Raton: CRC Press, pp. 97–121. doi: 10.1201/9781420037999.ch7

Kowarik I, Säumel I (2007) Biological flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. Perspect Plant Ecol Evol Syst 8:207–237. doi: 10.1016/j.ppees.2007.03.002

Kowarik I, Von Der Lippe M, Cierjacks A (2013) Prevalence of alien versus native species of woody plants in Berlin differs between habitats and at different scales. Preslia 85:113–132. doi: 10.1111/ddi.12028)

Kremen C (2005) Managing ecosystem services: What do we need to know about their ecology? Ecol Lett 8:468–479. doi: 10.1111/j.1461-0248.2005.00751.x

Kueffer C, Kull CA (2017) Non-native species and the aesthetics of nature. In: Vilà M, Hulme PE, Ruiz G (eds) Impact of Biological Invasions on Ecosystem Services. Springer, pp. 311-324

Kueffer C, Pysek P, Richardson DM (2013) Integrative invasion science: model organisms, multi-site studies, unbiased meta-analysis, and invasion syndromes (Tansley review). New Phytol 200:615-633

Kühn I, Brandl R, Klotz S (2004) The flora of German cities is naturally species rich. Evol Ecol Res 6:749–764

Kühn I, Klotz S (2006) Urbanization and homogenization– comparing the floras of urban and rural areas in Germany. Biol Conserv 127:292–300. doi:10.1016/j.biocon.2005.06.033

Kumschick S, Gaertner M, Vilà M, Essl F, Jeschke JM, Pyšek P et al. (2014) Ecological impacts of alien species: quantification, scope, caveats, and recommendations. BioScience 65(1):55-63

Luck GW, Harrington R, Harrison PA, et al. (2009) Quantifying the contribution of organisms to the provision of ecosystem services. Bioscience 59:223–235. doi: 10.1025/bio.2009.59.3.7

Luederitz C, Brink E, Gralla F, et al. (2015) A review of urban ecosystem services: six key challenges for future research. Ecosyst Serv 14:98–112. doi: 10.1016/j.ecoser.2015.05.001

Luz-Lezcano Caceres H, Gerold G (2009) The costs of invasion control measures subtropical *Ailanthus altissima* in Hesse. Conference on International Research on Food Security, Natural Resource Management and Rural Development, Tropentag

Mao Q, Ma K, Jianguo W, Rongli T, Shanghua L, Yuxin Z, Le B (2013). Distribution pattern of allergenic plants in the Beijing metropolitan region. Aerobiologia 29(2):217e231

Marozas V, Cekstere G, Laivins, M, Straigyte L (2015) Comparison of neophyte communities of *Robinia pseudoacacia* L. and *Acer negundo* L. in the eastern Baltic Sea region cities of Riga and Kaunas. Urban For Urban Green 14:826-834

Maxwell D, Levin C, Csete J (1998) Does urban agriculture help prevent malnutrition? Evidence from Kampala. Food Policy 23:411–424

McKinney ML (2002) Urbanization, biodiversity, and conservation. Bioscience 52:883–890

McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127:247–260. doi: 10.1016/j.biocon.2005.09.005

McKinney ML, Lockwood JL (1999) Biotic homogenization: A few winners replacing many losers in the next mass extinction. Trends Ecol Evol 14:450–453. doi: 10.1016/S0169-5347(99)01679-1

McLean P, Gallien L, Wilson JRU, Gaertner M, Richardson DM (2017) Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa. Biol Invasions. doi:10.1007/s10530-017-1600-4

Millard A (2008) Semi-natural vegetation and its relationship to designated urban green space at the landscape scale in Leeds, UK. Landsc Ecol 23:1231–1241. doi: 10.1007/s10980-008-9256-1

Millennium Ecosystem Assessment (MA) (2005) Ecosystems and human well-being. Washington, DC: Island Press

Millward AA, Sabir S (2011) Benefits of a forested urban park: What is the value of Allan Gardens to the city of Toronto, Canada? Landsc Urban Plan 100:177–188. doi: 10.1016/j.landurbplan.2010.11.013

Ming R, et al. (2008) The draft genome of the transgenic tropical fruit tree papaya (Carica papaya Linnaeus). Nature 452:991-997

Moodley D, Geerts S, Richardson DM, Wilson JRU (2013) Different traits determine introduction, naturalization and invasion success in woody plants: Proteaceae as a test case. PloS One 8(9): e75078. doi:10.1371/journal.pone.0075078

Mooney HA (2005) Invasive alien species: the nature of the problem. In: Mooney HA et al. (eds) Invasive Alien Species. Washington, DC: Island Press, pp. 1–15

Moser A, Rötzer T, Pauleit S, Pretzsch H (2015) Structure and ecosystem services of small-leaved lime (*Tilia cordata* Mill.) and black locust (*Robinia pseudoacacia* L.) in urban environments. Urban For Urban Green 14:1110–1121. doi: 10.1016/j.ufug.2015.10.005

Noe SM, Peñuelas J, Niinemets Ü (2008) Monoterpene emissions from ornamental trees in urban areas: A case study of Barcelona, Spain. Plant Biol 10:163–169. doi: 10.1111/j.1438-8677.2007.00014.x

OECD (2015) The Metropolitan Century: Understanding Urbanisation and its Consequences. Paris: OECD Publishing. doi: http://dx.doi.org/10.1787/9789264228733-en

Padayachee AL, Irlich UM, Faulkner KT, Gaertner M, Procheş S, Wilson JRU, Rouget M (2017) How do invasive species travel to and through urban environments? Biol Invasions. doi:10.1007/s10530-017-1596-9

Pauchard A, Aguayo M, Peña E, Urrutia R (2006) Multiple effects of urbanization on the biodiversity of developing countries: The case of a fast-growing metropolitan area (Concepcion, Chile). Biol Conserv 127:272–281. doi: 10.1016/j.biocon.2005.05.015

Pickett STA, Cadenasso ML, Grove JM, et al. (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu Rev Ecol Syst 32:127–157. doi: 10.1007/978-0-387-73412-5_7

Pimentel D, McNair S, Janecka J, et al. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agric Ecosyst Environ 84:1–20. doi: 10.1016/S0167-8809(00)00178-X

Piracha AL, Marcotullio PJ (2003) Urban ecosystem analysis: identifying tools and methods. United Nations University Institute for Advanced Studies, Tokyo, Japan

Potgieter LJ, Richardson DM, Wilson JRU (2014) Casuarina: Biogeography and ecology of an important tree genus in a changing world. Biol Invasions 16:609-633. doi: 10.1007/s10530-013-0613-x

Pyšek P (1998) Alien and native species in Central European urban floras: A quantitative comparison. J Biogeogr 25:155–163

Pyšek P, Jarošík V, Hulme PE, et al. (2012) A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. Glob Change Biol 18:1725–1737. doi: 10.1111/j.1365-2486.2011.02636.x

Pyšek P, Richardson DM (2010) Invasive species, environmental change, and health. Annu Rev Environ Resour 35:25–55. doi: 10.1146/annurev-environ-033009-095548

Reichard SH, White P (2001) Horticulture as a pathway of invasive plant introductions in the United States. BioScience 51:103–113

Richardson DM, Pyšek P, Carlton JT (2011) A compendium of essential concepts and terminology in invasion ecology. In: Richardson DM (ed.) Fifty years of invasion ecology. The legacy of Charles Elton. Wiley-Blackwell, Oxford, pp. 409-420

Rodriguez JP, et al. (2006) Trade-offs across space, time, and ecosystem services. Ecol Soc 11(1):28

Roy S, Byrne J, Pickering C (2012) A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban For Urban Gree 4(11):351–363

Scott M, Lennon M, Haase D, Kazmierczak A, Clabby G, Beatley T (2016) Nature-based solutions for the contemporary city. Plan Theory Prac 17:267-300

Shackleton CM, Ruwanza S, Sinasson Sanni GK, et al. (2016) Unpacking Pandora's box: understanding and categorising ecosystem disservices for eEnvironmental management and human wellbeing. Ecosystems 19:587–600. doi: 10.1007/s10021-015-9952-z

Shackleton RT, Le Maitre DC, Pasiecznik NM, Richardson DM (2014) Prosopis: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. AoB Plants 6: plu027. http://aobpla.oxfordjournals.org/content/6/plu027

Sjöman H, Morgenroth J, Sjöman JD, Sæbø A, Kowarik I (2016) Diversification of the urban forest—Can we afford to exclude exotic tree species?. Urban For Urban Green 18:237-241

Sladonja B, Sušek M, Guillermic J (2015) Review on invasive tree of heaven (*Ailanthus altissima* (Mill.) Swingle) conflicting values: assessment of its ecosystem services and potential biological threat. Environ Manage 56:1009–1034. doi: 10.1007/s00267-015-0546-5

Smith RM, Thompson K, Hodgson JG, et al. (2006) Urban domestic gardens (IX): composition and richness of the vascular plant flora, and implications for native biodiversity. Biol Conserv 129:312–322. doi: 10.1016/j.biocon.2005.10.045

Song IJ, Hong SK, Kim HO, et al. (2005) The pattern of landscape patches and invasion of naturalized plants in developed areas of urban Seoul. Landsc Urban Plan 70:205–219. doi: 10.1016/j.landurbplan.2003.10.018

Štajerová K, Šmilauer P, Brůna J, Pyšek P (2017) Distribution of invasive plants in urban environment is strongly spatially structured. Landsc Ecol 32:681-692

Sullivan JJ, Timmins SM, Williams PA (2005) Movement of exotic plants into coastal native forests from gardens in northern New Zealand. N Z J Ecol 29:1–10

Tratalos J, Fuller RA, Warren PH, Davies RG, Gaston KJ (2007) Urban form, biodiversity potential and ecosystem services. Landsc Urban Plan 83:308-317

UNFPA (2007) State of the world population 2007: unleashing the potential of urban growth, United Nations Population Fund

United Nations (2017) World Economic Situation and Prospects (WESP). United Nations publication. https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/2017wesp_full_en.pdf. Accessed 18 October 2016

Van Wilgen NJ, Richardson DM, Baard EHW (2008) Alien reptiles and amphibians in South Africa: Towards a pragmatic management strategy. S Afr J Sci 104:13–20

Vaz AS, Kueffer C, Kull CA, et al. (2017a) Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst Serv 23:94–107. doi: 10.1016/j.ecoser.2016.11.017

Vaz AS, Kueffer C, Kull CA, et al. (2017b) The progress of interdisciplinarity in invasion science. Ambio 46:428–442

Von Der Lippe M, Kowarik I (2007) Long-distance dispersal of plants by vehicles as a driver of plant invasions. Conserv Biol 21:986–996. doi: 10.1111/j.1523-1739.2007.00722.x

Von Döhren P, Haase D (2015) Ecosystem disservices research: A review of the state of the art with a focus on cities. Ecol Indic 52:490–497. doi: 10.1016/j.ecolind.2014.12.027

Walker GA, Robertson MP, Gaertner M, Gallien L, Richardson DM (2017) The potential range of Ailanthus altissima (tree of heaven) in South Africa: the roles of climate, land use and disturbance. Biol Invasions. doi:10.1007/s10530-017-1597-8

Wania A, Kühn I, Klotz S (2006) Plant richness patterns in agricultural and urban landscapes in central Germany - Spatial gradients of species richness. Landsc Urban Plan 75:97–110. doi:

10.1016/j.landurbplan.2004.12.006

Williams NSG, Hahs AK, Vesk PA (2015) Urbanisation, plant traits and the composition of urban floras. Perspect Plant Ecol Evol Syst 17:78–86. doi: 10.1016/j.ppees.2014.10.002

Williamson M, Fitter A (1996) The varying success of invaders. Ecology 77:1661–1666. doi: 10.2307/2265769

Winklerprins AMG a., de Souze P (2005) Surviving the city: urban home gardens and the economy of affection in the Brazilian Amazon. J Lat Am Geogr 4:107–126. doi: 10.1353/lag.2005.0033

2.10 Supplementary material

Appendix A List of all keywords searched.

Ecosystem Services

“urban*” OR “city” OR “cities” OR “town” OR “metropolitan” OR “built-up” AND "ecosystem service*" OR "environment* service*" OR "landscape service*" OR "ecologic* service*"

AND “food” OR “fibre” OR “fuel” OR “material” OR “water” OR “medicine” OR “mineral” OR “energy” OR “shade”

OR “air quality” OR “climate” OR “carbon” OR “sequestration” OR “decomposition” OR “pest control” OR “disease control” OR “purify*” OR “transpiration”

OR “cultural” OR “spiritual” OR “aesthetic” OR “recreation” OR “history*” OR “educat*” OR “therapeutic” OR “tourism”

OR “nutrient recycling” OR “nutrient cycling” OR “primary production” OR “soil formation” OR “erosion”

Ecosystem Disservices

“urban*” OR “city” OR “cities” OR “town” OR “metropolitan” OR “built-up” AND "ecosystem disservice*" OR "environment* disservice*" OR "landscape disservice*" OR "ecologic* disservice*" OR "ecosystem dis-service*"

OR “health” OR “pollen” OR “allerg*” OR ”disease” OR “emission” OR “volatile organic compound*” OR “bVOC”

OR “damage” OR “nuisance” OR “infrastructure” OR “drainage”

OR “safety” OR “secur*” OR “fear” OR “crime” OR “accident” OR “visibil*” OR “fire”

OR “cultural” OR “aesthetic” AND “irritat*” OR “unpleas*” OR “smell” OR “block” OR “sunlight” OR “dark*” OR “obscure” OR “view*” OR “drop*”

OR “cost” OR “maintain*” OR “property price” OR “prune” OR “repair” OR “thinning” OR “irrigat**

OR “water consum*” OR “waste” OR “displace” OR “displace native species”

Appendix B References list of all publications included in the review.

Abendroth S, Kowarik I, Müller N, Von der Lippe M (2012) The green colonial heritage: woody plants in parks of Bandung, Indonesia. Landsc Urban Plan 106:12–22. doi: 10.1016/j.landurbplan.2011.12.006

Akbari H (2002) Shade trees reduce building energy use and CO_2 emissions from power plants. Environ Pollut 116:119–126. doi: 10.1016/S0269-7491(01)00264-0

Akbari H, Pomerantz M, Taha H (2001) Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70:295–310. doi: 10.1016/S0038-092X(00)00089-X

Alavipanah S, Haase D, Lakes T, Qureshi S (2017) Integrating the third dimension into the concept of urban ecosystem services: A review. Ecol Indic 72:374–398. doi: 10.1016/j.ecolind.2016.08.010

Alcázar P, Cariñanos P, De Castro C, et al. (2004) Airborne plane-tree (*Platanus hispanica*) pollen distribution in the city of Córdoba, South-western Spain, and possible implications on pollen allergy. J Investig Allergol Clin Immunol 14:238–243

Alcázar P, Galán C, Torres C, Domínguez-Vilches E (2015) Detection of airborne allergen (Pla a 1) in relation to Platanus pollen in Córdoba, South Spain. Ann Agric Environ Med 22:96–101. doi: 10.5604/12321966.1141376

Alpert P, Bone E, Holzapfel C (2000) Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. Perspect Plant Ecol Evol Syst 3:52–66

Amir S, Misgav A (1990) A framework for street tree planning in urban areas in Israel. Landsc Urban Plan 19:203–212. doi: 10.1016/0169-2046(90)90022-T

Anderson LM, Cordell HK (1988) Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices. Landsc Urban Plan 15:153–164. doi: 10.1016/0169-2046(88)90023-0

Andrabi SM, Reshi ZA, Shah MA, Qureshi S (2015) Studying the patterns of alien and native floras of some habitats in Srinagar city, Kashmir, India. Ecol Process 4:2. doi: 10.1186/s13717-014-0030-9

Arévalo JR, Delgado JD, Otto R, et al. (2005) Distribution of alien vs. native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria (Canary Islands). Perspect Plant Ecol Evol Syst 7:185–202. doi: 10.1016/j.ppees.2005.09.003

Arianoutsou M, Bazos I, Delipetrou P, Kokkoris Y (2010) The alien flora of Greece: taxonomy, life traits and habitat preferences. Biol Invasions 12:3525–3549. doi: 10.1007/s10530-010-9749-0

Aronson MFJ, Handel SN, Clemants SE (2007) Fruit type, life form and origin determine the success of woody plant invaders in an urban landscape. Biol Invasions 9:465–475. doi: 10.1007/s10530-006-9053-1

Aslan CE, Rejmánek M, Klinger R (2012) Combining efficient methods to detect spread of woody invaders in urban-rural matrix landscapes: An exploration using two species of Oleaceae. J Appl Ecol 49:331–338. doi: 10.1111/j.1365-2664.2011.02097.x

Baldock KCR, Goddard MA, Hicks DM, et al. (2015) Where is the UK's pollinator biodiversity? The importance of urban areas for flower- visiting insects. Proc R Soc Biol Sci 282:20142849. doi: 10.1098

Ballero M, Ariu A, Falagiani P (2003) Allergy to *Ailanthus altissima* (tree of heaven) pollen. Allergy 58:532–533. doi: 10.1034/j.1398-9995.2003.00172.x

Balogun AA, Morakinyo TE, Adegun OB (2014) Effect of tree-shading on energy demand of two similar buildings. Energy Build 81:305–315. doi: 10.1016/j.enbuild.2014.05.046

Balvanera P, Siddique I, Dee L, et al. (2014) Linking biodiversity and ecosystem services: current uncertainties and the necessary next steps. Bioscience 64:49–57. doi: 10.1093/biosci/bit003

Barau AS, Al Hosani N (2015) Prospects of environmental governance in addressing sustainability challenges of seawater desalination industry in the Arabian Gulf. Environ Sci Policy 50:145–154. doi: 10.1016/j.envsci.2015.02.008

Baró F, Chaparro L, Gómez-Baggethun E, et al. (2014) Contribution of ecosystem services to air quality and climate change mitigation policies: The case of urban forests in Barcelona, Spain. Ambio 43:466–479. doi: 10.1007/s13280-014-0507-x

Basnou C, Iguzquiza J, Pino J (2015) Examining the role of landscape structure and dynamics in alien plant invasion from urban Mediterranean coastal habitats. Landsc Urban Plan 136:156–164. doi: 10.1016/j.landurbplan.2014.12.001

Bauer JT (2012) Invasive species: “back-seat drivers” of ecosystem change? Biol Invasions 14:1295–1304. doi: 10.1007/s10530-011-0165-x

Beatty R, Heckman C (1981) Survey of urban tree programs in the United States. Urban Ecol 5:81–102.

Belchí-Hernández J, Moreno-Grau S, Bayo J, et al. (2001) Pollinosis related to *Zygophyllum fabago* in a Mediterranean area. Aerobiologia (Bologna) 17:241–246. doi: 10.1023/A:1011818814840

Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. Ecol Lett 12:1394–1404. doi: 10.1111/j.1461-0248.2009.01387.x

Bernholt H, Kehlenbeck K, Gebauer J, Buerkert A (2009) Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. Agrofor Syst 77:159–179. doi: 10.1007/s10457-009-9236-8

Bertram C, Rehdanz K (2015) Preferences for cultural urban ecosystem services: Comparing attitudes, perception, and use. Ecosyst Serv 12:187–199. doi: 10.1016/j.ecoser.2014.12.011

Beumer C, Martens P (2016) BIMBY’s first steps: a pilot study on the contribution of residential front-yards in Phoenix and Maastricht to biodiversity, ecosystem services and urban sustainability. Urban Ecosyst 19:45–76. doi: 10.1007/s11252-015-0488-y

Bezák P, Lyytimäki J (2011) Complexity of urban ecosystem services in the context of global change. Ekológia (Bratislava) 30:22–35. doi: 10.4149/ekol_2011_01_22

Bigirimana J, Bogaert J, De Cannière C, et al. (2012) Domestic garden plant diversity in Bujumbura, Burundi: Role of the socio-economical status of the neighborhood and alien species invasion risk. Landsc Urban Plan 107:118–126. doi: 10.1016/j.landurbplan.2012.05.008

Bigirimana J, Bogaert J, De Canniere Charles C, et al. (2011) Alien plant species dominate the vegetation in a city of Sub-Saharan Africa. Landsc Urban Plan 100:251–267. doi: 10.1016/j.landurbplan.2010.12.012

Botham MS, Rothery P, Hulme PE, et al. (2009) Do urban areas act as foci for the spread of alien plant species? An assessment of temporal trends in the UK. Divers Distrib 15:338–345. doi: 10.1111/j.1472-4642.2008.00539.x

Brack CL (2002) Pollution mitigation and carbon sequestration by an urban forest. Environ Pollut 116:195-200. doi: 10.1016/S0269-7491(01)00251-2

Braquinho C, Cvejić R, Eler K, et al. (2015) A typology of urban green spaces, ecosystem services provisioning services and demands. Project report EU FP7 (ENV.2013.6.2-5-603567) GREEN SURGE project (2013-2017). http://greensurge.eu/working-packages/wp3/files/D3.1_Typology_of_urban_green_spaces_1_.pdf/D3.1_Typology_of_urban_green_spaces_v2_.pdf. Accessed 22 March 2016

Breuste J (2011) Urban ecosystem services on the local level: Urban green spaces as providers of urban ecosystem services. Ekológia (Bratislava) 32(3):12-31. https://doi.org/10.2478/eko-2013-0026

Bryant MM (2006) Urban landscape conservation and the role of ecological greenways at local and metropolitan scales. Landsc Urban Plan 76:23–44. doi: 10.1016/j.landurbplan.2004.09.029

Buonopane M, Snider G, Kerns BK, Doescher PS (2013) Complex restoration challenges: Weeds, seeds, and roads in a forested wildland urban interface. For Ecol Manage 295:87–96. doi: 10.1016/j.foreco.2013.01.013

Burton ML, Samuelson LJ, Pan S (2005) Riparian woody plant diversity and forest structure along an urban-rural gradient. Urban Ecosyst 8:93–106. doi: 10.1007/s11252-005-1421-6

Buters JTM, Alberternst B, Nawrath S, et al. (2015) *Ambrosia artemisiifolia* (ragweed) in Germany – current presence, allergological relevance and containment procedures. Allergo J Int 24:1–13. doi: 10.1007/s40629-015-0060-6

Calderón-Contreras R, Quiroz-Rosas LE (2017) Analysing scale, quality and diversity of green infrastructure and the provision of Urban Ecosystem Services: A case from Mexico City. Ecosyst Serv 23:127–137. doi: 10.1016/j.ecoser.2016.12.004

Calfapietra C, Fares S, Manes F, et al. (2013) Role of Biogenic Volatile Organic Compounds (BVOC) emitted by urban trees on ozone concentration in cities: A review. Environ Pollut 183:71–80. doi: 10.1016/j.envpol.2013.03.012

Cameron RWF, Blanuša T, Taylor JE, et al. (2012) The domestic garden - its contribution to urban green infrastructure. Urban for Urban Green 11:129–137. doi: 10.1016/j.ufug.2012.01.002

Cariñanos P, Alcázar P, Galán C, Domínguez E (2014) Environmental behaviour of airborne Amaranthaceae pollen in the southern part of the Iberian Peninsula, and its role in future climate scenarios. Sci Total Environ 470–471:480–487. doi: 10.1016/j.scitotenv.2013.10.024

Cariñanos P, Casares-Porcel M (2011) Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. Landsc Urban Plan 101:205–214. doi: 10.1016/j.landurbplan.2011.03.006

Carosso A, Gallesio MT (2000) Allergy to ragweed: Clinical relevance in Turin. Aerobiologia (Bologna) 16:155–158. doi: 10.1023/A:1007663506535

Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: Resilience of what to what? Ecosystems 4:765–781. doi: 10.1007/si0021-001-0045-9

Carver AD, Unger DR, Parks CL (2004) Modeling energy savings from urban shade trees: An assessment of the CITYgreen® energy conservation module. Environ Manage 34:650–655. doi: 10.1007/s00267-002-7003-y

Casella F, Vurro M (2013) *Ailanthus altissima* (tree of heaven): Spread and harmfulness in a case-study urban area. Arboric J Int J Urban For 35:172–181. doi: 10.1080/03071375.2013.852352

Castro-Diez P, Godoy O, Saldana A, Richardson DM (2011) Predicting invasiveness of Australian acacias on the basis of the native climatic affinities, life history traits and human use. Divers Distrib 17:934–945. doi: 10.1111/j.1472-4642.2011.00778.x

Cavanagh J-AE, Clemons J (2006) Do urban forests enhance air quality? Australas J Environ Manage 13:120–130. doi: 10.1080/14486563.2006.10648678

Celesti-Grapow L, Alessandrini A, Arrigoni PV, et al. (2010) Non-native flora of Italy: Species distribution and threats. Plant Biosyst 144:12–28. doi: 10.1080/11263500903431870

Celesti-Grapow L, Blasi C (1998) A comparison of the urban flora of different phytoclimatic regions in Italy. Glob Ecol Biogeogr Lett 7:367–378. doi: 10.1046/j.1466-822X.1998.00304.x

Celesti-Grapow L, Blasi C (2004) The role of alien and native weeds in the deterioration of archaeological remains in Italy. Weed Technol 18:1508–1513. doi: 10.1614/0890-037X(2004)018[1508:TROAAN]2.0.CO;2

Celesti-Grapow L, Capotorti G, Del Vico E, et al. (2013) The vascular flora of Rome. Plant Biosyst 147:1059–1087. doi: 10.1080/11263504.2013.862315

Celesti-Grapow L, Pyšek P, Jarošík V, Blasi C (2006) Determinants of native and alien species richness in the urban flora of Rome. Divers Distrib 12:490–501. doi: 10.1111/j.1366-9516.2006.00282.x

Čepelová B, Münzbergová Z (2012) Factors determining the plant species diversity and species composition in a suburban landscape. Landsc Urban Plan 106:336–346. doi: 10.1016/j.landurbplan.2012.04.008

Čeplová N, Lososová Z, Zelený D et al. (2015) Phylogenetic diversity of central-European urban plant communities. Preslia 87:1–16

Cervelli EW, Lundholm JT, Du X (2013) Spontaneous urban vegetation and habitat heterogeneity in Xi'an, China. Landsc Urban Plan 120:25–33. doi: 10.1016/j.landurbplan.2013.08.001

Chaparro L, Terrasdas J (2009) Ecological services of urban forest in Barcelona. Shengtai Xuebao/ Acta Ecol Sin 29:103. doi: 10.13140/RG.2.1.4013.9604

Cheptou P-O, Carrue O, Rouifed S, Cantarel A (2008) Rapid evolution of seed dispersal in an urban environment in the weed Crepis sancta. Proc Natl Acad Sci USA 105:3796–3799. doi: 10.1073/pnas.0708446105

Chocholoušková Z, Pyšek P (2003) Changes in composition and structure of urban flora over 120 years: a case study of the city of Plzeň. Flora - Morphol Distrib Funct Ecol Plants 198:366–376. doi: 10.1078/0367-2530-00109

Cierjacks A, Kowarik I, Joshi J, et al. (2013) Biological flora of the British Isles: *Robinia pseudoacacia*. J Ecol 101:1623–1640. doi: 10.1111/1365-2745.12162

Cilliers S, Cilliers J, Lubbe R, Siebert S (2013) Ecosystem services of urban green spaces in African countries-perspectives and challenges. Urban Ecosyst 16:681–702. doi: 10.1007/s11252-012-0254-3

Cilliers SS, Bredenkamp GJ (1999) Ruderal and degraded natural vegetation on vacant lots in the Potchefstroom Municipal Area , North West Province , South Africa. South African J Bot 65:163–173. doi: 10.1016/S0254-6299(15)30956-X

Cilliers SS, Bredenkamp GJ (2000) Vegetation of road verges on an urbanisation gradient in Potchefstroom, South Africa. Landsc Urban Plan 46:217–239. doi: 10.1016/S0169-2046(99)00057-2

Cilliers SS, Williams NSG, Barnard FJ (2008) Patterns of exotic plant invasions in fragmented urban and rural grasslands across continents. Landsc Ecol 23:1243–1256. doi: 10.1007/s10980-008-9295-7

Clarke LW, Li L, Jenerette GD, Yu Z (2014) Drivers of plant biodiversity and ecosystem service production in home gardens across the Beijing Municipality of China. Urban Ecosyst 741–760. doi: 10.1007/s11252-014-0351-6

Concepción ED, Obrist MK, Moretti M, et al. (2016) Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds: not only built-up area matters. Urban Ecosyst 19:225–242. doi: 10.1007/s11252-015-0474-4

Cook-Patton SC, Bauerle TL (2012) Potential benefits of plant diversity on vegetated roofs: A literature review. J Environ Manage 106:85–92. doi: 10.1016/j.jenvman.2012.04.003

Corchnoy SB, Arey J, Atkinson R (1992) Hydrocarbon emissions from twelve urban shade trees of the Los Angeles, California, Air Basin. Atmos Environ Part B, Urban Atmos 26:339–348. doi: 10.1016/0957-1272(92)90009-H

Costanza R, Wilson M, Troy A, Voinov A, Liu S, D'Agostino J (2007) The value of New Jersey's ecosystem services and natural capital. Project report to the New Jersey Department of Environmental Protection

Crowe TM (1979) Lots of weeds: insular phytogeography of vacant urban lots. J Biogeogr 6:169–181

Cumming GS, Buerkert A, Hoffmann EM, et al. (2014) Implications of agricultural transitions and urbanization for ecosystem services. Nature 515:50–57. doi: 10.1038/nature13945

Cusack DF, McCleery TL (2014) Patterns in understory woody diversity and soil nitrogen across native- and non-native-urban tropical forests. For Ecol Manage 318:34–43. doi: 10.1016/j.foreco.2013.12.036

Czarnecka J, Kitowski I, Sugier P, et al. (2013) Seed dispersal in urban green space - Does the rook *Corvus frugilegus* L. contribute to urban flora homogenization? Urban For Urban Green 12:359–366. doi: 10.1016/j.ufug.2013.03.007

D'Amato G (2000) Urban air pollution and plant-derived respiratory allergy. Clin Exp Allergy 30:628–636. doi: 10.1046/j.1365-2222.2000.00798.x

D'Amato G, Cecchi L, Bonini S, et al. (2007) Allergenic pollen and pollen allergy in Europe. Allergy Eur J Allergy Clin Immunol 62:976–990. doi: 10.1111/j.1398-9995.2007.01393.x

Dana E, Vivas S, Mota J (2002) Urban vegetation of Almeria City–a contribution to urban ecology in Spain. Landsc Urban Plan 59:203–216. doi: 10.1016/S0169-2046(02)00039-7

Davies ZG, Edmondson JL, Heinemeyer A, et al. (2011) Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale. J Appl Ecol 48:1125–1134. doi: 10.1111/j.1365-2664.2011.02021.x

Davis AJS, Singh KK, Thill J-C, Meentemeyer RK (2016) Accounting for residential propagule pressure improves prediction of urban plant invasion. Ecosphere 7(3):e01232. doi: 10.1002/ecs2.1232

Davis MA (2013) Invasive plants and animal species: Threats to ecosystem services. In: Davis MA (ed) Climate Vulnerability: Understanding and addressing threats to essential resources. Elsevier Inc., Academic Press, pp 51–59. doi: 10.1016/B978-0-12-384703-4.00405-6

DeCandido R (2004) Recent changes in plant species diversity in urban Pelham Bay Park, 1947-1998. Biol Conserv 120:129–136. doi: 10.1016/j.biocon.2004.02.005

DeCandido R, Muir A, Gargiullo MB (2004) A first approximation of the historical and extant vascular flora of New York City: Implications for native plant species conservation. J Torrey Bot Soc 131:243. doi: 10.2307/4126954

Dehnen-Schmutz, Katharina Touza J (2008) Plant invasions and ornamental horticulture: Pathway, propagule pressure and the legal framework. In: Teixeira da Silva JA (ed) Floriculture, ornamental and plant biotechnology: advances and topical issues. Global Science Books, pp 15-21

Dennis M, James P (2016) Site-specific factors in the production of local urban ecosystem services: A case study of community-managed green space. Ecosyst Serv 17:208–216. doi: 10.1016/j.ecoser.2016.01.003

Dobbs C, Kendal D, Nitschke CR (2014) Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics. Ecol Indic 43:44–55. doi: 10.1016/j.ecolind.2014.02.007

Dolan RW, Moore ME, Stephens JD (2011) Documenting effects of urbanization on flora using herbarium records. J Ecol 99:1055–1062. doi: 10.1111/j.1365-2745.2011.01820.x

Dolan RW, Moore ME, Stephens JD (2011) Documenting effects of urbanization on flora using herbarium records. J Ecol 99:1055–1062. doi: 10.1111/j.1365-2745.2011.01820.x

Dolan RW, Stephens JD, Moore ME (2015) Changes in plant species composition and structure in two peri-urban nature preserves over 10 years. Am Midl Nat 174:33–48

Donovan GH, Butry DT (2009) The value of shade: Estimating the effect of urban trees on summertime electricity use. Energy Build 41:662–668. doi: 10.1016/j.enbuild.2009.01.002

Donovan GH, Butry DT (2010) Trees in the city: Valuing street trees in Portland, Oregon. Landsc Urban Plan 94:77–83. doi: 10.1016/j.landurbplan.2009.07.019

Donovan GH, Butry DT (2011) The effect of urban trees on the rental price of single-family homes in Portland, Oregon. Urban For Urban Green 10:163–168. doi: 10.1016/j.ufug.2011.05.007

Dures SG, Cumming GS (2010) The confounding influence of homogenising invasive species in a globally endangered and largely urban biome: Does habitat quality dominate avian biodiversity? Biol Conserv 143:768–777. doi: 10.1016/j.biocon.2009.12.019

Dwyer JF, Mcpherson EG, Schroeder HW, Rowntree R (1992) Assessing the Benefits and Costs of the. J Arboric 18:227–234

Dwyer JF, Nowak DJ, Noble MH (2003) Sustaining urban forests. J Arboric 29:49–55

Dwyer JF, Schroeder HW, Gobster PH (1991) The significance of urban trees and forests: toward a deeper understanding of values. J Arboric 17:276–284.

Dyderski MK, Gdula AK, Jagodziński AM (2015) "The rich get richer" concept in riparian woody species – A case study of the Warta River Valley (Poznań, Poland). Urban For Urban Green 14:107–114. doi: 10.1016/j.ufug.2014.12.003

Dyderski MK, Jagodzinski AM (2016) Patterns of plant invasions at small spatial scale correspond with that at the whole country scale. Urban Ecosyst 19:983–998. doi: 10.1007/s11252-015-0524-y

Edmondson JL, O'Sullivan OS, Inger R, et al. (2014) Urban tree effects on soil organic carbon. PLoS One 9:1–6. doi: 10.1371/journal.pone.0101872

Ehrenfeld JG (1997) Invasion of deciduous forest preserves in the New York metropolitan region by Japanese barberry (*Berberis thunbergii* DC.). J Torrey Bot Soc 124:210–215. doi: 10.2307/2996586

Ehrenfeld JG (2008) Exotic invasive species in urban wetlands: Environmental correlates and implications for wetland management. J Appl Ecol 45:1160–1169. doi: 10.1111/j.1365-2664.2008.01476.x

Elmqvist T, Alfsen C, Colding J (2008) Urban Systems. In: Jørgensen SE, Fath BD (eds) Ecosystems. Vol. [5] of Encyclopedia of Ecology. Oxford: Elsevier pp. 3665-3672

Enrique E, Cistero-Bahima A, Bartolome B, et al. (2002) Short communication *Platanus acerifolia* pollinosis and food allergy. Allergy 57:351–356

Escobedo F, Varela S, Zhao M, et al. (2010) Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. Environ Sci Policy 13:362–372. doi: 10.1016/j.envsci.2010.03.009

Escobedo FJ, Kroeger T, Wagner JE (2011) Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. Environ Pollut 159:2078–2087. doi: 10.1016/j.envpol.2011.01.010

Escobedo FJ, Nowak DJ (2009) Spatial heterogeneity and air pollution removal by an urban forest. Landsc Urban Plan 90:102–110. doi: 10.1016/j.landurbplan.2008.10.021

Escobedo FJ, Nowak DJ, Wagner JE, et al. (2006) The socioeconomics and management of Santiago de Chile's public urban forests. Urban For Urban Green 4:105–114. doi: 10.1016/j.ufug.2005.12.002

Foster J, Sandberg LA (2004) Friends of Foe? Invasive species and public green space in Toronto. Geogr Rev 94:178–198

Francis RA, Chadwick MA (2015) Invasions: Non-native and invasive species in cities. Geography (Sheffield, England) 100(3):144-151

Frank S, Waters G, Beer R, May P (2006) An analysis of the street tree population of greater Melbourne at the beginning of the 21st century. Arboric Urban For 32:155–163

Friess DA (2016) Singapore as a long-term case study for tropical urban ecosystem services. Urban Ecosyst 1–15. doi: 10.1007/s11252-016-0592-7

Gairola S, Bhatt A, Govender Y, et al. (2013) Incidence and intensity of tree infestation by the mistletoe *Erianthemum dregei* (Eckl. & Zeyh.) V. Tieghem in Durban, South Africa. Urban For Urban Green 12:315–322. doi: 10.1016/j.ufug.2013.03.012

Galvin MF (1999) A methodology for assessing and managing biodiversity in street tree populations: A case study. J Arboric 25:124–128.

Gao X, Asami Y (2007) Effect of urban landscapes on land prices in two Japanese cities. Landsc Urban Plan 81:155–166. doi: 10.1016/j.landurbplan.2006.11.007

Garcia-Garcia MJ, Sánchez-Medina A, Alfonso-Corzo E, Gonzalez Garcia C (2016) An index to identify suitable species in urban green areas. Urban For Urban Green 16:43–49. doi: 10.1016/j.ufug.2016.01.006

Godefroid S (2001) Temporal analysis of the Brussels flora as indicator for changing environmental quality. Landsc Urban Plan 52:203–224. doi: 10.1016/S0169-2046(00)00117-1

Godefroid S, Koedam N (2003) Identifying indicator plant species of habitat quality and invasibility as a guide for peri-urban forest management. Biodivers Conserv 12:1699–1713. doi: 10.1023/A:1023606300039

Godefroid S, Koedam N (2007) Urban plant species patterns are highly driven by density and function of built-up areas. Landsc Ecol 22:1227–1239. doi: 10.1007/s10980-007-9102-x

Godefroid S, Monbaliu D, Koedam N (2007) The role of soil and microclimatic variables in the distribution patterns of urban wasteland flora in Brussels, Belgium. Landsc Urban Plan 80:45–55. doi: 10.1016/j.landurbplan.2006.06.001

Golivets M (2013) Ecological and biological determination of invasion success of non-native plant species in urban woodlands with special regard to short-lived monocarps. Urban Ecosyst 17:291–303. doi: 10.1007/s11252-013-0313-4

Gong C, Chen J, Yu S (2013) Biotic homogenization and differentiation of the flora in artificial and near-natural habitats across urban green spaces. Landsc Urban Plan 120:158–169. doi: 10.1016/j.landurbplan.2013.08.006

González-Moreno P, Pino J, Carreras D, et al. (2013) Quantifying the landscape influence on plant invasions in Mediterranean coastal habitats. Landsc Ecol 28:891–903. doi: 10.1007/s10980-013-9857-1

Goodness J, Andersson E, Anderson PML, Elmqvist T (2015) Exploring the links between functional traits and cultural ecosystem services to enhance urban ecosystem management. Ecol Indic 70:597–605. doi: 10.1016/j.ecolind.2016.02.031

Gorman J (2004) Residents' opinions on the value of street trees depending on tree location. J Arboric 30:36–44. doi: citeulike-article-id:7688660

Grapow LC, Blasi C (1998) A comparison of the urban flora of different phytoclimatic regions in Italy. Glob Ecol Biogeogr Lett 7:367–378. doi: 10.1046/j.1466-822X.1998.00304.x

Gratani L, Varone L (2007) Plant crown traits and carbon sequestration capability by Platanus hybrida Brot. in Rome. Landsc Urban Plan 81:282–286. doi: 10.1016/j.landurbplan.2007.01.006

Gregor T, Bönsel D, Starke-Ottich I, Zizka G (2012) Drivers of floristic change in large cities - A case study of Frankfurt/Main (Germany). Landsc Urban Plan 104:230–237. doi: 10.1016/j.landurbplan.2011.10.015

Grimmond CSB, Souch C, Hubble MD (1996) Influence of tree cover on summertime surface energy balance fluxes, San Gabriel Valley, Los Angeles. Clim Res 6:45–57. doi: 10.3354/cr006045

Guitart D, Pickering C, Byrne J (2012) Past results and future directions in urban community gardens research. Urban For Urban Green 11:364–373. doi: 10.1016/j.ufug.2012.06.007

Gulezian PZ, Nyberg DW (2010) Distribution of invasive plants in a spatially structured urban landscape. Landsc Urban Plan 95:161–168. doi: 10.1016/j.landurbplan.2009.12.013

Guo Q, Qian H, Ricklefs R, Xi W (2006) Distributions of exotic plants in eastern Asia and North America. Ecol Lett 9:827–834. doi: 10.1111/j.1461-0248.2006.00938.x

Haines-Young R, Potschin M (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelii DG, Frid CLJ (eds) Ecosystem Ecology: a new synthesis. Cambridge University Press, pp 110–139

Hansen R, Frantzeskaki N, McPhearson T, et al. (2015) The uptake of the ecosystem services concept in planning discourses of European and American cities. Ecosyst Serv 12:228–246. doi: 10.1016/j.ecoser.2014.11.013

Hartman KM, Mccarthy BC (2007) A dendro-ecological study of forest overstorey productivity following the invasion of the non-indigenous shrub *Lonicera maackii*. Appl Veg Sci 10:3–14. doi: 10.1111/j.1654-109X.2007.tb00498.x

Hausmann SL, Petermann JS, Rolff J (2016) Wild bees as pollinators of city trees. Insect Conserv Divers 9:97–107. doi: 10.1111/icad.12145

Hayasaka D, Akasaka M, Miyauchi D, et al. (2012) Qualitative variation in roadside weed vegetation along an urban-rural road gradient. Flora Morphol Distrib Funct Ecol Plants 207:126–132. doi: 10.1016/j.flora.2011.11.005

Heisler GM (1986) Effects of individual trees on the solar radiation climate of small buildings. Urban Ecol 9:337–359. doi: 10.1016/0304-4009(86)90008-2

Hejda M, Pyšek P (2006) What is the impact of *Impatiens glandulifera* on species diversity of invaded riparian vegetation? Biol Conserv 132:143–152. doi: 10.1016/j.biocon.2006.03.025

Hejda M, Pyšek P, Jarošík V (2009) Impact of invasive plants on the species richness, diversity and composition of invaded communities. J Ecol 97:393–403. doi: 10.1111/j.1365-2745.2009.01480.x

Hill MO, Roy DB, Thompson K (2002) Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. J Appl Ecol 39:708–720.

Hitchmough J (2011) Exotic plants and plantings in the sustainable, designed urban landscape. Landsc Urban Plan 100:380–382. doi: 10.1016/j.landurbplan.2011.02.017

Ho M, Richardson CJ (2013) A five year study of floristic succession in a restored urban wetland. Ecol Eng 61:511–518. doi: 10.1016/j.ecoleng.2013.05.001

Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. Trends Ecol Evol 24:599–605. doi: 10.1016/j.tree.2009.05.012

Holt AR, Mears M, Maltby L, Warren P (2015) Understanding spatial patterns in the production of multiple urban ecosystem services. Ecosyst Serv 16:33–46. doi: 10.1016/j.ecoser.2015.08.007

Hong SK, Song IJ, Kim HO, Lee EK (2003) Landscape pattern and its effect on ecosystem functions in Seoul Metropolitan area: Urban ecology on distribution of the naturalized plant species. J Environ Sci 15:199–204

Horn J, Escobedo FJ, Hinkle R, et al. (2014) The role of composition, invasives, and maintenance emissions on urban forest carbon stocks. Environ Manage 55:431–442. doi: 10.1007/s00267-014-0400-1

Hostetler M, Allen W, Meurk C (2011) Conserving urban biodiversity? Creating green infrastructure is only the first step. Landsc Urban Plan 100:369–371. doi: 10.1016/j.landurbplan.2011.01.011

Hulme PE (2009) Trade, transport and trouble: Managing invasive species pathways in an era of globalization. J Appl Ecol 46:10–18. doi: 10.1111/j.1365-2664.2008.01600.x

Hynes P, Howe G (2004) Urban horticulture in the contemporary united states: Personal and community benefits. Acta Hortic 643:171–181. doi: 10.17660/ActaHortic.2004.643.21

Jaafar HH, Woertz E (2016) Agriculture as a funding source of ISIS: A GIS and remote sensing analysis. Food Policy 64:14–25. doi: 10.1016/j.foodpol.2016.09.002

Jäger S (2000) Ragweed (Ambrosia) sensitisation rates correlate with the amount of inhaled airborne pollen. A 14-year study in Vienna, Austria. Aerobiologia (Bologna) 16:149–153. doi: 10.1023/A:1007603321556

Janhäll S (2015) Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmos Environ 105:130–137. doi: 10.1016/j.atmosenv.2015.01.052

Jarošik V, Pyšek P, Kadlec T (2011) Alien plants in urban nature reserves: from red-list species to future invaders? NeoBiota 10:27. doi: 10.3897/neobiota.10.1262

Jenerette GD, Harlan SL, Stefanov WL, Martin CA (2011) Ecosystem services and urban heat riskcape moderation: water, green spaces, and social inequality in Phoenix, USA. Ecol Appl 21:2637–2651. doi: 10.1890/10-1493.1

Jianan X, Zhiyun O, Hua Z, et al. (2007) Allergenic pollen plants and their influential factors in urban areas. Acta Ecol Sin 27:3820–3827. doi: 10.1016/S1872-2032(07)60082-1

Jim CY (1992) Tree-habitat relationships in urban Hong Kong. Environ Conserv 19:209–218. doi: 10.1016/0006-3207(93)90180-9

Jim CY, Chen WY (2008) Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J Environ Manage 88:665–676. doi: 10.1016/j.jenvman.2007.03.035

Jim CY, Chen WY (2008) Pattern and divergence of tree communities in Taipei's main urban green spaces. Landsc Urban Plan 84:312–323. doi: 10.1016/j.landurbplan.2007.09.001

Jim CY, Chen WY (2009) Diversity and distribution of landscape trees in the compact Asian city of Taipei. Appl Geogr 29:577–587. doi: 10.1016/j.apgeog.2009.01.002

Jim CY, Chen WY (2009) Ecosystem services and valuation of urban forests in China. Cities 26:187–194. doi: 10.1016/j.cities.2009.03.003

Jonsson P (2004) Vegetation as an urban climate control in the subtropical city of Gaborone, Botswana. Int J Climatol 24:1307–1322. doi: 10.1002/joc.1064

Josic D, Delic D, Rasulic N, et al. (2012) Indigenous pseudomonads from rhizosphere of maize grown on pseudogley soil in Serbia. Bulg J Agric Sci 18:197–206. doi: 10.1007/sl

Kaya LG (2009) Assessing forests and lands with carbon storage and sequestration amount by trees in the State of Delaware, USA. Sci Res Essays 4:1100–1108.

Kiss M, Takács Á, Pogácsás R, Gulyás Á (2015) The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). Morav Geogr Reports 23:36–46. doi: 10.1515/mgr-2015-0016

Knapp S, Kühn I, Stolle J, Klotz S (2010) Changes in the functional composition of a Central European urban flora over three centuries. Perspect Plant Ecol Evol Syst 12:235–244. doi: 10.1016/j.ppees.2009.11.001

Knight KS, Kurylo JS, Endress AG, Stewart JR, Reich PB (2007) Ecology and ecosystem impacts of common buckthorn (*Rhamnus cathartica*): a review. Biol Invasions 9: 925–937

Konarska J, Uddling J, Holmer B, et al. (2016) Transpiration of urban trees and its cooling effect in a high latitude city. Int J Biometeorol 60:159–172. doi: 10.1007/s00484-015-1014-x

Konijnendijk CC, Annerstedt M, Nielsen AB, Maruthaveeran S (2013) Benefits of urban parks. A systematic review. A Report for IFPRA. http://www.ifpra.org/images/park-benefits.pdf. Accessed 26 April 2016

Kowarik I (2003) Human agency in biological invasions: secondary releases foster naturalisation and population expansion of alien plant species. Biol Invasions 5:293–312. doi: 10.1023/B:BINV.0000005574.15074.66

Kowarik I (2005) Urban ornamentals escaped from cultivation. In: Gressel J (ed) Crop ferality and volunteerism: a threat to food security in the transgenic era? CRC Press, Boca Raton pp. 97–121

Kowarik I (2011) Novel urban ecosystems, biodiversity, and conservation. Environ Pollut 159:1974–1983. doi: 10.1016/j.envpol.2011.02.022

Kowarik I, Säumel I (2007) Biological flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. Perspect Plant Ecol Evol Syst 8:207–237. doi: 10.1016/j.ppees.2007.03.002

Kowarik I, Von Der Lippe M, Cierjacks A (2013) Prevalence of alien versus native species of woody plants in Berlin differs between habitats and at different scales. Preslia 85:113–132. doi: 10.1111/ddi.12028)

Kremer P, Andersson E, McPhearson T, Elmqvist T (2015) Advancing the frontier of urban ecosystem services research. Ecosyst Serv 12:149–151. doi: 10.1016/j.ecoser.2015.01.008

Kremer P, Hamstead ZA, McPhearson T (2016) The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios. Environ Sci Policy 62:57–68. doi: 10.1016/j.envsci.2016.04.012

Kronenberg J (2015) Why not to green a city? Institutional barriers to preserving urban ecosystem services. Ecosyst Serv 12:218–227. doi: 10.1016/j.ecoser.2014.07.002

Kühn I, Klotz S (2006) Urbanization and homogenization - Comparing the floras of urban and rural areas in Germany. Biol Conserv 127:292–300. doi: 10.1016/j.biocon.2005.06.033

Kuittinen M, Moinel C, Adalgeirsdottir K (2016) Carbon sequestration through urban ecosystem services: A case study from Finland. Sci Total Environ 563–564:623–632. doi: 10.1016/j.scitotenv.2016.03.168

Kuruneri-Chitepo C, Shackleton CM (2011) The distribution, abundance and composition of street trees in selected towns of the Eastern Cape, South Africa. Urban For Urban Green 10:247–254. doi: 10.1016/j.ufug.2011.06.001

La Sorte FA, Aronson MFJ, Williams NSG, et al. (2014) Beta diversity of urban floras among European and non-European cities. Glob Ecol Biogeogr 23:769–779. doi: 10.1111/geb.12159

La Sorte FA, McKinney ML (2006) Compositional similarity and the distribution of geographical range size for assemblages of native and non-native species in urban floras. Divers Distrib 12:679–686. doi: 10.1111/j.1472-4642.2006.00276.x

La Sorte FA, McKinney ML, Pyšek P (2007) Compositional similarity among urban floras within and across continents: Biogeographical consequences of human-mediated biotic interchange. Glob Chang Biol 13:913–921. doi: 10.1111/j.1365-2486.2007.01329.x

La Sorte FA, Mckinney ML, Pyšek P, et al. (2008) Distance decay of similarity among European urban floras: The impact of anthropogenic activities on β diversity. Glob Ecol Biogeogr 17:363–371. doi: 10.1111/j.1466-8238.2007.00369.x

Langemeyer J (2014) The generation of ecosystem services in urban gardens from a socio-ecological systems perspective. Institute for Environmental Science and Technology 27

Larondelle N, Haase D (2013) Urban ecosystem services assessment along a rural-urban gradient: A cross-analysis of European cities. Ecol Indic 29:179–190. doi: 10.1016/j.ecolind.2012.12.022

Larondelle N, Lauf S (2016) Balancing demand and supply of multiple urban ecosystem services on different spatial scales. Ecosyst Serv 22:18–31. doi: 10.1016/j.ecoser.2016.09.008

Lee YC, Ahern J, Yeh CT (2015) Ecosystem services in peri-urban landscapes: The effects of agricultural landscape change on ecosystem services in Taiwan’s western coastal plain. Landsc Urban Plan 139:137–148. doi: 10.1016/j.landurbplan.2015.02.023

Lenda M, Skórka P, Knops JMH, et al. (2012) Plant establishment and invasions: an increase in a seed disperser combined with land abandonment causes an invasion of the non-native walnut in Europe. Proc R Soc B 279:1491–7. doi: 10.1098/rspb.2011.2153

Li F, Liu X, Zhang X, et al. (2016) Urban ecological infrastructure: an integrated network for ecosystem services and sustainable urban systems. J Clean Prod 1–7. doi: 10.1016/j.jclepro.2016.02.079

Li YY, Wang XR, Huang CL (2011) Key street tree species selection in urban areas. African J Agric Res 6:3539–3550. doi: 10.5897/AJAR11.461

Liu C, Li X (2012) Carbon storage and sequestration by urban forests in Shenyang, China. Urban For Urban Green 11:121–128. doi: 10.1016/j.ufug.2011.03.002

Liu L, Li F, Yang Q, et al. (2014) Long-term differences in annual litter production between alien (*Sonneratia apetala*) and native (*Kandelia obovata*) mangrove species in Futian, Shenzhen, China. Mar Pollut Bull 85:747–753. doi: 10.1016/j.marpolbul.2014.04.047

Livingstone S, Yasui S-L, Cadotte M (2015) Do invasive plants impact ecosystem services? In: Ontario Nat. Blog. https://www.ontarionature.org/connect/blog/how-an-invasive-plant-impacts-ecosystem-services-in-the-rouge/. Accessed 6 Mar 2016

Lohr VI, Pearson-Mims CH, Tarnai J, Dillman DA (2004) How urban residents rate and rank the benefits and problems associated with trees in cities. J Arboric 30:28–35

Lookingbill TR, Minor ES, Bukach N, et al. (2014) Incorporating risk of reinvasion to prioritize sites for invasive species management. Nat Areas J 34:268–281. doi: 10.3375/043.034.0303

Loram A, Thompson K, Warren PH, et al. (2008) Urban domestic gardens (XII): The richness and composition of the flora in five UK cities. J Veg Sci 19:321–330. doi: 10.3170/2007-8-18373

Lorenzoni-Chiesura F, Giorato M, Marcer G (2000) Allergy to pollen of urban cultivated plants. Aerobiologia (Bologna) 16:313–316. doi: 10.1023/A:1007652602113

Lososová Z, Chytrý M, Kühn I, et al. (2006) Patterns of plant traits in annual vegetation of man-made habitats in central Europe. Perspect Plant Ecol Evol Syst 8:69–81. doi: 10.1016/j.ppees.2006.07.001

Lososová Z, Chytrý M, Tichý L, et al. (2012) Biotic homogenization of Central European urban floras depends on residence time of alien species and habitat types. Biol Conserv 145:179–184. doi: 10.1016/j.biocon.2011.11.003

Lososová Z, Chytrý M, Tichý L, et al. (2012) Native and alien floras in urban habitats: A comparison across 32 cities of central Europe. Glob Ecol Biogeogr 21:545–555. doi: 10.1111/j.1466-8238.2011.00704.x

Lovell ST, Taylor JR (2013) Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landsc Ecol 28:1447–1463. doi: 10.1007/s10980-013-9912-y

Lovett GM, Mitchell MJ (2016) Frontiers in Ecology and the Environment. Front Ecol Environ 2:81–88

Lowenstein DM, Matteson KC, Minor ES (2015) Diversity of wild bees supports pollination services in an urbanized landscape. Oecologia 179:811–821. doi: 10.1007/s00442-015-3389-0

Luck GW, Harrington R, Harrison PA, et al. (2009) Quantifying the contribution of organisms to the provision of ecosystem services. Bioscience 59:223–235. doi: 10.1025/bio.2009.59.3.7

Lugo AE (2009) The emerging era of novel tropical forests. Biotropica 41:589–591. doi: 10.1111/j.1744-7429.2009.00550.x

Lundholm J, Heim A, Tran S, Smith T (2014) Leaf and life history traits predict plant growth in a green roof ecosystem. PLoS One 9:1–10. doi: 10.1371/journal.pone.0101395

Lundholm JT (2015) Green roof plant species diversity improves ecosystem multifunctionality. J Appl Ecol 52:726–734. doi: 10.1111/1365-2664.12425

Luz-Lezcano Caceres H, Gerold G (2009) The costs of invasion control measures subtropical *Ailanthus altissima* in Hesse. Conference on International Research on Food Security, Natural Resource Management and Rural Development, Tropentag

Mack RN, Lonsdale WM (2001) Humans as global plant dispersers: Getting more than we bargained for. Bioscience 51:95. doi: 10.1641/0006-3568(2001)051[0095:HAGPDG]2.0.CO;2

Mack RN, Simberloff D, Lonsdale M, et al. (2000) Issues in Ecology. Ecol Appl 10:689–710

Maco SE, Mcpherson EG (2003) A practical approach to assessing structure, function, and value of street tree populations in small communities. J Arboric 29:84–97

Makra L, Juhász M, Borsos E, Béczi R (2004) Meteorological variables connected with airborne ragweed pollen in Southern Hungary. Int J Biometeorol 49:37–47. doi: 10.1007/s00484-004-0208-4

Mandrioli P, Cecco M, Andina G (1998) Ragweed pollen: The aeroallergen is spreading in Italy. Aerobiologia (Bologna) 14:13–20. doi: 10.1007/BF02694590

Manes F, Incerti G, Salvatori E, et al. (2012) Urban ecosystem services: tree diversity and stability of tropospheric ozone removal. Ecol Appl 22:349–60. doi: 10.1890/11-0561.1

Mao Q, Ma K, Jianguo W, Rongli T, Shanghua L, Yuxin Z, Le B (2013). Distribution pattern of allergenic plants in the Beijing metropolitan region. Aerobiologia 29(2):217e231

Marozas V, Cekstere G, Laivins M, Straigyte L (2015) Comparison of neophyte communities of *Robinia pseudoacacia* L. and *Acer negundo* L. in the eastern Baltic Sea region cities of Riga and Kaunas. Urban For Urban Green 14:826–834. doi: 10.1016/j.ufug.2015.08.003

Maskell LC, Bullock JM, Smart SM, et al. (2006) The distribution and habitat associations of non-native plant species in urban riparian habitats. J Veg Sci 17:499–508. doi: 10.1111/j.1654-1103.2006.tb02471.x

McCarthy HR, Pataki DE (2010) Drivers of variability in water use of native and non-native urban trees in the greater Los Angeles area. Urban Ecosyst 13:393–414. doi: 10.1007/s11252-010-0127-6

McDonnell MJ, Pickett ST (1990) Ecosystem structure and function along gradients: an unexploited urban-rural opportunity for ecology. Ecology 71:1232–1237. doi: 10.2307/1938259

McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127:247–260. doi: 10.1016/j.biocon.2005.09.005

McKinney ML, Lockwood JL (1999) Biotic homogenization: A few winners replacing many losers in the next mass extinction. Trends Ecol Evol 14:450–453. doi: 10.1016/S0169-5347(99)01679-1

McPherson EG (2003) A benefit-cost analysis of ten street tree species in Modesto, California, U.S. J Arboric 29:1–8

McPherson EG (2010) Selecting reference cities for i-Tree streets. Arboric Urban For 36:230–240

McPherson EG, Nowak D, Heisler G, et al. (1997) Quantifying urban forest structure, function, and value: the Chicago urban forest project. Urban Ecosyst 1:49–61. doi: 10.1023/A:1014350822458

McPherson EG, Nowak DJ, Heisler G, et al. (1997) Quantifing urban forest structure, function and value, Chicago Urban Forest Climate Project. Urban Ecosyst 1:49–61. doi: 10.1023/A:1014350822458

McPherson EG, Nowak DJ, Rowntree RA (1994) Chicago's urban forest ecosystem: Results of the Chicago urban forest climate project (Report NE-186). Washington, DC: USDA Forest Service, Northeastern Forest Experiment Station

McPherson EG, Scott KI, Simpson JR (1998) Estimating cost effectiveness of residential yard trees for improving air quality in Sacramento, California, using existing models. Atmos Environ 32:75–84. doi: 10.1016/S1352-2310(97)00180-5

McPherson EG, van Doorn N, de Goede J (2016) Structure, function and value of street trees in California, USA. Urban For Urban Green 17:104–115. doi: 10.1016/j.ufug.2016.03.013

McPherson G, Simpson JR, Peper PJ, et al. (2005) Municipal forest benefits and costs in five US cities. J For 103:411–416

Meek CS, Richardson DM, Mucina L (2010) A river runs through it: Land-use and the composition of vegetation along a riparian corridor in the Cape Floristic Region, South Africa. Biol Conserv 143:156–164. doi: 10.1016/j.biocon.2009.09.021

Mensah S, Veldtman R, Assogbadjo AE, et al. (2017) Ecosystem service importance and use vary with socio-environmental factors: A study from household-surveys in local communities of South Africa. Ecosyst Serv 23:1–8. doi: 10.1016/j.ecoser.2016.10.018

Meurk CD, Blaschke PM, Simcock RC (2013) Ecosystem services in New Zealand cities. In: Dymond JR (ed) Ecosystem services in New Zealand - conditions and trends. Manaaki Whenua Press, Lincoln, pp 254–273

Millard A (2008) Semi-natural vegetation and its relationship to designated urban green space at the landscape scale in Leeds, UK. Landsc Ecol 23:1231–1241. doi: 10.1007/s10980-008-9256-1

Millward AA, Sabir S (2011) Benefits of a forested urban park: What is the value of Allan Gardens to the city of Toronto, Canada? Landsc Urban Plan 100:177–188. doi: 10.1016/j.landurbplan.2010.11.013

Morani A, Nowak DJ, Hirabayashi S, Calfapietra C (2011) How to select the best tree planting locations to enhance air pollution removal in the MillionTreesNYC initiative. Environ Pollut 159:1040–1047. doi: 10.1016/j.envpol.2010.11.022

Morgan JW, Journal S, Apr N, John W (2016) Patterns of Invasion of an Urban Remnant of a Species-Rich Grassland in Southeastern Australia by Non-Native Plant Species Stable. J Veg Sci 9:181–190

Morimoto Y (2011) Biodiversity and ecosystem services in urban areas for smart adaptation to climate change: “Do you Kyoto”? Landsc Ecol Eng 7:9–16. doi: 10.1007/s11355-010-0140-1

Moro MF, Castro ASF (2015) A check list of plant species in the urban forestry of Fortaleza, Brazil: where are the native species in the country of megadiversity? Urban Ecosyst 18:47–71. doi: 10.1007/s11252-014-0380-1

Moser A, Rötzer T, Pauleit S, Pretzsch H (2015) Structure and ecosystem services of small-leaved lime (*Tilia cordata* Mill.) and black locust (*Robinia pseudoacacia* L.) in urban environments. Urban For Urban Green 14:1110–1121. doi: 10.1016/j.ufug.2015.10.005

Mosina GK, Maroyi A, Potgieter MJ (2014) Comparative analysis of plant use in peri-urban domestic gardens of the Limpopo Province, South Africa. J Ethnobiol Ethnomed 10:35. doi: 10.1186/1746-4269-10-35

Mullaney J, Lucke T, Trueman SJ (2015) A review of benefits and challenges in growing street trees in paved urban environments. Landsc Urban Plan 134:157–166. doi: 10.1016/j.landurbplan.2014.10.013

Müller N, Werner P (2010) Urban biodiversity and the case for implementing the convention on biological diversity in towns and cities. In: Müller N, Werner P Kelcey JG (eds) Urban Biodiversity and Design. Wiley-Blackwell, Oxford, UK. doi: 10.1002/9781444318654.ch1

Muthulingam U, Thangavel S (2012) Density, diversity and richness of woody plants in urban green spaces: A case study in Chennai metropolitan city. Urban For Urban Green 11:450–459. doi: 10.1016/j.ufug.2012.08.003

Myeong S, Nowak DJ, Duggin MJ (2006) A temporal analysis of urban forest carbon storage using remote sensing. Remote Sens Environ 101:277–282. doi: 10.1016/j.rse.2005.12.001

Nagendra H, Gopal D (2010) Street trees in Bangalore: Density, diversity, composition and distribution. Urban For Urban Green 9:129–137. doi: 10.1016/j.ufug.2009.12.005

Nemec KT, Allen CR, Alai A, et al. (2011) Woody invasions of urban trails and the changing face of urban forests in the Great Plains, USA. Am Midl Nat 165:241–256. doi: 10.1674/0003-0031-165.2.241

Ng E, Chen L, Wang Y, Yuan C (2012) A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Build Environ 47:256–271. doi: 10.1016/j.buildenv.2011.07.014

Niemelä J, Saarela SR, Söderman T, et al. (2010) Using the ecosystem services approach for better planning and conservation of urban green spaces: A Finland case study. Biodivers Conserv 19:3225–3243. doi: 10.1007/s10531-010-9888-8

Niinemets Ü, Peñuelas J (2008) Gardening and urban landscaping: significant players in global change. Trends Plant Sci 13:60–65. doi: 10.1016/j.tplants.2007.11.009

Nobis MP, Jaeger JAG, Zimmermann NE (2009) Neophyte species richness at the landscape scale under urban sprawl and climate warming. Divers Distrib 15:928–939. doi: 10.1111/j.1472-4642.2009.00610.x

Noe SM, Peñuelas J, Niinemets Ü (2008) Monoterpene emissions from ornamental trees in urban areas: A case study of Barcelona, Spain. Plant Biol 10:163–169. doi: 10.1111/j.1438-8677.2007.00014.x

Nowak D, Greenfield E, Hoehn R, Lapoint E (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. Environ Pollut 178:229e236

Nowak D, McBride J, Beatty R (1990) Newly planted street tree growth and mortality. J Arboric 16:124–129

Nowak DJ (1996) Estimating leaf area and leaf biomass of open-grown deciduous urban trees. For Sci 42:504–507

Nowak DJ (2004) The effects of urban trees on air quality. New York pp 1-4. http://www.fs.fed.us/ne/syracuse/ TREE%20Air%20Qual.pdf. Accessed 15 April 2016

Nowak DJ, Civerolo KL, Trivikrama Rao S, et al. (2000) A modeling study of the impact of urban trees on ozone. Atmos Environ 34:1601–1613. doi: 10.1016/S1352-2310(99)00394-5

Nowak DJ, Crane DE (2002) Carbon storage and sequestration by urban trees in the USA.pdf. Environ Pollut 116:381–389

Nowak DJ, Crane DE, Dwyer JF (2002) Compensatory value of urban trees in the United States. J Arboric 28:194–199

Nowak DJ, Crane DE, Stevens JC (2006) Air pollution removal by urban trees and shrubs in the United States. Urban For Urban Green 4:115–123. doi: 10.1016/j.ufug.2006.01.007

Nowak DJ, Hoehn R, Crane DE (2007) Oxygen production by urban trees in the United States. Arboric urban For 33:220–226.

Nowak DJ, Hoehn RE, Bodine AR, et al. (2013) Urban forest structure, ecosystem services and change in Syracuse, NY. Urban Ecosyst 1–23. doi: 10.1007/s11252-013-0326-z

Nzokou P, Simons J, Wheatherspoon A (2011) A hedonic analysis of the impact of tree shade on, summertime residential energy consumption. Arborculture Urban For 37:13–18

Olden JD, Tamayo M (2014) Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. PLoS One. doi: 10.1371/journal.pone.0110458

Oldfield EE, Warren RJ, Felson AJ, Bradford MA (2013) Challenges and future directions in urban afforestation. J Appl Ecol 50:1169–1177. doi: 10.1111/1365-2664.12124

Padullés Cubino J, Vila Subirós J, Barriocanal Lozano C (2015) Propagule pressure from invasive plant species in gardens in low-density suburban areas of the Costa Brava (Spain). Urban For Urban Green 14:941–951. doi: 10.1016/j.ufug.2015.09.002

Pan E, Bassuk NL (1986) Establishment and distribution of *Ailanthus altissima* in the urban environment. J Environ Hortic 4:1–4

Pataki DE, Alig RJ, Fung AS, et al. (2006) Urban ecosystems and the North American carbon cycle. Glob Chang Biol 12:2092–2102. doi: 10.1111/j.1365-2486.2006.01242.x

Pauchard A, Aguayo M, Peña E, Urrutia R (2006) Multiple effects of urbanization on the biodiversity of developing countries: The case of a fast-growing metropolitan area (Concepcion, Chile). Biol Conserv 127:272–281. doi: 10.1016/j.biocon.2005.05.015

Pautasso M (2007) Scale dependence of the correlation between human population presence and vertebrate and plant species richness. Ecol Lett 10:16–24. doi: 10.1111/j.1461-0248.2006.00993.x

Pedersen Zari M (2015) Ecosystem services analysis: Mimicking ecosystem services for regenerative urban design. Int J Sustain Built Environ 4:145–157. doi: 10.1016/j.ijsbe.2015.02.004

Pellissier V, Muratet A, Verfaillie F, Machon N (2012) Pollination success of *Lotus corniculatus* (L.) in an urban context. Acta Oecologica 39:94–100. doi: 10.1016/j.actao.2012.01.008

Pickett STA, Burch WR, Dalton SE, et al. (1997) A conceptual framework for the study of human ecosystems in urban areas. Urban Ecosyst 1:185–189. doi: Export Date 19 June 2013

Piwowarski JP, Granica S, Kiss AK (2015) *Lythrum salicaria* L. - Underestimated medicinal plant from European traditional medicine. A review. J Ethnopharmacol 170:226–250. doi: 10.1016/j.jep.2015.05.017

Potgieter LJ, Richardson DM, Wilson JRU (2014) Casuarina: Biogeography and ecology of an important tree genus in a changing world. Biol Invasions 16:609-633. doi: 10.1007/s10530-013-0613-x

Poudyal NC, Siry JP, Bowker JM (2011) Quality of urban forest carbon credits. Urban For Urban Green 10:223–230. doi: 10.1016/j.ufug.2011.05.005

Price C (2003) Quantifying the aesthetic benefits of urban forestry. Urban For Urban Green 1:123–133. doi: 10.1078/1618-8667-00013

Priso RJ, Traoré S, Din N, et al. (2012) Comparative analysis of plants close to houses in urban and rural areas in the littoral region of Cameroon. Nord J Bot 30:482–489. doi: 10.1111/j.1756-1051.2012.01043.x

Profous G (1992) Trees and Urban Forestry in Beijing, China. J Arboric 18:145–154

Pyšek P (1998) Alien and native species in Central European urban floras: A quantitative comparison. J Biogeogr 25:155–163

Pyšek P, Jarošík V, Hulme PE, et al. (2012) A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. Glob Chang Biol 18:1725–1737. doi: 10.1111/j.1365-2486.2011.02636.x

Pyšek P, Jarošík V, Pergl J (2011) Alien plants introduced by different pathways differ in invasion success: Unintentional introductions as a threat to natural areas. PLoS One. doi: 10.1371/journal.pone.0024890

Pyšek P, Jarošík V, Pergl J, et al. (2009) The global invasion success of Central European plants is related to distribution characteristics in their native range and species traits. Divers Distrib 15:891–903. doi: 10.1111/j.1472-4642.2009.00602.x

Pyšek P, Křivánek M, Jarošík V, et al. (2016) Planting intensity, residence time, and species traits determine invasion success of alien woody. Ecology 90:2734–2744

Pysek P, Richardson DM (2010) Invasive species, environmental change, and health. Annu Rev Environ Resour 35:25–55. doi: 10.1146/annurev-environ-033009-095548

Qian S, Qi M, Huang L, et al. (2016) Biotic homogenization of China's urban greening: A meta-analysis on woody species. Urban For Urban Green 18:25–33. doi: 10.1016/j.ufug.2016.05.002

Rai PK, Singh MM (2015) *Lantana camara* invasion in urban forests of an Indo-Burma hotspot region and its ecosustainable management implication through biomonitoring of particulate matter. J Asia-Pacific Biodivers 8:375–381. doi: 10.1016/j.japb.2015.09.003

Reichard S, Hamilton C (1997) Predicting invasions of woody plants introduced into North America. Predicción de Invasiones de Plantas Leñosas Introducidas a Norteamérica. Conserv Biol 11:193–203. doi: 10.1046/j.1523-1739.1997.95473.x

Richards NA (1983) Diversity and stability in a street tree population. Urban Ecol 7:159–171. doi: 10.1016/0304-4009(83)90034-7

Ricotta C, La Sorte FA, Pyšek P, et al. (2009) Phyloecology of urban alien floras. J Ecol 97:1243–1251. doi: 10.1111/j.1365-2745.2009.01548.x

Robinson SL, Lundholm JT (2012) Ecosystem services provided by urban spontaneous vegetation. Urban Ecosyst 15:545–557. doi: 10.1007/s11252-012-0225-8

Roe AD, Macquarrie CJK, Gros-Louis MC, et al. (2014) Fitness dynamics within a poplar hybrid zone: Impact of exotic sex on native poplars in an urban jungle. Ecol Evol 4:1876–1889. doi: 10.1002/ece3.1028

Roy S, Byrne J, Pickering C (2012) A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban For Urban Green 11:351–363. doi: 10.1016/j.ufug.2012.06.006

Rupprecht CDD, Byrne JA, Garden JG, Hero JM (2015) Informal urban green space: A trilingual systematic review of its role for biodiversity and trends in the literature. Urban For Urban Green 14:883–908. doi: 10.1016/j.ufug.2015.08.009

Sabrina I, Nik Hanita NM (2012) Role of ornamental vegetation for bird's habitats in urban parks: Case study FRIM, Malaysia. Procedia – Soc Behav Sci 68:894-909. doi: 10.1016/j.sbspro.2012.12.275

Sachse U, Starfinger U, Kowarik I (1990) Synanthropic woody species in the urban area of Berlin (West). In: Sukopp H, Hejny S, Kowarik I (eds) Urban Ecology. SPB Academic Publishing, The Hague, pp 233–243

Salisbury A, Armitage J, Bostock H, et al. (2015) Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): Should we plant native or exotic species? J Appl Ecol 52:1156–1164. doi: 10.1111/1365-2664.12499

Sander H, Polasky S, Haight RG (2010) The value of urban tree cover: A hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. Ecol Econ 69:1646–1656. doi: 10.1016/j.ecolecon.2010.03.011

Sanders RA (1981) Diversity in the street trees of Syracuse, New York. Urban Ecol 5:33–43. doi: 10.1016/0304-4009(81)90019-X

Sanders RA (1986) Urban vegetation impacts on the hydrology of Dayton, Ohio. Urban Ecol 9:361–376. doi: 10.1016/0304-4009(86)90009-4

Säumel I, Weber F, Kowarik I (2015) Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move. Environ Sci Policy 62:24–33. doi: 10.1016/j.envsci.2015.11.012

Schaefer V (2009) Alien invasions, ecological restoration in cities and the loss of ecological memory. Restor Ecol 17:171–176. doi: 10.1111/j.1526-100X.2008.00513.x

Schindler S, Staska B, Adam M, et al. (2015) Alien species and public health impacts in Europe: a literature review. NeoBiota 27:1–23. doi: 10.3897/neobiota.27.5007

Schmidt KJ, Poppendieck H-H, Jensen K (2014) Effects of urban structure on plant species richness in a large European city. Urban Ecosyst 17:427–444. doi: 10.1007/s11252-013-0319-y

Schneider SC, Miller JR (2014) Response of avian communities to invasive vegetation in urban forest fragments. Condor 116:459–471. doi: 10.1650/CONDOR-13-009R1.1

Seburanga JL, Kaplin BA, Zhang QX, Gatesire T (2014) Amenity trees and green space structure in urban settlements of Kigali, Rwanda. Urban For Urban Green 13:84–93. doi: 10.1016/j.ufug.2013.08.001

Seto KC, Reenberg A, Boone CG, et al. (2012) Urban land teleconnections and sustainability. Pnas 109:7687–7692. doi: 10.1073/pnas.1117622109

Sfriso A, Facca C (2013) Annual growth and environmental relationships of the invasive species *Sargassum muticum* and *Undaria pinnatifida* in the lagoon of Venice. Estuar Coast Shelf Sci 129:162–172. doi: 10.1016/j.ecss.2013.05.031

Shackleton C (2006) Urban forestry – A cinderella science in South Africa? South African For J 208:1–4

Shackleton C (2016) Do indigenous street trees promote more biodiversity than alien ones? Evidence using mistletoes and birds in South Africa. Forests 7:134. doi: 10.3390/f7070134

Shackleton CM, Ruwanza S, Sinasson Sanni GK, et al. (2016) Unpacking Pandora's Box: Understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19:587–600. doi: 10.1007/s10021-015-9952-z

Shashua-Bar L, Hoffman ME (2000) Vegetation as a climatic component in the design of an urban street. Energy Build 31:221–235. doi: 10.1016/S0378-7788(99)00018-3

Shashua-Bar L, Hoffman ME (2004) Quantitative evaluation of passive cooling of the UCL microclimate in hot regions in summer, case study: Urban streets and courtyards with trees. Build Environ 39:1087–1099. doi: 10.1016/j.buildenv.2003.11.007

Sieber J, Pons M (2015) Assessment of urban ecosystem services using ecosystem services reviews and GIS-based tools. Procedia Eng 115:53–60. doi: 10.1016/j.proeng.2015.07.354

Simonová D, Lososová Z (2008) Which factors determine plant invasions in man-made habitats in the Czech Republic? Perspect Plant Ecol Evol Syst 10:89–100. doi: 10.1016/j.ppees.2007.11.003

Simpson JR, McPherson EG (2011) The tree BVOC index. Environ Pollut 159:2088–2093. doi: 10.1016/j.envpol.2011.02.034

Sirakaya A, Cliquet A, Harris J (2017) Ecosystem services in cities: Towards the international legal protection of ecosystem services in urban environments. Ecosyst Serv 1–8. doi: 10.1016/j.ecoser.2017.01.001

Sitzia T, Campagnaro T, Weir RG (2016) Novel woodland patches in a small historical Mediterranean city: Padova, Northern Italy. Urban Ecosyst 19:475–487. doi: 10.1007/s11252-015-0475-3

Sjöman H, Östberg J, Bühler O (2012) Diversity and distribution of the urban tree population in ten major Nordic cities. Urban For Urban Green 11:31–39. doi: 10.1016/j.ufug.2011.09.004

Sladonja B, Sušek M, Guillermic J (2015) Review on invasive tree of heaven (*Ailanthus altissima* (Mill.) Swingle) conflicting values: Assessment of its ecosystem services and potential biological threat. Environ Manage 56:1009–1034. doi: 10.1007/s00267-015-0546-5

Smith M, Cecchi L, Skjøth CA, et al. (2013) Common ragweed: A threat to environmental health in Europe. Environ Int 61:115–126. doi: 10.1016/j.envint.2013.08.005

Smith RM, Thompson K, Hodgson JG, et al. (2006) Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity. Biol Conserv 129:312–322. doi: 10.1016/j.biocon.2005.10.045

Soares AL, Rego FC, McPherson EG, et al. (2011) Benefits and costs of street trees in Lisbon, Portugal. Urban For Urban Green 10:69–78. doi: 10.1016/j.ufug.2010.12.001

Sodhi NS, Koh LP, Clements R, et al. (2010) Conserving Southeast Asian forest biodiversity in human-modified landscapes. Biol Conserv 143:2375–2384. doi: 10.1016/j.biocon.2009.12.029

Sołtysiak J, Brej T (2014) Invasion of *Fallopia* genus plants in urban environment. Polish J Environ Stud 23:449–458.

Song IJ, Hong SK, Kim HO, et al. (2005) The pattern of landscape patches and invasion of naturalized plants in developed areas of urban Seoul. Landsc Urban Plan 70:205–219. doi: 10.1016/j.landurbplan.2003.10.018

Speak AF, Mizgajski A, Borysiak J (2015) Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. Urban For Urban Green 14:772–781. doi: 10.1016/j.ufug.2015.07.007

Spear D, Foxcroft LC, Bezuidenhout H, McGeoch MA (2013) Human population density explains alien species richness in protected areas. Biol Conserv 159:137–147. doi: 10.1016/j.biocon.2012.11.022

Staley DC (2013) Urban forests and solar power generation: partners in urban heat island mitigation. Int J Low-Carbon Technol 10:78–86. doi: 10.1093/ijlct/ctt058

Staudhammer CL, Escobedo FJ, Holt N, et al. (2015) Predictors, spatial distribution, and occurrence of woody invasive plants in subtropical urban ecosystems. J Environ Manage 155:97–105. doi: 10.1016/j.jenvman.2015.03.012

Stjepanović B, Svečnjak Z, Hrga I, et al. (2015) Seasonal variation of airborne ragweed (*Ambrosia artemisiifolia* L.) pollen in Zagreb, Croatia. Aerobiologia (Bologna) 31:525–535. doi: 10.1007/s10453-015-9384-4

Sudha P, Ravindranath NH (2000) A study of Bangalore urban forest. Landsc Urban Plan 47:47–63. doi: 10.1016/S0169-2046(99)00067-5

Sullivan JJ, Meurk C, Whaley KJ, Simcock R (2009) Restoring native ecosystems in urban Auckland: Urban soils, isolation, and weeds as impediments to forest establishment. N Z J Ecol 33:60–71

Sullivan JJ, Timmins SM, Williams PA (2005) Movement of exotic plants into coastal native forests from gardens in northern New Zealand. N Z J Ecol 29:1–10

Sun WQ, Bassuk NL (1991) Approach to determine effective sampling size for urban street tree survey. Landsc Urban Plan 20:277–283. doi: 10.1016/0169-2046(91)90001-3

Sung CY, Li MH, Rogers GO, et al. (2011) Investigating alien plant invasion in urban riparian forests in a hot and semi-arid region. Landsc Urban Plan 100:278–286. doi: 10.1016/j.landurbplan.2010.12.014

Swan CM, Healey B, Richardson DC (2008) The role of native riparian tree species in decomposition of invasive tree of heaven (*Ailanthus altissima*) leaf litter in an urban stream. Ecoscience 15:27–35. doi: 10.2980/1195-6860(2008)15[27:TRONRT]2.0.CO;2

Taha H, Douglas S, Haney J (1997) Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation. Energy Build 25:169–177. doi: 10.1016/S0378-7788(96)01006-7

Tallent-Halsell NG, Watt MS (2009) The invasive *Buddleja davidii* (butterfly bush). Bot Rev 75:292–325. doi: 10.1007/s12229-009-9033-0

Tallis M, Taylor G, Sinnett D, Freer-Smith P (2011) Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. Landsc Urban Plan 103:129–138. doi: 10.1016/j.landurbplan.2011.07.003

Tan Z, Ng E (2014) Influence of greenery in cooling the urban atmosphere and surfaces in compact old residential building blocks: A building morphology approach. In: 30th International Plea Conference. Ahmedabad, pp 1–8

Taramarcaz P, Lambelet C, Clot B, et al. (2005) Ragweed (Ambrosia) progression and its health risks: Will Switzerland resist this invasion? Swiss Med Wkly 135:538–548. doi: 2005/37/smw-11201

Thaiutsa B, Puangchit L, Kjelgren R, Arunpraparut W (2008) Urban green space, street tree and heritage large tree assessment in Bangkok, Thailand. Urban For Urban Green 7:219–229. doi: 10.1016/j.ufug.2008.03.002

The Nature Conservancy (2016) Planting healthy air: A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. https://global.nature.org/content/planting-healthy-air. Accessed 24 April 2016

Thompson K, McCarthy MA (2008) Traits of British alien and native urban plants. J Ecol 96:853–859. doi: 10.1111/j.1365-2745.2008.01383.x

Tiwary A, Sinnett D, Peachey C, et al. (2009) An integrated tool to assess the role of new planting in PM 10 capture and the human health benefits: A case study in London. Environ Pollut 157:2645–2653. doi: 10.1016/j.envpol.2009.05.005

Trammell TLE, Carreiro MM (2011) Vegetation composition and structure of woody plant communities along urban interstate corridors in Louisville, KY, U.S.A. Urban Ecosyst 14:501–524. doi: 10.1007/s11252-011-0193-4

Tratalos J, Fuller RA, Warren PH, et al. (2007) Urban form, biodiversity potential and ecosystem services. Landsc Urban Plan 83:308–317. doi: 10.1016/j.landurbplan.2007.05.003

Tredici P Del (2010) Spontaneous urban vegetation: Reflections of change in a globalized world. Nat Cult 5:299–315. doi: 10.3167/nc.2010.050305

Trentanovi G, von der Lippe M, Sitzia T, et al. (2013) Biotic homogenization at the community scale: Disentangling the roles of urbanization and plant invasion. Divers Distrib 19:738–748. doi: 10.1111/ddi.12028

Tsiotsiou V, Christodoulakis D (2010) Woody plants in urban biotopes: Studies in patras (Greece) Fresenius Environ Bull 19:2958-2965

Tsiros IX (2010) Assessment and energy implications of street air temperature cooling by shade trees in Athens (Greece) under extremely hot weather conditions. Renew Energy 35:1866–1869. doi: 10.1016/j.renene.2009.12.021

Turner K, Lefler L, Freedman B (2005) Plant communities of selected urbanized areas of Halifax, Nova Scotia, Canada. Landsc Urban Plan 71:191–206. doi: 10.1016/j.landurbplan.2004.03.003

Tyrväinen L (1997) The amenity value of the urban forest: an application of the hedonic pricing method. Landsc Urban Plan 37:211–222. doi: 10.1016/S0169-2046(97)80005-9

UN-Habitat (2014) The State of African Cities - Re-imagining sustainable urban transitions. United Nations Human Settlements Programme (UN-Habitat)

United Nations (2016) World Economic Situation Prospects. New York

Vähä-Piikkiö I, Kurtto A, Hahkala V (2004) Species number, historical elements and protection of threatened species in the flora of Helsinki, Finland. Landsc Urban Plan 68:357–370. doi: 10.1016/S0169-2046(03)00149-X

Vakhlamova T, Rusterholz HP, Kamkin V, Baur B (2016) Recreational use of urban and suburban forests affects plant diversity in a Western Siberian city. Urban For Urban Green 17:92–103. doi: 10.1016/j.ufug.2016.03.009

Vakhlamova T, Rusterholz HP, Kanibolotskaya Y, Baur B (2014) Changes in plant diversity along an urban-rural gradient in an expanding city in Kazakhstan, Western Siberia. Landsc Urban Plan 132:111–120. doi: 10.1016/j.landurbplan.2014.08.014

Van Mechelen C, Dutoit T, Hermy M (2015) Vegetation development on different extensive green roof types in a Mediterranean and temperate maritime climate. Ecol Eng 82:571–582. doi: 10.1016/j.ecoleng.2015.05.011

Varela S, Subiza J, Subiza JL, et al. (1997) Platanus pollen as an important cause of pollinosis. J Clininal Immunol 100:748–754

Vaz AS, Kueffer C, Kull CA, et al. (2017) Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst Serv 23:94–107. doi: 10.1016/j.ecoser.2016.11.017

Velasco E, Roth M, Norford L, Molina LT (2016) Does urban vegetation enhance carbon sequestration? Landsc Urban Plan 148:99–107. doi: 10.1016/j.landurbplan.2015.12.003

Vesely ÉT (2007) Green for green: The perceived value of a quantitative change in the urban tree estate of New Zealand. Ecol Econ 63:605–615. doi: 10.1016/j.ecolecon.2006.12.019

Vidra RL (2004) Implications of exotic species invasion for restoration of urban riparian forests. Ph.D. dissertation. North Carolina State University, Department of Forestry, Raleigh, NC. 110 pp

Vidra RL, Shear TH (2008) Thinking locally for urban forest restoration: A simple method links exotic species invasion to local landscape structure. Rest Ecol 16:217-220

Vidra RL, Shear TH, Wentworth TR (2006) Testing the paradigms of exotic species invasion in urban riparian forests. Nat Areas J 26:339–350. doi: 10.3375/0885-8608(2006)26[339:TTPOES]2.0.CO;2

Vilà M, Tessier M, Suehs CM, et al. (2006) Local and regional assessments of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. J Biogeogr 33:853–861. doi: 10.1111/j.1365-2699.2005.01430.x

Von Der Lippe M, Säumel I, Kowarik I (2005) Cities as drivers of biological invasions: The role of climate changes and traffic. Die Erde, 136:123-143

Von Döhren P, Haase D (2015) Ecosystem disservices research: A review of the state of the art with a focus on cities. Ecol Indic 52:490–497. doi: 10.1016/j.ecolind.2014.12.027

Von Ehrenstein OS, Von Mutius E, Illi S, et al. (2000) Reduced risk of hay fever and asthma among children of farmers. Clin Exp Allergy 30:187–193. doi: 10.1046/j.1365-2222.2000.00801.x

Wang G, Jiang G, Zhou Y, et al. (2007) Biodiversity conservation in a fast-growing metropolitan area in China: A case study of plant diversity in Beijing. Biodivers Conserv 16:4025–4038. doi: 10.1007/s10531-007-9205-3

Wang H-F, López-Pujol J, Meyerson L, et al. (2011) Biological invasions in rapidly urbanizing areas: a case study of Beijing, China. Biodivers Conserv 20:2483–2509. doi: 10.1007/s10531-011-9999-x

Wang HF, Qureshi S, Knapp S, et al. (2015) A basic assessment of residential plant diversity and its ecosystem services and disservices in Beijing, China. Appl Geogr 64:121–131. doi: 10.1016/j.apgeog.2015.08.006

Wang HF, Qureshi S, Qureshi BA, et al. (2016) A multivariate analysis integrating ecological, socioeconomic and physical characteristics to investigate urban forest cover and plant diversity in Beijing, China. Ecol Indic 60:921–929. doi: 10.1016/j.ecolind.2015.08.015

Wania A, Kühn I, Klotz S (2006) Plant richness patterns in agricultural and urban landscapes in Central Germany - Spatial gradients of species richness. Landsc Urban Plan 75:97–110. doi: 10.1016/j.landurbplan.2004.12.006

Warren II RJ, Potts DL, Frothingham KM (2015) Stream structural limitations on invasive communities in urban riparian areas. Invasive Plant Sci Manage 8:353–362. doi: 10.1614/IPSM-D-14-00081.1

Watson G (2002) Comparing formula methods of tree appraisal. J Arboric 28:11–18

Welch JM (1994) Street and park trees of Boston: a comparison of urban forest structure. Landsc Urban Plan 29:131–143. doi: 10.1016/0169-2046(94)90023-X

White RJ, Carreiro MM, Zipperer WC (2014) Woody plant communities along urban, suburban, and rural streams in Louisville, Kentucky, USA. Urban Ecosyst 17:1061–1094. doi: 10.1007/s11252-014-0376-x

Williams NSG, Hahs AK, Vesk PA (2015) Urbanisation, plant traits and the composition of urban floras. Perspect Plant Ecol Evol Syst 17:78–86. doi: 10.1016/j.ppees.2014.10.002

Williams NSG, McDonnell MJ, Seager EJ (2005) Factors influencing the loss of an endangered ecosystem in an urbanising landscape: A case study of native grasslands from Melbourne, Australia. Landsc Urban Plan 71:35–49. doi: 10.1016/j.landurbplan.2004.01.006

Williamson M, Fitter A (1996) The varying success of invaders. Ecology 77:1661–1666. doi: 10.2307/2265769

Wolf D, Lundholm JT (2008) Water uptake in green roof microcosms: Effects of plant species and water availability. Ecol Eng 33:179–186. doi: 10.1016/j.ecoleng.2008.02.008

Wratten S, Sandhu H, Cullen R, Costanza R (2013) Ecosystem Services in Agricultural and Urban Landscapes. Wiley-Blackwell, Oxford, UK

Wurster D, Artmann M (2014) Development of a concept for non-monetary assessment of urban ecosystem services at the site level. Ambio 43:454–465. doi: 10.1007/s13280-014-0502-2

Yang J, McBride J, Zhou J, Sun Z (2004) The urban forest in Beijing and its role in air pollution reduction. Urban For Urban Green 3:65–78. doi: 10.1016/j.ufug.2004.09.001

Yang L, Zhang L, Li Y, Wu S (2015) Water-related ecosystem services provided by urban green space: A case study in Yixing City (China). Landsc Urban Plan 136:40–51. doi: 10.1016/j.landurbplan.2014.11.016

Young RF (2013) Mainstreaming urban ecosystem services: A national survey of municipal foresters. Urban Ecosyst 16:703–722. doi: 10.1007/s11252-013-0287-2

Zerbe S, Choi IK, Kowarik I (2004) Characteristics and habitats of non-native plant species in the city of Chonju, southern Korea. Ecol Res 19:91–98. doi: 10.1111/j.1440-1703.2003.00616.x

Zerbe S, Maurer U, Peschel T, et al. (2004) Diversity of flora and vegetation in European cities as a potential for nature conservation in urban-industrial areas–with examples from Berlin and Potsdam (Germany). 4th Int Urban Wildl Symp 35–49

Zhang H, Jim CY (2014) Contributions of landscape trees in public housing estates to urban biodiversity in Hong Kong. Urban For Urban Green 13:272–284. doi: 10.1016/j.ufug.2013.12.009

Zhao J, Ouyang Z, Zheng H, et al. (2010) Plant species composition in green spaces within the built-up areas of Beijing, China. Plant Ecol 209:189–204. doi: 10.1007/s11258-009-9675-3

Zhou Y, Smith SJ, Zhao K, et al. (2015) A global map of urban extent from nightlights. Environ Res Lett 10:54011. doi: 10.1088/1748-9326/10/5/054011

Zipperer WC (2002) Species composition and structure of regenerated and ramnant forest patches within an urban landscape. Urban Ecosyst 6:271–290

Zisenis M (2014) Alien plant species: A real fear for urban ecosystems in Europe? Urban Ecosyst 355–370. doi: 10.1007/s11252-014-0400-1

Appendix C Number of records in the literature of urban ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005) provided by all recorded alien plant species.

Species	**Family**	**Growth Form**	**Ecosystem Service Category**				**Total**
			Cultural	Provisioning	Regulating	Supporting	
Acalypha wilkesiana Mull.Arg.	Euphorbiaceae	Evergreen shrub	0	2	0	0	2
Acer negundo L.	Aceraceae	Deciduous tree	2	0	1	1	4
Acer platanoides L.	Aceraceae	Deciduous tree	1	2	4	0	7
Acer saccharinum L.	Aceraceae	Deciduous tree	1	0	0	0	1
Acer saccharum Marshall	Aceraceae	Deciduous tree	0	0	1	0	1
Adenanthera pavonina L.	Fabaceae	Deciduous tree	0	0	0	1	1
Aesculus hippocastanum L.	Hippocastanaceae	Deciduous tree	1	0	0	0	1
Agave americana L.	Agavaceae	Perennial succulent	0	2	0	0	2
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	4	15	6	7	32
Albizia julibrissin Durazz.	Fabaceae	Deciduous tree	0	0	1	0	1
Albizia lebbeck (L.) Benth.	Fabaceae	Deciduous tree	0	1	0	0	1
Albizia procera (Roxb.) Benth.	Fabaceae	Deciduous tree	0	0	0	1	1
Albizia saman (Jacq.) F.Muell.	Fabaceae	Deciduous tree	1	4	0	0	5
Allamanda cathartica L.	Apocynaceae	Evergreen, woody, perennial vine	1	0	0	0	1
Alliaria petiolata Cavara & Grande	Brassicaceae	Biennial herb	1	0	0	0	1
Allium cepa L.	Amaryllidaceae	Biennial herb	0	1	0	0	1
Allium porrum L.	Amaryllidaceae	Biennial herb	0	1	0	0	1
Allium sativum L.	Amaryllidaceae	Annual herb	0	1	0	0	1
Aloe arborescens Mill.	Aloaceae	Perennial succulent	0	0	1	0	1
Aloe aristata Haw.	Aloaceae	Perennial succulent	0	1	0	0	1
Aloe maculata All.	Aloaceae	Perennial succulent	1	0	0	0	1
Aloe nobilis Haw.	Aloaceae	Perennial succulent	0	1	0	0	1
Aloe vera Mill.	Aloaceae	Perennial succulent	0	1	0	0	1
Alpinia galanga Willd.	Zingiberaceae	Perennial herb	0	1	0	0	1

Alternanthera philoxeroides Griseb.	Amaranthaceae	Perennial herb	1	0	0	0	1
Alternanthera tenella Colla	Amaranthaceae	Perennial herb	1	0	0	0	1
Amaranthus caudatus L.	Amaranthaceae	Annual herb	0	1	0	0	1
Amaranthus graecizans L.	Amaranthaceae	Annual herb	0	1	0	0	1
Amaranthus viridis L.	Amaranthaceae	Annual herb	1	0	0	0	1
Ambrosia artemisiifolia L.	Asteraceae	Annual herb	0	1	0	0	1
Ampelopsis brevipedunculata Koehne	Vitaceae	Deciduous, woody, perennial vine	2	0	0	0	2
Ananas comosus (L.) Merr.	Bromeliaceae	Perennial herb	1	1	0	0	2
Anethum graveolens L.	Apiaceae	Annual herb	0	1	0	0	1
Annona muricata L.	Annonaceae	Evergreen tree	0	1	0	0	1
Annona squamosa L.	Annonaceae	Semi-deciduous tree	0	3	0	0	3
Antigonon leptopus Hook. & Arn.	Polygonaceae	Perennial herbaceous vine	1	0	0	0	1
Apium graveolens L.	Apiaceae	Biennial herb	0	1	0	0	1
Arachis hypogaea L.	Fabaceae	Annual herb	0	2	0	0	2
Ardisia elliptica Thunb.	Myrsinaceae	Evergreen tree	0	0	0	1	1
Artocarpus altilis (Du Roi) O.Deg. & I.Deg.	Moraceae	Evergreen tree	0	0	0	1	1
Artocarpus heterophyllus Lam.	Moraceae	Evergreen tree	0	1	0	0	1
Artocarpus integer Spreng.	Moraceae	Evergreen tree	0	1	0	0	1
Aster ericoides L.	Asteraceae	Perennial herb	1	0	0	0	1
Averrhoa bilimbi L.	Oxalidaceae	Evergreen tree	0	1	0	0	1
Azadirachta indica A.Juss.	Meliaceae	Evergreen tree	1	1	0	0	2
Basella rubra L.	Basellaceae	Perennial herbaceous vine	0	1	0	0	1
Bellis perennis L.	Asteraceae	Perennial herb	0	1	0	0	1
Berberis thunbergii DC.	Berberidaceae	Deciduous shrub	3	0	0	0	3
Beta vulgaris L.	Chenopodiaceae	Biennial herb	0	1	0	0	1
Bougainvillea spectabilis Willd.	Nyctaginaceae	Deciduous, woody, perennial vine	2	0	0	0	2
Brassica oleracea L.	Brassicaceae	Annual herb	0	1	0	0	1
Brassica rapa L.	Brassicaceae	Biennial herb	0	1	0	0	1
Broussonetia papyrifera (L.) Vent.	Moraceae	Deciduous shrub/tree	0	0	1	0	1
Buchloe dactyloides (Nutt.) Engelm.	Poaceae	Perennial grass	0	0	0	1	1

Buddleja davidii Franch.	Buddlejaceae	Deciduous shrub	1	0	0	0	1
Cajanus cajan (L.) Millsp.	Fabaceae	Perennial shrub	0	1	0	0	1
Canna indica L.	Cannaceae	Perennial herb	1	0	0	0	1
Cannabis sativa L.	Cannabaceae	Annual herb	0	1	0	0	1
Capsicum annuum L.	Solanaceae	Perennial herb	0	1	0	0	1
Capsicum frutescens L.	Solanaceae	Perennial herb	0	1	0	0	1
Caragana arborescens Lam.	Fabaceae	Deciduous shrub	0	1	0	0	1
Carica papaya L.	Caricaceae	Evergreen herbaceous tree	0	9	0	0	9
Carpobrotus edulis (L.) L.Bolus	Aizoaceae	Perennial succulent	1	0	0	0	1
Cassia fistula L.	Fabaceae	Deciduous tree	1	1	0	0	2
Cassia obtusifolia L.	Fabaceae	Annual herb	0	1	0	0	1
Cassia spectabilis DC.	Fabaceae	Deciduous tree	1	0	0	0	1
Casuarina equisetifolia L.	Casuarinaceae	Evergreen tree	1	0	0	0	1
Catalpa speciose (Warder) Engelm.	Bignoniaceae	Deciduous tree	1	0	0	0	1
Catharanthus roseus (L.) G.Don	Apocynaceae	Evergreen subshrub	2	2	0	0	4
Cedrus libani A.Rich.	Pinaceae	Evergreen tree	1	0	0	0	1
Ceiba pentandra (L.) Gaertn.	Bombacaceae	Deciduous tree	0	1	0	0	1
Celastrus orbiculatus Thunb.	Celastraceae	Deciduous, woody, perennial vine	1	0	0	0	1
Celtis occidentalis L.	Ulmaceae	Deciduous tree	1	0	1	0	2
Celtis sinensis Pers.	Ulmaceae	Deciduous tree	1	0	2	0	3
Cinnamomum camphora (L.) T.Nees & C.H.Eberm.	Lauraceae	Evergreen tree	0	0	1	0	1
Cissus quadrangularis L.	Vitaceae	Perennial herbaceous climber	0	1	0	0	1
Cissus rotundifolia Vahl	Vitaceae	Perennial shrub/vine	1	0	0	0	1
Citrus aurantiifolia (Christm.) Swingle	Rutaceae	Evergreen tree	0	2	0	0	2
Citrus limon (L.) Burm.f.	Rutaceae	Evergreen tree	0	3	0	0	3
Citrus reticulata Blanco	Rutaceae	Evergreen tree	0	1	0	0	1
Citrus sinensis Pers.	Rutaceae	Evergreen tree	0	3	0	0	3
Clematis vitalba L.	Ranunculaceae	Deciduous, woody shrub	1	0	0	0	1
Cocculus laurifolius DC.	Menispermaceae	Evergreen shrub/tree	0	0	1	0	1
Cocos nucifera L.	Arecaceae	Evergreen tree	0	1	0	0	1

Codiaeum variegatum (L.) A.Juss.	Euphorbiaceae	Evergreen shrub	2	1	0	0	3
Colocasia esculenta (L.) Schott	Araceae	Perennial herb	0	1	0	0	1
Combretum indicum (L.) Jongkind	Combretaceae	Evergreen, woody, perennial vine	1	0	0	0	1
Conyza canadensis (L.) Cronquist	Asteraceae	Annual herb	0	0	1	0	1
Cordyline fruticosa (L.) A.Chev.	Agavaceae	Evergreen shrub	2	1	0	0	3
Coriandrum sativum L.	Apiaceae	Annual herb	0	1	0	0	1
Cornus alba L.	Cornaceae	Deciduous shrub	1	0	0	0	1
Cornus sericea L.	Cornaceae	Deciduous shrub	1	0	0	0	1
Cortaderia selloana Asch. & Graebn.	Poaceae	Perennial grass	1	0	0	0	1
Corymbia citriodora (Hook.) K.D.Hill & L.A.S.Johnson	Myrtaceae	Evergreen tree	0	0	0	1	1
Cosmos caudatus Kunth	Asteraceae	Annual herb	0	1	0	0	1
Crataegus pedicellata Sarg.	Rosaceae	Deciduous shrub	1	0	0	0	1
Crescentia cujete Sessé & Moc.	Bignoniaceae	Evergreen tree	0	1	0	0	1
Cucumis sativus L.	Cucurbitaceae	Annual herbaceous vine	0	1	0	0	1
Cucurbita maxima Duchesne	Cucurbitaceae	Annual herbaceous vine	0	1	0	0	1
Cucurbita pepo L.	Cucurbitaceae	Annual herbaceous vine	0	1	0	0	1
Cupressus macrocarpa Hartw.	Cupressaceae	Evergreen tree	0	1	0	0	1
Curcuma longa L.	Zingiberaceae	Perennial herb	0	1	0	0	1
Cymbopogon citratus Stapf	Poaceae	Perennial grass	0	2	0	0	2
Cyperus involucratus Poir.	Cyperaceae	Perennial herb	1	0	0	0	1
Cyrtostachys renda Blume	Arecaceae	Evergreen shrub/tree	0	1	0	0	1
Daucus carota L.	Apiaceae	Biennial herb	0	1	0	0	1
Delonix regia (Bojer) Raf.	Fabaceae	Deciduous tree	2	1	0	0	3
Dieffenbachia seguine Baill.	Araceae	Perennial herb	1	0	0	0	1
Dillenia suffruticosa Martelli	Dilleniaceae	Evergreen shrub	0	1	0	0	1
Dracaena reflexa Lam.	Dracaenaceae	Evergreen shrub/tree	0	2	0	0	2
Duranta erecta L.	Verbenaceae	Evergreen shrub	2	2	0	0	4
Echinocystis lobata Torr. & A.Gray	Cucurbitaceae	Annual herb	1	0	0	0	1
Echinopsis spachiana (Lem.) H.Friedrich & G.D.Rowley	Cactaceae	Perennial succulent	2	2	0	0	4
Egeria densa Planch.	Hydrocharitaceae	Submerged, aquatic, perennial herb	0	0	1	0	1

Elaeagnus angustifolia L.	Elaeagnaceae	Deciduous shrub/tree	1	0	0	0	1
Elaeagnus umbellata Thunb.	Elaeagnaceae	Deciduous shrub	2	0	0	0	2
Elaeocarpus mastersii King	Elaeocarpaceae	Evergreen tree	0	1	0	0	1
Elaeocarpus obtusus Blume	Elaeocarpaceae	Evergreen tree	0	1	0	0	1
Eleusine indica Gaertn.	Poaceae	Annual grass	0	0	0	1	1
Ensete ventricosum (Welw.) Cheesman	Musaceae	Perennial herb	1	0	0	0	1
Epipremnum pinnatum (L.) Engl.	Araceae	Herbaceous vine	1	0	0	0	1
Eriobotrya japonica (Thunb.) Lindl.	Rosaceae	Evergreen tree	0	2	0	0	2
Eruca sativa Mill.	Brassicaceae	Annual herb	0	1	0	0	1
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Evergreen tree	0	1	1	1	3
Euonymus fortunei (Turcz.) Hand.-Mazz.	Celastraceae	Evergreen shrub	1	0	0	0	1
Euphorbia candelabrum Trémaux ex Kotschy	Euphorbiaceae	Perennial succulent tree	1	0	0	0	1
Euphorbia tirucalli L.	Euphorbiaceae	Perennial succulent shrub/tree	0	1	0	0	1
Fagus sylvatica L.	Fagaceae	Deciduous tree	0	1	0	0	1
Fallopia japonica (Houtt.) Ronse Decr.	Polygonaceae	Perennial herb	2	0	0	0	2
Ficus altissima Blume	Moraceae	Evergreen tree	0	1	0	0	1
Ficus benjamina L.	Moraceae	Evergreen tree	4	0	0	0	4
Ficus carica L.	Moraceae	Deciduous tree	0	1	0	0	1
Forsythia x intermedia Zabel	Oleaceae	Deciduous shrub	1	0	0	0	1
Fragaria x ananassa Duchesne	Rosaceae	Perennial herb	0	1	0	0	1
Fraxinus pennsylvanica Marshall	Oleaceae	Deciduous tree	1	0	0	0	1
Galinsoga parviflora Cav.	Asteraceae	Annual herb	1	0	0	0	1
Ginkgo biloba L.	Ginkgoaceae	Deciduous tree	1	1	0	0	2
Gliricidia sepium Kunth	Fabaceae	Deciduous tree	0	1	0	0	1
Gmelina arborea Roxb.	Lamiaceae	Deciduous tree	0	1	0	0	1
Gossypium hirsutum L.	Malvaceae	Perennial shrub	0	1	0	0	1
Grevillea robusta A.Cunn.	Proteaceae	Evergreen tree	1	0	0	0	1
Helianthus annuus L.	Asteraceae	Annual herb	1	0	0	0	1
Hibiscus rosa-sinensis L.	Malvaceae	Evergreen shrub	3	0	0	0	3
Hibiscus syriacus L.	Malvaceae	Deciduous shrub	1	1	0	0	2

Hippophaë rhamnoides L.	Elaeagnaceae	Deciduous shrub	1	0	0	0	1
Imperata cylindrica (L.) P.Beauv.	Poaceae	Perennial grass	0	0	1	0	1
Ipomoea batatas (L.) Lam.	Convolvulaceae	Perennial herb	0	3	0	0	3
Ipomoea quamoclit L.	Convolvulaceae	Annual herbaceous vine	1	0	0	0	1
Ixora coccinea L.	Rubiaceae	Evergreen shrub	0	1	0	0	1
Jacaranda mimosifolia D.Don	Bignoniaceae	Deciduous tree	3	1	1	0	5
Jasminum sambac (L.) Aiton	Oleaceae	Evergreen shrub	1	0	0	0	1
Jatropha curcas L.	Euphorbiaceae	Semi-evergreen shrub/tree	0	1	0	0	1
Jatropha podagrica Hook.	Euphorbiaceae	Sub-woody shrub	1	0	0	0	1
Juglans regia L.	Juglandaceae	Deciduous tree	0	4	0	0	4
Justicia brandegeeana Wassh. & L.B.Sm.	Acanthaceae	Evergreen shrub	0	1	0	0	1
Justicia carnea Hook.	Acanthaceae	Evergreen shrub	0	1	0	0	1
Khaya senegalensis A.Juss.	Meliaceae	Semi-deciduous tree	0	1	0	0	1
Lactuca sativa L.	Asteraceae	Annual succulent	0	1	0	0	1
Lantana camara L.	Verbenaceae	Perennial shrub	0	0	1	0	1
Larix decidua Mill.	Pinaceae	Deciduous tree	0	1	0	0	1
Laurus nobilis L.	Lauraceae	Evergreen shrub/tree	1	0	0	0	1
Lawsonia inermis L.	Lythraceae	Herbaceous shrub	1	0	0	0	1
Ligustrum sinense Lour.	Oleaceae	Deciduous shrub/tree	1	0	0	0	1
Ligustrum vulgare L.	Oleaceae	Semi-evergreen shrub	3	0	0	0	3
Livistona chinensis R.Br.	Oleaceae	Evergreen tree	0	1	0	0	1
Lolium temulentum L.	Poaceae	Annual grass	0	1	0	0	1
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	1	0	4	5
Lonicera tatarica L.	Caprifoliaceae	Deciduous shrub	1	0	0	0	1
Luffa acutangula (L.) Roxb.	Cucurbitaceae	Annual herbaceous vine	0	1	0	0	1
Lycopersicon esculentum Mill.	Solanaceae	Annual herb	0	1	0	0	1
Lythrum salicaria L.	Lythraceae	Perennial herb	1	0	0	0	1
Magnolia grandiflora L.	Magnoliaceae	Evergreen tree	1	0	2	0	3
Malus domestica Baumg.	Rosaceae	Deciduous tree	0	1	0	0	1
Mangifera indica L.	Anacardiaceae	Evergreen tree	0	5	0	0	5

Manihot esculenta Crantz	Euphorbiaceae	Perennial shrub	0	2	0	0	2
Maranta arundinacea L.	Marantaceae	Perennial herb	1	0	0	0	1
Markhamia lutea K.Schum.	Bignoniaceae	Evergreen tree	1	0	0	0	1
Melaleuca quinquenervia (Cav.) S.T.Blake	Myrtaceae	Evergreen tree	0	0	1	0	1
Melia azedarach L.	Meliaceae	Deciduous tree	0	1	1	0	2
Mentha haplocalyx Briq.	Lamiaceae	Perennial herb	0	2	0	0	2
Michelia × alba DC.	Magnoliaceae	Evergreen tree	0	1	0	0	1
Millingtonia hortensis L.f.	Bignoniaceae	Evergreen tree	1	0	0	0	1
Moringa oleifera Lam.	Moringaceae	Deciduous tree	0	2	0	0	2
Morus alba L.	Moraceae	Deciduous tree	2	4	1	0	7
Murraya koenigii (L.) Spreng.	Rutaceae	Semi-deciduous tree	0	1	0	0	1
Musa × paradisiaca L.	Musaceae	Perennial herb	0	2	0	0	2
Musa acuminata Colla	Musaceae	Deciduous tree	0	1	0	0	1
Musa sapientum L.	Musaceae	Perennial herb	0	1	0	0	1
Musanga leo-errerae Hauman & J.Léonard	Cecropiaceae	Evergreen tree	1	0	0	0	1
Nasturtium officinale W.T.Aiton	Brassicaceae	Semi-aquatic, perennial herb	2	0	0	0	2
Nephelium lappaceum L.	Sapindaceae	Evergreen tree	0	1	0	0	1
Nephrolepis exaltata (L.) Schott	Nephrolepidaceae	Perennial herb	2	0	0	0	2
Ocimum basilicum L.	Lamiaceae	Annual herb	0	1	0	0	1
Opuntia ficus-indica Mill.	Cactaceae	Succulent shrub/tree	3	2	0	0	5
Oryza sativa L.	Poaceae	Annual grass	0	1	0	0	1
Oxalis corniculata L.	Oxalidaceae	Annual/perennial herb	1	0	0	0	1
Pandanus utilis Bory	Pandanaceae	Evergreen shrub/tree	0	1	0	0	1
Panicum miliaceum L.	Poaceae	Annual grass	0	1	0	0	1
Parthenocissus inserta (A.Kern.) Fritsch	Vitaceae	Deciduous, woody, perennial vine	1	0	0	0	1
Paspalum notatum Flüggé	Poaceae	Perennial grass	2	0	0	0	2
Passiflora edulis Sims	Passifloraceae	Perennial herb	0	3	0	0	3
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	Fabaceae	Deciduous tree	1	1	0	0	2
Persea americana Mill.	Lauraceae	Semi-evergreen tree	1	2	0	0	3
Petroselinum crispum (Mill.) Nyman	Apiaceae	Biennial herb	0	1	0	0	1

Phacelia tanacetifolia Benth.	Hydrophyllaceae	Annual herb	0	1	0	0	1
Phalaris arundinacea L.	Poaceae	Perennial grass	1	0	0	0	1
Phaseolus vulgaris L.	Fabaceae	Annual herb	0	1	0	0	1
Phoenix dactylifera L.	Arecaceae	Evergreen tree	0	1	1	0	2
Phragmites australis (Cav.) Steud.	Poaceae	Perennial grass	0	0	1	0	1
Phyllostachys aureosulcata McClure	Poaceae	Evergreen bamboo	0	1	0	0	1
Physalis angulata L.	Solanaceae	Annual herb	0	1	0	0	1
Phytolacca dioica L.	Phytolaccaceae	Evergreen tree	0	0	1	0	1
Pinus nigra Aiton	Pinaceae	Evergreen tree	0	1	0	0	1
Pinus radiata D.Don	Pinaceae	Evergreen tree	0	1	0	0	1
Pisum sativum L.	Fabaceae	Annual herb	0	1	0	0	1
Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	3	2	5	0	10
Plectranthus scutellarioides R.Br.	Lamiaceae	Perennial herb	0	1	0	0	1
Plumeria rubra L.	Apocynaceae	Deciduous tree	1	0	1	0	2
Polyalthia longifolia (Sonn.) Thwaites	Annonaceae	Evergreen tree	1	0	0	0	1
Polyscias balfouriana L.H.Bailey	Araliaceae	Evergreen shrub	1	0	0	0	1
Polyscias guilfoylei L.H.Bailey	Araliaceae	Evergreen shrub	1	0	0	0	1
Populus × canadensis Moench	Salicaceae	Deciduous tree	1	0	0	0	1
Populus nigra L.	Salicaceae	Deciduous tree	1	0	0	0	1
Portulaca grandiflora Hook.	Portulacaceae	Annual herb	1	1	0	0	2
Portulaca oleracea L.	Portulacaceae	Annual herb	0	1	0	0	1
Prosopis juliflora (SW.) DC.	Fabaceae	Deciduous tree	0	1	0	0	1
Prunus cerasifera Ehrh.	Rosaceae	Deciduous tree	1	0	0	0	1
Prunus cerasus L.	Rosaceae	Deciduous tree	0	1	0	0	1
Prunus mahaleb L.	Rosaceae	Deciduous tree	1	0	0	0	1
Prunus persica (L.) Batsch	Rosaceae	Deciduous tree	0	3	0	0	3
Prunus serotine Ehrh.	Rosaceae	Deciduous tree	0	1	0	0	1
Prunus serrulata Lindl.	Rosaceae	Deciduous tree	1	0	1	0	2
Pseudotsuga menziesii (Mirb.) Franco	Pinaceae	Evergreen tree	0	0	1	0	1
Psidium guajava L.	Myrtaceae	Evergreen shrub/tree	1	4	1	0	6

Punica granatum L.	Lythraceae	Deciduous shrub/tree	1	2	0	0	3
Pyrus calleryana Decne.	Rosaceae	Deciduous tree	0	1	0	0	1
Pyrus communis L.	Rosaceae	Deciduous tree	0	1	0	0	1
Quercus rubra L.	Fagaceae	Deciduous tree	0	1	0	0	1
Raphanus sativus L.	Brassicaceae	Annual herb	0	1	0	0	1
Rhamnus cathartica L.	Rhamnaceae	Deciduous shrub/tree	2	0	0	2	4
Rhus typhina L.	Anacardiaceae	Deciduous shrub	3	0	0	0	3
Ribes alpinum C.A.Mey.	Grossulariaceae	Deciduous shrub	1	0	0	0	1
Ribes aureum Pursh	Grossulariaceae	Deciduous shrub	1	0	0	0	1
Ribes rubrum L.	Grossulariaceae	Deciduous shrub	0	1	0	0	1
Ribes uva-crispa L.	Grossulariaceae	Deciduous shrub	0	1	0	0	1
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	2	1	3	0	6
Rosa multiflora Thunb.	Rosaceae	Perennial shrub	3	0	0	1	4
Rosa rugosa Thunb.	Rosaceae	Deciduous shrub	1	0	0	0	1
Roystonea regia O.F.Cook	Arecaceae	Evergreen tree	1	0	0	0	1
Rumex japonicus Houtt.	Polygonaceae	Perennial herb	0	1	0	0	1
Rumex usambarensis (Engl. ex Dammer) Dammer	Polygonaceae	Perennial herbaceous climber	0	1	0	0	1
Saccharum officinarum L.	Poaceae	Perennial grass	1	1	0	0	2
Salix × sepulcralis Simonk.	Salicaceae	Deciduous tree	1	0	0	0	1
Salix acutifolia Borrer ex Hook.	Salicaceae	Deciduous tree	0	0	1	0	1
Sansevieria trifasciata Prain	Dracaenaceae	Perennial herb	0	1	0	0	1
Schefflera arboricola (Hayata) Merr.	Araliaceae	Evergreen shrub	1	0	0	0	1
Schinus terebinthifolius Raddi	Anacardiaceae	Evergreen tree	2	2	0	0	4
Senna occidentalis (L.) Link	Fabaceae	Annual herb	0	1	0	0	1
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae	Evergreen tree	0	1	0	0	1
Sesamum indicum L.	Pedaliaceae	Annual herb	0	1	0	0	1
Sesbania grandiflora (L.) Pers.	Fabaceae	Semi-deciduous tree	1	0	0	0	1
Solanum lycopersicum L.	Solanaceae	Perennial herb	0	2	0	0	2
Solanum melongena L.	Solanaceae	Perennial herb	0	1	0	0	1
Solanum tuberosum L.	Solanaceae	Perennial herb	0	1	0	0	1

Solidago canadensis L.	Asteraceae	Perennial herb	1	0	0	0	1
Sorbus intermedia (Ehrh.) Pers.	Rosaceae	Deciduous tree	1	0	0	0	1
Spathodea campanulata Buch.-Ham. ex DC.	Bignoniaceae	Evergreen tree	2	0	0	0	2
Spiraea chamaedryfolia L.	Rosaceae	Perennial shrub	1	0	0	0	1
Styphnolobium japonicum (L.) Schott	Fabaceae	Deciduous tree	0	0	1	0	1
Swietenia macrophylla King	Meliaceae	Evergreen tree	0	4	0	0	4
Symphoricarpos albus (L.) S.F.Blake	Caprifoliaceae	Deciduous shrub	1	0	0	0	1
Syngonium angustatum Schott	Araceae	Perennial herb	1	0	0	0	1
Syngonium podophyllum Schott	Araceae	Evergreen herbaceous vine	1	0	0	0	1
Syringa vulgaris L.	Oleaceae	Deciduous shrub	1	0	0	0	1
Syzygium jambos (L.) Alston	Myrtaceae	Evergreen tree	0	0	0	1	1
Tabebuia argentea Britton	Bignoniaceae	Semi-deciduous tree	1	0	0	0	1
Tagetes erecta L.	Asteraceae	Annual herb	0	1	0	0	1
Tamarindus indica L.	Fabaceae	Evergreen tree	0	1	0	0	1
Tamarix gallica Thunb.	Tamaricaceae	Deciduous shrub/tree	1	0	0	0	1
Tamarix parviflora DC.	Tamaricaceae	Deciduous shrub/tree	1	0	0	0	1
Taxus baccata L.	Taxaceae	Evergreen tree	1	0	0	0	1
Tecoma stans (L.) Kunth	Bignoniaceae	Perennial, evergreen shrub	2	0	0	0	2
Terminalia catappa L.	Combretaceae	Deciduous tree	0	2	0	1	3
Terminalia mantaly H.Perrier	Combretaceae	Semi-deciduous tree	1	1	0	0	2
Terminalia superba Engl. & Diels	Combretaceae	Semi-deciduous tree	1	0	0	0	1
Theobroma cacao L.	Sterculiaceae	Evergreen tree	0	1	0	0	1
Thevetia peruviana K.Schum.	Apocynaceae	Evergreen shrub/tree	1	0	0	0	1
Thunbergia erecta T.Anderson	Acanthaceae	Perennial herbaceous vine	1	0	0	0	1
Tilia cordata Rose ex Bush	Tiliaceae	Deciduous tree	0	1	0	0	1
Tilia platyphyllos Scop.	Tiliaceae	Deciduous tree	1	0	0	0	1
Tipuana tipu (Benth.) Kuntze	Fabaceae	Deciduous tree	0	0	0	1	1
Tradescantia pallida (Rose) D.R.Hunt	Commelinaceae	Perennial herb	1	0	0	0	1
Ulmus glabra Huds.	Ulmaceae	Semi-deciduous tree	0	0	2	0	2
Ulmus pumila L.	Ulmaceae	Deciduous tree	0	1	0	0	1

Vaccaria segetalis (Neck.) Garcke ex Asch.	Caryophyllaceae	Annual herb	0	1	0	0	1
Viburnum lantana L.	Caprifoliaceae	Deciduous shrub	1	0	0	0	1
Vigna unguiculata (L.) Walp.	Fabaceae	Annual herb	0	1	0	0	1
Vinca minor Sm.	Apocynaceae	Perennial subshrub	1	0	0	0	1
Vitis vinifera L.	Vitaceae	Deciduous, woody, perennial vine	2	2	0	0	4
Warburgia salutaris (G.Bertol.) Chiov.	Canellaceae	Evergreen tree	0	1	0	0	1
Xanthosoma sagittifolium (L.) Schott	Araceae	Perennial herb	0	1	0	0	1
Yucca gloriosa L.	Yuccagloriosa	Evergreen shrub	1	0	0	0	1
Zea mays L.	Poaceae	Annual grass	0	2	0	0	2
Zelkova serrata (Thunb.) Makino	Ulmaceae	Deciduous tree	0	1	0	0	1
Zingiber officinale Roscoe	Zingiberaceae	Perennial herb	0	1	0	0	1
Ziziphus mauritiana Lam.	Rhamnaceae	Evergreen tree	0	1	0	0	1
Ziziphus spina-christi (L.) Willd.	Rhamnaceae	Evergreen tree	0	1	0	0	1
			180	249	50	26	**505**

Appendix D Number of records in the literature of urban ecosystem disservices (categorised according to Vaz et al. 2017a and Roy et al. 2012) provided by all recorded alien plant species.

Species	Family	Growth Form	Ecosystem Disservice Category							Total
			Cultural and aesthetic	Economic problems	Environmental problems	Health	Leisure and recreation	Material	Security and safety	
Acacia saligna H.L.Wendl.	Fabaceae	Evergreen tree	0	0	1	0	0	0	0	1
Acer negundo L.	Aceraceae	Deciduous tree	0	0	1	0	0	0	0	1
Acer platanoides L.	Aceraceae	Deciduous tree	0	0	0	1	0	0	0	1
Ailanthus altissima (Mill.) Swingle	Simaroubaceae	Deciduous tree	1	0	5	6	0	5	2	19
Albizia julibrissin Durazz.	Fabaceae	Deciduous tree	0	0	0	1	0	0	0	1
Amaranthus albus L.	Amaranthaceae	Annual herb	0	0	0	1	0	0	0	1
Amaranthus retroflexus L.	Amaranthaceae	Annual herb	0	0	0	1	0	0	0	1
Ambrosia artemisiifolia L.	Asteraceae	Annual herb	0	0	0	9	0	0	0	9
Bidens frondosa L.	Asteraceae	Annual herb	0	0	1	0	0	0	0	1
Buchloe dactyloides (Nutt.) Engelm.	Poaceae	Perennial grass	0	0	0	1	0	0	0	1
Casuarina cunninghamiana Miq.	Casuarinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Catalpa speciose (Warder) Engelm.	Bignoniaceae	Deciduous tree	0	0	0	1	0	0	0	1
Cedrus deodara (Roxb. ex D.Don) G.Don	Pinaceae	Evergreen tree	0	0	0	2	0	0	0	2
Cedrus libani A.Rich.	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Cupania anacardioides A.Rich.	Sapindaceae	Evergreen tree	0	0	0	1	0	0	0	1
Erigeron acer L.	Asteraceae	Biennial herb	0	0	0	1	0	0	0	1
Eucalyptus nicholii Maiden & Blakely	Myrtaceae	Evergreen tree	0	0	0	1	0	0	0	1

Eucalyptus polyanthemos Schauer	Myrtaceae	Evergreen tree	0	0	0	1	0	0	0	1
Ginkgo biloba L.	Ginkgoaceae	Deciduous tree	0	0	0	1	0	0	0	1
Hedera helix L.	Araliaceae	Evergreen, woody, perennial vine	0	0	1	0	0	0	0	1
Jacaranda mimosifolia D.Don	Bignoniaceae	Semi-evergreen tree	0	0	0	1	0	0	0	1
Juniperus chinensis L.	Cupressaceae	Evergreen shrub/tree	0	0	0	1	0	0	0	1
Koelreuteria paniculate Laxm.	Sapindaceae	Deciduous tree	0	0	0	1	0	0	0	1
Lagerstroemia indica L.	Lythraceae	Deciduous tree	0	0	0	1	0	0	0	1
Laurus nobilis L.	Lauraceae	Evergreen shrub/tree	0	0	0	1	0	0	0	1
Ligustrum sinense Lour.	Oleaceae	Deciduous shrub/tree	0	0	1	0	0	0	0	1
Lolium perenne L.	Poaceae	Perennial grass	0	0	0	1	0	0	0	1
Lonicera maackii (Rupr.) Herder	Caprifoliaceae	Deciduous shrub	0	0	2	0	0	0	0	2
Magnolia grandiflora L.	Magnoliaceae	Evergreen tree	0	0	0	1	0	0	0	1
Microstegium vimineum (Trin.) A.Camus	Poaceae	Annual grass	0	0	1	0	0	0	0	1
Myriophyllum spicatum L.	Haloragaceae	Aquatic perennial herb	0	1	0	0	1	0	0	2
Pinus bungeana Zucc. Ex Endl.	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Pinus canariensis C.Sm. ex DC	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Pinus halepensis Mill.	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Pinus nigra Aiton	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Pinus pinea L.	Pinaceae	Evergreen tree	0	0	0	1	0	0	0	1
Platanus occidentalis L.	Platanaceae	Deciduous tree	0	0	0	1	0	0	0	1

Platanus x acerifolia (Aiton) Willd.	Platanaceae	Deciduous tree	0	0	0	4	0	0	0	4
Populus × canadensis Moench	Salicaceae	Deciduous tree	0	0	0	1	0	0	0	1
Prunus serotine Ehrh.	Rosaceae	Deciduous tree	0	0	1	0	0	0	0	1
Punica granatum L.	Lythraceae	Deciduous shrub/tree	0	0	0	1	0	0	0	1
Rhamnus cathartica L.	Rhamnaceae	Deciduous shrub/tree	0	0	3	0	0	0	0	3
Rhus typhina L.	Anacardiaceae	Deciduous shrub	0	0	0	2	0	0	0	2
Robinia pseudoacacia L.	Fabaceae	Deciduous tree	0	0	3	2	0	0	0	5
Rosa multiflora Thunb.	Rosaceae	Perennial shrub	0	0	1	0	0	0	0	1
Schinus molle L.	Anacardiaceae	Evergreen tree	0	0	0	1	0	0	0	1
Schinus terebinthifolius Raddi	Anacardiaceae	Evergreen tree	0	0	0	1	0	0	0	1
Tamarix gallica Thunb.	Tamaricaceae	Deciduous shrub/tree	0	0	0	1	0	0	0	1
Tamarix parviflora DC.	Tamaricaceae	Deciduous shrub/tree	0	0	0	1	0	0	0	1
Taxus baccata L.	Taxaceae	Evergreen tree	0	0	0	1	0	0	0	1
Toona sinensis (Juss.) M.Roem.	Meliaceae	Deciduous tree	0	0	0	1	0	0	0	1
Viburnum lantana L.	Caprifoliaceae	Deciduous shrub	0	0	0	1	0	0	0	1
Vincetoxicum rossicum (Kleopow) Barbar.	Asclepiadaceae	Perennial herbaceous vine	0	0	3	0	0	0	0	3
			1	1	24	60	1	5	2	**94**

Chapter 3. Perceptions of impact: invasive alien plants in the urban environment

This chapter has been published.

Citation: Potgieter LJ, Gaertner M, O'Farrell PJ, Richardson DM (2018) Perceptions of impact: Invasive alien plants in the urban environment. J Environ Manage. doi:10.1016/j.jenvman.2018.05.080

Luke J. Potgieter[1], Mirijam Gaertner[1,2], Patrick J. O'Farrell[3,4], David M. Richardson[1]

[1] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa.

[2] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

[3] Natural Resources and Environment CSIR, Biodiversity and ES Research Group, P.O. Box 320, Stellenbosch, 7599, South Africa.

[4] Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa.

3.1 Abstract

Many alien plant species are introduced to urban areas to create, augment or restore ecosystem services (ES). However, many of these species spread beyond original plantings, sometimes causing negative effects on existing ES or creating novel ecosystem disservices (EDS). An understanding of the perceptions of urban residents regarding invasive alien plants (IAPs) and the ES and EDS they provide is needed for the effective prioritization of land parcels for IAP management efforts in cities. Using the city of Cape Town, South Africa as a case study, we conducted questionnaire-based surveys (online and face-to-face) to determine the perceptions of urban residents regarding IAPs and their capacity to provide ES and EDS.

Most urban residents perceive IAPs negatively (i.e. agreeing that they create EDS), but many recognise their importance in providing ES. Although most residents are not opposed to the management of IAPs, such actions are not perceived as a high priority relative to other environmental problems. Socio-demographic variables such as age, education, environmental awareness, and ethnicity shape urban residents' perceptions of IAPs in urban areas. Older, more educated respondents were more likely to perceive IAPs negatively, while respondents with greater environmental awareness were aware of the

benefits provided by IAPs. This study highlights the need to integrate public perceptions into the planning and management of IAPs and emphasises the importance of including ES assessments into the decision-making process, particularly in urban areas.

Keywords: Biological invasions • Ecosystem services • Ecosystem disservices • Invasive alien plants • Management • Perceptions • Tree invasions • Urban ecology • Urban invasions

3.2 Introduction

Conserving biodiversity is a fundamental objective of nature conservation (Ehrlich and Wilson 1991, UNEP 1992). An aligned and complimentary approach is to emphasise ecosystem services (ES), focusing efforts and resources on both biodiversity conservation and the sustainable provision of ES to support human well-being (MA 2005; Tallis et al. 2009). Ecosystem services are the benefits people obtain from ecosystems (MA 2005). These include provisioning services such as food, water and timber; regulating services that affect climate, floods and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling.

As human populations grow and concerns regarding the sustainability of different land-use practices increase, more attention is being given to evaluating both the ES and ecosystem disservices (EDS) provided by alien species (Shackleton et al. 2016; Vaz et al. 2017). Following Shackleton et al. (2016), we define EDS as *"the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing"*.

Many alien plant species were (and still are) introduced to urban areas to provide, augment or restore specific ES. However, besides providing the desired ES, some of these species negatively impact existing ES and/or create novel EDS within the urban milieu (Potgieter et al. 2017). Some of these species also spread into surrounding natural areas where they can alter ecosystem functions, disrupt the flows of ES, reduce native biodiversity, and negatively affect local economies and human well-being (Levine et al. 2003; Pejchar and Mooney 2009; Le Maitre et al. 2011; Jeschke et al. 2014; Shackleton et al. 2016). We define invasive alien plants (IAPs) as naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (Richardson et al. 2000).

Although the ecological impacts of invasive species are well documented, less attention has been given to the social dimensions that mediate responses to biological invasions (McNeely et al. 2001; García-Llorente et al. 2008, 2011), particularly in urban areas (Gaertner et al. 2017b). This is partly because it is difficult to measure social impacts (Bacher et al. 2018) and complex conflicts between different stakeholders frequently complicate efforts to manage invasions (Novoa et al. 2018). Managers, decision-makers and researchers are increasingly recognizing the need to consider the human dimensions of invasive species management (Stokes et al. 2006; Reed et al. 2009; Novoa et al., 2017).

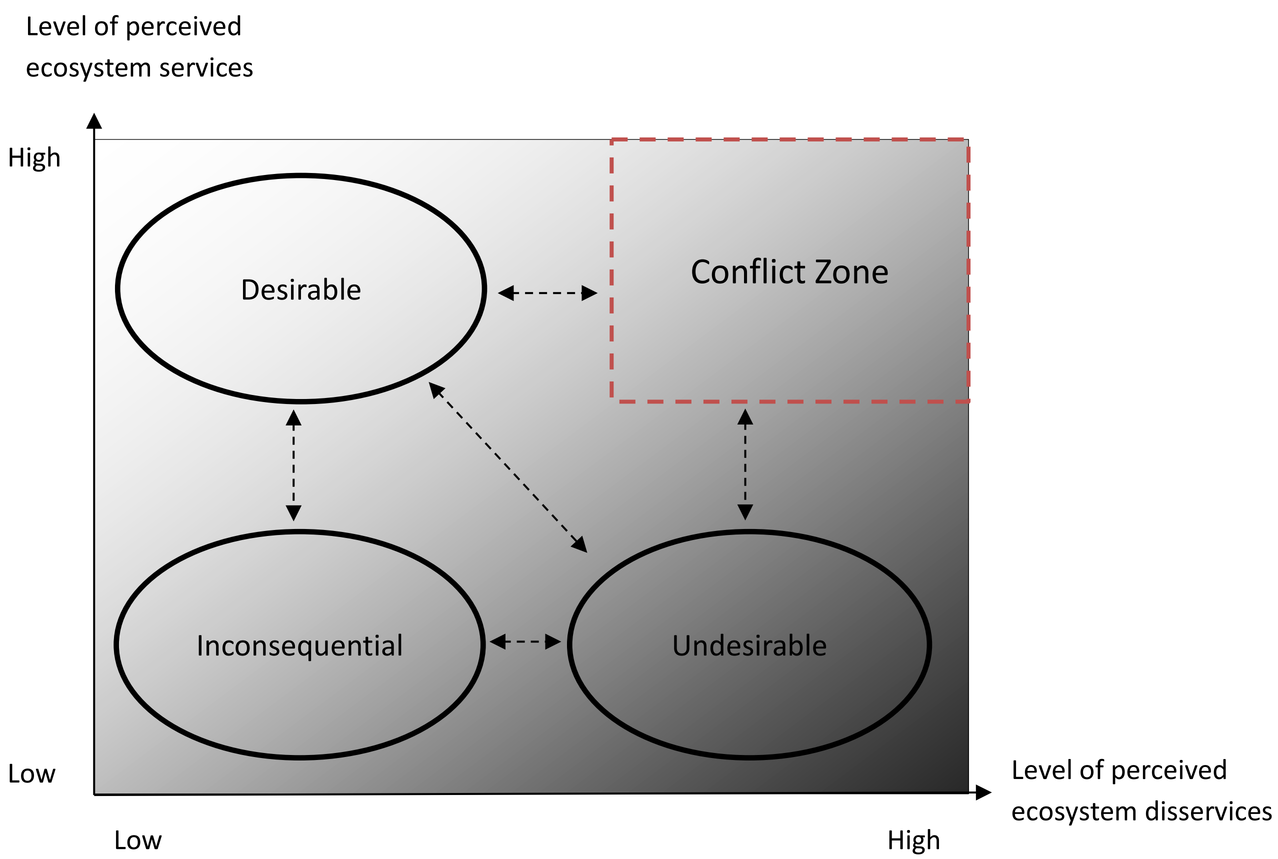


Figure 3.1. A conceptual classification of invasive alien plant species based on their perceived benefits (ecosystem services) and negative impacts (ecosystem disservices) (inspired by van Wilgen and Richardson (2014), Gaertner et al. (2016) and Novoa et al. (2018)). Arrows indicate potential category changes for a particular species over time. Shading reflects the perception of management of a particular species (light to dark = 'against' and 'in favour of' management). Conflicts of interest, and thus the management outcome for invasive alien plants, are mediated largely by stakeholder perceptions. The 'Conflict Zone' may thus shift in size and position according to the ratio of perceived ecosystem services and disservices provided by invasive alien plants. Perceptions are context dependant and may change over space and time.

Arguments for and against managing IAPs in urban areas increasingly hinge on the contributions of IAPs to the delivery of ES and EDS (Vaz et al. 2017). Conflicts of interest often arise when the real or perceived benefits (ES) associated with a species are weighed against the potential of the species to generate significant negative impacts (EDS). IAPs that provide both ES and EDS usually lead to conflicts around both their use and management (Fig. 3.1, Dickie et al. 2014; Novoa et al. 2016; Zengeya et al. 2017). Local circumstances govern the context of the complex interactions that arise between socio-cultural and ecological relationships with urban plant invasions (Foster and Sandberg 2004; see also Dickie et al. 2014 regarding tree invasions in urban areas). Such conflicts of interests mean that management efforts are often contested or delayed. Consequently, many widespread IAPs within urban areas may need to be tolerated at specific sites for a combination of social and pragmatic reasons (Gaertner et al. 2016). In such instances, targeted awareness and educational campaigns are needed to improve understanding of the effects of IAPs.

Each urban area presents a unique set of challenges requiring city-specific management approaches (Irlich et al. 2017). Such approaches need to consider stakeholder views and social consequences of management actions and complex, adaptable management frameworks are needed (e.g. Gaertner et al. 2016; Gaertner et al. 2017b). Until now, environmental managers in cities have managed IAPs using approaches and paradigms developed for a rural context (Gaertner et al. 2017b), despite the fundamental differences in social, ecological and economic pressures that exist in urban environments (Elmqvist et al. 2013). To justify the allocation of resources to control urban plant invasions, an objective quantification of the impacts (perceived or real) of these species is required. However, the perceived ES and EDS of an IAP can be difficult to quantify. While some information exists in the literature and invasive species databases, the full range of understanding and perceptions needs to be explored through stakeholder engagement.

The perceptions of IAPs and the ES or EDS they provide or influence inevitably varies between stakeholders of different socio-economic groups - urban areas typically have a greater number and diversity of stakeholders compared to rural areas (Gaston et al. 2013; Shackleton et al. 2018). Changes in ecological conditions may affect human perceptions and attitudes and influence the formulation of policies which have an impact on land-use (Pauleit and Breuste 2011). IAPs can be viewed from diverse perspectives, each of which is strengthened by different values and experiences (Foster and Sandberg, 2004; Kull et al. 2011; Estévez et al. 2015; Shackleton et al. 2018). Understanding how people perceive IAPs is essential for environmental decision-making because it can indicate where management interventions should be focused, either by defining high-priority areas for control or determining the scale at which IAPs should be managed.

Few attempts have been made to achieve objective and transparent integration of different human perceptions of IAPs in urban areas when formulating management strategies (e.g. Gaertner et al. 2016; Lindemann-Matthies 2016; Gaertner et al. 2017a). Using the city of Cape Town, South Africa - a rapidly urbanising city within a global biodiversity hotspot - we aim to assess urban residents' perceptions of the benefits (ES) and negative impacts (EDS) of IAPs and their management.

3.3 Methods

3.3.1 Study area

The city of Cape Town (hereinafter referred to as "the City") has a population of 3.8 million people and is growing more rapidly than any other southern African city (Boraine et al. 2006). The municipal boundary covers an area of 2 460 km^2; 26% of this area has been transformed for urban development, 35% for agricultural use, while 39% remains under natural and semi-natural vegetation in mountainous areas (mainly within Table Mountain National Park) (Holmes et al. 2012).

The City is situated within the greater Cape Floristic Region (CFR) – a global biodiversity hotspot with high levels of endemism. The region has a Mediterranean-type climate and the indigenous vegetation, termed fynbos, is a fire-prone and fire-adapted shrubland occurring on sandy, infertile soils (Cowling et al. 1996). The high concentration of biodiversity within the urban matrix poses major challenges for conservation (Richardson et al. 1998). Nineteen vegetation types occur within the City's municipal boundaries, six of which are endemic (Rebelo et al. 2011). ES provided by natural, functioning ecosystems and their biodiversity underpin the City's Integrated Development Plan. However, urban expansion, agriculture and IAPs (Richardson et al. 1996) are major threats to the loss of habitat and native biodiversity and have considerable impacts on the provisioning of ES such as surface water run-off (van Wilgen et al. 2008).

Cape Town's urban spatial arrangement is typical of post-apartheid cities in South Africa with racially defined spatial planning still evident and aligned with significant wealth disparities (Swilling 2010). Informal settlements (inhabited mostly by poorer communities), and "townships" established during the previous century and enforced through apartheid planning, are mostly located along the outskirts of the City. Major socio-economic challenges within the City include the provision of education, housing, nutrition and healthcare, and transport infrastructure (Goodness and Anderson 2013). Pressure to address development issues of unemployment, poverty, and the formal housing shortfall, all place considerable demand on remaining vegetation patches which are highly sought after for conversion to housing or industrial development (Goodness and Anderson 2013). The result is a population with diverse and often divergent needs, which shapes the demand for ES provision in the City.

The City has a long history of alien plant introductions and management, and despite various attempts to control IAPs, they remain embedded in the landscape, and ES remain at risk and are undergoing detrimental changes (van Wilgen 2012). For example, *Pinus* species introduced to provide timber and other benefits have subsequently spread significantly beyond the borders of formal plantations, impacting negatively on surface water runoff, grazing resources and biodiversity, and exacerbating the problem of wildfires (see Appendix E; van Wilgen et al. 2008; van Wilgen and Richardson 2012). However, despite their negative impacts, some IAPs still provide benefits to many of the City's residents (Fig. 3.2).

Figure 3.2. Examples of ecosystem services and disservices provided by invasive alien plants in Cape Town. (a) *Pennisetum setaceum* planted in a residential garden for ornamental purposes (cultural services) (Photo: LJ Potgieter). (b) *Eucalyptus* sp. providing shade for a street vendor (regulating

service) (Photo: LJ Potgieter). (c) An urban park wetland covered by a dense mat of *Myriophyllum aquaticum* (environmental problem) (Photo: LJ Potgieter). (d) A pine tree catches fire and intensifies a blaze which broke out in an informal settlement (environmental, and safety and security problem) (Photo: J Sullivan). (e) A pine tree blown over during strong winds resulting in considerable infrastructural damage (safety and security problem) (Photo: Friends of Tokai Park).

3.3.2 Data collection

A two-phase questionnaire-based survey was conducted with residents (≥ 18 years of age) of the City (see Appendix F). First, an online questionnaire was used to quantify respondents' perceptions of the benefits, negative impacts and management of listed IAPs (as per the Alien and Invasive Species Regulations promulgated under the National Environmental Management: Biodiversity Act (No. 10 of 2004) (NEM:BA)) in Cape Town.

The questionnaire (available in English only), developed using Google Docs (https://docs.google.com), was posted in September 2017 on the social media platforms Facebook and Twitter and was active for four months (at the beginning of each month, the questionnaire link was reposted on the same platforms). The link was posted on various groups within each social media platform (e.g. community and friends' groups) and was subsequently shared or reposted by many of the recipients. The online questionnaire yielded 121 responses.

The questionnaire consisted of the following sections (see Supplementary Material for further detail): (1) respondents' socio-demographic information; (2) general environmental awareness and knowledge (including their involvement in conservation and outdoor activities); (3) invasive species awareness and knowledge (including awareness of the Alien and Invasive Species Regulations); (4) invasive alien plant awareness and knowledge; (5) perceived benefits and negative impacts of specific widespread listed invasive alien plant taxa (namely *Acacia saligna* (Labill.) H.L.Wendl. (Fabaceae), *Eucalyptus* spp. (Myrtaceae), *Myriophyllum aquaticum* Verdc. (Haloragaceae), *Pennisetum setaceum* (Forssk.) Chiov. (Poaceae), and *Pinus* spp. (Pinaceae)); (6) attitudes towards management of these taxa (see Appendix B). The main criterion for species selection was familiarity: species had to be well known to a broad lay audience, as widespread lack of familiarity would have resulted in meaningless data. Species selection also ensured that different growth forms were appropriately represented (e.g. tree, grass and aquatic herbaceous). The species selected are widespread across the City and have a long history of introduction and use.

Picture panels for each invasive alien plant taxon were embedded in the questionnaire. Species-level classification for the genera *Eucalyptus* and *Pinus* was not provided due to the challenges associated with identification of some species in these genera. Respondents were also afforded the opportunity to add other invasive alien plant taxa to the species list. The questionnaire included a combination of closed- and open-ended questions. The former allowed the quantitative measurement of key constructs, while the latter allowed respondents' perceptions of the benefits (ES) and negative impacts (EDS) of the five invasive plant taxa to emerge. Draft versions of the questionnaire were jointly developed by the authors and extensively pilot-tested.

Electronic surveys are limited to those with access to a personal computer, email and internet access, creating immediate sample bias. To counteract this bias, face-to-face interviews were conducted based on the questionnaire predominantly in informal settlements (identified using data from www.ismaps.org.za) around the City. Due to potential safety and security risks to the interviewer(s), sites were selected in collaboration with the City's Invasive Species Unit (ISU, a specialist unit aimed at streamlining and facilitating invasive species management across the metro; Gaertner et al. 2016; Irlich et al. 2017). The ISU actively manages species invasion across the City and selects sites based on predetermined priorities which consider factors such as accessibility, available funding, density of invasion, and biodiversity importance. Site selection was therefore aligned with that of the ISU and comprised of populated areas (predominantly informal settlements) adjacent to the invaded sites on which the ISU were working (e.g. conservation areas, riparian areas, vacant lots). The interviewer(s) linked site visits with that of the ISU teams, as accessibility was prearranged, and ISU team members could assist in overcoming any translation barriers. Respondents included residents and/or general members of the public.

A total of 37 face-to-face interviews were conducted at five sites (an average of six respondents were interviewed per site). The interviews took place from 07h30 to 15h00 and were conducted on weekdays (and one Saturday). Respondents were selected based on their proximity to the invaded site and a combination of street and household interviews were conducted. With the assistance of the ISU, the interviews could be conducted in Afrikaans, English and isiXhosa.

3.3.3 Ethics approval and consent to participate

Before commencing with the project, the study proposal was submitted to the Departmental Ethics Screening Committee of the Department of Botany and Zoology for review and approved by the Research Ethics Committee of Stellenbosch University. Participation was voluntary - all participants were informed about their right to refuse to answer any questions and to withdraw from participation at any time. Informed consent was obtained, anonymity and confidentiality were explicitly granted, and questionnaires did not include any information that could be used to identify individual respondents. All data was thus anonymised prior to analysis.

3.3.4 Data analysis

ES were categorised according to the MA (2005) (namely cultural, regulating, supporting and provisioning). EDS were categorised according to the typology proposed by Vaz et al. (2017) (namely health, material, safety and security, cultural and aesthetic, and leisure and recreation), with two additional categories (economic and environmental problems) included based on the categorisation of Roy et al. (2012). A contingency table was constructed in which perceived ES and EDS were compared using the percentage respondents (Table 3.1).

Table 3.1. Total percentage respondents (n = 158) who perceived the five invasive alien plant taxa to provide ecosystem services and disservices.

Ecosystem Disservice	**Ecosystem Service**			**Total (%)**
	Yes	No	N/A	
Yes	43	37	4	83
No	3	3	1	6
N/A	2	1	8	11
Total (%)	47	41	12	100

The relationships between socio-demographic data variables namely age (categorical); duration of residence (time as a resident in Cape Town) (categorical); education (categorical), environmental awareness (ordinal) and ethnicity (categorical) were analysed using the Kendall rank correlation (a non-parametric test that measures the strength of dependence between variables). Each variable was recoded into indicator variables (dummy coding).

Environmental awareness was determined by ranking respondents' environmental behaviour (e.g. do any aspects of their job involve environmental management, do they volunteer for any environmental causes, are they a member of any conservation organisation and do they partake in any outdoor activities). Environmental awareness was categorised into four groups; (1) not environmentally aware; (2) somewhat environmentally aware; (3) environmentally aware; (4) very environmentally aware. For example, respondents who satisfy all requirements were categorised as 'very environmentally aware'. All statistical analyses were performed using STATISTICA ver.12.0 software (StatSoft Inc. 2005).

The questionnaire responses were grouped into multiple categories describing respondents' perceptions of IAPs in Cape Town (Table 3.3). Participants were asked whether they view: (1) IAPs as part of the natural environment in and around Cape Town (*IAP*); (2) one or more of the five IAP taxa as providing any benefits (to people and/or the environment) in Cape Town (*ES*); (3) one or more of the five IAP taxa to have negative impacts (on people and/or the environment) in Cape Town (*EDS*); (4) IAPs as a threat to the biodiversity in and around Cape Town (*ThBd*); (5) controlling IAPs as a necessary intervention to help conserve the environment and protect biodiversity (*Bd*); (6) controlling IAPs as a necessary intervention to protect the well-being of people (*Wb*) and (7) the removal of one or more of the five IAP taxa from Cape Town as a futile exercise (*Mgmt*).

3.4 Results

Our online questionnaire yielded 121 responses, and 37 face-to-face interviews were conducted (n = 158). Respondents (55% female, 45% male) were between the ages of 18 and 80. Roughly 11% were aged between 18 and 24 years, 25% between 25 and 34, 19% between 35 and 44, 15% between 45 and 54, 13% between 55 and 64, 7% between 65 and 74, and 9% were 75 years or older. About 51% had a tertiary-level education, 12% received a diploma, 7% had a secondary-level education, and 25% had no education.

All questionnaire-based studies have limitations regarding the representativeness of public they seek to sample (Sapsford 1999). There does appear to be a degree of non-response bias in the respondents of this survey; younger people and those with fewer formal qualifications were less likely to respond; this is a common finding in surveys of this nature (Sapsford 1999). Self-selection amongst respondents would also mean those people with a strong interest in the topic are more likely to respond. In terms of assessing public perception in relation to IAPs, however, those who are strongly in favour and those strongly against control may be equally likely to respond.

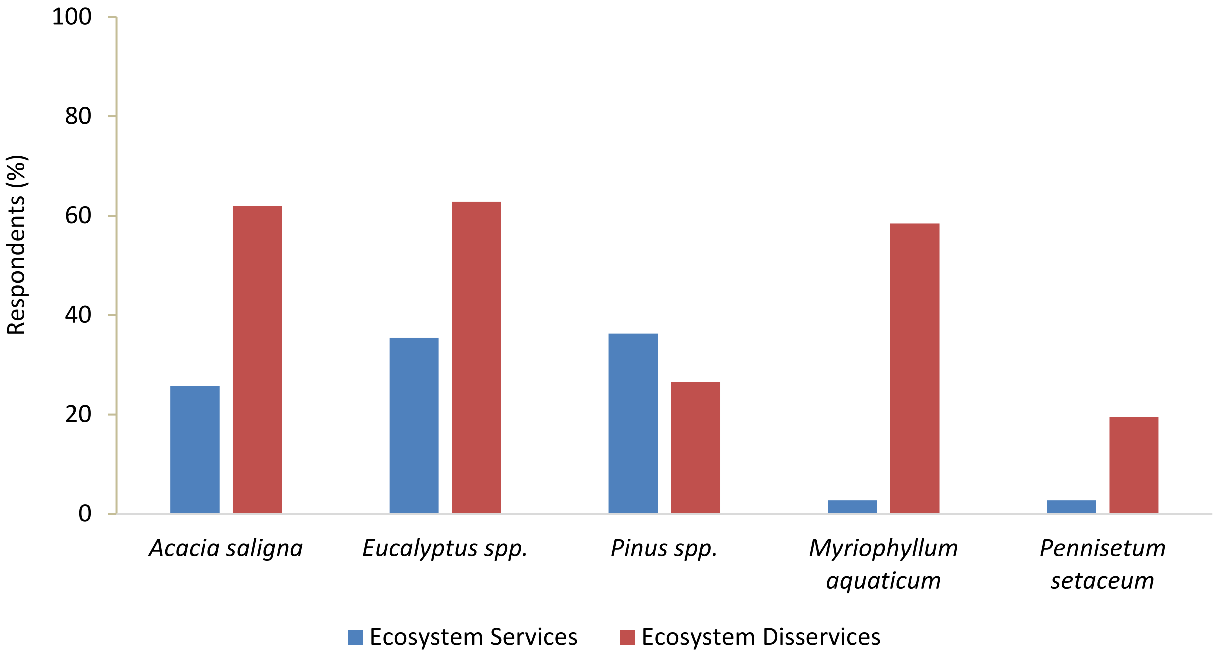


Figure 3.3. Respondents' perceptions of the ecosystem services and disservices provided by the five invasive alien plant taxa.

3.4.1 Ecosystem services and disservices

Although most urban residents perceive IAPs negatively (i.e. creating EDS), many still recognise their importance in providing ES (Fig. 3.3). Our analysis showed that 98% of respondents were familiar with at least one of the five IAP taxa. Most respondents (83%) perceived the five IAP taxa to have negative impacts (EDS), and 37% perceived them to provide no benefit (ES) (Table 3.1). However, in addition to the perceived EDS, 42% of respondents familiar with IAPs perceived the five IAP taxa to provide at least one ES. Only 2% of these respondents perceived them to provide ES with no associated EDS. The majority (91%) of respondents agreed that IAPs pose a threat to the biodiversity in and around the City.

Respondents noted 16 and 18 different ES and EDS respectively for all five IAP taxa (Table 3.2). The provision of fuelwood was the most commonly perceived ES for *A. saligna*, and *Eucalyptus* spp.*,* while shade was perceived as the most important ES provided by *Pinus spp*. Aesthetics was the only perceived ES noted for both *M. aquaticum* and *P. setaceum* (Fig. 3.2a). The displacement of native plant species was a commonly perceived EDS for all five IAP taxa, while increased water consumption was perceived as a major EDS for all three tree species. No responses related to economic problems were received and therefore no additions to the economic problem categorisation were made.

Table 3.2. Individual perceived ecosystem services (categorised according to the Millennium Ecosystem Assessment 2005) and disservices (categorised according to Roy et al. 2012 and Vaz et al. 2017) provided by selected invasive alien plant taxa in Cape Town, South Africa (values in brackets indicate the percentage respondents for each taxon).

Ecosystem Service Category	**Ecosystem Services**				
	Acacia saligna	*Eucalyptus* spp.	*Myriophyllum aquaticum*	*Pennisetum setaceum*	*Pinus* spp.
Cultural	Aesthetic (14%)	Aesthetic (12%) Heritage (4%) Recreation (1%)	Aesthetic (100%)	Aesthetic (100%)	Aesthetic (9%) Recreation (9%) Heritage (3%)
Provisioning	Fuelwood (44%) Fodder (2%) Honey production (2%) Tanning (2%) Timber (2%)	Fuelwood (26%) Honey production (13%) Timber (6%) Essential oils (1%)			Fuelwood (21%) Timber (15%) Paper (2%)
Regulating	Soil stabilization (9%) Carbon storage (2%) Shade (16%)	Soil stabilization (3%) Carbon storage (1%) Screening (1%) Shade (22%)			Soil stabilization (3%) Carbon storage (2%) Windbreaks (2%) Shade (29%)
Supporting	Habitat provision (5%)	Habitat provision (9%)			Habitat provision (6%)
Ecosystem Disservice Category	**Ecosystem Disservices**				
Cultural and Aesthetic	Unattractive (1%)	Unattractive (1%)			Unattractive (1%)
Environmental Problem	Displace native plant species (38%) Increases water consumption (31%)	Increases water consumption (44%) Displace native plant species (26%)	Displace native plant species (50%) Reduces streamflow (28%)	Displace native plant species (62%) Increases water consumption (7%)	Increases water consumption (39%) Displace native plant species (31%)

	Supresses understory growth (3%) Alters soil fertility (1%) Disrupts native plant pollination (1%) Habitat transformation (2%) Increases erosion (1%) Soil degradation (1%)	Supresses understory growth (5%) Alters soil fertility (3%) Habitat transformation (2%) Disrupts native plant pollination (1%) Increases erosion (1%) Soil degradation (1%)	Eutrophication (10%) Habitat transformation (3%) Increases water consumption (3%)	Habitat transformation (3%) Soil degradation (3%)	Supresses understory growth (6%) Alters soil fertility (4%) Habitat transformation (2%) Increases erosion (1%) Soil degradation (1%)
Environmental Problem / Health			Reduces water quality (5%)		
Environmental Problem / Safety and Security	Increased fire risk (16%)	Increased fire risk (14%)		Increased fire risk (21%)	Increased fire risk (15%)
Health	Allergies (4%)		Poisonous (3%)	Allergies (3%)	
Material		Leaf litter nuisance (1%)			
Safety and Security	Hiding place for criminals (2%)	Safety risk (2%)			

3.4.2 Management

Managing IAPs in the City was perceived positively, and 91% of respondents agreed that controlling IAPs is necessary to conserve the environment and protect biodiversity (Fig. 3.4). Although 66% of respondents agree that controlling IAPs is necessary to protect the well-being of people, 27% remained neutral. Most respondents (84%) were not opposed to the management of one or more of the five IAP taxa (Fig. 3.4). However, only 39% of respondents assigned the problem of IAPs as a 'high management priority' in relation to the other environmental problems, while 49% considered it a 'medium management priority' and 12% a 'low management priority'.

Respondents whom perceive IAPs as providing negative impacts (r = -0.31, $p < 0.05$) and a threat to biodiversity (r = -0.26, $p < 0.05$), were not opposed to management interventions and perceived the control of IAPs as a necessary measure to conserve biodiversity (r = 0.20, $p < 0.05$) and protect human well-being (r = -0.23, $p < 0.05$; Table 3.3). Respondents whom perceived IAPs as beneficial are less likely to view the control of IAPs as a necessary intervention to protect human well-being (r = -0.24, $p < 0.05$).

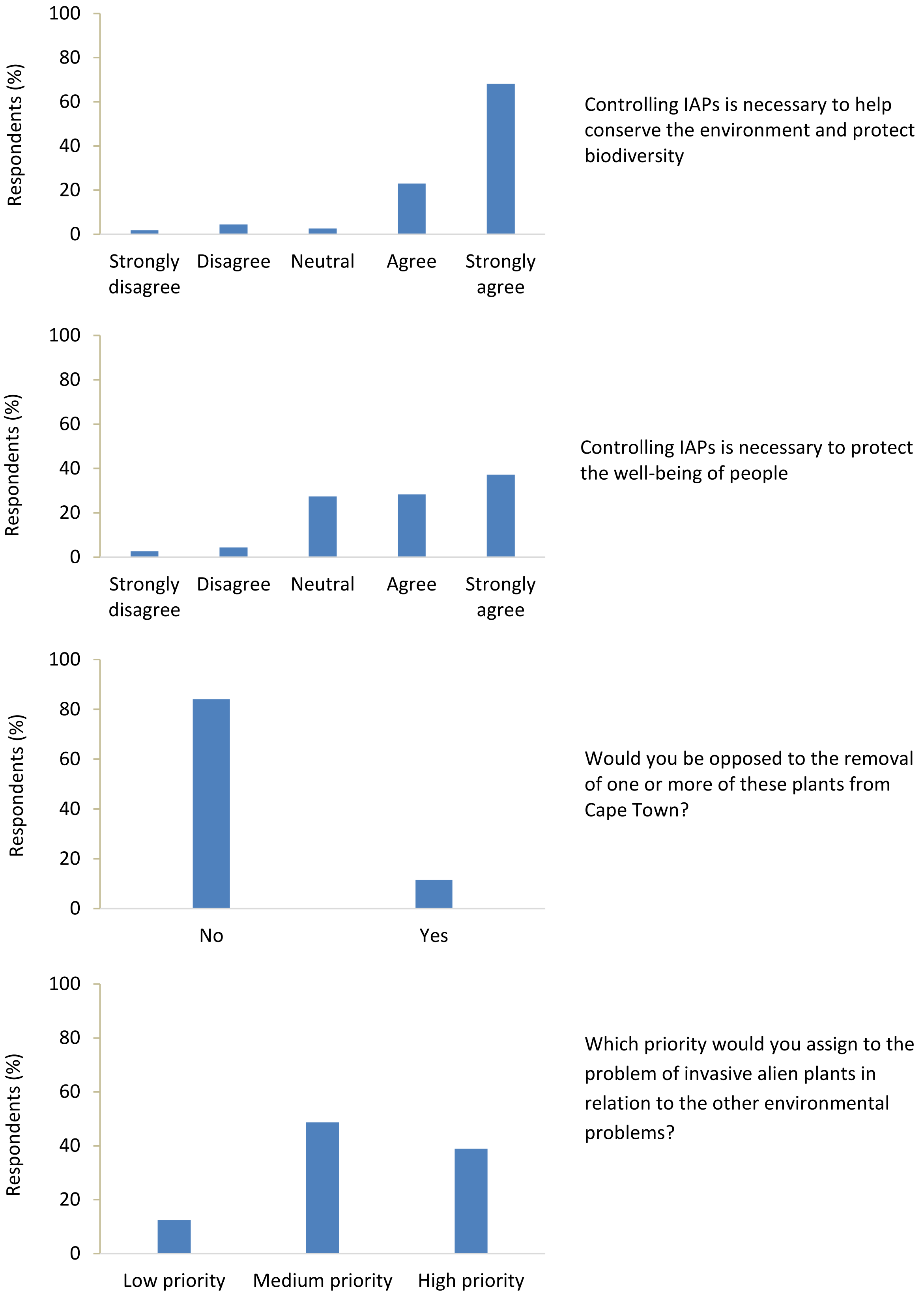


Figure 3.4. Respondents' perceptions of the management of invasive alien plants in Cape Town, South Africa.

Table 3.3. Kendall Tau correlation matrix showing the strength of dependence between socio-demographic variables and their influence on residents' perceptions of invasive alien plant species in Cape Town, South Africa (p-values in bold indicate a significant relationship i.e. p < 0.05).

		Socio-demographics				General Perception	Perception of Benefits	Perception of Impacts		Management Perception		
Variables		Environmental awareness	Age	Duration of residence	Education	IAP	ES	ThBd	EDS	Bd	Wb	Mgmt
Environmental awareness		1,00	**0,20**	**0,14**	**0,19**	**-0,17**	**0,22**	**0,21**	0,05	**0,25**	**0,35**	0,04
Age		**0,20**	1,00	**0,37**	-0,04	**-0,20**	0,09	**0,15**	**0,16**	**0,17**	**0,17**	0,09
Duration of residence		**0,14**	**0,37**	1,00	-0,10	-0,04	0,07	0,07	**0,22**	**0,14**	0,12	0,02
Education		**0,19**	-0,04	-0,10	1,00	**-0,18**	-0,09	0,12	**0,30**	**0,14**	0,00	-0,03
Ethnicity*	Black African	**-0,22**	-0,19	**-0,18**	0,08	-0,04	-0,12	-0,05	0,06	**-0,19**	**-0,18**	0,05
	Coloured	-0,04	**-0,18**	**-0,15**	-0,10	0,04	0,05	0,07	**-0,19**	0,06	0,06	-0,12
	Indian/Asian	**-0,13**	0,00	**-0,13**	0,09	0,09	-0,11	-0,06	0,03	-0,04	0,01	-0,05
	White	**0,15**	**0,23**	**0,21**	0,01	-0,00	-0,05	0,00	0,07	0,04	0,00	0,12
IAP		**-0,17**	**-0,20**	-0,04	**-0,18**	1,00	0,09	**-0,43**	**-0,23**	**-0,35**	**-0,24**	0,11
ES		**0,22**	0,09	0,07	-0,09	0,09	1,00	-0,12	0,02	0,00	**-0,24**	0,10
ThBd		**0,21**	**0,15**	0,07	0,12	**-0,43**	-0,12	1,00	**0,16**	**0,48**	**0,38**	**-0,26**
EDS		0,05	**0,16**	**0,22**	**0,30**	**-0,23**	0,02	**0,16**	1,00	**0,41**	**0,18**	**-0,31**
Bd		**0,25**	**0,17**	**0,14**	**0,14**	**-0,35**	0,00	**0,48**	**0,41**	1,00	**0,54**	**-0,23**
Wb		**0,35**	**0,17**	0,12	0,00	**-0,24**	**-0,24**	**0,38**	**0,18**	**0,54**	1,00	**-0,20**
Mgmt		0,04	0,09	0,02	-0,03	0,11	0,10	**-0,26**	**-0,31**	**-0,23**	**-0,20**	1,00

*The classification of population by ethnic group is useful as a means of stratifying the population given South Africa's history and has been accepted as the best measure of previous socio-economic deprivation (Statistics South Africa 2016). The four most distinct population groups in South Africa are: Black African, Coloured, Indian/Asian and White.

3.4.3 Significant socio-demographic variables

Our analysis shows a significant positive correlation between environmental awareness, age (r = 0.20, $p < 0.05$) and duration of residence (r = 0.14, $p < 0.05$; Table 3.3). This indicates that older respondents and those that have resided in the City longer, are more environmentally aware.

Age

Older respondents are less likely to view IAPs as part of the natural environment (r = -0.20, $p < 0.05$). Age is positively correlated with the perception of the negative impacts provided by IAPs - older respondents are more likely to perceive IAPs as a threat to biodiversity (r = 0.15, $p < 0.05$) and are more inclined to view IAPs as creating EDS (r = 0.16, $p < 0.05$). Respondents between the ages 25 and 34 (36%) and 35 and 44 years (24%) are more likely to perceive IAPs as a threat to local biodiversity (Fig. 3.5a). Older respondents are also more likely to perceive the control of IAPs as necessary to conserve biodiversity (r = 0.17, $p < 0.05$) and protect human well-being (r = 0.17, $p < 0.05$).

Education

There is a significant positive correlation between education and environmental awareness (r = 0.19, $p < 0.05$; Table 3.3). This indicates that respondents with a higher education are more environmentally aware. More educated respondents are less likely to view IAPs as part of the natural environment (r = -0.18, $p < 0.05$). Education is positively correlated with the perception of the negative impacts provided by IAPs. This indicates that respondents with a higher education are more likely to perceive IAPs as creating EDS (r = 0.30, $p < 0.05$) - 75% of respondents who perceived IAPs as creating EDS had at least a tertiary-level education (Fig. 3.5b). More educated respondents are also more likely to perceive the control of IAPs as necessary to conserve biodiversity (r = 0.14, $p < 0.05$). Furthermore, 71% of respondents who are not opposed to the removal of one or more of the target IAP taxa have at least a tertiary-level education (Fig. 3.5b).

Environmental awareness

Respondents with greater environmental awareness are less likely to view IAPs as part of the natural environment (r = -0.17, $p < 0.05$; Table 3.3). Interestingly, environmental awareness is positively correlated with the perception of benefits (ES) provided by IAPs (r = 0.22, $p < 0.05$) – respondents with greater environmental awareness are more likely to perceive IAPs as beneficial.

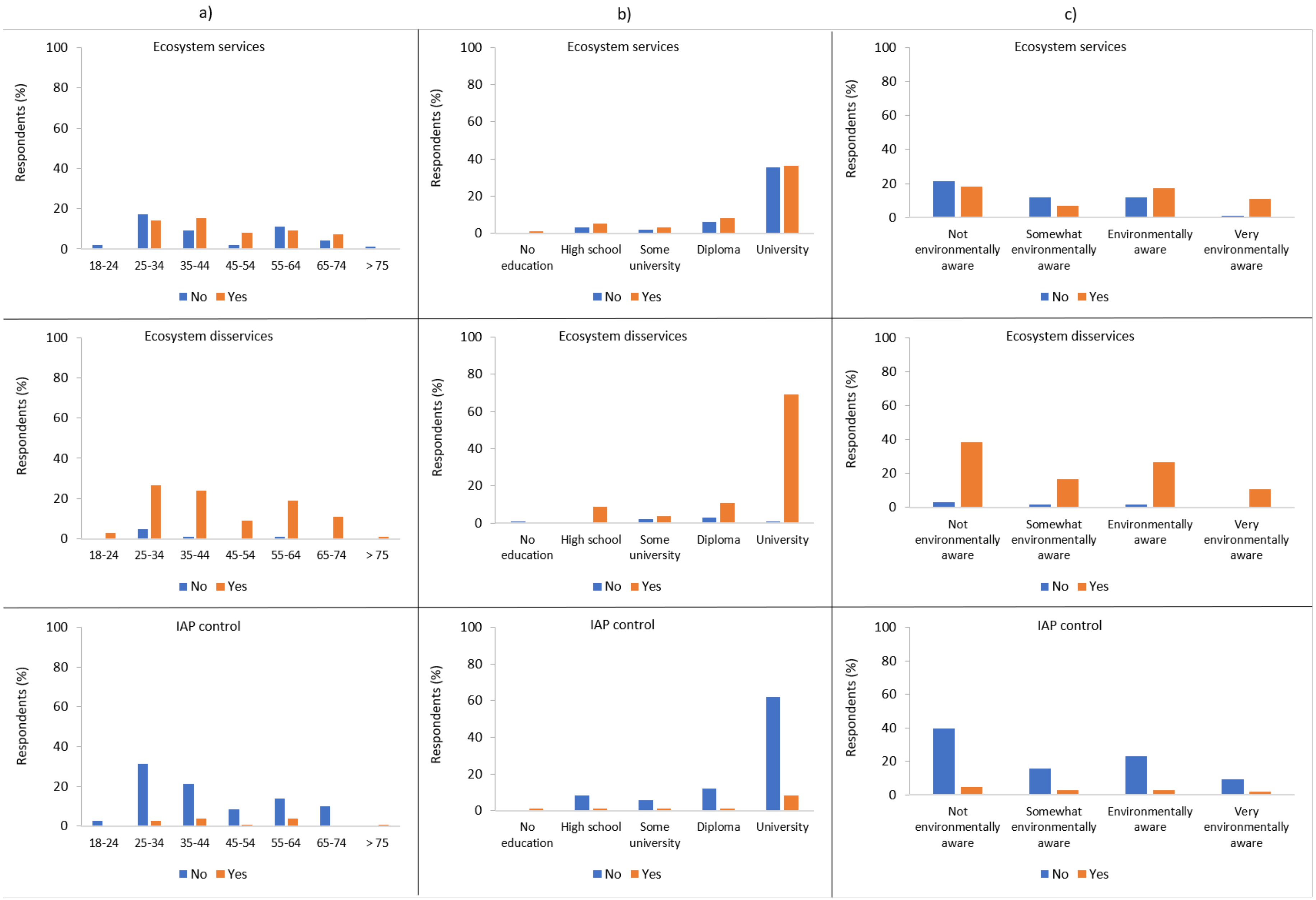

a)
b)
c)
Ecosystem services
Ecosystem disservices
IAP control
Respondents (%)
100
80
60
40
20
0
18-24
25-34
35-44
45-54
55-64
65-74
> 75
No education
High school
Some university
Diploma
University
Not environmentally aware
Somewhat environmentally aware
Environmentally aware
Very environmentally aware
No
Yes

Figure 3.5. Respondents' perceptions of the ecosystem services and disservices provided by invasive alien plant species and their control in Cape Town, South Africa, grouped according to a) age; b) education; and c) environmental awareness. 'Ecosystem services' – respondents were asked if they perceived one or more of the five invasive alien plant taxa as beneficial (to people and/or the environment). 'Ecosystem disservices' – respondents were asked if they perceived one or more of the five invasive alien plant taxa as having negative impacts (on themselves, people and/or the environment). 'IAP control' – respondents were asked whether they were opposed to the control of one or more of the five IAP taxa.

However, respondents with greater environmental awareness are more likely to perceive IAPs as a threat to biodiversity ($r = 0.21$, $p < 0.05$) and are more likely to perceive the control of IAPs as necessary to conserve biodiversity ($r = 0.25$, $p < 0.05$) and protect human well-being ($r = 0.35$, $p < 0.05$). Respondents who are less environmentally aware are also more likely to take a neutral stance regarding the management of IAPs to protect and enhance human well-being (Fig. 3.5c).

Ethnicity

Our results show that White respondents are more environmentally aware ($r = 0.15$, $p < 0.05$; Table 3.3), and Black African ($r = -0.22$, $p < 0.05$) and Indian/Asian ($r = -0.13$, $p < 0.05$) respondents are less environmentally aware. Furthermore, Black African respondents are less likely to perceive the control of IAPs as necessary to conserve biodiversity ($r = -0.19$, $p < 0.05$) and protect human well-being ($r = -0.18$, $p < 0.05$). Coloured respondents are less likely are to perceive IAPs as creating EDS ($r = -0.19$, $p < 0.05$).

3.5 Discussion

The purpose of this study was to explore urban residents' perceptions of IAPs in terms of the ES and EDS they provide, using the city of Cape Town as a case study. Our analysis shows that although most urban residents perceive IAPs negatively (i.e. realizing that they create EDS), many people appreciate the importance of some IAPs for providing ES. While most residents are not opposed to the management of IAPs, our findings suggest that underlying conflicts of interest are likely to arise when attempting to control IAPs, particularly where contrasting perceptions exist within the same area.

3.5.1 Ecosystem services

There is a widespread belief that all trees are desirable, because they are perceived to promote rainfall, stabilise catchments, sequester carbon, and provide shade and habitat for wildlife (van

Wilgen, 2012). However, invasive alien trees may also be perceived as undesirable because of their impacts on biodiversity and ES (van Wilgen et al. 2008; Roy et al. 2012; Dickie et al. 2014).

Provisioning (fuelwood) and regulating services (shade) were perceived as most important for all three invasive alien tree taxa (Table 2.2). The establishment of trees in an environment where they were naturally scarce, or were severely depleted by early colonists for timber, was the original motivation for the importation of many tree species into Cape Town, particularly *Pinus* spp. (van Wilgen 2012). As there are relatively few widespread native tree species available as a source of fuelwood and shade, many residents utilise invasive alien trees for these purposes. Many plantation areas (mostly *Pinus radiata* in Cape Town) are heavily utilised by urban residents for recreation (picnicking, cycling, walking), mainly because of the shade they provide (see Appendix E).

An important aspect to consider in the assessment of ES from a social approach is the risk that people do not perceive the ecosystem functions underlying the benefits to society (Peterson et al. 2009). The effects of provisioning services are likely to be felt more acutely, and are thus more likely to catalyse perceptions, in relation to ES from other categories (Potgieter et al. 2017). In contrast to regulating and supporting services (which in most cases are recognised as public goods or externalities especially in urban environments), provisioning services are more easily valued by people; this includes a monetary value and economic system in which provisioning services are the most perceived benefits for society. Regulating services (such as pollination) provide the foundations which allow other directly used ES (e.g. provision of food) to exist. Similarly, supporting services do not directly benefit people, but are essential to the functioning of ecosystems and are therefore indirectly responsible for all other services (Haines-Young and Potschin 2010). Therefore, such services provided by IAPs seldom influence residents' perceptions of the species as the lay people are likely not aware of the provision of these services.

Aesthetics (cultural service) was the most commonly perceived ES for the invasive grass *P. setaceum* as well as the aquatic weed *M. aquaticum*. This is unsurprising as the horticultural trade was (and to a large extent still is) one of the major introduction pathways for both species (Milton et al. 1998; Coetzee et al. 2011). Dehnen-Schmutz et al. (2007) note that ornamental plants can be viewed as having aesthetic benefits when confined to private gardens but shifts in perceptions may occur when they become widespread in the wild, leading to economic and environmental costs. Our results suggest that this is indeed the case with *P. setaceum* and *M. aquaticum* as the perceived EDS outweigh the perceived ES (Fig. 3.3).

Individual's perceptions are largely influenced by the biological factors, such as a species' traits and their taxonomic and functional characteristics (Veitch and Clout 2001; Dickie et al. 2014; Shackleton et al. 2018). Many of the traits that lead to a species becoming invasive, including hardiness and high fecundity, are also likely to increase a species' usefulness within different contexts (Bardsley and Edwards-Jones 2007). Therefore, understanding the perceptions of IAPs and the ES and EDS they provide, can shed light on the characteristics contributing to the delivery of such services.

3.5.2 Ecosystem disservices

Negative impacts on the environment (displacement of native plant species) were perceived as the most common EDS perceived for the five IAP taxa, followed by increased water consumption for the woody IAPs and increased fire risk and reduced stream flow for *P. setaceum* and *M. aquaticum* respectively (Table 3.2).

Following the definition of EDS by Shackleton et al. (2016), we regard the displacement of native species resulting from plant invasions as an "ecosystem process" that may result in predominantly indirect (perceived or real) negative impacts on human well-being; we therefore categorised this change as an EDS. For example, the displacement of fynbos vegetation by *A. saligna* close to residential housing may result in a safety and security risk (e.g. an increase in criminal activity) to those residents whom utilise the area for recreational purposes (cultural services). As a result, the well-being of such residents may be impacted, and their behaviour and perception of IAPs may change. Therefore, the displacement of native species can be regarded as the EDS which results in a constrained supply of ES (Escobedo et al. 2011; Ferrini et al. 2017).

The majority (91%) of respondents agreed that IAPs pose a threat to the biodiversity in and around the City. Cape Town occurs within a global biodiversity hotspot with high levels of endemism (Cowling et al. 1996). Many of its residents are aware of the regions' high conservation significance (e.g. Turpie 2003; Ferketic et al. 2010; Ferreira 2011) and the many threats to this rich biodiversity. This knowledge and awareness may influence the way in which they perceive IAPs.

Woody IAPs were perceived as providing a greater number of EDS. This is in line with findings from Potgieter et al. (2017). The fynbos biome, in which the City is embedded, is intrinsically devoid of native trees (Rundel et al. 2014) and as a result, the presence of tall alien trees (especially those with long residence times) in the treeless biome will certainly trigger diverse perceptions. Moreover, the role of woody alien plant species in creating EDS may be more apparent than that of the less conspicuous herbaceous species (Potgieter et al. 2017).

Increased water consumption was perceived as a significant EDS and was only noted for invasive alien tree taxa (Table 3.2). Since 2015, the City has been experiencing the worst drought in over a century and the availability of water has become a major problem. Most of Cape Town's water is sourced from outside the City's boundaries. Most natural surface water options in the region have been depleted and the focus of water management in the City has shifted towards the social dimensions of demand management (Anderson and O'Farrell 2012). IAPs have proliferated in the catchments that supply the City's water. Invasive stands of alien trees use significantly more water than the low-statured native vegetation, thereby decreasing surface run-off and ultimately water supply and security (Le Maitre et al. 1996). Awareness around the causes of this issue has increased considerably and the effects of IAPs on water resources are receiving increased attention (e.g. media, Democratic Alliance 2017). This may influence how residents perceive IAPs – either by solidifying or shifting current perceptions.

Fire is an important process in fynbos, which is both fire-adapted and fire-dependent (van Wilgen, 2009). However, accidental (and often intentional) fires started by people have led to overly frequent and uncontrolled fires, which threaten property and the safety of people (van Wilgen and Scott 2001). The increase in biomass resulting from alien plant invasions (particularly woody plant taxa such as acacias, eucalypts, and pines) close to urban infrastructure represents a substantial fire risk (van Wilgen et al. 2012). Other areas such as vacant properties, public open spaces and riparian areas have also become invaded to the degree that they pose a fire risk to infrastructure. The City has experienced several large-scale fires over that last two decades and many properties have been destroyed. As a result, awareness of the effects of IAPs on fire intensity and frequency have received greater attention in the media. As with the link between IAPs and water production from catchments, increased awareness of the link between IAPs and the fire regime is increasingly influencing perceptions of IAPs, either solidifying or shifting current views.

3.5.3 Socio-demographic variables

Greater understanding of the socio-demographic factors that influence residents' perceptions of IAPs could assist with targeting awareness and educational campaigns in sections of society where knowledge is low.

Urban residents are more likely to have higher levels of education and be exposed to higher levels of environmental degradation (e.g. pollution), resulting in attitudes, beliefs and values that are more amenable to environmental protection (Huddart-Kennedy et al. 2009). Respondents with a higher education are more environmentally aware and are more likely to perceive IAPs as having negative impacts. They also perceive the control of IAPs as being necessary to conserve biodiversity. Interestingly, respondents with greater environmental awareness are more likely to perceive IAPs as beneficial. In addition, however, respondents with greater environmental awareness are more likely to perceive IAPs as a threat to biodiversity and view the control of IAPs as necessary to conserve biodiversity. Such contradictory perceptions suggest the potential for conflicts of interest as residents are aware of the capacity for IAPs to provide ES, but also aware of their potential negative impacts on ES and biodiversity and the need for management interventions. This may also suggest that specific ES provided by certain IAPs are perceived as inconsequential and have no value to residents, can be provided either by other alien plants or native plants (Potgieter et al. 2017), or can be supplied by technological solutions (Cumming et al. 2014). These findings coincide with those of Gaertner et al. (2017a, b) who reported mixed perceptions among stakeholders on both the benefits and impacts of invasive species and their management.

Our results show that White respondents have greater environmental awareness, while Black African and Indian/Asian respondents are less environmentally aware. Coloured respondents are less likely to perceive IAPs as creating EDS. Racially centred repression and discrimination, institutionalised and maintained by both the colonial and apartheid political systems have resulted in a racially divided and unequal contemporary South African society (Terreblanche 2002; Seekings and Nattrass 2005; Stander 2014). This enduring social exclusion has resulted in a phenomenon whereby class has become (to some extent) a racial inheritance for South Africans (Stander 2014). The composition of socio-economic class in South Africa, including Cape Town, is therefore significantly racialized; notably, the majority (46%) of all Black Africans fall within the (self-identified) lower (socio-economic) class category (World Values Survey 2013). It is important to note here that those within the lower socio-economic classes in South Africa usually live below the upper poverty line (R992.00 per person per month). Such people typically live in informal dwellings, with little or no access to public utilities (such as electricity or water), basic education, or healthcare services. The areas in which they live are also subject to higher than average crime rates. Given these circumstances and the state in which the lower socio-economic classes live, environmental knowledge and awareness is likely to be of low importance to such residents and justifying the prioritization of conservation over their immediate needs becomes difficult (Ferketic et al. 2010). This is consistent with findings by White and Hunter (2009), who reported more awareness of environmental issues among higher socio-economic groups. Respondents with lower levels of environmental awareness are more likely to take a neutral stance regarding the management of IAPs to protect and enhance human well-being. In particularly, Black African respondents perceive the control of IAPs as an unnecessary measure to conserve biodiversity and protect human well-being. This may be due to the provisioning services (e.g. firewood) supplied by some IAPs on which many of their livelihoods (and well-being) depend. In line with the findings by Novoa et al. (2017), an increase in public awareness may increase public support for IAP management. These findings highlight the need for improved knowledge and awareness around the impacts of IAPs.

3.5.4 Decision-making and management

Conflicts are context dependent and can originate from a wide variety of different views (Novoa et al. 2017). Effective management strategies for conflict species depend largely on cooperation and support from all stakeholders, both those supporting the use of these species and those supporting their control. Understanding perceptions of a single IAP amongst different stakeholders and landscapes can help to direct funding to areas where negative perceptions (often linked to greater impacts) are highest and to protect stakeholders who are most vulnerable (Shackleton et al. 2015).

Conflicts may arise when decision-making processes lack participation and transparency, a situation that can lead local communities to mistrust government agencies (Estévez et al. 2015). Differences in value systems and to a lesser extent stakeholder and decision maker's risk perceptions regarding IAPs can also result in conflict (Estévez et al. 2015). Integrating the range of environmental values into invasive species management through structured decision-making methods can be used to confront or avoid such decisions. Structured decision making provides a multi-criteria decision analysis process which can be applied to invasive species management (e.g. Lui et al. 2011). The process is collaborative, participatory and transparent and considers opinions, perspectives and values of a wide range of stakeholders involved in urban land-use and ecosystem management decisions (De Lange et al. 2012; Forsyth et al. 2012). Scientists and managers, therefore, need to adapt their strategies to incorporate socio-ecological scenarios that involve conceptual, practical, and ethical considerations.

Our study reveals the perceived benefits and negative impacts of specific IAP taxa in Cape Town, and highlights some of the key socio-demographic factors influencing perceptions of IAPs. This information can not only be used to prioritise management of the IAP species assessed in this study but also provides guidelines for managing other targeted IAPs in the City. We also emphasise the potential for conflicts of interest when attempting to manage IAPs and urge city planners and managers to integrate public perceptions into the decision-making process.

3.6 Conclusions

The state of Cape Town's environment and the well-being of its residents are becoming increasingly entwined and there is a growing understanding of this complex relationship (Anderson and O'Farrell 2012). Societal expectations and perceptions inform ecological process and managing these attitudes is one of the greatest challenges in enhancing ES provision in urban areas (van Wilgen 2012). We have provided insight into the perceived ES and EDS provided by IAPs in Cape Town and highlight the potential for conflicts of interest inherent in IAP management.

Management decisions must give explicit and transparent consideration to divergent stakeholder perceptions (e.g. Gaertner et al. 2017a). An improved understanding can help mitigate conflicts of interest associated with IAPs, facilitate prioritization and decision-making, and make stakeholder engagement processes, collaboration and dialogue more effective by considering different knowledge systems.

While this study highlights the need to integrate public perceptions into the planning and management of IAPs, it also emphasises the importance of including ES assessments into the decision-making process, particularly in urban areas. This approach is becoming increasingly important as the demand for the sustainable provision of urban ES grows.

3.7 Acknowledgements

Funding for this work was provided by the DST-NRF Centre of Excellence for Invasion Biology and the Working for Water Programme through their collaborative research project on "Integrated Management of invasive alien species in South Africa" and the National Research Foundation (grant 85417 to DMR). We thank the Invasive Species Unit for their assisting with fieldwork, and Elnari Potgieter (Institute for Justice and Reconciliation) for her advice on the survey design.

3.8 References

Anderson PML, O'Farrell PJ (2012). An ecological view of the history of the establishment of the City of Cape Town. Ecol Soc 17:28. http://dx.doi.org/10.5751/ ES-04970-170328

Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul W-C, Scalera R, Vilà M, Wilson JRU, Kumschick S (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods Ecol Evol 9:159-168

Bardsley D, Edward-Jones G (2007) Invasive species policy and climate change: social 558 perceptions of environmental change in the Mediterranean. Environ Sci Policy 10:230-242

Boraine A, Crankshaw O, Engelbrecht C, Gotz G, Mbanga S, Narsoo M, Parnell S (2006) The state of South African cities a decade after democracy. Urban Stud 43:259-284 http://dx.doi.org/10.1080/00420980500416990

Coetzee JA, Hill MP, Byrne MJ, Bownes A (2011) A review of the biological control programmes on *Eichhornia crassipes* (C.Mart.) Solms (Pontederiaceae), *Salvinia molesta* D.S.Mitch. (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) Verdc.

(Haloragaceae) and *Azolla filiculoides* Lam. (Azollaceae) in South Africa. Afr Entomol 19:451–468

Cowling RM, Macdonald IAW, Simmons MT (1996) The Cape Peninsula, South Africa: physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. Biodivers Conserv 5:527–550

Cumming GS, Buerkert A, Hoffmann EM, Schlecht E, von Cramon-Taubadel S, Tscharntke T (2014) Implications of agricultural transitions and urbanization for ecosystem services. Nature 515:50–57

De Lange WJ, Stafford WHL, Forsyth GG, Le Maitre DC (2012) Incorporating stakeholder preferences in the selection of technologies for using invasive alien plants as a bio-energy feedstock: Applying the analytical hierarchy process. J Environ Manage 99:76–83. doi: 10.1016/j.jenvman.2012.01.014

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007) The horticultural trade and ornamental plant invasions in Britain. Conserv Biol 21:224–231

Democratic Alliance (2017) Removal of alien vegetation at Wemmershoek Dam will help City save water and stretch supply. https://www.da.org.za/municipality-news/removal-alien-vegetation-wemmershoek-dam-will-help-city-save-water-stretch-supply/. Accessed 13-02-2018

Dickie IA, Bennett BM, Burrows LE, et al. (2014) Conflicting values: ecosystem services and invasive tree management. Biol Invasions 16:705–719. doi: 10.1007/s10530-013-0609-6

Dye PJ, Poulter AG (1995) A field demonstration of the effect on streamflow of clearing invasive pine and wattle trees from a riparian zone. S Afr For J 173:27–30

Ehrlich PR, Wilson EO (1991) Biodiversity studies, science and policy. Science 253:758-762

Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC, Wilkinson C (2013) Urbanisation, biodiversity and ecosystem services: Challenges and opportunities. Europe: Springer

Escobedo FJ, Kroeger T, Wagner JE (2011) Urban forests and pollution mitigation: analyzing ecosystem services and disservices. Environ Pollut 159:2078–2087

Estévez RA, Anderson CB, Pizarro JC, Burgman MA (2015) Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. Cons Biol 29:19-30

Ferketic JS, Latimer AM, Silander JA (2010) Conservation justice in metropolitan Cape Town: A study at the Macassar Dunes conservation area. Biol Conserv 143:1168–1174

Ferreira S (2011) Balancing people and park: Towards a symbiotic relationship between Cape Town and Table Mountain National Park. Curr Issues Tour 14:275–293

Ferrini F, Van Den Bosch CCK, Fini A (2017) Routledge Handbook of Urban Forestry. Taylor & Francis, New York

Fischer A, Selge S, van der Wal R, Larson BWH (2014) The public and professionals reason similarly about the management of non-native invasive species. A quantitative investigation of the relationship between beliefs and attitudes. PLoS One. https://doi.org/10.1371/journal.pone.0105495

Forsyth GG, Le Maitre DC, O'Farrell PJ, van Wilgen BW (2012) The prioritisation of invasive alien plant control projects using a multi-criteria decision model informed by stakeholder input and spatial data. J Environ Manage 103:51–57. https://doi.org/10.1016/j.jenvman.2012.01.034

Foster J, Sandberg LA (2004) Friends or foe? Invasive species and public green space in Toronto. Geogr Rev 94:178–198

Gaertner M, Larson BMH, Irlich UM, et al. (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape Urban Plan 151:1–9. doi: 10.1016/j.landurbplan.2016.03.010

Gaertner M, Novoa A, Fried J, Richardson DM (2017a) Managing invasive species in cities: A decision support framework applied to Cape Town. Biol Invasions 19:3707-3723

Gaertner M, Wilson JRU, Cadotte MW, MacIvor JS, Zenni RD, Richardson DM (2017b) Non-native species in urban environments: Patterns, processes, impacts and challenges. Biol Invasions 19:3461-3469

García-Llorente M, Martín-López B, González JA, Alcorlo P, Montes C (2008) Social perceptions of the impacts and benefits of invasive alien species: implications for management. Biol Conserv 141:2969e2983

García-Llorente M, Martín-López B, Nunes P, Gonzáles JA, Alcorlo P, Montes C (2011) Analyzing the social factors that influence willingness to pay for invasive alien species management under two different strategies: eradication and prevention. Environ Manage 48:418–435

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) Managing urban ecosystems for goods and services. J Appl Ecol 50:830–40

Goodness J, Anderson P (2013) Local assessment of Cape Town: navigating the management complexities of urbanization, biodiversity, and ecosystem services in the Cape Floristic Region. In: Elmqvist T, Fragkias M, Goodness J, et al. (eds) Urbanization, biodiversity and ecosystem services: challenges and opportunities. Dordrecht: Springer, pp. 461- 484

Haines-Young R, Potschin M (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelii DG, Frid CLJ (eds) Ecosystem Ecology: a new synthesis. Cambridge: Cambridge University Press, pp. 110–139

Holmes PM, Rebelo AG, Dorse C, Wood J (2012) Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. Ecol Soc 17 https://doi.org/org/10.5751/ES-04552-170228

Huddart-Kennedy E, Beckley TM, McFarlane BL, Nadeau S (2009) Rural–urban differences in environmental concern in Canada. Rural Sociol 74:309–329. doi:10.1526/003601109789037268

Irlich UM, Potgieter LJ, Stafford L, Gaertner M (2017) Recommendations for municipalities to become compliant with national legislation on biological invasions. Bothalia 47:1–11. https://doi.org/10.4102/abc.v47i2.2156

Jeschke JM, Bacher S, Blackburn TM, Dick JTA, Essl F, Evans T, Gaertner M, Hulme PE, Kühn I, Mrugala A, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Winter M, Kumschick S (2014) Defining the impact of non-native species. Conserv Biol 28:1188e1194

Kull CA, Shackleton CM, Cunningham PJ, Ducatillon C, Dufour-Dror J, Esler KJ, Friday JB, Gouveia AC, Griffin AR, Marchante E, Midgley SJ, Pauchard A, Rangan H, Richardson DM, Rinaudo T, Tassin J, Urgenson LS, von Maltitz GP, Zenni RD, Zylstra MJ (2011) Adoption, use and perception of Australian acacias around the world. Divers Distrib 17:822-836

Le Maitre DC, Gaertner M, Marchante E, Ens E, Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J, Richardson DM (2011) Impacts of invasive Australian acacias: implications for management and restoration. Divers Distrib 17:1015–1029

Le Maitre DC, van Wilgen BW, Chapman RA et al. (1996) Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. J Appl Ecol 33:161–172

Le Maitre DC, van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA, Nel JA (2002) Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecol Manage 160:143–159

Levine JM, Vilà M, D'Antonio CM, Dukes JS, Grigulis K, Lavorel S (2003) Mechanisms underlying the impacts of exotic plant invasions. Proc R Soc B 270:775–781

Lindemann-Matthies P (2016) Beasts or beauties? Laypersons' perception of invasive alien plant species in Switzerland and attitudes towards their management. NeoBiota 29:15–33

Liu S, Sheppard A, Kriticos D, Cook D (2011) Incorporating uncertainty and social values in managing invasive alien species: a deliberative multi-criteria evaluation approach. Biol Invasions 13:2323–2337

McNeely JA, Mooney HA, Neville LE, Johan Schei P, Waage JK (2001) Global strategy on invasive alien species. IUCN, Gland

Millennium Ecosystem Assessment (MA) (2005) Ecosystems and human well-being. Washington, DC: Island Press

Milton SJ, Hoffmann JH, Bowie RCK, D'Amico J, Griffiths M, Joubert D et al. (1998) Invasive fountain grass on the Cape Peninsula. S Afr J Sci 94:57–58

Novoa A, Dehnen-Schmutz K, Fried J, Vimercati G (2017) Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. Biol Invasions 19:3707-3723. doi:10.1007/s10530-017-1592-4

Novoa A, Kaplan H, Wilson JRU, Richardson DM (2016) Resolving a prickly situation: Involving stakeholders in invasive cactus management in South Africa. Environ Manage 57:998–1008. https://doi.org/10.1007/s00267-015- 0645-3

Novoa A, Shackleton RT, Canavan S, Cybèle C, Davies SJ, Dehnen-Schmutz K, Fried J, Gaertner M, Geerts S, Griffiths C, Kaplan H, Kumschick S, Le Maitre DC, Measey GJ, Nunes AL, Richardson DM, Robinson TB, Touza J, Wilson JRU (2018) A framework for engaging stakeholders on the management of alien species. J Environ Manage 205:286-297

Pauleit S, Breuste JH (2011) Land-use and surface-cover as urban ecological indicators. In: Niamela J, Breuste J, Elmqvist T, Guntenspergen G, James P, MacIntyre N (eds) Urban Ecology: Patterns, Processes and Applications. Oxford: Oxford Biology, pp. 19-30

Pejchar L, Mooney HA (2009) Invasive species, ecosystem services and human wellbeing. Trends Ecol Evolut 24:497–504

Peterson MJ, Hall DM, Feldpausch-Parker AM, Rai Peterson T (2009) Obscuring ecosystem function with application of the ecosystem services concept. Conserv Biol 24:113e119

Potgieter LJ, Gaertner M, Kueffer C, Larson BMH, Livingston S, O'Farrell P, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588

Rebelo AG, Holmes PM, Dorse C, Wood J (2011) Impacts of urbanization in a biodiversity hotspot: Conservation challenges in Metropolitan Cape Town. S Afr J Bot 77:20–35. https://doi.org/10.1016/j.sajb.2010.04.006

Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn CH, Stringer LC (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management. J Environ Manage 90:1933–1949

Richardson DM et al. (2000) Naturalization and invasion of alien plants – concepts and definitions. Divers Distrib 6:93–108

Richardson DM, Gelderblom C, van Wilgen BW, Trinder-Smith TH (1998) Managing biodiversity on the Cape Peninsula, South Africa: A hotspot under pressure. In: Rundel PW, Montenegro G, Jaksic F (eds) Landscape disturbance and biodiversity in Mediterranean-type ecosystems. Berlin: Springer-Verlag, pp. 189-204

Richardson DM, van Wilgen BW, Higgins SI, Trinder-Smith TH, Cowling RM, McKell DH (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. Biodivers Conserv 5:607–47

Roy S, Byrne J, Pickering C (2012) A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban For Urban Green 4:351–363

Rundel PW, Dickie IA, Richardson DM (2014) Tree invasions into treeless areas: Mechanisms and ecosystem processes. Biol Invasions 16:663–675. doi:10.1007/s10530-013-0614-9

Sapsford R (1999) Survey research, Sage Publications, London

Seekings J, Nattrass N (2005) Class, race, and inequality in South Africa. Yale University Press

Shackleton CM, Ruwanza S, Sinasson Sanni GK, Bennett S, Lacy P, Modipa R, Mtati N, Sachikonye M, Thondhlana G (2016) Unpacking Pandora's Box: understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19:587–600

Shackleton RT, Le Maitre DC, Richardson DM (2015) Stakeholder perceptions and practices regarding Prosopis (mesquite) invasions and management in South Africa. Ambio 44:569e581

Shackleton RT, Richardson DM, Shackleton CM, Benett B, Crowley S, Dehnen-Schmutz K, Estévez R, Fischer A, Kueffer C, Kull C, Merchante E, Novoa A, Potgieter LJ, Vaas J, Vaz AS, Larson BHM (2018) Explaining people's perceptions of invasive alien species: A conceptual framework. J Environ Manage (in press). https://doi.org/10.1016/j.jenvman.2018.04.045

Sharp RL, Larson LR, Green GT (2011) Factors influencing public preferences for invasive alien species management. Biol Conserv 144:2097e2104

Statistics South Africa (2016) Community survey 2016, statistical release. Available at: http://cs2016.statssa.gov.za/wp-content/uploads/2016/07/NT-30-06-2016-RELEASE-for-CS-2016-_Statistical-releas_1-July-2016.pdf

StatSoft Inc. (2005) STATISTICA (Data analysis software) version 7. Available at: http:www.statsoft.com.

Stander GM (2014) Class, race and locus on control in democratic South Africa. MA Thesis, Stellenbosch University, South Africa

Stokes KE, O'Neill KP, Montgomery WI, Dick JTA, Maggs CA, McDonald RA (2006) The importance of stakeholder engagement in invasive species management: a cross-jurisdictional perspective in Ireland. Biodivers Conserv 15:2829–2852

Swilling M (2010) Sustainability, poverty and municipal services: the case of Cape Town, South Africa. Sustain Dev 18:194-201. http://dx.doi.org/10.1002/sd.489

Tallis H, Goldman R, Uhl M, Brosi B (2009) Integrating conservation and development in the field: implementing ecosystem service projects. Front Ecol Environ 7:12–20

Terreblanche SJ (2002) A history of inequality in South Africa, 1652 to 2002. University of Natal Press, Pietermaritzburg

Turpie JK (2003) The existence value of biodiversity in South Africa: How interest, experience, knowledge, income and perceived level of threat influence local willingness to pay. Ecol Econ 46:99–216

United Nations Environment Programme (UNEP) (1992) Convention on Biological Diversity. Nairobi, Kenya

van Wilgen BW (2009) The evolution of fire and invasive alien plant management practices in fynbos. S Afr J Sci 105:335–342

van Wilgen BW (2012) Evidence, perceptions, and trade-offs associated with invasive alien plant control in the Table Mountain National Park, South Africa. Ecol Soc 17:23. https://doi.org/10.5751/ES-04590-170223

van Wilgen BW, Forsyth GG, Prins P (2012) The management of fire-adapted ecosystems in an urban setting: the case of Table Mountain National Park, South Africa. Ecol Soc 17:8. http://dx.doi.org/10.5751/ES-04526-170108

van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L (2008) A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manage 89:336–349. https://doi.org/10.1016/j.jenvman.2007.06.015

van Wilgen BW, Richardson DM (2012) Three centuries of managing introduced conifers in South Africa: benefits, impacts, changing perceptions and conflict resolution. J Environ Manage 106:56-68

van Wilgen BW, Richardson DM (2014) Challenges and trade-offs in the management of invasive alien trees. Biol Invasions 16:721-734. https://doi.org/10.1007/s10530-013-0615-8

van Wilgen BW, Scott DF (2001) Managing fires on the Cape Peninsula: dealing with the inevitable. J Medit Ecol 2:197e208

Vaz AS, Kueffer C, Kull CA et al. (2017) Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst Serv 23:94–107. doi: 10.1016/j.ecoser.2016.11.017

Veitch CR, Clout MN (2001) Human dimensions in the management of invasive species in New Zealand. In: McNeely JA (ed.) The great reshuffling: human dimensions of invasive alien species. Gland, Switzerland and Cambridge: IUCN, pp. 63-71

World Values Survey (2013) World Values Survey Wave 6: 2010-2014. [Online] Available at: http://www.worldvaluessurvey.org/WVSOnline.jsp [Accessed 12 February 2018]

White MJ, Hunter LM (2009) Public perception of environmental issues in a developing setting: environmental concern in coastal Ghana. Soc Sci Q 9:960–982

Zengeya T, Ivey P, Woodford DJ, Weyl O, Novoa A, Shackleton R et al. (2017) Managing conflict-generating invasive species in South Africa: Challenges and trade-offs. Bothalia 47:a2160. https://doi.org/10.4102/abc.v47i2.2160

3.9 Supplementary material

Appendix E. *Pinus radiata* plantations established within the fire-driven fynbos biome, along the urban edge result in considerable conflicts of interest and contrasting perceptions regarding their management – the case of Tokai Park, Cape Town, South Africa.

Tokai Plantation was established in 1885 on the eastern slopes of Table Mountain and still functions as a commercial pine plantation. In 2005, however, 1000 ha of publicly owned land within the Cape Peninsula Protected Natural Environment was assigned to SANParks, and Tokai Plantation became part of Table Mountain National Park (TMNP). Surrounded by the suburbs of Tokai and Constantia, Tokai Plantation extends from the lowlands to the upper mountain slopes within TMNP. Tokai Park (previously known as "Tokai Forest" as it includes the Tokai Plantation), is a small section, about 600 ha, of the TMNP and falls within the municipal boundaries of the City of Cape Town. It is made up of two sections: upper and lower Tokai Park (Fig. S1). TMNP contains an extremely diverse flora with many endemic species and has been granted World Heritage Site status in recognition of this unique biodiversity.

South African National Parks (SANParks) permitted the felling of the Tokai Planation in the Lower Tokai Park to begin ahead of schedule, prompted by intense fires in March 2015 which damaged many pine trees. The felling was to be carried out by Mountains to Oceans (MTO), a forestry company which was awarded the public tender by the then Department of Water Affairs and Forestry (DWAF) in 2004.

Much of the Tokai Plantation had already been felled apart from one section called the Dennedal compartment and other small remnant plantations (Fig. S1). Once the plantation trees had been harvested, the land went through the process of being proclaimed and incorporated as part of TMNP. However, the felling of these pine trees was strongly opposed by a newly formed public non-profit organisation called Parkscape (consisting of ±2500 residents) who filed an urgent court application to halt any further felling of pine trees from the Dennedal plantation. The grounds for this application were that Parkscape were not adequately informed of the accelerated felling schedule, the consequence whereof would be the immediate loss of shaded recreational areas.

The Western Cape High Court granted the order applied for by Parkscape and ruled that the decision by SANParks to expedite the felling schedule was procedurally unfair and ordered that no further harvesting should take place unless and until valid and lawful decisions are taken. Comprehensive stakeholder engagement in the form of a new public participation process is required before any further harvesting can take place.

Under the Dennedal pine plantation, an intact seed bank from the Critically Endangered Cape Flats Sand Fynbos remains. Only 11% of the former extent of this vegetation type remains – less than one percent of which is formally protected. This area is of vital international conservation importance. Pine trees self-seed and have spread prolifically beyond the managed plantations into the natural areas of TMNP. Pine trees are one of the most significant threats to the conservation of biodiversity in TMNP (van Wilgen 2012) and negatively impact on the provisioning of ES by using a disproportionate amount of water and displacing native vegetation (Dye and Poulter 1995; Le Maitre et al. 2002). In argument of this, Parkscape were concerned that restoring the plantation to Cape Flats Sand Fynbos would increase the risk of crime and fire along the urban edge.

The case of Tokai Park highlights the types of complex socio-ecological issues that occur when urban areas abut areas of high conservation value. It also highlights the contrasting perceptions and resulting conflicts of interest regarding the management of invasive alien plants in the urban matrix.

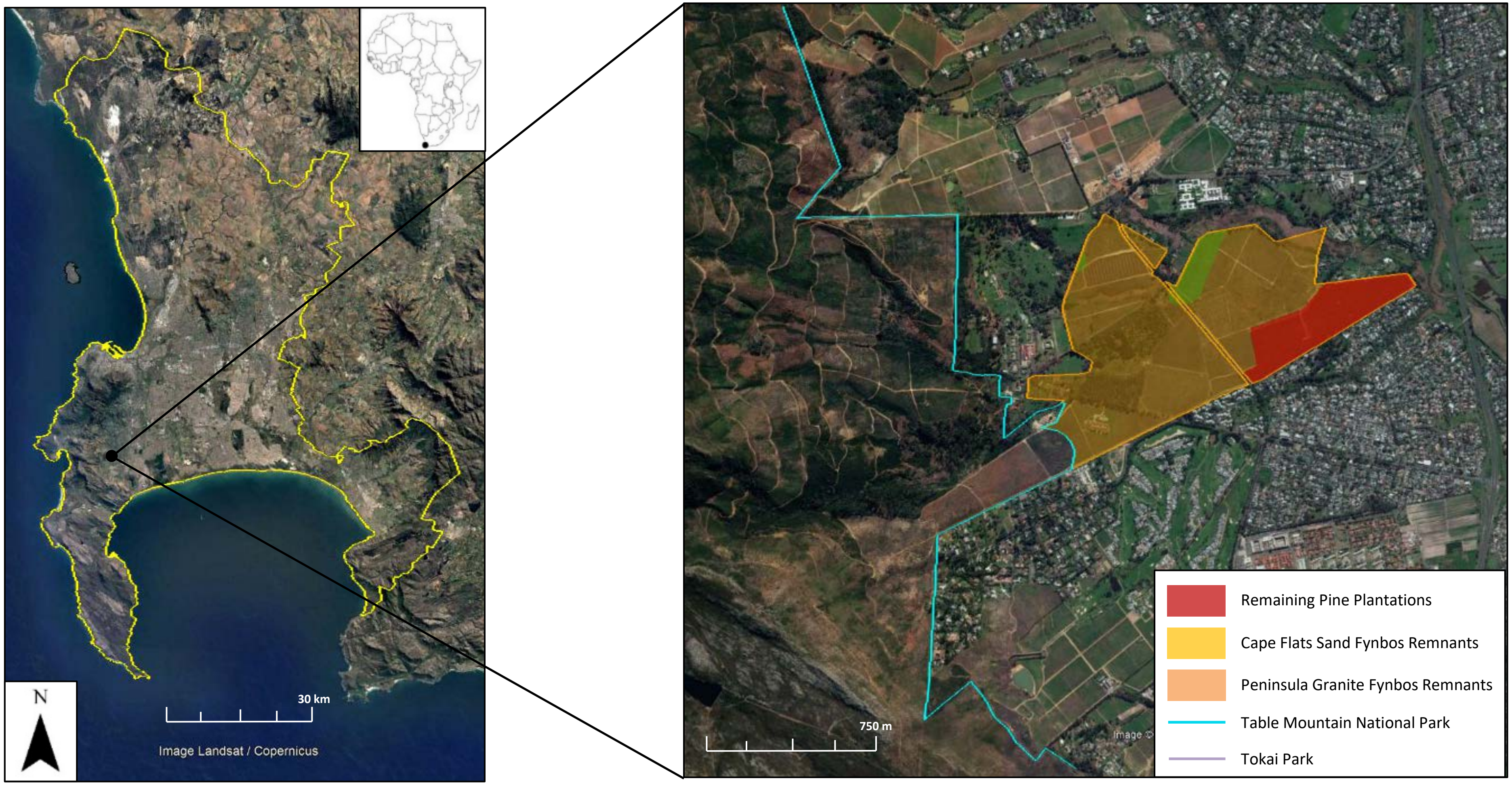


Figure S1. Map showing the city of Cape Town municipal boundary and the location of Tokai Park (images from Google Earth).

Appendix F. Questionnaire structure and content.

1) Socio-demographic information

Social and demographic variables included age, sex, ethnicity, place and duration of residence, level of education, and employment.

2) General environmental awareness and knowledge

a. This was measured employing traditional variables that are considered indicators of a respondent's interest in nature:
b. If any aspects of the respondent's job involved environmental management.
c. If the respondent volunteered for any environmental cause.
d. If the respondent held a membership in an environmental organization.
e. If the respondent took part in any outdoor activities in the past year.

3) Invasive species awareness and knowledge

a. Familiarity with the term invasive alien species (IAS).
b. Familiarity with any laws/policies concerning invasive alien species in South Africa.
c. Knowledge of Cape Town's environmental problems in general.
d. The priority a respondent would assign to the problem of invasive alien plants in relation to the other environmental problems.

4) Perceived benefits and negative impacts of specific widespread listed invasive alien plant taxa

a. If the respondent considered invasive alien plants as a threat to the native biodiversity.
b. If the respondent considered invasive alien plants as part of the natural environment in and around Cape Town.
c. Respondents' familiarity with five selected invasive alien plant taxa. For this question, we showed 5 widespread invasive alien plant taxa in Cape Town with different levels of impacts; each species was illustrated with picture panels. These species were: *Acacia saligna*, *Eucalyptus* sp., *Myriophyllum aquaticum*, *Pennisetum setaceum*, and *Pinus* sp. Respondents could also suggest other species not listed, or ones that they thought were important.
d. If the respondent perceived any of the above taxa to provide any benefits (to themselves, people and/or the environment) in Cape Town. In an open-ended question, the respondent was asked to specify these benefits, referencing the relevant taxa.
e. If the respondent perceived any of the above taxa to have any negative impacts (on themselves, people and/or the environment) in Cape Town. In an open-ended question, the respondent was asked to specify these impacts, referencing the relevant taxa.

5) Attitudes towards invasive alien plant management

a. If the respondent would be opposed to the removal of one or more of the five invasive alien plant taxa from Cape Town.
b. If the respondent felt that controlling invasive alien plants is necessary to help conserve the environment and protect biodiversity.
c. If the respondent felt that controlling invasive alien plants is necessary to protect the well-being of people.
d. If the respondent was familiar with any programmes aimed at controlling invasive alien plants in Cape Town? If the respondent answered 'Yes', they were asked to specify which programmes.

Chapter 4. Managing urban plant invasions: a multi-criteria prioritization approach

This chapter has been published.

Citation: Potgieter LJ, Gaertner M, Irlich UM, O'Farrell PJ, Stafford L, Vogt H, Richardson DM (2018) Managing urban plant invasions: a multi-criteria prioritization approach. Environ Manage doi:10.1007/s00267-018-1088-4

Luke J. Potgieter[1], Mirijam Gaertner[1,2], Ulrike M. Irlich[1,3], Patrick J. O'Farrell[4,5], Louise Stafford[3], Hannah Vogt[3], David M. Richardson[1]

[1] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa.

[2] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

[3] Invasive Species Unit, Environmental Resource Management Department, City of Cape Town, Westlake Conservation Office, South Africa.

[4] Natural Resources and Environment CSIR, P.O. Box 320, Stellenbosch, 7599, South Africa.

[5] Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa.

4.1 Abstract

Alien plant invasions in urban areas can have considerable impact on biodiversity and ecosystem services (ES). Managing urban plant invasions is particularly challenging given the complex interactions between ecological, economic and social elements that exist in the urban milieu. Strategic landscape-scale insights are crucial for guiding management, as are tactical site-scale perspectives to plan and coordinate control efforts on the ground. Integrating these requirements to enhance management efficiency is a major challenge.

Decision-support models have considerable potential for guiding and informing management strategies when problems are complex. This study uses multi-criteria decision tools to develop a prioritization framework for managing invasive alien plants (IAPs) in urban areas at landscape and local scales. We used the Analytic Hierarchy Process (AHP; a multi-criteria decision support model) to develop and rank criteria for prioritising land parcels for IAP management in the city of Cape Town, South Africa. Located within a global biodiversity hotspot, Cape Town has a long history of alien plant introductions and a complex socio-political make-up, creating a useful system to explore the challenges associated with managing urban plant invasions. To guide the prioritization of land parcels for IAP management across the City, a stakeholder workshop was held to identify a goal and criteria for consideration, and to assess the relative importance given to each criterion in IAP management. Workshop attendees were drawn from multiple disciplines involved with different aspects of IAP research and management: government departments, scientists and researchers, and managers with a diverse set of skills and interests.

We selected spatial datasets and applied our multi-criteria decision analysis in a Geographic Information System (GIS) to develop a landscape-scale prioritization map. To address issues relevant in an urban setting, we also modified an existing IAP management framework to develop a tactical (site-level) prioritization scheme for guiding on-the-ground control operations. High-priority land parcels for IAP management were identified at landscape- and local scales across the study area. Criteria related to safety and security emerged as pivotal features for setting spatially-explicit priorities for management. The approach applied in this study can be useful for managers in all urban settings to guide the selection and prioritization of land parcels for IAP management.

Keywords: • Biological invasions • Ecosystem services • Invasive alien plants • Multi-criteria analysis • Prioritization • Urban ecosystems

4.2 Introduction

In an increasingly human-dominated world, biodiversity and ecosystem services (ES) are threatened not only by the expansion of urban areas and the proliferation of anthropogenic features that drive land-cover change, but also by invasive species (Aronson et al. 2014; Zhou et al. 2015). Invasive alien species in human-dominated environments pose threats to infrastructure, property, and the lives and livelihoods of communities in many ways. For example, invasive alien plants (IAPs) increase the frequency and severity of fires, exacerbate the impacts of floods, and (especially in developing countries) can serve as hiding places for people engaged in criminal activity, ultimately compromising the safety of communities (Allsopp et al. 2014).

Management of IAPs is needed to alleviate such negative impacts (van Wilgen et al. 1994, 1998; Wilson et al. 2013). However, managing IAPs in urban areas is particularly challenging due to the diversity in the landscape, land use, mandates, threats and pressures, and existing management frameworks and paradigms for dealing with urban plant invasions are inadequate for guiding effective and sustainable interventions (Gaertner et al. 2016, 2017). The challenges are compounded where urban areas adjoin or enclose regions of high conservation value, when actions required to safeguard biodiversity may conflict with those deemed appropriate for requirements of urban residents. For example, managing urban plant invasions often requires deviation from the standard approach of prioritising less dense areas over dense areas (which is most cost-effective and beneficial in preventing impacts; Higgins et al. 2000) - dense stands of IAPs pose immediate risks in terms of fire, and safety and security and must often be prioritized. Managers frequently also need to deviate from strategic plans based on cost-effectiveness and biodiversity considerations to accommodate prioritisation for socio-political reasons (e.g. public complaints). Such considerations often draw attention away from areas of high conservation value and reduce the overall efficiency of actions in achieving long-term aims.

Additional barriers hindering the effective management of urban plant invasions include funding insecurity, inadequate management capacity (uncertain mandates and uncoordinated management), and a lack of effective monitoring (especially due to the lack of detailed and up-to-date data on the distribution of IAPs) (Table 4.1). Control efforts may also be disrupted, especially when applied to areas under multi-purpose management, due to misaligned or conflicting management mandates (Gaston et al. 2013). Added pressures from communities and political agendas further shape management decisions. Such challenges are particularly complex in developing countries where inefficient resources and land use leads to negative environmental consequences and negative social impacts in the long term (Piracha and Marcotullio 2003). Managing urban plant invasions therefore requires a strategic approach to guide management across the urban landscape, and a tactical approach to plan and coordinate control efforts on the ground. The challenge is to integrate these perspectives into a unified framework.

Table 4.1. Barriers affecting the allocation of resources for invasive alien plant management in the city of Cape Town, South Africa.

Barriers	Description	Source
Conflicting priorities	Available budget allocated to 'higher priority' issues such as housing development and service delivery.	Ruwanza and Shackleton (2016)
Finance	Budget cuts; ineffective planning and budgeting.	Ruwanza and Shackleton (2016)
Enforcement	Lack of enforcement of legislation.	Cronin et al. (2017)
Awareness/Knowledge	Awareness of invasive species impacts is generally poor, and knowledge of the relevant legal requirements pertaining to invasive species is lacking.	Irlich et al. (2017)
Political will	Lack of political buy-in and support for particular interventions.	Nunan et al. (2012)
Interest	Lack of interest within local government constituencies for environment-related issues.	Ruwanza and Shackleton (2016)
Capacity and skills	Lack of capacity and skills to develop, implement, monitor and report on invasive species management.	Irlich et al. (2017)
Information	Lack of detailed and up-to-date data on the distribution and impact of invasive species, fire histories and other key environment factors.	Roura-Pascual et al. (2009)
Government structures	Depending on the local government structures, different functions or departments are responsible for managing different parcels of land. Departments have different mandates, access to resources, and varying expertise in managing invasive species, while some are not structured or mandated to perform their environmental responsibilities at all.	Irlich et al. (2017)
Integration into existing plans and strategies	Current invasive species strategies and management plans have yet to be fully integrated into existing governmental plans.	Ruwanza and Shackleton (2016)

An efficient prioritisation strategy of land parcels for IAP management is one that distributes resources in time and space in a way that results in the greatest progress from the resources available (Grice 2000). Decisions on managing IAPs are often informal (i.e., based on experience, ad hoc consultation, or short-term opportunities or emergencies), or are based on regional species-level rankings (Fox and Gordon 2009), or legal requirements (Gaertner et al. 2016). They thus seldom consider local perspectives (e.g. public opinion). This approach to decision-making potentially squanders resources and fails to address the range and spatial variability of IAP impacts. Management approaches for urban plant invasions are often confounded, and in some cases disrupted, by conflicts of interest that arise when the ES provided by alien plants are weighed against the ecosystem disservices provided by the same species (Dickie et al. 2014; Gaertner et al. 2016; Potgieter et al. 2017). Such conflicts exemplify the extent to which IAP management, especially in human-dominated areas, is increasingly viewed as a "wicked problem" (*sensu* Rittel and Webber 1973) as there are seldom straightforward "win-win" solutions. The key challenge in prioritizing land parcels for IAP management in such situations is to integrate ecological, economic, conservation, and social needs into a comprehensive management strategy that includes multiple considerations across the entire urban matrix (Cilliers et al. 2012). Such decisions must be transparent and should consider opinions, perspectives and values of a wide range of stakeholders involved in urban land-use and ecosystem management decisions (De Lange et al. 2012; Forsyth et al. 2012).

We know of no guidelines for a general approach to prioritize land parcels for IAP management in urban systems; such insights are clearly needed to optimize investments. Climate, geography, disturbance history, and cultural factors that affect how countries and different sectors of society place value on particular sites, all contribute to the complex dynamics of urban ecosystems and ways of integrating such factors in a transparent way must be sought. Few studies have explicitly examined how spatial characteristics of a heterogeneous, urban landscape can affect IAP control strategies and how these factors need to be integrated to inform where management efforts should be applied.

This study aims to develop a dual approach for landscape-scale and site-level prioritization of land parcels for IAP management in urban areas, using the city of Cape Town, South Africa as a case study. We include multiple stakeholders in the decision-making process and provide a transparent methodology which is applicable to urban centres across different geographic regions and spatial scales. We also discuss the challenges associated with developing and implementing IAP management in urban areas. This dual approach provides guidance on where best to focus IAP management efforts across the urban landscape and assists managers in prioritizing on-the-ground IAP control operations at the site level.

4.3 Methods

4.3.1 Study area

4.3.1.1 Urban landscape

Covering 2 460 km^2, the City has a population of 3.8 million people and is growing more rapidly than any other southern African metropolis (Boraine et al. 2006). Land-use at the edges of the City includes high-density urban development and informal settlements, rural residential development, agriculture, industrial uses, and conservation (Fig. 4.1a). Twenty-six percent of the City's municipal area is under urban development, 35% is under agriculture, while 39% has natural and semi-natural vegetation in mountainous areas, mainly within the Table Mountain National Park (TMNP; Holmes et al. 2012). Most of the lowland areas of the City, where the bulk of the diversity of vegetation types lie, have been transformed and all (semi-natural) vegetation that remains in the lowlands is under considerable threat from further development (Holmes et al. 2012; Goodness and Anderson 2013).

Cape Town has a long history of European colonization and the associated introductions of alien plant species present significant challenges to people and the landscape (Anderson and O'Farrell 2012; van Wilgen 2012). Many residential properties along the urban edge border the fire-prone fynbos vegetation (Alston and Richardson 2006), and the presence of IAPs pose a significant fire risk (Richardson et al. 1994) (Fig. 4.1b). Cape Town's urban spatial arrangement is typical of post-apartheid cities in South Africa with racially defined spatial planning still evident and aligned with significant wealth disparities (Swilling 2010; Fig. 4.1c). Major socio-economic challenges within the City include the provision of education, housing, nutrition and healthcare, and transport infrastructure (Goodness and Anderson 2013). Pressure to address development issues of unemployment, poverty, and the formal housing shortfall, all place considerable demand on remaining vegetation patches, which are highly sought after for conversion to housing or industrial development (Goodness and Anderson 2013). Additional pressures such as those relating to service delivery frequently divert funding away from environment-related issues (Table 4.1). The result is a population with diverse and often divergent needs, which shapes the demand for ES provision in the City.

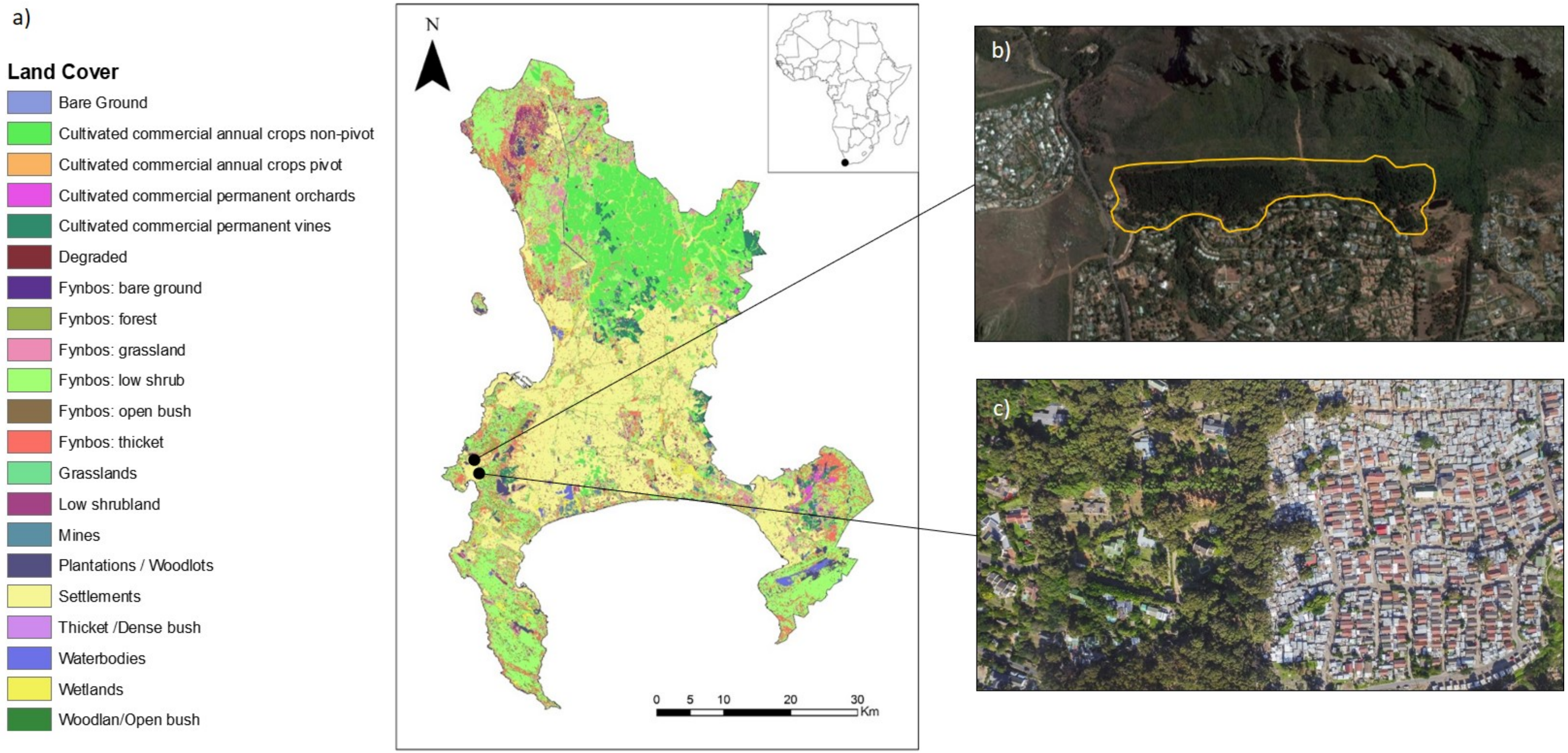


Figure 4.1. (a) Location of the city of Cape Town, South Africa, showing land cover (2013/2014), data from Department of Environmental Affairs (2016); (b) Stands of alien trees bordering residential properties (Hout Bay) invade the fire-prone fynbos vegetation, Photo: Google Earth; (c) Spatial inequality in the city of Cape Town (affluent housing estate adjoining a high-density informal settlement, Hout Bay), Photo: Johnny Miller

4.3.1.2 Biodiversity conservation and ecosystem services

Cape Town is located at the southwestern tip of Africa, in the Cape Floristic Region (CFR) - a globally recognized biodiversity hotspot (Holmes et al. 2012). The City is home to 19 of South Africa's 435 national recognized vegetation types and hosts 52% of the country's critically endangered vegetation types (Rebelo et al. 2011). The region has a Mediterranean-type climate and the indigenous vegetation, termed fynbos, is a fire-prone and fire-adapted shrubland occurring on sandy, infertile soils (Cowling and Richardson 1995). The high concentration of biodiversity within the urban matrix poses major challenges for conservation (Richardson et al. 1998).

Biodiversity plays an important role in the delivery of ES - as a regulator of underpinning ecosystem processes and as a service itself (Mace et al. 2005). Consequently, the loss of biodiversity can potentially reduce the provision of ES that are essential for human well-being and for creating sustainable urban ecosystems. Many of these services, and the biodiversity and ecological infrastructure on which they depend, have been degraded. The City's Biodiversity Strategy (2003) required, among other things, that a Biodiversity Network (BioNet) be established to enable the conservation of Critical Biodiversity Areas (CBAs) – these are considered the minimum areas of terrestrial and freshwater habitat required to meet the City's biodiversity conservation targets (Holmes et al. 2012). The CBAs are crucial for conserving biodiversity and maintaining ecological functioning and are used to guide decision-making about where best to locate urban development. Such plans are, however, often overlooked in favour of fulfilling development and housing requirements.

4.3.2 Strategic prioritization

In this study, "strategic prioritization" involves identifying and prioritizing land parcels for IAP management across the urban landscape. "Tactical prioritization" involves dividing these strategically prioritized areas into smaller management areas (Management Units; see Box 1) for further prioritization based on specific site-level characteristics. Tactics for IAP management refer to all possible control actions, and more importantly, the most appropriate combination of those actions that will yield the desired result.

Box 1. Definitions and concepts relating to the prioritization framework for managing invasive alien plants (IAPs) in urban areas at landscape and local scales

Area approach: an approach used to manage areas invaded by alien plants. This differs to the species approach in which individual species are targeted for management.

Early Detection and Rapid Response (EDRR): A management tactic aimed at managing individual invasive alien species that are detected early enough to warrant extirpation attempts. Targeted species management plans are being developed.

*Follow-up Treatment***:** consistent repeat control to prevent IAPs from flowering, until the seed bank is exhausted.

Management Units (MUs): each site is divided into different manageable units (management units, MUs), based on, for example, the location of natural boundaries (rivers/streams) or infrastructure (roads, fences). Each unit is assigned an alpha-numeric identification number. The rationale for dividing properties into smaller MUs is to make surveying, planning and management easier.

Size classes: a set of predefined size categories used to describe the age of IAPs (for example; 'Seedlings' <2cm stem diameter; 'Young' 3-20cm in diameter; 'Mature' >20cm in diameter; 'Mixed' combination of mature, young and seedlings).

Stewardship sites: sites of critical importance for biodiversity conservation and/or the provision of ecosystem services in which a partnership between landowners and conservation organizations or departments have been established to ensure the security and appropriate management of the ecosystems.

Tactics: a site-level prioritization approach. Sites may denote parcels of land such as protected areas, public open space, vacant land, road verges, riverine areas, wetlands or clusters of different land parcels.

Workload Assessments: a site assessment in which each *MU* is surveyed and baseline information captured. All alien species present within each *MU* are listed and categorised according to predefined size classes (i.e. seedlings, young, mature). The density of alien plant cover (% cover) is also estimated for each *MU*. If possible, clearing history is also noted. Workload assessment are used to determine the resources need to control IAPs per *MU*.

4.3.2.1 Multi-criteria Approach

Decision-support models have considerable potential for guiding management strategies when problems are complex. A multi-criteria approach using the AHP method (Saaty 1990) was applied to develop a decision-making framework for prioritising management of IAPs across the City. AHP is used to determine the relative importance of criteria in relation to a specific goal (Saaty 1980). Pair-wise comparisons of criteria can be made to derive accurate ratio-scale priorities, as opposed to the traditional approach of assigning single weights (Saaty 1980). It has been successfully used to prioritize species and quaternary catchments for IAP control (van Wilgen et al. 2008; Forsyth et al. 2009; Roura-Pascual et al. 2009, 2010; Forsyth and Le Maitre 2011; Forsyth et al. 2012). This technique, used to synthesize information derived from stakeholders, provides an objective way of ranking the criteria involved in the selection of land parcels for IAP management.

Criteria against which to compare alternative land parcels were identified at a workshop hosted by the City (8 April 2016), and used to prioritize land parcels for IAP management (Fig. 4.2). The workshop was attended by 15 stakeholders drawn from three broad groups: (1) government departments responsible for nature conservation; (2) scientists and researchers focussing on the ecology and control of IAPs; and (3) managers responsible for the implementation of alien plant control operations. While we acknowledge the number of workshop attendees is limited, the stakeholders have significant experience in key decision-making and management positions within leading scientific authorities and governmental organisations. Including stakeholders from such diverse disciplines can also strengthen the decision model, allowing for more defendable outcomes. Prior to conducting the AHP, a presentation was given to provide stakeholders with background knowledge of the process and the aims of the workshop (see Appendix G for a step-by-step methodological guideline).

Based on the impacts identified, an overarching strategic goal for managing IAPs in the City was identified (Fig. 4.2). Criteria and sub-criteria used to assess how well a particular alternative will achieve the goal, were identified and used to construct the framework (Arroyo et al. 2015). The goal and criteria were discussed further to ensure all participants were aware of the meaning, value, and implications of each element. The advantage of group consensus is that it allows for the discussion of pairwise comparisons which, in turn, improves participants' understanding of the problem and criteria, ensuring that participants answer less inconsistently.

Using Super Decisions software version 2.4.0, these criteria and their sub-criteria were then compared pairwise to each other to establish weightings to denote the importance of each criterion relative to one another (Arroyo et al. 2015). Variation in pair-wise judgments was examined to identify how consistent stakeholders were when comparing the relative importance of criteria. We used a consistency ratio (measure of consistency), which describes the probability that a stakeholder-provided judgment matrix differs from a randomly generated judgment matrix (Saaty 1977).

4.3.3 Analysis

The final weights developed by stakeholders during the workshop were assigned spatial data layers whereby each criterion and sub-criterion are assigned those layers that best represent each, e.g. vegetation type is represented by the map of remnants of indigenous vegetation within the boundaries of the City (see Table 4.2).

The weights derived from the AHP process were applied to each spatial data layer and were aggregated using Weighted Sum Tool under the Overlay Spatial Analyst tool in ArcGIS 10.3. A weighted sum analysis provides the ability to weight and combine multiple inputs to create an integrated analysis; it combines multiple raster inputs, representing multiple criteria, of different weights or relative importance. A final map was created showing land parcels of high to low priority for IAP management across the City.

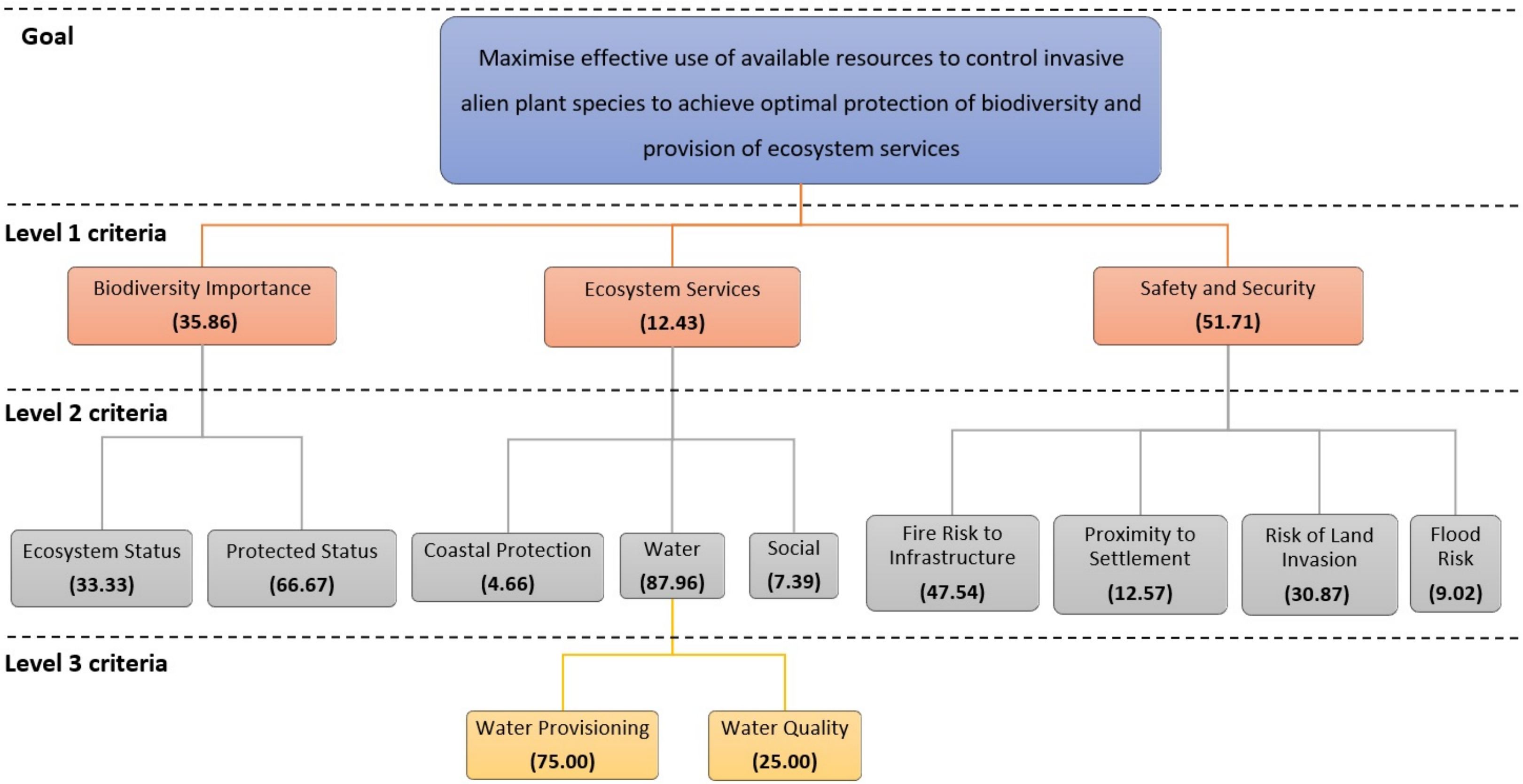


Figure 4.2. Overall goal, criteria and sub-criteria of the city of Cape Town's decision-making framework for the management of invasive alien plants, showing the relative weights (%) in bold of each criterion when compared other criteria of the same level.

Table 4.2. Criteria and sub-criteria identified at the stakeholder workshop and the corresponding spatial data layers and data sources.

Criteria	Sub-criteria	Spatial Data	Data Source
Biodiversity Importance	Ecosystem Status	Vegetation Remnants; Biodiversity Agreement Sites; Stewardship Sites	City of Cape Town data portal; SANBI BGIS data portal
	Protected Status	Biodiversity Network (CBA Rank)	Biodiversity Network (2015); SANBI BGIS data portal
Ecosystem Services	Coastal Protection	Coastal Protection Zone	O'Farrell et al. (2012)
	Water (water provisioning and water quality)	Dams, Aquifers, Rivers	City of Cape Town data portal; Invasive Species Unit (August 2016)
	Social	Heritage, education, tourism	O'Farrell et al. (2012)
Safety and Security	Fire Risk to Infrastructure	IAP density data	Invasive Species Unit (August 2016); Distance of densely invaded vegetation (≥ 75%) to infrastructure – calculated from layer
	Flood Risk	Aquatic sites; Flood prone areas	Flood Prone Areas (Directorate: Disaster Risk Reduction); Invasive Species Unit (August 2016)
	Proximity to Settlement	IAP density data; Infrastructure	Invasive Species Unit (August 2016); Distance of densely invaded vegetation (≥ 75%) to infrastructure – calculated from layer
	Risk of Land Invasion	Land Invasion hotspots	Invasive Species Unit (August 2016); Anti Land Invasion Unit

4.3.4 Tactical prioritization

The tactical prioritization was based on the approach taken by Roura-Pascual et al. (2009) who applied two methodologies, namely the Driver-Pressure-State-Impacts-Response (DPSIR) framework and AHP, at several workshops with experts on woody IAP management in South Africa. DPSIR was used to identify the criteria involved in prioritizing areas for management, while AHP provided an objective way of ranking these criteria. Roura-Pascual et al. (2009) used this process to identify 28 main criteria, which were subdivided into a smaller number of sub-criteria and assigned specific weights. Criteria were divided into four overarching groups: 1) Species attributes, 2) Stand attributes, 3) Environmental context and 4) Management context.

Only the criteria grouped as "stand attributes" (fire history, density of IAPs, spread based on topography, fire risk, age of IAPs, identity of IAPs and last clearing operation) were considered for this prioritization. Since the scale of prioritizing management units (MUs; Box 1) within a site corresponds well with the local-scale prioritization scheme of Roura-Pascual et al. (2009), the same stand-attribute criteria are appropriate for prioritizing management actions in the City. Using this scheme, MUs within a site are prioritized according to an area approach (Box 1). Criteria within the species attributes category, specifically the stand attributes criterion "Identity of IAPs", correspond with the City's species approach (Early Detection Rapid Response (EDRR) programme; Box 1). These criteria are already considered when prioritizing individual species for control interventions and creating the EDRR target species list and were therefore not included under this area approach. The criteria grouped within the environmental context were not considered as they formed part of the strategic prioritization presented in this study. Criteria within the management category were not expected to affect the final prioritization, but rather to act as constraints to IAP management, and were therefore also not considered for the prioritization of areas.

The first step in the area prioritization process was to clearly define each of the stand attribute criteria. Recent fires were defined as those that occurred over the last 12 months, as this corresponds to the minimum time that most IAPs take to mature after fire (van Wilgen et al. 1994). Incidences of fire alter management priorities, as fire stimulates the regrowth of certain IAPs e.g. *Acacia* species (Richardson and Kluge 2008). Accordingly, areas burnt in the last 12 months become a high priority for management.

Potential for spread was defined, following Roura-Pascual et al. (2009), based on the presence of wind-dispersed species on upper slopes and/or water-dispersed species in riparian areas (Table 3.3). Areas with a high probability of fire were defined according to the density of IAPs, the age of IAP stands, the position in the landscape and the presence of adjacent points of fire ignition. A high density of IAPs, as well as mature IAP stands, increase the amount of flammable biomass and therefore increase the fire risk in that MU, posing a threat to infrastructure and human safety. Regarding position in the landscape, the steeper the slope, the closer the fuels are to the flames, and thus the higher the risk of fire. Position on a slope also influences fuel availability, with more fuel available at the base of slope than on the top. MUs located at the bottom of a slope or in a valley have a higher fire risk (Teie 2009), while those located on mountain ridges have a lower risk of fire. MUs that adjoin residential areas or unmanaged natural areas where stands of IAPs provide shelter for illegal activities are also a higher fire risk due to the increased chance of ignition. Finally, the combination of all risk factors determines whether a MU is at a high, medium or low risk of fire (Table 3.3).

The IAP density sub-criteria were adjusted to correspond with the density categories used by the City (Table 3.3). The highest management priority is given to MUs that have a low IAP density, as IAP control within these MUs requires the least resources. The scheme was updated to include the size classes used by the City (see Box 1). In the case of mixed stands, i.e. when seedlings, young and mature plants are present in a MU, the 'adult' size class is adopted.

The timing of previous control interventions also influenced the prioritization of MUs for control in the upcoming financial year. MUs where follow-up treatments (see Box 1) have been conducted and where control interventions are scheduled for the next 12 months were given the highest priority for management. MUs where initial control of IAPs has taken place were given the second highest priority, whereas MUs that are currently at "maintenance-level" (which is the coordinated and consistent management of IAPs to maintain the plant population at low levels) were given the second lowest priority (Table 4.3). MUs where no control of IAPs has taken place given the lowest management priority.

After defining each of the stand-attribute criteria, the individual weightings of main and sub- criteria were adjusted to add up to one. During this process, care was taken to retain the original ranking of the stand-attribute criteria. Using ArcGIS 10.3, a map of each site was produced showing areas of high, medium and low priority MUs.

Table 4.3. Main and sub- criteria and corresponding weights (adjusted accordingly) for the tactical (site-level) prioritization of management units based on the stand attribute categorisation and weightings from Roura-Pascual et al. (2009). Values associated with each criterion indicate its importance (0–1) within the stand attribute category. For example, the criterion relating to density of IAPs based has an importance of 0.18 compared to the rest of the criteria within the stand-attributes category, and the sub-criterion ''<1 % cover" an importance of 0.41 within this criterion. Invasive alien plant density sub-criteria were adjusted to correspond with the density categories used by the city of Cape Town. Individual weightings of main and sub-criteria were adjusted to add up to one, while retaining the original rankings of the stand attribute criteria from Roura-Pascual et al. 2009).

Main criteria **(stand attributes)**	**Weighting of main** criteria	**Sub-** criteria	**Weighting of sub-** criteria
Area burned in the last 12 months	0.4	Yes: Area burned in the last 12 months	0.9
		No: Area burned more than 12 months ago	0.1
Density of IAPs (% cover)	0.18	>75	0.06
		51 – 75	0.07
		26 – 50	0.09
		6 – 25	0.13
		1 – 5	0.24
		<1	0.41
Spread based on topography	0.18	Low: Neither wind-dispersed species on upper slopes, nor water-dispersed species in riparian area	0.07
		Medium: Wind-dispersed species on upper slopes OR water-dispersed species in riparian area	0.3
		High: Wind-dispersed species on upper slopes AND water-dispersed species in riparian area	0.63
Area at fire risk	0.13	Low: Density of IAP < 50% AND situated on flat ground	0.07
		Medium: Density of IAP 50 - 75% AND situated on a gentle slope, top of slope or on a ridge	0.3

		High: Density of IAP > 75% AND mature IAP stands AND situated on a steep slope, bottom of a slope or in a valley AND adjacent to points of fire ignition	0.63
Size class of IAPs	0.07	Adult: Stem diameter > 5cm, Height > 1m; includes mixed stands	0.1
		Young: Stem diameter 1 - 5cm, Height 40cm - 1m	0.64
		Seedling: Stem diameter < 1cm, Height < 40cm	0.26
Last clearing operation	0.04	No treatment	0.05
		Initial	0.3
		Follow-up (1st, 2nd, 3rd or 4th)	0.55
		Maintenance (5th follow-up)	0.1

4.4 Results

4.4.1 Strategic prioritization

The strategic goal identified by the stakeholders was to maximise effective use of available resources to control IAPs to achieve optimal protection of biodiversity and provision of ES. To achieve this goal, the participants identified three criteria (divided hierarchically into nine sub-criteria, Fig. 4.2). The most important criterion influencing the selection of invaded areas for management within the City was safety and security (52%). The next level of priority was given to areas that are important for biodiversity conservation (36%). Areas important for the provision of ES received the lowest weighting (12%).

Issues relating to safety and security were evaluated at four levels. The most important of these was the fire risk to infrastructure - areas containing high plant biomass (mainly woody shrubs and trees) close to infrastructure received highest priority (48%). Areas at risk of being illegally occupied was given a relatively high priority (31%) as such sites represent security threats. Proximity of areas to settlements and areas at risk of flooding received relatively low priorities (13% and 9% respectively).

Biodiversity was evaluated at two levels. The most important of these was the protected status of CBAs (67%), which were identified as part of the original BioNet analysis. These areas represent the minimum amount of terrestrial and freshwater habitat required to meet the City's biodiversity conservation targets (including protected areas). Ecosystem status of remaining vegetation remnants (critically endangered, endangered, vulnerable or protected ecosystems) received a lower weighting (33%). This also included stewardship sites (see Box 1).

Ecosystem services were evaluated at three levels, with "water" receiving the highest weighting (88%). This broad category was further evaluated at two levels, the most important of which was water provisioning (75%) followed by water quality (25%). The two other criteria (coastal protection, and social aspects such as education, heritage and tourism) were identified, but each was given a weight of <10%, and thus contributed relatively little to the outcome of the prioritisation exercise.

4.4.1.1 Model outputs

A final map was developed to show overall priority areas for IAP management across the City (Fig. 3.3). By implementing the AHP in a GIS, output was generated as a raster layer with a value in each cell representing management priority. Areas identified as highest management priority are difficult to detect on the priority map that was produced as they are relatively small. These areas are densely invaded sites close to urban settlements and are important for biodiversity and the provisioning of ES.

Other high-priority management areas were clustered primarily in the north-western part of the City (Fig. 3.3). This area has several informal settlements and much of the land is densely invaded with woody alien species (especially *Acacia saligna* (Labill.) Wendl.; family Fabaceae). Consequently, this area represents a significant fire risk as well as a safety and security risk. It also contains some of the last relatively intact and ecologically functional remnants of critically endangered and poorly protected (at ca. 2%) Atlantis Sand Fynbos, as well as the endangered Cape Flats Dune Strandveld habitat. Lower-priority management sites were broadly distributed throughout the City and were typically vacant, transformed land of low biodiversity and ES value situated far from urban settlements.

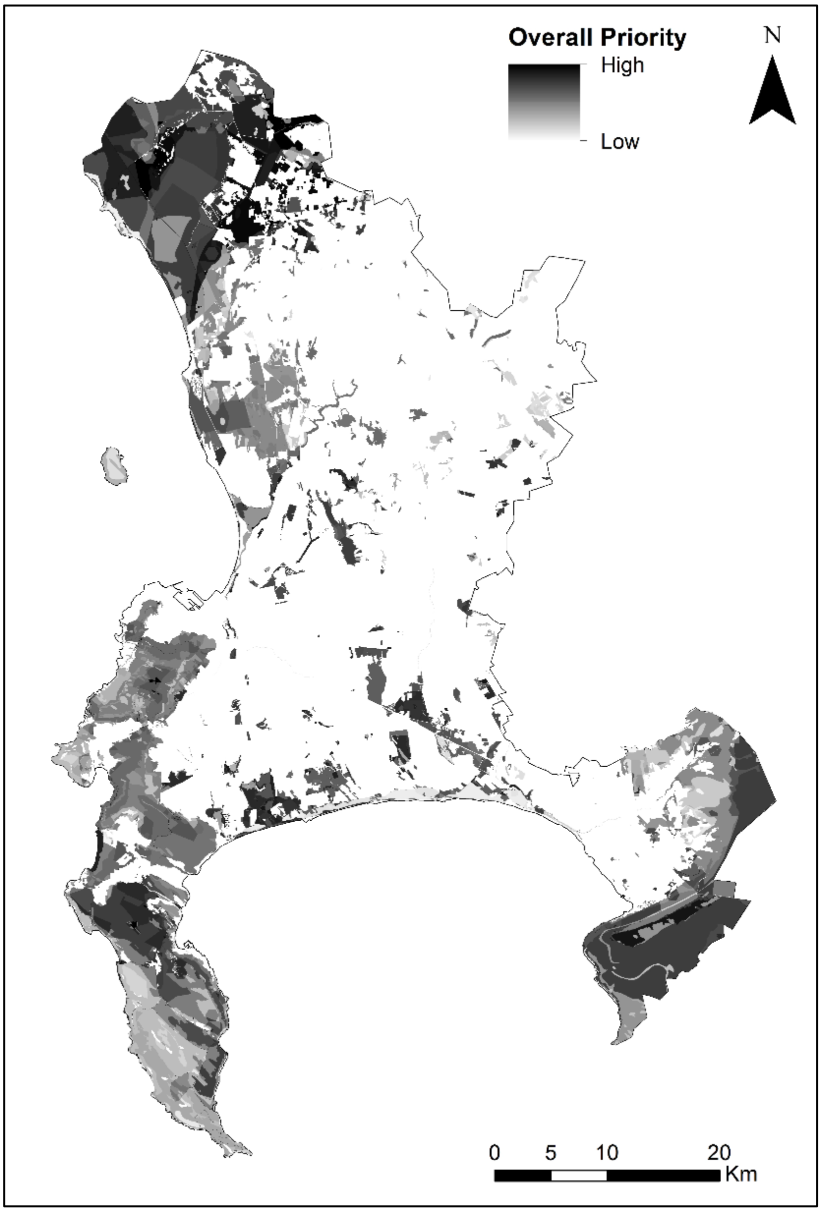


Figure 4.3. Overall priority areas for the management of invasive alien plants across the City of Cape Town, South Africa. Priority areas were determined using a multi-criteria approach in which criteria were identified, weighted and assigned spatial data layers - each criterion and sub-criterion are assigned spatial data layers best representing each criterion.

4.4.2 Tactical prioritization

According to the weightings provided by Roura-Pascual et al. (2009), the most important criterion influencing the selection of invaded areas for management within a specific region is the post-fire window of opportunity to remove IAPs when plants are relatively easy to remove and before they produce seeds (Table 4.3). Moreover, priority is given to parts of the landscape with low-density coverage of IAPs (<25% cover) – to prevent densification associated with fires – and to areas where the potential for spread into neighbouring areas is high. Additionally, areas with a high fire risk (based on stand age, position in the landscape, and fire frequency) are also prioritized for clearing (Table 4.3).

4.4.2.1 Case study: Kenilworth Racecourse Conservation Area, City of Cape Town, South Africa

Our strategic prioritization identified the Kenilworth Racecourse Conservation Area (KRCA) as a high priority for management based on the level of plant invasion, the rich biodiversity and its proximity to infrastructure. It therefore represents a useful case study to test our tactical prioritization approach.

KRCA is an area of 52 hectares situated in the centre of Kenilworth Racecourse and is the largest conservation area surrounded by urbanisation remaining in the City 's southern suburbs. It contains some of the last remnants of Cape Flats Sand Fynbos – a vegetation type of which only 14% remains. In addition to the critically endangered vegetation, the site has several wetlands (permanent and seasonal) which are of considerable ecological importance. Prescribed burns are conducted, and vegetation is actively restored, and although IAPs are actively managed, they have yet to be completely extirpated. The many challenges associated with managing IAPs in urban areas (Table 4.1) may, however, impede control operations or divert the management focus to other high priority sites. For example, despite its conservation significance, the owners of the Kenilworth Racecourse (in which the KRCA is located) have received permission from the City to subdivide and develop certain sections of the site – a decision which may redirect management efforts and influence strategic and tactical prioritization.

We applied this tactical prioritization scheme to identify priority MUs using the KRCA as a case study (Fig. 4.4). Of the 12 recognized MUs, eight were scored as 'low' priority for management, three as 'medium' priority and one as 'high' priority (Table 4.4). The 'high priority' MUs burned within the last 12 months and therefore require urgent management to remove IAPs before they mature and to prevent densification and spread of IAPs. This case study underlines some of the challenges IAP managers encounter in urban areas and emphasizes the need to fulfil development requirements while attempting to meet conservation targets.

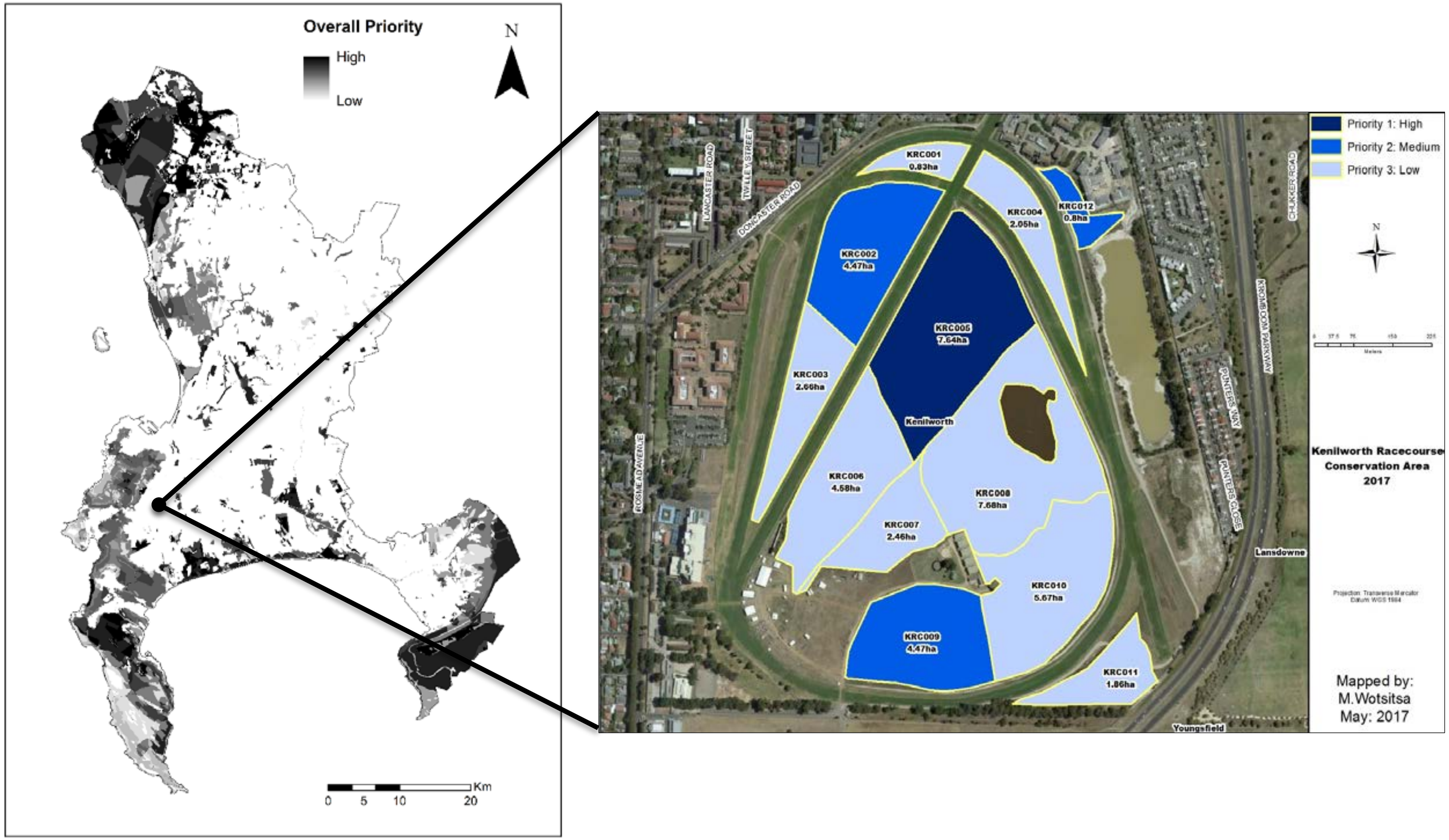


Figure 4.4. A tactical (site-level) map of priorities for invasive alien plant management in the Kenilworth Racecourse Conservation Area showing areas of high, medium and low priority management units. Priority was determined based on a framework presented by Roura-Pascual et al. (2009) in which key criteria involved in prioritizing areas for management were identified and assigned weights. Sites were divided onto Management Units and, using information on stand attributes, were weighted accordingly and assigned priorities.

Table 4.4. Sub- criterion details for each management unit of Kenilworth Racecourse Conservation Area. The total weightings of all management units were compared and assigned high, medium and low priorities. Total weighting scores of 0.2 and above correspond with the highest management priority, whereas scores between 0.13 and 0.2 correspond to a medium priority. The lowest management priority was given to management units with a total score below 0.13.

Management Unit	Area burned in the last 12 months	Percentage cover of IAPs	Spread based on topography	Area at fire risk (stand age, position, fire frequency)	Size class of IAPs	Last clearing operation	Total Weighting	Management priority
KRC001	0,04	0,0162	0,0126	0,0091	0,0070	0,004	0,089	Low
KRC002	0,04	0,0162	0,0126	0,0091	0,0448	0,004	0,127	Medium
KRC003	0,04	0,0162	0,0126	0,0091	0,0070	0,004	0,089	Low
KRC004	0,04	0,0234	0,0126	0,0091	0,0070	0,004	0,096	Low
KRC005	0,36	0,0162	0,0126	0,0091	0,0070	0,004	0,409	High
KRC006	0,04	0,0162	0,0126	0,0091	0,0070	0,004	0,089	Low
KRC007	0,04	0,0234	0,0126	0,0091	0,0070	0,004	0,096	Low
KRC008	0,04	0,0162	0,0126	0,0091	0,0070	0,004	0,089	Low
KRC009	0,04	0,0162	0,0126	0,0091	0,0448	0,004	0,127	Medium
KRC010	0,04	0,0234	0,0126	0,0091	0,0070	0,004	0,096	Low
KRC011	0,04	0,0162	0,0126	0,0091	0,0070	0,004	0,089	Low
KRC012	0,04	0,0108	0,0126	0,0390	0,0448	0,004	0,151	Medium

4.5 Discussion

Various approaches have been developed in the last decade to guide the prioritization of IAPs in complex landscapes (e.g. Forsyth et al. 2012; Hohmann et al. 2013; Nielsen and Fei 2015). This study builds on these methods and introduces novel ways of approaching IAP management at a landscape and local scale. We provide a framework for spatially prioritizing land parcels for IAP management across a complex and challenging urban landscape. Our strategic prioritization framework shifts the management focus away from *ad hoc* approaches and provides guidance on where best to focus IAP management efforts across an urban landscape (Fig. 4.5). Furthermore, by modifying and applying an existing IAP management framework in an urban setting, we also provided tactical guidance for on-the-ground IAP control operations at the site level (Fig. 4.6). The formalized prioritization approach of land parcels for IAP management we have applied here is collaborative, defensible, reproducible, spatially explicit, systematic, and transparent. Such advantages are particularly desirable when multiple management objectives add to the complexity of urban planning.

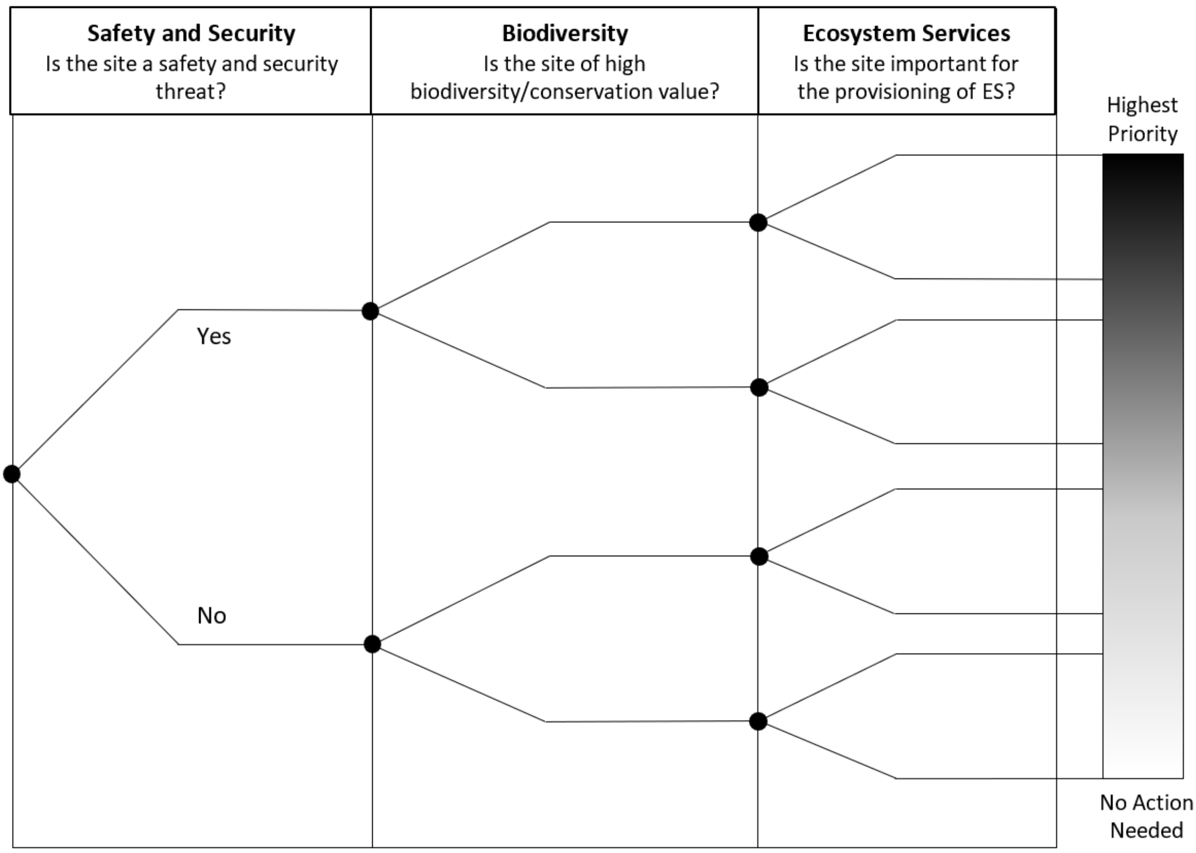


Figure 4.5. Decision framework for strategic prioritization of areas for the management of invasive alien plants in urban areas.

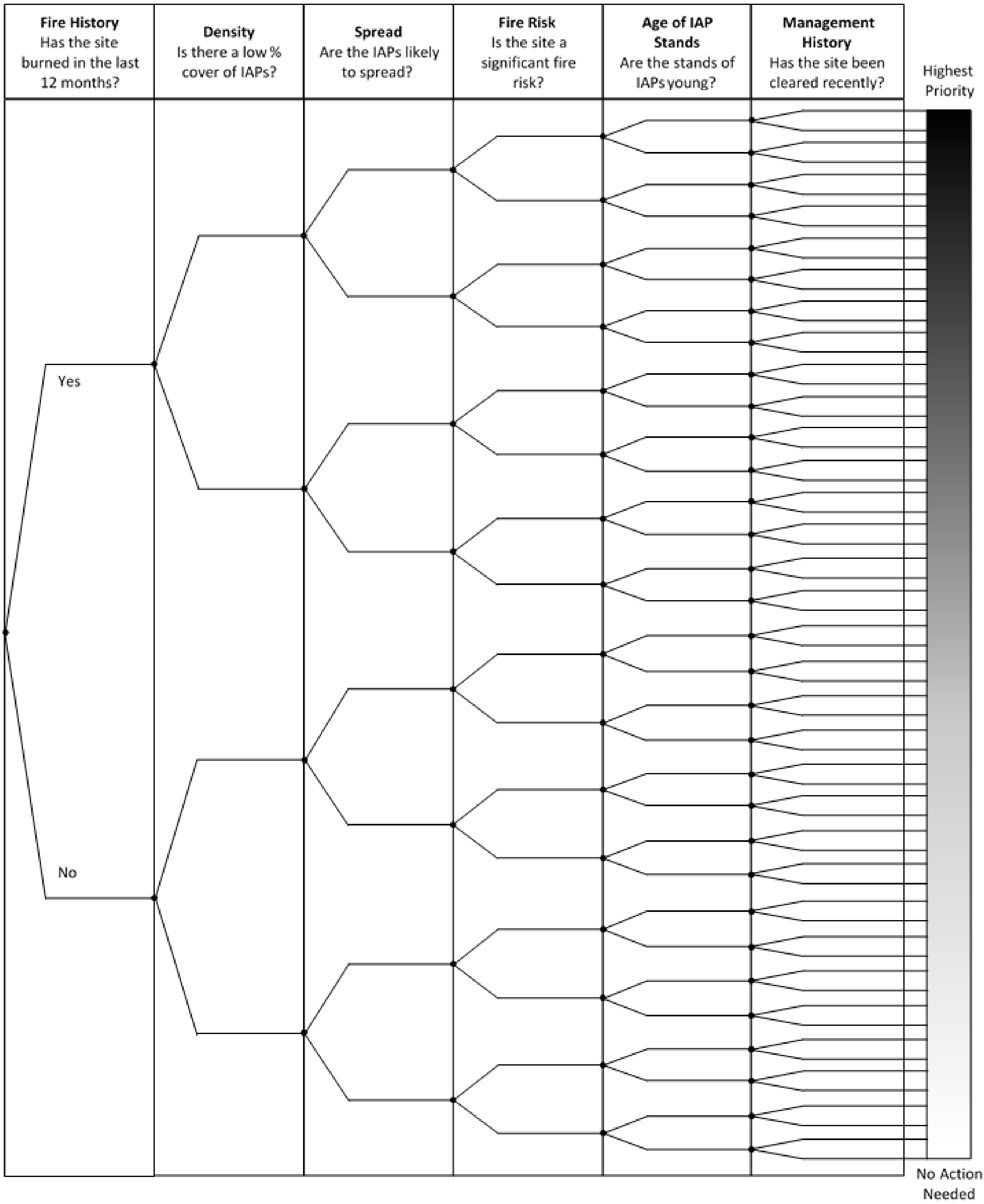


Figure 4.6. Decision framework for tactical prioritization of Management Units for on-the-ground control operations of invasive alien plants in urban areas.

While the City presents a useful system to explore the unique challenges associated with managing urban plant invasions in South Africa, our dual prioritization approach can be tailored to address different IAP management objectives specific to other urban centres around the world.

4.5.1 Safety and security

'Safety and security' was the most important criterion influencing the selection of invaded areas for management within the City (Fig. 4.2). The most important sub-criteria were 'fire risk to infrastructure' and 'risk of land invasion'.

Fire Risk to Infrastructure

Fire is an important process in fynbos, which is both fire-adapted and fire-dependent (van Wilgen 2009) and managing fynbos equates to managing fire. Fire has a considerable influence on decision-making in the City and remains a critical component of integrated invasive plant management (van Wilgen et al. 1994); managers often reprioritise clearing operations and reallocate funding in response to fires (Roura-Pascual et al. 2009). Fragmentation associated with urban development interrupts the natural fire regime (Regan et al. 2010), and maintaining this essential process is a major challenge within the urban matrix.

Many residential properties along the urban edge within the City border fynbos vegetation (Alston and Richardson, 2006). Many of these properties are regular sources of alien plant propagules, which disperse, establish and spread into the natural vegetation, posing a risk to biodiversity (see also McLean et al. (2017) for discussion of the role of urban gardens as launch sites for plant invasions in the Western Cape). The increase in biomass resulting from alien plant invasions close to urban infrastructure represents a substantial fire risk (Fig. 4.1b) (van Wilgen et al. 2012) - accidental (and often intentional) fires started by people may lead to overly frequent and uncontrolled fires, which can threaten property and the safety of people (van Wilgen and Scott 2001). Other areas such as vacant properties, public open spaces and riparian areas also become invaded to the degree that they pose a fire risk to infrastructure. Cape Town is currently experiencing one of the worst droughts in recent history. Drought and fire contribute to the spread of IAPs, which in turn can worsen the effects of drought and fire (Littell et al. 2016). This results in a feedback loop where stress from increased drought and fire severity leads to increases in plant invasions, which places further pressure on biodiversity and ES.

Management of the fire-adapted and fire-prone fynbos often results in conflict due to the need for prescribed burning to achieve ecological goals versus the prevention and suppression of wildfires for the safety of humans - public safety becomes the primary goal and not biodiversity conservation (van Wilgen et al. 2012). This requires integration of both ecological and societal aspects in the development of an adaptive fire management plan.

Risk of Land Invasion and criminal activity

Some communities in Cape Town view vegetation remnants as unsafe places characterised by criminal activities (CoCT 2018). This is largely because the sites are covered in thickets of IAPs (especially Australian acacias) and receive little to no management (CoCT 2018). For example, in poorer suburbs, open spaces invaded by Australian acacias are associated with crime and are referred to colloquially as the 'bush of evil' (Rebelo et al. 2011; Allsopp et al. 2014). The dense alien vegetation, which grows taller than the indigenous vegetation, screens illegal activities and may provide shelter for vagrants. As a result, these areas are often points of ignition for fires, which are difficult to control due to the high levels of alien plant biomass. Problems of this nature in the City have led to vegetation clearing efforts with the purpose of preventing crime, often in response to outcries from nearby communities. For example, land earmarked for future housing developments are often high-risk areas for land invasion, criminal activities and fires and the responsible department will control dense stands of IAPs to satisfy their primary objective, which is to improve public safety. Follow up control, however, is seldom scheduled until the IAPs reach maturity and the stands are once again densely invaded. Coordination of IAP control across the City has, to date, been *ad hoc* and is only initiated when sources of funding become available. Thus, when crime levels increase in a particular area, local communities request removal of alien vegetation, and only then is funding released. Such programmes generally do not result in sustainable, nor effective IAP control. This approach has however, started to change as departments begin to realise the value of clearing and maintaining invaded sites, which often results in cost-saving and reduction in public complaints.

Managing urban plant invasions is largely a social necessity, because controlling IAPs and maintaining the appropriate fire regime for the indigenous vegetation will maintain it in a state that is less attractive to criminals and less threatening to local communities. Improving public safety is an effective means of motivating for the conservation of poorly managed or unmanaged sites. The challenge is to manage these sites in such a way to restore biodiversity and ES provision, while improving public safety.

4.5.2 Urban ecosystem services

While the science of ES is advancing rapidly (Guerry et al. 2015), knowledge of how decision-makers and decision-making processes at different levels apply such notions in planning is poor. Although there has been widespread adoption of ES-based frameworks in policy and practice, both ethical and operational challenges related to using ES as the foundation for management remain, particularly in the developing country context (Sitas et al. 2016). This necessitates a better understanding of the ES concept, particularly as it relates to the planning and implementation of strategies aimed at promoting human well-being. Funk et al. (2013) argue that managers must make a broader case for investing in the control of invasive species to prevent the loss of ES.

Despite the use of some IAPs to provide ES, there is a general lack of understanding of how to predict and manage, or even measure the effects of IAPs on ES (Eviner et al. 2012). This can limit the decision-making ability of conservation managers. In the case of our study, 'ecosystem services' received the lowest weighting of all three criteria identified in the workshop (12.43%). While this may be an accurate depiction of stakeholder views, we argue that, given the importance of ES in enhancing human well-being and the role IAPs have in the provisioning of such services (including associated conflicts of interest; Potgieter et al. 2018), the complexities associated with ES (particularly in an urban environment) may have been poorly understood and consequently underrepresented in the decision model. An additional factor which may explain the low weighting given to ES is that water provision (a vital ES obtained mainly from surface water from catchment areas) occurs mostly outside the City's boundaries - of the six dams supplying water to the City, only two are managed by the City as the catchments are managed by the provincial governmental organisation. IAPs have, however, become a dominant feature in the catchments that supply Cape Town with water. Vegetation dominated by IAPs uses significantly more water than native vegetation without IAPs, reducing surface run-off and compromising the supply of water to the City (Le Maitre et al. 2007). These effects are exacerbated by the current drought conditions in the City.

4.5.3 Resource allocation

The outcome of our strategic prioritization suggests that an alternative approach to secure consistent levels of funding for IAP control in an urban environment may be to motivate for improving public safety and security rather than conserving biodiversity - biodiversity is not well understood and often not highly valued as an asset by urban decision and policy makers.

Timely intervention to control the spread of IAPs can minimize economic and ecological damages, whereas lapses or delays in funding control efforts can be extremely costly in the long run (Funk et al. 2013). Consistent funding levels allow for more effective invasive species control; however, many barriers affect the allocation of resources to IAP management (Table 4.1). Allocating funding for managing IAPs is challenging, because of competing priorities and the absence of a long-term strategy. Environment-related matters in South Africa fall within both national and provincial levels of legislative competence, and consequently local government prioritizes development and service delivery over environmental aspects, such as invasive species control (Ruwanza and Shackleton 2016). Invasive species management is not independently funded, but is mostly reliant on available, short-term operational funding from the different departments responsible for managing land parcels within the City (Irlich et al. 2017). Furthermore, operational funds and access to funding fluctuates widely between financial years, which complicates planning efforts. Existing planning frameworks for the City do not provide adequate tools for prioritizing land parcels for IAP management (e.g. Integrated Development Plan, IDP; Spatial Development Framework, SDF), which consequently hinders implementation and obstructs potential budget allocation (Irlich et al. 2017). Thus, IAP planning frameworks should rather inform such agendas.

4.5.4 Tactical control operations

In addition to funding constraints, managers in urban areas encounter numerous challenges that may affect IAP control operations on the ground, many of which are particularly prevalent in developing countries. Many of the criteria identified in our tactical prioritization approach may be influenced by the complex mechanisms associated with urban areas.

Unlike most other ecosystems, urban environments have exceedingly large numbers of land managers present (e.g. privately-owned property, national and provincial government land, municipal property managed by different departments). This can make coordination of management activities extremely difficult (Gaston et al. 2013). A greater number of landowners also means a greater likelihood that different landowners will have different incentives, policies, or practices for managing invasive plants. For example, road verges (which are particularly susceptible to plant invasions; von der Lippe and Kowarik 2008) in the City are managed by the Recreation and Parks Department who have different, and often conflicting management objectives, to that of IAP managers. These different departments may carry out IAP control operations to achieve these alternate objectives (e.g. to improve public safety), however, such management decisions are seldom made in coordination with specialist IAP managers, resulting in ineffective IAP control. For example, initial clearing operations may achieve the desired goal in the short-term, but follow-ups are often neglected (due to funding uncertainties or other constraints) or are no longer seen as a priority. Only once the alien plants have re-established, does the area become a priority again.

Accessibility also presents a considerable challenge in controlling alien plant invasions in the urban landscape. Various parcels of land fall under different management authorities and accessing these properties can be challenging. For example, a private property may be identified as a high priority for management, but the owner may not be contactable or alternatively may forbid access to the property.

The safety and security of IAP control teams themselves is often at-risk due to criminal activity at sites on which they work, and there have been several cases of team members being robbed at gun point.

Tension may also result from sites being cleared of IAPs without considering the social ties associated with the target species (Dickie et al. 2014).

4.6 Limitations

A limitation to this approach is that results are only as good as the quality of data, which is particularly important for criteria with highest weights (Forsyth 2013). The composition of the workshop participants is important for reaching consensus since individuals within the group could have opposing priorities or may be unwilling to deliberate and potentially change their views on contentious issues, thereby making it impossible to reach unanimous decisions. Including stakeholders from diverse disciplines (e.g. government representatives, social scientists, and members of the public) in such workshops potentially strengthens the decision model, allowing for more defendable outcomes.

4.7 Conclusions

Experience has shown that successful IAP management requires well established priorities, clear time-based goals, adequate resources to achieve the desired level of control, and support from multiple stakeholders (e.g. Januchowski-Hartley et al. 2011; Forsyth et al. 2012; Hohmann et al. 2013). Efficient management of IAPs in urban landscapes is especially complicated, because of the multiple interacting environmental and socio-economic factors. IAP managers in urban areas across all geographic regions need to overcome the barriers characteristic of urban areas to effectively manage urban plant invasions and ensure the continued provision of ES that are essential for human well-being.

Our application of the AHP used available data, expert opinion, and science-based heuristics to inform the prioritization of land parcels for IAP management. It can, however, also be expanded to incorporate new insights provided by additional data, more stakeholders, or new models of relevant system processes. The weights and rankings can have application in areas with similar ecological and socio-economical characteristics (De Lange et al. 2012), but the approach applied in this study should be useful in all urban settings to guide the selection and prioritization of land parcels for IAP management. As new data become available and as levels of understanding of the dynamics of plant invasion improve, rankings and weights can be adjusted, and criteria can be added or removed.

The process followed here has established a set of clear, transparent and agreed priorities which can be used to guide the allocation of available funds. The overall approach used to prioritize land parcels for IAP management resulted in an intuitive framework for dealing with the complexities involved in decision-making processes in urban environments. It also offers managers and scientists the opportunity to share experiences and knowledge on best-management practices for controlling IAPs in a quantifiable and transparent way, while simultaneously identifying barriers that hinder the effectiveness of IAP management operations.

Applying the AHP within a GIS allowed us to generate a spatial prioritization of land parcels for IAP management across a complex urban landscape. Modifying an existing IAP management framework and applying it to an urban landscape proved useful in guiding tactical management actions at the site level.

4.8 Acknowledgements

Invited stakeholders for the prioritisation workshop were: David Le Maitre (CSIR), Brian van Wilgen (Centre for Invasion Biology), Nicola van Wilgen (SANParks), Greg Forsyth (CSIR), Patricia Holmes (City of Cape Town), Luca Afonso (Centre for Invasion Biology), Chandre Rhoda (City of Cape Town), Chad Cheney (SANParks), Karen Esler (Centre for Invasion Biology) and Leighan Mossop (City of Cape Town). Funding for this work was provided by the DST-NRF Centre of Excellence for Invasion Biology and the Working for Water Programme through their collaborative research project on “Integrated Management of invasive alien species in South Africa” and the National Research Foundation (grant 85417 to DMR). We thank the City of Cape Town (City Maps and Invasive Species Unit) and SANBI (BGIS) for access to spatial data.

4.9 Conflict of interest

The authors declare that they have no competing interests.

4.10 References

Allsopp N, Anderson PML, Holmes PM, Melin A, Farrell PJO (2014) People, the Cape Floristic Region, and sustainability. In: Allsopp N, Colville JF, Verboom GA (Eds) Fynbos Ecology, Evolution and Conservation of a Megadiverse Region. Oxford: Oxford University Press, pp. 337–362

Alston KP, Richardson DM (2006) The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol Conserv 132:183–198. https://doi.org/10.1016/j.biocon.2006.03.023

Anderson PML, O'Farrell PJ (2012) An ecological view of the history of the establishment of the City of Cape Town. Ecol Soc 17:28. http://dx.doi.org/10.5751/ ES-04970-170328

Aronson MFJ, La Sorte FA, Nilon CH, Katti M, Goddard MA, Lepczyk CA, Warren PS, Williams NSG, Cilliers S, Clarkson B, Dobbs C, Dolan R, Hedblom M, Klotz S, Kooijmans JL, Kuhn I, MacGregor-Fors I, McDonnell M, Mortberg U, Pyšek P, Siebert S, Sushinsky J, Werner P, Winter M (2014) A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc R Soc Lond [Biol] 281:8. doi: 10.1098/rspb.2013.3330

Arroyo P, Tommelein ID, Ballard G (2015) Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. J Constr Eng Manage 141:04014063. doi:10.1061/(ASCE)CO.1943-7862.0000915

Boraine A, Crankshaw O, Engelbrecht C, Gotz G, Mbanga S, Narsoo M, Parnell S (2006) The state of South African cities a decade after democracy. Urban Stud 43:259-284. http://dx.doi.org/10.1080/00420980500416990

Cilliers SS, Cilliers J, Lubbe R, Siebert S (2012) Ecosystem services of urban green spaces in African countries – perspectives and challenges. Urban Ecosyst 16:681-702

City of Cape Town (CoCT) (2018) Biodiversity Report. [Online]. [Accessed 18 May 2018]. Available at: http://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/CCT_Biodiversity_Report_2018-07-27.pdf

City of Cape Town (CoCT) (2003). Biodiversity Strategy. Integrated Metropolitan Environmental Policy

Cowling R, Richardson D (1995) Fynbos: South Africa's unique floral kingdom. Fernwood Press, Cape Town

Cronin K, Kaplan H, Gaertner M, Irlich UM, Hoffman MT (2017) Aliens in the nursery: Assessing the attitudes of nursery managers to invasive species regulations. Biol Invasions 19:925–937. https://doi.org/10.1007/ s10530-016-1363-3

De Lange WJ, Stafford WHL, Forsyth GG, Le Maitre DC (2012) Incorporating stakeholder preferences in the selection of technologies for using invasive alien plants as a bio-energy feedstock: Applying the analytical hierarchy process. J Environ Manage 99:76–83. doi: 10.1016/j.jenvman.2012.01.014

Dickie IA, Bennett BM, Burrows LE, Nuñez MA, Peltzer DA, Porté A, Richardson DM, Rejmánek M, Rundel PW, van Wilgen BW (2014) Conflicting values: ecosystem services and invasive tree management. Biol Invasions 16:705-719

Eviner VT, Garbach K, Baty JH, Hoskinson SA (2012) Measuring the effects of invasive plants on ecosystem services: Challenges and prospects. Invasive Plant Sci Manage 5:125–136

Forsyth DR (2013) Group dynamics (6th ed), Wadsworth Cengage Learning, Belmont, California

Forsyth GG, Le Maitre DC (2011) Prioritising national parks for the management of invasive alien plants: Report on the development of models to prioritise invasive alien plant control operations, CSIR Natural Resources and the Environment Report number: CSIR/NRE/ECO/ER/2011/0036/B, CSIR, Stellenbosch

Forsyth GG, Le Maitre DC, O'Farrell PJ, van Wilgen BW (2012) The prioritisation of invasive alien plant control projects using a multi-criteria decision model informed by stakeholder input and spatial data. J Environ Manage 103:51–57. https://doi.org/10.1016/j.jenvman.2012.01.034

Forsyth GG, Le Maitre DC, van Wilgen BW (2009) Prioritising quaternary catchments for invasive alien plant control within the Fynbos and Karoo biomes of the Western Cape Province. CSIR Report CSIR/NRE/ECO/ER/2009/0094/B. Natural Resources and the Environment, CSIR, Stellenbosch

Fox AM, Gordon DR (2009) Approaches for assessing the status of nonnative plants: a comparative analysis. Invasive Plant Sci Manage 2:166–184

Funk JL, Matzek V, Bernhardt M, Johnson D (2013) Broadening the case for invasive species management to include impacts on ecosystem services. BioScience 64:58–63

Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landsc Urban Plan 151:1–9. https://doi.org/10.1016/j.landurbplan.2016.03.010

Gaertner M, Novoa A, Fried J, Richardson DM (2017) Managing invasive species in cities: A decision support framework applied to Cape Town. Biol Invasions 19:3707-3723

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) Managing urban ecosystems for goods and services. J Appl Ecol 50:830–40

Goodness J, Anderson P (2013) Local assessment of Cape Town: navigating the management complexities of urbanization, Biodiversity, and Ecosystem Services in the Cape Floristic Region. In: Elmqvist T, Fragkias M, Goodness J, et al. (eds) Urbanization, biodiversity and ecosystem services: challenges and opportunities. Dordrecht: Springer, pp. 461- 484

Grice AC (2000) Weed management in Australian rangelands. In: Sindel BM (ed) Australian weed management systems. Melbourne: R.G. and F.J. Richardson, pp. 431–458

Guerry AD, Polasky S, Lubchenco J. et al. (2015) Natural capital and ecosystem services informing decisions: from promise to practice. Proc Natl Acad Sci USA 112:7348–7355

Higgins SI, Richardson DM, Cowling RM (2000) Using a dynamic landscape model for planning the management of alien plant invasions. Ecol Appl 10:1833–1848

Hohmann, M. G., Just, M. G., Frank, P. J., Wall, W. A., and Gray, J. B. (2013). Prioritizing invasive plant management with multi-criteria decision analysis. Invasive Plant Sci Manage 6:339–351. https://doi.org/10.1614/IPSM-D-11-00080.1

Holmes PM, Rebelo AG, Dorse C, Wood J (2012) Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. Ecol Soc 17:28. https://doi.org/org/10.5751/ES-04552-170228

Irlich UM, Potgieter L, Stafford L, Gaertner M (2017) Recommendations for municipalities to become compliant with national legislation on biological. Bothalia 47:1–11. https://doi.org/10.4102/abc.v47i2.2156

Januchowski-Hartley SR, Visconti P, Pressey RL (2011) A systematic approach for prioritizing multiple management actions for invasive species. Biol Invasions 13:1241–53

Le Maitre DC, Gaertner M, Marchante E, Ens E, Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J, Richardson DM (2011) Impacts of invasive Australian acacias: implications for management and restoration. Divers Distrib 17:1015–1029

Littell JS, Peterson DL, Riley KL, et al. (2016) Fire and drought. In: Vose JM, Clark JS, Luce CH, Patel-Weynard T (eds) Effects of drought on forests and rangelands in the United States: a comprehensive science synthesis. Washington DC: U.S. Department of Agriculture, Forest Service, pp. 135–154

Mace G, Masundire H, Baillie J, Ricketts T, Brooks T, Hoffmann M, Stuart S, Balmford A, Purvis A, Reyers B, Wang J, Revenga C, Kennedy E, Naeem S, Alkemade R, Allnutt T, Bakarr M, Bond W, Chanson J, Cox N, Fonseca G, Hilton-Taylor C, Loucks C, Rodrigues A, Sechrest W, Stattersfield A, van Rensburg BJ, Whiteman C (2005) Ecosystems and human well-being: current state and trends: Findings of the Condition and Trends Working Group. Washington, DC: Island Press

McLean P, Gallien L, Wilson JRU, Gaertner M, Richardson DM (2017) Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa. Biol Invasions 19:3541-3555

Nielsen AM, Fei S (2015) Assessing the flexibility of the Analytic Hierarchy Process for prioritization of invasive plant management. NeoBiota 27:25-36. https://doi.org/10.3897/neobiota.27.4919

Nunan F, Campbell A, Foster E (2012) Environmental mainstreaming: the organizational challenges of policy integration. Public Adm Dev 32:262–277. http://dx.doi.org/10.1002/pad.1624

O'Farrell PJ, Anderson PML, Le Maitre DC, Holmes PM (2012) Insights and opportunities offered by a rapid ecosystem service assessment in promoting a conservation agenda in an urban biodiversity hotspot. Ecol Soc 17:1–25. http://dx.doi.org/10.5751/ES-04886-170327

Piracha AL, Marcotullio PJ (2003) Urban ecosystem analysis: identifying tools and methods. United Nations University Institute for Advanced Studies, Tokyo, Japan

Potgieter LJ, Kueffer C, Larson BMH, Livingston S, O'Farrell P, Gaertner M, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588

Potgieter LJ, Gaertner M, O'Farrell PJ, Richardson DM (2018) Perceptions of impact: Invasive alien plants in the urban environment. J Environ Manage. doi:10.1016/j.jenvman.2018.05.080

Rebelo AG, Holmes PM, Dorse C, Wood J (2011) Impacts of urbanization in a biodiversity hotspot: Conservation challenges in Metropolitan Cape Town. S Afr J Bot 77:20–35. https://doi.org/10.1016/j.sajb.2010.04.006

Regan HM, Crookston JB, Swab R, Franklin J, Lawson DM (2010) Habitat fragmentation and altered fire regime create trade-offs for an obligate seeding shrub. Ecology 91:1114–1123

Richardson DM, Gelderblom C, van Wilgen BW, Trinder-Smith TH (1998) Managing biodiversity on the Cape Peninsula, South Africa: A hotspot under pressure. In: Rundel PW, Montenegro G, Jaksic

F (eds) Landscape disturbance and biodiversity in Mediterranean-type ecosystems. Berlin: Springer-Verlag, pp. 189-204

Richardson DM, Kluge RL (2008) Seed banks of invasive Australian Acacia species in South Africa: Role in invasiveness and options for management. Perspect Plant Ecol Evol Syst 10:161-177. https://doi.org/10.1016/j.ppees.2008.03.001

Richardson DM, van Wilgen BW, Le Maitre DC, Higgins KB, Forsyth GG (1994). A computer-based system for fire management in the mountains of the Cape Province, South Africa. Int J Wildl Fire 4:17-32

Rittel HWJ, Webber MM (1973) Dilemmas in a General Theory of Planning. Policy Sci 4:155-169

Roura-Pascual N, Krug RM, Richardson DM, Hui C (2010) Spatially-explicit sensitivity analysis for conservation management: Exploring the influence of decisions in invasive alien plant management. Divers Distrib 16:426–438. https://doi.org/10.1111/j.1472-4642.2010.00659.x

Roura-Pascual N, Richardson DM, Krug RM, et al. (2009) Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. Biol Cons 142:1595–1604. https://doi.org/10.1016/j.biocon.2009.02.029

Ruwanza S, Shackleton CM (2016) Incorporation of environmental issues in South Africa’s municipal Integrated Development Plans. Int J Sust Dev World 23:28–39. https://doi.org/10.1080/13504509.2015.1062161

Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15:234–281

Saaty TL (1980) The Analytic Hierarchy Process. New York: McGraw-Hill Inc.

Saaty TL (1990) How to make a decision: the Analytic Hierarchy Process. Eur J Oper Res 48:9–26

Sitas N, Reyers B, Cundill G, Prozesky HE, Nel JL, Esler KJ (2016) Fostering collaboration for knowledge and action in disaster management in South Africa. Curr Opin Environ Sustain 19:94-102. https://doi.org/10.1016/j.cosust.2015.12.007

Swilling M (2010) Sustainability, poverty and municipal services: the case of Cape Town, South Africa. Sustain Dev 18:194-201. http://dx.doi.org/10.1002/sd.489

Teie WC (2009) Fire manager's handbook on veld and forest fires. Strategy, tactics and safety - 2nd Edition. Menlo Park: Southern African Institute of Forestry

van Wilgen BW (2012) Evidence, perceptions, and trade-offs associated with invasive alien plant control in the Table Mountain National Park, South Africa. Ecol Soc 17:23. https://doi.org/10.5751/ES-04590-170223

van Wilgen BW (2009) The evolution of fire and invasive alien plant management practices in fynbos. S Afr J Sci 105:335–342

van Wilgen BW, Forsyth GG, Prins P (2012). The management of fire-adapted ecosystems in an urban setting: the case of Table Mountain National Park, South Africa. Ecol Soc 17:8. https://doi.org/10.5751/ES-04526-170108

van Wilgen BW, Cowling RM, Le Maitre DC (1998) Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water programme. Trends Ecol Evol 13:378

van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L (2008) A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manage 89:336–349. https://doi.org/10.1016/j.jenvman.2007.06.015

van Wilgen BW, Scott DF (2001) Managing fires on the Cape Peninsula: dealing with the inevitable. J Mediterr Ecol 2:197e208

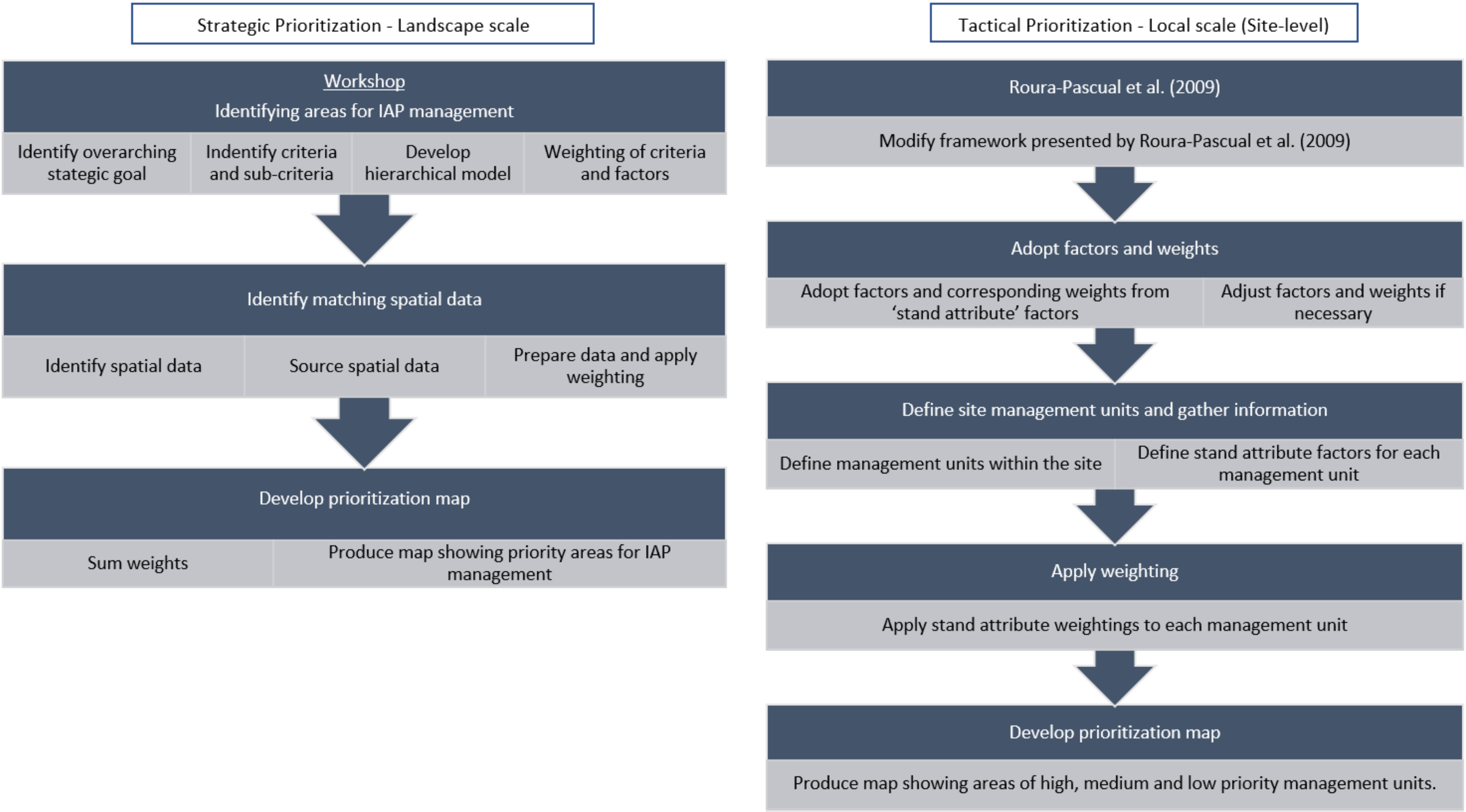
van Wilgen BW, Richardson DM, Seydack AHW (1994) Managing fynbos for biodiversity: constraints and options in a fire-prone environment. S Afri J Sci 90:322-329

von der Lippe M, Kowarik I (2008) Do cities export biodiversity? Traffic as dispersal vector across urban–rural gradients. Divers Distrib 14:18–25

Wilson JRU, Ivey P, Manyama P, Nänni I (2013) A new national unit for invasive species detection, assessment and eradication planning. S Afr J Sci 109:1-13. https://doi.org/10.1590/sajs.2013/20120111gae

Zhou Y, Smith SJ, Zhao K, et al. (2015) A global map of urban extent from nightlights. Environ Res Lett 10:54011. https://doi.org/10.1088/1748-9326/10/5/054011

4.11 Supplementary material



Appendix G A step-by-step guideline for strategic and tactical prioritization of areas for the management of invasive alien plants in urban areas.

Chapter 5. Alien plants and criminal activity: a novel ecosystem disservice?

This chapter has been submitted to the journal *Frontiers of Biogeography*.

Luke J. Potgieter[1], Mirijam Gaertner[1,2], Patrick J. O'Farrell[3,4], David M. Richardson[1]

[1] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa.

[2] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

[3] Natural Resources and Environment CSIR, Biodiversity and ES Research Group, P.O. Box 320, Stellenbosch, 7599, South Africa.

[4] Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa.

5.1 Abstract

Invasive alien plants can have considerable negative impacts on biodiversity, ecosystem services and human well-being. Complex interactions between humans and invasive plants allow these impacts to manifest in many ways. Dense vegetation, especially thickets of trees or shrubs, has been associated with actual and perceived crime risk in several parts of the world. However, the role of alien plant invasions in mediating criminal activity remains poorly documented and elaborated.

We conducted questionnaire-based surveys, analysed court cases, and searched the grey literature to examine the relationship between vegetation and criminal activity in Cape Town, South Africa. Using several case studies of vegetation-associated crime, we show that the incidence of crime is not always determined by the biogeographical status of dominant plants (i.e. whether vegetation is dominated by native, alien, or invasive alien species), but rather on the structure/habitat they provide. However, a stronger link between crime and vegetation is likely to occur in areas (such as the Cape Floristic Region) where plant invasions have drastically altered vegetation structure.

The study draws attention to a novel interaction between humans and vegetation and highlights the need for context-specific approaches when managing plant invasions, particularly in urban areas. The findings will be useful for urban managers in Cape Town and worldwide to guide the selection and prioritization of areas for vegetation management.

Keywords: Biological invasions; management; safety and security; tree invasions; urban invasions; vegetation structure.

5.2 Introduction

Urbanization is increasing rapidly worldwide. The resulting increases in population density places considerable strain on the functionality of ecosystems and the services they provide, challenging the resilience of urban environments (Elmqvist et al. 2013). A by-product of urbanisation, particularly in developing countries with complex socio-political histories and limited resources, is an increase in criminal activity. While many strategies for crime prevention focus on increased surveillance and harsher penalties for infringements, it is well known that physical and social aspects of the environment can facilitate or mitigate criminal activity (Brantingham and Brantingham 1991; Eck and Weisburd 1995; Lersch 2007).

There are two contrasting schools of thought regarding the association between vegetation features and criminal activity. The first, more recent, view posits that the presence of vegetation might deter crime. The second holds that vegetation facilitates crime because it provides cover, and therefore hiding opportunities for criminals. Kuo and Sullivan (2001) suggest that high-canopy trees and other forms of vegetation which are low in stature (e.g. grassy areas) do not promote crime, but rather deter it by increasing visibility and thus options for surveillance. Green spaces promote social inclusion, generate citizenship and local pride (Gaston 2010). Well-designed green spaces may be associated with high perceived personal safety and can decrease crime by attracting people to spend time outdoors (Kuo et al. 1998; Kuo 2003). The presence of more people in these spaces means that it is harder for criminals to escape attention, resulting in an informal system of surveillance (Kuo and Sullivan 2001). A caveat to these studies is that under some circumstances, the presence of vegetation – particularly vegetation perceived as being overgrown or that obstructs views – can generate negative reactions and feelings of insecurity (Brownlow 2005). For many people uncontrolled plant growth and secluded spaces instil a sense of fear in urban landscapes (Kuo and Sullivan 2001; Nasar and Fisher 1993). Several studies have suggested that low, dense vegetation is positively associated with actual or perceived crime risk because it provides criminals with hiding places (Fisher and Nasar 1992; Nasar et al. 1993).

Vegetation is also thought to play a more indirect role in facilitating crime by serving as an indicator of (a lack of) social control over the environment. The "broken window theory" suggests that neighbourhoods displaying visual cues of neglect, disorder or poor maintenance experience higher crime because such cues suggest to criminals a lack of effective law enforcement (Wilson and Kelling 1982). Overgrown vegetation may also increase people's fear of crime and elements of wildlife that are perceived as dangerous (e.g. snakes). There is often a contradiction in that some people may prefer green spaces as their surroundings, yet these same spaces also instil a fear of crime (Jorgensen et al. 2005). For example, while poorly managed public parks may invoke a sense of fear in some residents due to overgrown vegetation and lack of effective law enforcement (Jorgensen 2004; Jorgensen et al. 2007), the same conditions may create recreational attractions for others (e.g. shade or bird watching) which in turn provide opportunities for criminal activities. These contrasting theories regarding vegetation and crime suggest that the type or configuration of urban vegetation matters. Few studies showing a relationship between vegetation and crime are explicit about the characteristics of vegetation being studied (e.g. species, height, age, density). Complexity in vegetation structure is vital for wildlife as it provides shelter, connectivity and foraging opportunities (e.g. Brearley et al. 2010). The same vegetation features may indeed be utilized in the same way by humans engaged in criminal activities.

In an increasingly urbanised world, urban biodiversity and ecosystem services (ES) are threatened by the proliferation of anthropogenic features such as the expansion of urban areas and other types of land cover change, but also by invasive alien plants (IAPs) (Aronson et al. 2014; Zhou et al. 2015). Many alien plant species are introduced into urban areas to provide ES (e.g. aesthetic enhancement or food provision). Some of these alien species become invasive, and have negative impacts on existing ES, in the process creating novel ES and/or ecosystem disservices (EDS) (Potgieter et al. 2017). These impacts include effects on public safety and security such as increased fire risk and criminal activity (e.g. van Wilgen et al. 2012). For example, *Arundo donax* (Poaceae; giant reed) which has invaded the banks of the Rio Grande River along the Mexico-USA border provides dense cover for drug smugglers and illegal crossers and impedes line of sight for law enforcement officials (Aguilar 2016; Goolsby et al. 2016).

The nature of plant invasions (e.g. forming dense stands on vacant lots) can create a habitat structure that is very different to that provided by native vegetation (Fig. 5.1; van Wilgen and Richardson 1985; Richardson and Cowling 1992; Le Maitre et al. 2011), and a such change can serve as an indicator of neglect, disorder or poor maintenance. This change in vegetation structure can provide diverse new opportunities for those engaged in criminal activities (Gaertner et al. 2016). Invasive plant species promoting criminal activity have been reported in many rural contexts, particularly in South Africa. In their study of the role of invasive alien species in rural livelihoods in the Eastern Cape, South Africa, Shackleton et al. (2007) found that some villagers deemed the invasive tree *Acacia mearnsii* De Wild. (Fabaceae; black wattle) undesirable as they feared possible attack or rape from criminals hiding in dense wattle stands. de Neergaard et al. (2005) found that rural communities in the Drakensberg region of South Africa perceived *A. dealbata* A. Cunn. (Fabaceae; silver wattle) and *A. mearnsii* negatively as these alien tree species provide cover for thieves and criminals. Invasive stands of alien mesquite trees (*Prosopis* species; Fabaceae) in some rural villages in South Africa's Northern Cape Province also provide refuge for criminal activities (Shackleton et al. 2015).

While several studies have explored the link between urban flora and criminal activity, few have assessed whether the biogeographical status of these plants is a significant factor, or whether vegetation structure is the key factor that mediates criminal activity. Furthermore, analyses of the association between vegetation and criminal activity have focused almost exclusively on large US cities (e.g. Kuo and Sullivan 2001; Donovan and Prestomon 2012; Wolfe and Mennis 2012), leaving unexplored the role of vegetation in facilitating crime in cities of developing countries. Using detailed case studies describing different scenarios characteristic of urban floras, we aim to answer several key questions: Do IAPs, specifically, promote criminal activity or do native plants serve a similar function? Is the biogeographical status of dominant plants significant in areas where the natural vegetation structure has been drastically altered, or is vegetation structure the overriding factor mediating criminal activity?

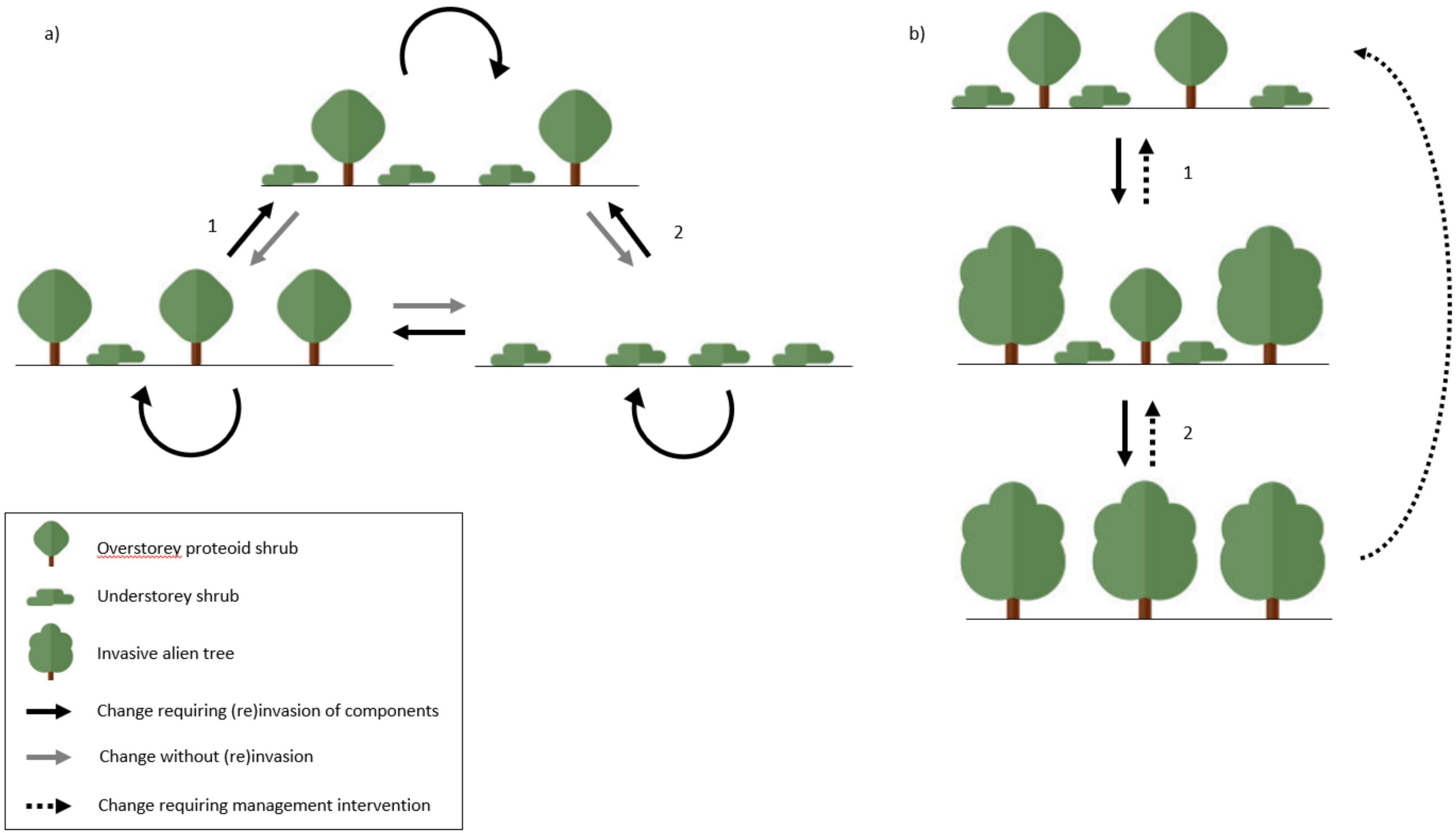


Figure 5.1. Schematic representation of disturbance-induced changes (e.g. fire) in the structure of native fynbos vegetation in a) the absence of invasive alien trees, and b) invaded by alien trees (inspired by Richardson and Cowling, 1992). In the absence of invasive alien trees, recruitment of overstorey shrubs

(predominantly a proteoid component) is highly variable. They may proliferate and supress understorey species (a1). Adverse conditions during or after a disturbance event may result in poor recruitment or local exclusion of overstorey shrubs (a2). Once invasive alien trees (such as Australian Acacia species) are established in fynbos communities, their resilience to disturbances disrupts the natural successional processes. As the invasive alien trees proliferate (b2), they outcompete native species and alter the vegetation structure. Management interventions (dashed lines) are required to return the system back to the native state.

5.3 Methods

5.3.1 Study Area

Located at the southwestern tip of Africa within the Cape Floristic Region (CFR), a globally recognized biodiversity hotspot, and covering an area of 2 460 km^2, the city of Cape Town has a population of 3.8 million people (Holmes et al. 2012). The City is home to 19 of South Africa's 435 nationally recognized vegetation types and hosts 52% of the country's critically endangered vegetation types (Rebelo et al. 2011). The dominant natural vegetation in the area is fynbos, a short shrubland vegetation type that grows on infertile soils and displays various adaptations for persistence in a fire-prone environment. Native trees are scarce in remaining natural vegetation (Richardson and Cowling 1992; Rundel et al. 2014), and native forests only cover about 3% of the area of the City (Cowling et al. 1996).

The City has a long history of European colonization and associated introductions of alien plant species (van Wilgen 2012; Pooley 2018). Many alien plant species have spread into the natural and semi-natural vegetation where they negatively impact ES provision and human well-being (van Wilgen et al. 2008). Despite substantial attempts to control IAPs, they remain embedded in the landscape. Invasions by tall alien trees and shrubs have drastically altered the vegetation structure (Fig. 5.1), negatively impacting on existing ES, and creating novel ES and/or EDS (Gaertner et al. 2016).

The structure of fynbos is strongly influenced by the frequency of fires (Cowling et al. 1996). Very dense tall fynbos (persisting more than 10 years after fire) is becoming scarcer on the Cape Peninsula as the frequency of fires increases. Fynbos is quickly degraded in areas that are highly disturbed at the urban-wildland interface. For example, the tall proteoid element is easily eliminated by fires at short intervals or by harvesting for wood (Fig. 5.1a). However, alien trees and shrubs like Australian wattles (*Acacia* species) are extremely resilient to changes in fire frequency and can form dense, often impenetrable thickets in a much shorter time after fire; even fires at the shortest possible interval will not eliminate the stands but just make them denser (Gaertner et al. 2014; Fig. 5.1b).

As a legacy of the apartheid regime, Cape Town remains highly divided, both socially and spatially (Swilling 2010), in the form of race-based residential segregation. Migration to the City has resulted in rapidly expanding informal settlements that were initially established during the previous century and enforced through apartheid planning. These are mostly located along the outskirts of the City and are home to the poorest, most marginalized urban populations. Many of these communities lack access to basic services and amenities like electricity, sanitation, waste disposal, and water (Graham and Ernstson 2012). The provision of education, housing, nutrition and healthcare, and transport infrastructure remain major socio-economic challenges in the City (Goodness and Anderson, 2013). High levels of poverty and unemployment, a propensity for violence, drug and alcohol abuse within many communities, combined with a criminal justice system that is ineffective in many respects, result in exceptionally high levels of crime (Kruger and Landman 2008).

Cape Town's crime statistics highlight a major challenge for the City and its residents. The City experienced the highest overall crime rate of all South African metropolitan areas in 2014/15 (CoCT 2016a). This has been attributed to a significantly higher rate of drug-related crimes, coupled with relatively high rates of property crime compared to other cities. In terms of violent crime, Cape Town continues to experience the highest incidence of murder, attempted murder, sexual crime and common assault crime, and the highest rate of robbery with aggravated circumstances of all South African cities (CoCT 2016b).

5.3.2 Data collection

To explore the role of vegetation structure in facilitating criminal activity across Cape Town, we used several approaches to gather quantitative and qualitative data from different sources regarding crime associated with vegetation.

5.3.2.1 Questionnaire

In May 2018, a questionnaire-based survey (available in English only), developed using Google Forms (https://docs.google.com/forms), was sent via email to land managers from three leading conservation authorities responsible (either directly or indirectly) for managing IAPs in Cape Town (CapeNature, the City's Biodiversity Branch and the Working for Water (WfW) programme). The questionnaire consisted of five questions which sought to identify the respondent's employment position, their area of responsibility, and their experiences with criminal activity and vegetation (native and alien/invasive). The questionnaire included a combination of closed- and open-ended questions. Incidence of vegetation-related crime recorded in the participants' responses were grouped according to the nature reserve crime categories from the City's Biodiversity Branch.

Electronic surveys are limited to those with access to a personal computer, email and internet access. To counteract this bias, telephonic interviews (based on the questionnaire) were conducted with participants with limited online access.

5.3.2.2 Court cases

We searched the South African Legal Information Institute (SAFLII) database and identified all case judgements (±4300 cases) handed down through the Western Cape High Court (Cape Town) from 1993 to 2017 and the Constitutional Court from 1995 to 2017. For each case, we searched for keywords relating to vegetation to determine whether a link exists between the criminal offence and features of the vegetation. Examples of keywords used for the search included: “vegetation” OR “trees” OR “bush” OR “shrub” OR “plants” OR “plantation” OR “forest” OR “branches” OR “thicket” OR “wood”. If a case only mentioned non-specific keywords such as “vegetation” or “bush”, further analysis was conducted to determine whether the vegetation was dominated by alien, invasive alien, or native plants. The location at which the incident took place (usually detailed in the ‘judgement on sentence’) was analysed using aerial imagery (in most cases Google Earth Street View) to discern the features of the vegetation. When this analysis was inconclusive, field observations were conducted to identify the taxa.

5.3.2.3 Grey literature

We searched the grey literature (including government reports, online media sources such as news articles and local online newspapers, and theses) to identify criminal incidents where special mention of vegetation was made. A grey literature search plan was developed using several searching strategies: (1) grey literature databases, (2) customized Google search engines, (3) targeted websites, and (4) consultation with contact experts. These complementary strategies were used to minimize the risk of omitting relevant sources. As abstracts are rarely available in grey literature documents, abstracts, executive summaries, or table of contents (where available) were screened first, followed by screening of the documents’ full-text. Identified incidents were further analysed to determine whether the vegetation was alien, invasive alien, or native following the same methods described above.

5.3.3 Mapping vegetation-associated crime areas

5.3.3.1 Invasive alien plant density

We obtained spatial data on invasive plant density from the City’s Invasive Species Unit (Biodiversity Management Branch; hereafter ISU); such data is used to inform invasive species management across the City (Gaertner et al. 2016). The ISU conducts clearing operations in areas managed by multiple departments within the City, including many conservation areas. At each area identified as a priority for control operations, the ISU conducts a site assessment in which management units (MU) are delineated and surveyed and baseline information captured (see Potgieter et al. 2018). All IAPs present within each MU are listed and categorised according to predefined size categories used to describe the age of plants (for example; 'seedlings' <2cm stem diameter; 'young' 3-20cm in diameter; 'mature' >20cm in diameter; 'mixed' combination of mature, young and seedlings). The density of alien plant cover (% cover) is also estimated for each MU. This information is captured in a geographic information system.

Using ArcGIS version 10.4, we mapped biodiversity agreement sites (negotiated legal agreements between the conservation agency and a landowner for conserving biodiversity in the medium term), nature reserves (managed by the City's Biodiversity Management Branch), stewardship sites, and other conservation areas (including estuaries), and symbolised each site according to the total density of invasive alien shrubs and trees (>1m in height) (as of 2017). This was also done for all sites managed by different departments on which the ISU have conducted clearing operations. We also mapped built-up areas (using 2013/2014 land cover data from the Department of Environmental Affairs 2016) and informal settlements (data from OpenUp, www.openup.org.za).

a)

1 30m

Urban park

Alien and/native trees and shrubs. Uniform structure, clear understory.

2 3m

Native semi-aquatic plants

Dense, low visibility. Medium to low manoeuvrability.

3 15m

Native forest

Low visibility, dark. Medium manoeuvrability.

4 3m

Fynbos (native)

Dense, low visibility. Low manoeuvrability.

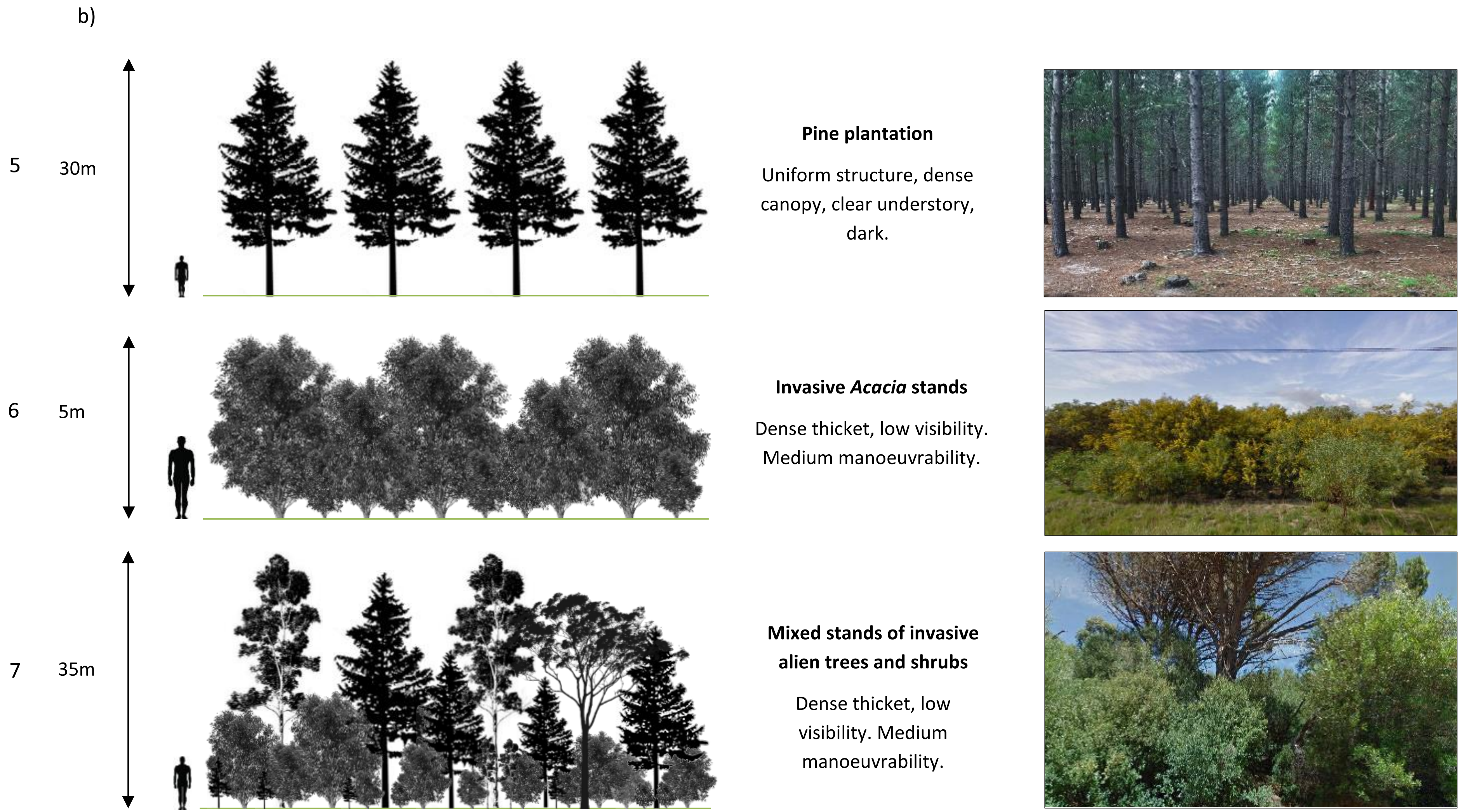


Figure 5.2. Conceptual scenarios of vegetation structure involving (a) alien and/or native and (b) alien invasive plants across Cape Town.

5.3.3.2 Crime statistics

We obtained regional data on crime incidence between 2008 and 2017 for all nature reserves managed by the City's Biodiversity Management Branch. These reserves are grouped into four regions; north, south, east, and central. We also accessed crime statistics (incidence of crime) for 60 precincts in Cape Town between 2008 and 2017 (Crime Stats SA 2017, www.crimastatssa.com). Using IAP densities, proximity to informal settlements, and total number of crime incidents for each precinct in the City from 2008 to 2017, we identified and mapped police precincts with a 'high probability' of crime associated with IAPs.

5.4 Results

Using insights from the questionnaire surveys and our analyses of court cases and the grey literature, we selected four case studies of criminal activity in which vegetation played a prominent role in facilitating the criminal act. These case studies represent common scenarios of vegetation structure and signify different ecological, economic and social contexts around Cape Town. They do not represent isolated incidents, but rather exemplify commonly occurring incidents across the City. Further assessment of the vegetation composition and structure of each case study site (which included site visits) led us to develop a conceptual diagram of seven key vegetation structure scenarios found within the Cape Town urban landscape (Fig. 5.2). Below we provide background information for each case study area and give details on the particular criminal act and associated vegetation.

5.4.1 Stakeholder perspectives

Our online questionnaire yielded 15 responses from conservation managers around the City. Most respondents (77%) associated safety and/or security risks with IAPs in their area of responsibility, but 92% also associated such risks with native plants (Fig. 5.3a). All respondents agreed (69% strongly agreed and 31% agreed) that crime can occur in vegetation dominated by both native and invasive alien plants, and that vegetation structure is the ultimate factor facilitating criminal activity (Fig. 5.3b). However, a paired-sample t-test showed a significant difference in the number of cited criminal incidents associated with IAPs (44 incidents from 12 categories) than with native plants (20 incidents from 11 categories) ($p < 0.01$; Table 1). As the average percentage cover of IAPs for protected areas within the City boundary is only 7%, this finding becomes more significant.

Half of all respondents (50%) cited *A. saligna* (Labill.) H.L.Wendl. (Fabaceae) to be associated with criminal activity. Other IAPs mentioned included *A. cyclops* A.Cunn. ex Don (Fabaceae) and *A. longifolia* Andrews Willd. (Fabaceae), *Eucalyptus* spp. (Myrtaceae) and *Pinus* spp. (Pinaceae). Conservation managers did, however, report a higher number criminal incidence associated with IAPs (44 incidents from 12 categories) than with native plants (20 incidents from nine categories) (Table 5.1). Most commonly cited crimes associated with IAPs were theft, trespassing, illegal dumping and muggings, and for native plants were trespassing, illegal infrastructure, illegal dumping and theft (Table 5.1).

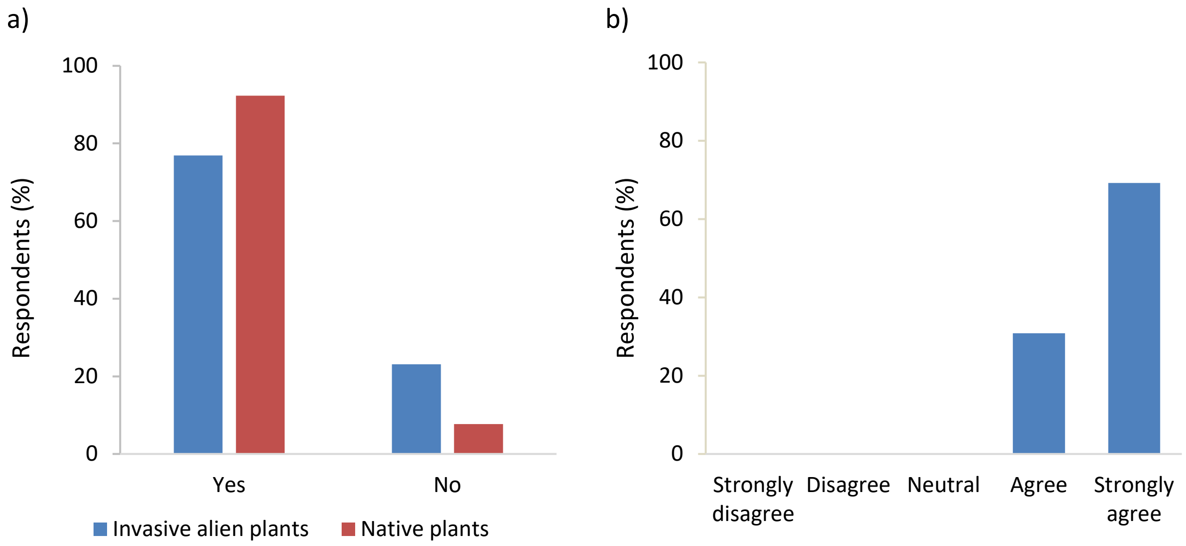


Figure 5.3. Managers' views on the association between criminal activity and vegetation in Cape Town, South Africa. Respondents were asked whether a) they were aware of any safety and/or security risks associated with invasive alien and native plants, and b) criminal activity occurs in both native and invasive vegetation, and whether the vegetation structure the ultimate factor facilitating criminal activity.

Table 5.1. Number of vegetation-related crime incidents mentioned by respondents in the online questionnaire surveys for native plants species and invasive alien plant species (grouped according to the nature reserve crime categories from the city of Cape Town Biodiversity Branch) (t-value = -2.54; p < 0.01).

	Number of incidents	
Crime category	Native plants	Invasive alien plants
Breaking and entering	2	3

Damage to infrastructure	1	0
Dead body*	0	2
Drug use	2	3
Illegal dumping	2	5
Illegal structures	2	3
Illegal trade /collection of fauna	2	3
Illegal trade /collection of flora	1	2
Muggings	0	4
Prostitution	1	2
Rape	1	1
Theft	2	8
Trespassing	4	8
	20	**44**

*The presence of bodies is not always the result of a criminal act but is included based on the context of manager's responses.

5.4.2 Case Studies

5.4.2.1 Case study 1: Tokai Park (Table Mountain National Park)

Our search and examination of court cases from the SAFLII database yielded eight cases in which a criminal incident was directly associated with vegetation – three of these cases occurred within the City's municipal boundary. The remaining five cases were not analysed further as they either occurred in rural areas or the taxa could not be identified based on vague descriptions of the location of the criminal incident.

The associated plant taxa could only be identified in one case which involved an incident of violent crime linked to both alien and native vegetation. This case study describes a violent criminal incident (rape and murder) which is associated with a plantation of the alien tree *Pinus radiata* D. Don (Pinaceae) (Fig. 5.2b, scenario 5) and native fynbos vegetation (Fig. 5.2a, scenario 4) in the suburb of Tokai, Cape Town.

Background

Tokai Plantation was established in 1885 on the southern slopes of Table Mountain and still functions as a commercial pine plantation. Surrounded by the suburbs of Tokai and Constantia, Tokai Plantation extends from the lowlands to the upper mountain slopes within Table Mountain National Park (TMNP). Tokai Park (previously known as "Tokai Forest" as it includes the Tokai Plantation), is a small section, about 600 ha, of the TMNP and falls within the municipal boundaries of the city of Cape Town. TMNP is uniquely situated in an urban setting and must therefore meet a broad range of local user needs. Management strategies for the TMNP must therefore be specific to meet the demands of an increasingly densifying city environment. Local users and managers must contend with issues and concerns that relate primarily to crime and fire.

Pine trees are one of the most significant threats to the conservation of biodiversity in TMNP (Richardson et al. 1996; van Wilgen 2012) and negatively impact on the provisioning of ES by using a disproportionate amount of water and displacing native vegetation (Dye and Poulter 1995; Le Maitre et al. 2002). However, Parkscape (a non-profit organisation consisting of about 2500 residents; http://parkscape.org.za/) argued that proposed plans to remove the remaining plantation and restore the vegetation to the native and highly fragmented Cape Flats Sand Fynbos would increase the risk of crime and fire along the urban edge.

Criminal activity

Tokai Park is a popular recreational area where residents make use of the shade provided by the large pine trees to walk their dogs and enjoy picnics. Apart from several incidents of theft, muggings and vehicle burglary, the area is not known for violent crime. The habitat structure of the pine plantation not only creates shade which makes the site popular among residents for recreational purposes, but also offers a darker environment which can help conceal criminal activity (Fig. 5.2a, scenario 4). In this particular incident, the judgement on the sentence of the perpetrator stated the following:

"The accused watched her from between the pine trees of the forest where he waited and planned his attack from the shadows before launching it." – Case No: CC47/2016, Section 32, page 14.

This indicates the role the pine plantation played in facilitating this criminal act. Native vegetation (fynbos in this case), however, also played a significant role in the execution of this criminal act.

"The accused left the deceased alone, murdered in the fynbos bushes of Tokai Forest, and walked home…" – Case No: CC47/2016, Section 31, page 13.

The denser structure and lower stature of the fynbos relative to the pine plantation provided an opportunity to conceal the body of the victim. The contrasting vegetation structure of the plantation and fynbos served different roles in facilitating the criminal act. The relatively clear understory and high potential visibility (depending on the time of day) of pine plantations may deter criminals, while the more open structure of younger fynbos may reduce the incidence of crime since criminals may theoretically be more visible. Conflicts of interest now exist given the demand for ES (e.g. recreation from the general public/neighbouring residents), the need for managers to meet biodiversity conservation goals, and the need to ensure public safety and security.

Although a criminal act of this nature is exceptional for this area, this case study shows the role two different vegetation structures can play in facilitating criminal activity. It also highlights the conflicts of interest that exist, and which need to be considered when evaluating options for managing both alien and native vegetation in the urban matrix.

5.4.2.2 Case study 2: Los Angeles informal settlement (Driftsands Nature Reserve)

Our search and examination of the grey literature revealed a community risk assessment report for the Los Angeles informal settlement, compiled by the Research Alliance for Disaster and Risk Reduction (RADAR) in 2016 (RADAR 2016). Criminal activity in and around the Los Angeles informal settlement was examined in detail as part of the community risk and vulnerability assessment. This case study describes criminal activity associated with the native but weedy bulrush, *Typha capensis* Rohrb. (Typhaceae) (Fig. 5.2a, scenario 2) in the Los Angeles informal settlement, Cape Town.

Background

Covering approximately 25 hectares, the Los Angeles informal settlement forms part of a naturally low-lying wetland located within the Driftsands Nature Reserve (DNR) which conserves 658 ha of land and is the only Provincial Nature Reserve (managed by provincial conservation authority, CapeNature) within the limits of the City's municipal boundary. DNR has become increasingly vulnerable to land invasions by those seeking space for informal dwelling. The reserve is surrounded by the low-income suburbs, however, other than providing basic housing, the area offers few other socio-economic opportunities to its growing number of residents.

DNR comprises the endangered Cape Flats Dune Strandveld, and as such is rated as the highest priority area in the City's Biodiversity Network. Despite its conservation status, residents from surrounding areas make use of the DNR for grazing cattle and for growing and harvesting medicinal plants. The land is also utilised for recreational purposes and initiation rituals.

Criminal activity

Residents of Los Angeles experience high levels of crime. Crimes range from petty theft and muggings, to physical assault and rape, most recently involving several child victims. Residents in the settlement have noted that most criminals come from outside the settlement and often hide out "in the long reeds". A site visit to the Los Angeles settlement confirmed that the 'reeds' described in the report are bulrush (*Typha capensis*).

Typha capensis, a rhizomatous perennial herb, is widespread across Cape Town, and is found in most shallow-water wetlands, particularly at the inflows to, or outflows from, seeps, pans and lakes (Hall 1993). Although native to South Africa, it exhibits weedy behaviour and disrupts wetland circulation and drainage, blocking access to recreational water bodies, replacing less competitive species and reducing habitat diversity (Hall 1993).

According to local residents, *T. capensis* was historically less ubiquitous and has spread considerably since the settlement was established. Nutrient-rich run-off from the settlement may have led to the subsequent proliferation of *T. capensis*, which has now become a haven for criminal activity. In addition to the theft, muggings, physical assault and rape, murders have also been reported, and several bodies have been found in dense *T. capensis* stands. The lack of electricity provision in Los Angeles is in many ways negatively impacting on the quality of life of residents, contributing to crime and unemployment. Due to the lack of lighting, crime is worse at night. Residents have pinpointed hotspots of criminal activity - most of them located close to dense stands of *T. capensis*. Illegal dumping also occurs regularly, generally by outside contractors who see informal settlements as convenient sites for dumping. Several cases of child rape in *T. capensis* stands have resulted in so-called 'mob justice', with known criminals being attacked by community members in the absence of law enforcement.

While *T. capensis* has been cleared in some areas to reduce crime risk, the location of the settlement in an ecologically sensitive wetland limits options for such vegetation management. This is particularly challenging for managers who need to address both ecological-function concerns and the safety needs of the community. The community, however, considers the clearing of *T. capensis* to be crucial for preventing crime.

5.4.2.3 Case study 3: Ocean View

Our search and examination of the grey literature revealed several dozen online news articles reporting an incident of violent crime linked to native fynbos vegetation. This case study describes the rape and murder of a 14-year-old girl whose body was discovered in dense native fynbos vegetation (Fig. 5.2a, scenario 4) near the suburb of Ocean View, Cape Town.

Background

Ocean View is a densely populated township on the south peninsula of Cape Town. It was established in the late 1960s when a portion of farmland and fynbos was appropriated by the government to house coloured people who had been forcibly removed from nearby whites-only seaside towns during the apartheid era.

Ocean View borders the TMNP and the predominant vegetation type is Peninsula Sandstone Fynbos. Apart from small patches of *Acacia saligna* (Labill.) H.L.Wendl. (Fabaceae) close to the township and along the road verges, the surrounding vegetation remains relatively uninvaded by alien plants.

Criminal activity

Residents of Ocean View face many challenges including unemployment, widespread drug use, alcoholism, gang activity, prostitution and violence. The settlement experiences a high rate of crime and gangs are a main source of violence as they attempt to manage the drug trade and prostitution industry. Ocean View experienced a 19% increase in the total number of crime incidents between 2016 and 2017, the highest being drug-related crime, theft, assault and burglary (Crime Stats SA 2017).

In this case, several online news articles reported that a victim was attacked in the fynbos vegetation, which also provided an opportunity to conceal the body.

"A frantic search ended in horror the following morning, 2 July, when [she] was found by her younger brother in the fynbos." – Thamm (2017).

The perpetrator also constructed a dugout in the fynbos vegetation in which to hide, and concealed the entrance using surrounding vegetation.

"The bunker was discovered in a bush along Slangkop Street, a few metres from where {the deceased's} body was found... The hole in the ground was covered with shrubs and branches and wooden planks." – Serra (2017).

This case study highlights that dense, native vegetation (fynbos) can provide habitat for criminal activity (see Appendix H). It also highlights the many socio-economic challenges residents and managers face, particularly when low-income areas border areas of high conservation value.

5.4.2.4 Case study 4: Wolfgat Nature Reserve

Our search and examination of the grey literature revealed a socio-ecological study which explored the threat crime poses to conservation of Wolfgat Nature Reserve (WNR) using newspaper content and stakeholder network analysis (Abrahams 2013). This case study describes criminal activity associated with invasive Australian wattles (Fig. 5.2b, scenario 6) in the WNR, Cape Town.

Background

WNR is a coastal urban nature reserve neighbouring Cape Town's two largest townships, namely Mitchell's Plain and Khayelitsha, which are also among the largest in the South Africa. The reserve's proximity to these areas has created substantial challenges for effective management (SACN 2003). Legacy effects of the apartheid regime have been exacerbated by the failure of current governance strategies to meet development and crime prevention goals (Samara 2011).

WNR comprises an endemic and endangered vegetation subtype known as Cape Flats Dune Strandveld (Rebelo et al. 2011), which is rapidly approaching critically endangered status. This is in part due to IAPs such as *Acacia cyclops* A. Cunn. ex G. Don (Fabaceae) and *A. saligna*, and the increased pressures of urbanisation and issues related to urban decay (Rebelo et al. 2011; Walters 2011).

Criminal activity

A safety and security audit carried out on twelve reserves under the jurisdiction of the City's Biodiversity Branch categorised WNR as a 'severe' threat level for violent crime, citing the location and socio-economic status as the primary cause (CoCT 2010). Media reports, particularly in the form of newspaper articles, have created awareness of the high incidence of crime on or near the reserve. Violent crime including murder, rape, and gang-related violence has become public knowledge and have been identified as the major factor deterring the local community from using the reserve and preventing conservation staff from accessing the reserve to perform their duties (Manuel 2006; Phelan and Thornhill 2010; Walters 2011). The lack of effective law enforcement, poor surveillance, uncontrolled access, and the social challenges faced by the neighbouring community, has contributed to the high levels of crime experienced at WNR.

The security audit for the City's nature reserves has cited WNR as a severe security threat level due to violent crime owing to its location and the social challenges faced by the neighbouring communities (Phelan and Thornhill 2010). Analysis of articles reporting violent crime provides insight into the problems facing the WNR such as the notoriety of WNR's vegetation and dune systems in providing sites for violent crime and other criminal acts, and the lack of effective law enforcement and surveillance in the area.

In 1994, several newspaper articles reported on the kidnapping, molestation and murder of four young boys at WNR (Yeld 1994). An outraged and fearful community proceeded to slash and burn around 50 hectares of the reserve on the premise that the alien *Acacia* stands provided cover for the murderer. These murders were part of a string of serial killings of 22 known victims (Bailey 2005) which took place over nearly a decade until 1995 when the alleged killer was apprehended. Several news articles described the fear and concern felt by the local community and conservation staff, regarding the reserve and adjacent dune systems and its use by criminals (Cape Argus 2008; Papier 2011; Majiet 2012; Papier 2012).

"Criminals have made the bush their home, creating spaces where they do drugs and conduct other criminal activities. They break into homes in the area and use the bush as an escape route" - Papier 2012.

The mounting pressure exerted by the local community to clear the vegetation forced the municipal Parks and Forest branch to conduct clearing operations at considerable cost to the state (approximately R5.8 million at the time) (Die Burger 1994).

The WNR presents a rich case study which highlights the strong association between poverty, crime and alien plant invasions within a complex economic, ecological, political and social landscape. Specifically, it shows a clear link between invasive alien plants and criminal activity.

5.4.3 Vegetation-related crime areas

Using IAP densities, proximity to informal settlements, and total number of crime incidents for each precinct in the City from 2008 to 2017, we identified and mapped areas (at precinct level) with a 'high probability' of crime associated with IAPs (Fig. 5.4c). Below we place our four case studies in the context of these areas.

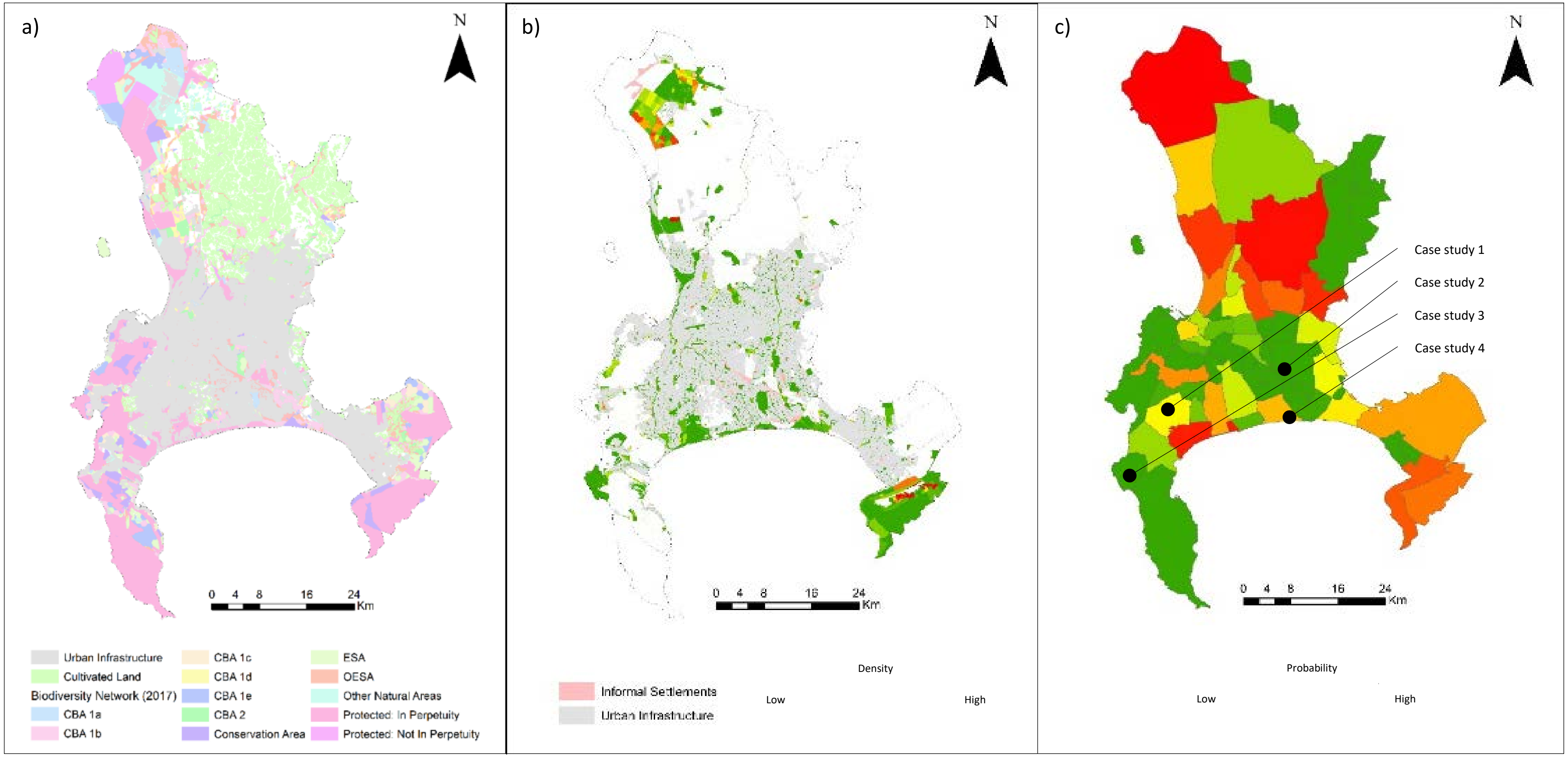
Tokai Park experiences a relatively low incidence of crime and considering that the area comprises mostly native fynbos and small managed plantations of the alien (and invasive) tree *Pinus radiata*, there is a low probability of vegetation-associated crime (Fig. 5.4c). Tokai Park is also located among wealthy suburbs, far from informal settlements, suggesting a lower risk of criminal activity (Fig. 5.4b). While our case study (Case study 1) describes an incident of violent crime associated with alien and native vegetation, cases of this nature are isolated.

As there is a lack of data on the density of IAPs around the Los Angeles informal settlement (as DNR is managed by a provincial conservation authority), we were unable to accurately map the probability of crime associated with IAPs. However, the extent of *T. capensis* in the area (Case study 2; Fig. 5.2a, scenario 2), coupled with the relatively high incidence of past reported crimes in the Khayelitsha precinct, suggests a high probability of continued criminal activity associated with *T. capensis* (and other taxa providing similar vegetation structure).

The density of IAPs near Ocean View are relatively low and the incidence of crime in the precinct has also been relatively low over the past decade, resulting in a low-probability of crime associated with

IAPs for the suburb (Fig. 5.4c). However, as our case study shows (Case study 3; Fig. 5.2a, scenario 4), criminal activity can also be associated with native plant species, highlighting the need to gather and incorporate native plant density data to map potential vegetation-related crime hotspots. Crime statistics show an upward trend in criminal activity for the Ocean View area (CrimeStats SA 2017), suggesting that vegetation-related crime may increase with increasing densities of IAPs and native plants species.

The density of IAPs on WNR is relatively low (Fig. 5.4b). However, the high incidence of reported crimes over the last decade from the precinct in which is it situated, increases the probability of vegetation-related crime (Fig. 5.4c). Furthermore, the proximity of the reserve to informal settlements increases the risk of criminal activity in the reserve (CoCT 2018).



CBA - Critical Biodiversity Area; ESA - Ecological Support Area (ESA); OESA - Other Ecological Support Area

Figure 5.4. The city of Cape Town municipal boundary showing a) urban infrastructure, cultivated land and the City's Biodiversity Network, b) Density of invasive alien plants per management unit for conservation areas (biodiversity agreement sites, nature reserves, stewardship sites, and other conservation areas) and other departmental sites, in relation to urban infrastructure and informal settlements, and c) 'High probability' of crime associated with invasive

alien plants (per precinct) based on invasive alien plant density, proximity to informal settlements, and crime incident data (data from Crime Stats SA, 2017). The Table Mountain National Park is managed by the national conservation authority and IAP density data could not be obtained.

5.5 Discussion

Our case studies show that the juxtaposition of poorly-resourced human settlements with dense stands of invasive trees and shrubs around Cape Town has created novel opportunities for crime. Invasions that transform the native shrubland vegetation to dense thickets and woodlands of alien trees and shrubs have radically changed vegetation structure over large parts of the study area (e.g. van Wilgen and Richardson 1985). Alien trees and shrubs like Australian wattles are more resilient to major human-mediated disturbances and can form dense thickets in a much shorter time, resulting in an increase in dense alien-dominated vegetation (Fig. 5.1). Despite substantial efforts to reduce the distribution and density of invasive alien trees and shrubs, dense stands are becoming more common, especially at the urban-wildland interface. Furthermore, the increased frequency of fires on the Cape Peninsula has resulted in dense fynbos stands becoming scarcer. Certain native species, such as *T. capensis*, are expanding in some areas due to human-mediated disturbances and now play an important role in facilitating criminal activity. Given this trend in changing vegetation structure and resilience, our precinct-level maps can serve as 'warning bells' to law enforcement regarding future trends in the link between vegetation and crime (Fig. 5.4).

Responses from our questionnaire survey and discussions with conservation managers suggest that the role of vegetation in facilitating crime is a significant management problem and the magnitude of problem has likely been underestimated due to the lack of quantitative data. In the next section we discuss the complex interactions between humans and vegetation, and the challenges faced by planners and managers in dynamic urban systems such as Cape Town.

5.5.1 Socio-political status

Current socio-economic factors in South Africa and the history of forced segregation have resulted in a distinct relationship between crime and the physical environment. Despite many interventions and huge efforts over the last two decades, the form and structure of Cape Town as an apartheid city has remained largely unchanged. Apartheid policies of the past still contribute to disproportionate levels of crime in different communities (Kruger and Landman 2008). Crime patterns and trends differ substantially between affluent suburbs and poorer areas such as townships and informal settlements (Lemanski 2004). Crime levels are highest in poorer communities where there is a general lack of resources, and where infrastructure is poorly developed. Residents in lower income areas are more exposed, not only to violence in terms of property crimes, but also to interpersonal crimes such as assault, murder and rape (Shaw and Louw 1998).

Australian *Acacia* species were introduced in the mid-nineteenth century to stabilize the mobile sands on the low-lying, biodiversity-rich dune fields to the north and east of Cape Town, known as the Cape Flats (Anderson and O'Farrell 2012; Donaldson et al. 2014; Pooley 2018). In the mid-twentieth century, under apartheid spatial planning, people of colour were forcibly removed from the central areas of Cape Town and relocated on the urban edge to the north and east of the City. Many were forced to reside in the Cape Flats where Australian wattles had flourished (Kull et al. 2011). The community was consequently forced to interact with a difficult ecology, and the rising poverty (the cause of which is complex and multi-dimensional; de Swardt et al. 2005) forged a strong association with crime and invasive plants. Today, criminal activity remains closely linked with Australian wattles which are referred to colloquially as the 'bush of evil' (Rebelo et al. 2011; Holmes et al. 2012; Allsopp et al. 2014).

5.5.2 Habitat structure

Vegetation structure may indeed determine the type of crime committed. For example, someone considering carrying out a violent crime such as murder would seek taller, denser vegetation to conceal the criminal act, while the open nature of managed urban parks may only see opportunistic crime such as muggings or vandalism. Different vegetation structures may also play different roles in the execution of criminal acts. For example, a perpetrator may use an urban park to gain access to residential houses to carry out a burglary, or in the case of Tokai Park, use a pine plantation as a means of launching an attack (Fig. 5.2b, scenario 5). Specific plant traits may also influence the likelihood and type of crime being committed. For example, vegetation dominated by thorny shrubs is less likely to be used by criminals (D. Gibbs pers. comm.).

Our case studies detail specific criminal incidents associated with selected vegetation structure scenarios, but our search could not identify case studies associated with the remaining vegetation structure scenarios presented in Figure 5.2 (scenario 1, 3 and 7). However, this does not mean there is no associated crime. While it may suggest that lower levels of crime occur in these vegetation structures, access to information on criminal activity is limited to what is reported, and the types of associated crime may have not met the threshold required for reporting - there is generally a bias towards extreme and atypical offences in terms of reporting frequency (O'Connell 1999). For example, criminal incidents occurring in informal green spaces (which receive little to no management) in poorer neighbourhoods are less likely to be reported than incidents occurring in formal, managed green spaces such as national parks or nature reserves.

We do not suggest that vegetation causes crime, but rather provides opportunities to commit it. The interaction between criminal activity and vegetation does not always occur in isolation and can be influenced by other features of the landscape which aid in facilitating crime and may also determine the type of crime committed. Criminal activity is unevenly distributed across the urban landscape and is facilitated or limited by physical features of the landscape. Topographical features such as hills, water bodies and rivers can influence the incidence of crime in specific areas. For example, hills or dunes can be used to conceal illegal poaching of marine wildlife (see Appendix H), and rivers can be used as routes to gain access to targeted sites. Furthermore, the location of sites in relation to specific land uses and access routes (e.g. major highways) determine the site's accessibility, privacy, and ease of escape (Brantingham and Brantingham 1978).

5.5.3 Managed and unmanaged areas

Factors relating to safety and security have been identified as crucial features influencing the selection of invaded areas for management within Cape Town; these factors clearly need to be considered when planning for biodiversity conservation in general (Potgieter et al. 2018). Coordination and implementation of IAP control efforts across the City has, however, been largely *ad hoc* and interventions are only initiated when funding becomes available (Irlich et al. 2017). For example, when crime incidence associated with vegetation increases in certain areas, local communities demand the clearing of dense vegetation, resulting in the allocation of funds. In the absence of management interventions by municipal authorities, communities opt to control problematic vegetation themselves (e.g. Abrahams 2013). Highlighting the need and importance of these efforts in areas where crime has become a problem can provide an extra incentive and focus for IAP management activities.

Land parcels in urban environments are smaller and more numerous than in more rural areas, and they fall under the jurisdiction of many landowners (e.g. privately-owned property, national and provincial government land, municipal property managed by different departments). This makes coordination of management activities challenging as landowners have different incentives, policies, priorities and approaches for managing IAPs (Gaston et al. 2013; Irlich et al. 2017). Consequently, many land parcels may be neglected or poorly managed, often resulting in the establishment and proliferation of IAPs. In Cape Town, well-managed vegetation remnants generally support relatively low-stature vegetation, whereas unmanaged remnants have old, dense stands of fynbos or are invaded by alien trees which grow taller than the native vegetation, thereby providing opportunities for crimes to take place (see Appendix H). This is more likely to occur in the lower-income areas, as limited resources are directed disproportionally towards more affluent areas (Lemanski 2007).

Therefore, effective vegetation management can contribute to reducing criminal activity in local areas. While not ecologically sustainable, a short-term solution that managers may need to consider (at least in the context of Cape Town) is to cut old stands of fynbos at regular intervals to prevent opportunities for crime to take place.

Nature reserves

The location of nature reserves with their own unique social context dictates the degree of crime risk. Although social ills extend into the reserves, the occurrence thereof is mostly localised and relates to prostitution, substance abuse, theft and illegal harvesting of plants for the herbal medicine trade. Theft, trespassing and muggings are associated with a threat to staff and visitors (Table 5.1). Conservation areas are at greater risk when located adjacent to dense informal settlements with high concentrations of unemployed people (CoCT 2010). Staff are more likely to experience violent crimes in such circumstances than where reserves are in rural or medium- to high-income areas (CoCT 2010).

Planning and management challenges

Planning and managing vegetation in urban green spaces presents further challenges. For example, urban park users may avoid areas with poor lighting and dense vegetation (Madge 1997) but managing this vegetation to combat safety concerns not only presents additional costs but risks a reduction of the many associated ES such as habitat provision (Jansson et al. 2013). Furthermore, once vegetation is managed, increased maintenance problems (such as regular pruning of low-hanging tree branches) are likely to emerge.

Severe levels of poverty and inequality add to the complexity of developing crime prevention strategies and the implementation of appropriate responses aimed at reducing crime. For example, in many townships and informal settlements around Cape Town, poor infrastructure, electricity and water services forces residents to travel some distance (mostly on foot) to access toilets. Many residents fall victim to crime during this activity, especially at night. City managers must make many decisions on how to divide and prioritise funding for aspects such as increasing levels of surveillance in the area, improving lighting, supplying additional toilets, and managing the vegetation which may be facilitating or exacerbating criminal behaviour.

5.5.4 Limitations and the way forward

Many key questions regarding the link between vegetation and crime are difficult to answer through empirical research. Such questions include: Is the link between crime and vegetation merely coincidental or is there a causal relationship? Do features of the vegetation facilitate crime, or do they change the dimensions of crime? Does the clearing of dense vegetation in crime hotspots ultimately reduce the incidence of crime, temporarily deter it, shift the location of incidents, or does it have no effect? Does vegetation structure determine the nature of the crime committed? Can the removal of dense vegetation in crime hotspots affect the types of crime committed? What interventions are needed to curb criminal activity in these areas?

Difficulties in quantifying local-scale crime occurrence and vegetation (native and alien/invasive) age and density at the city scale complicate testing for a causal relationship between crime and vegetation. The steep socio-economic gradient in many urban areas, especially in developing countries (such as Cape Town), suggests that the association between crime and vegetation is likely to differ substantially within and between neighbourhoods of different socio-economic classes. Urban environments are dynamic systems, and both crime and vegetation change considerably over space and time. A comparative assessment of criminal cases *not* associated with vegetation may not be useful. Besides the limitations associated with reporting bias, reported criminal incidents seldom contain information about the surrounding vegetation (as such information is typically not deemed important in the context of the case) unless there is a direct causal link (such as in cases presented in this paper). This does not necessarily mean that features of the vegetation do not play a role in the criminal act. Additional challenges include poorly maintained police records which are seldom easily accessible. Given these challenges and limitations, an experimental, multivariate approach is not feasible.

Long-term, transdisciplinary studies on crime incidence and vegetation changes across the socio-economic gradient using a range of approaches are needed. It may be more feasible to assess individual aspects of the crime-vegetation association using methodologies suited to specific objectives. Stakeholder involvement should be a fundamental prerequisite underpinning such approaches.

Further work is required to determine whether controlling IAPs in crime-ridden areas reduces the incidence of crime in these areas, or whether crime merely shifts to adjacent neighbourhoods. Indeed, allocating limited resources to clearing IAPs in crime-ridden areas solely to reduce levels of crime may not resolve safety and security issues in the long term, although other benefits to communities may emerge (e.g. improved perceived safety, increased provision of water and reduced fire risk).

Perceptions of urban green space differ among urban residents (Bogar and Beyer 2015). Green spaces provide recreation opportunities for urban residents (e.g. Fig. 5.2a, scenario 1; Shanahan et al. 2015), enhance feelings of safety, and are important components of a ‘‘sense of place’’ for many urban residents. However, residents may also perceive green space (especially unmanaged spaces) as areas which harbour crime and violence (e.g. “bush of evil”, Fig. 5.2b, scenario 6). More work is needed to understand perceived personal safety in relation to vegetation.

Alternative approaches to combatting crime require further examination such as the strategy of Crime Prevention through Environmental Design. This approach aims to reduce the causes of, and opportunities for, criminal events by implementing effective planning, design and management principles to the urban environment (Jeffery 1977). Environmental design interventions can, however, only be implemented to address certain types of crime in specific locations and the approach needs to be adapted to ensure the intervention is applied in a site-specific manner and with sensitivity to the conditions of a specific site (CoCT 2014). Given the current socio-economic conditions in Cape Town, crime reduction measures (especially those involving environmental design interventions) may not have any significant short-term impacts and the extreme levels of violent crime may limit the effectiveness of environmental design interventions.

5.6 Conclusions

The case studies reviewed in this paper show that the incidence of crime is not determined by the origin and biogeographic status of plants, but that the structure that dominant plants provide is important. While alien plant invasions dramatically alter vegetation structure (van Wilgen and Richardson 1985), old stands of fynbos can provide similar opportunities for criminal activity. The extent to which alien plants are important in the context of vegetation as a mediator of crime depends largely on features of the native vegetation at a given site. Where the native vegetation is dense and resilient, the impact of invasions is likely to be small. However, where the native vegetation is short and less resilient to major human-mediated disturbances (as in Cape Town), the contrast between native- and alien-dominated vegetation is much greater.

Stands of multiple alien plant species at different stages of invasion/densification within a managed landscape can pose complex direct and indirect impacts that are likely to be overlooked by informal decision-making methods. Conservation managers face considerable challenges in urban areas – they need to apply management strategies that restore biodiversity and ES provision, while also improving public safety. Reactive management approaches may persist as crime continues unabated and the association with vegetation becomes stronger as invasive plants continue to spread. A major challenge will be to identify and implement context-specific management approaches for vegetation (whether dominated by native, alien or invasive alien species) in urban areas to provide fewer opportunities for crime to occur. Our analysis shows that the link between crime and plant invasions provides an important dimension of the "long and entangled history of humans and invasive introduced plants on South Africa's Cape Peninsula" (Pooley 2018). This aspect has not been given the attention it deserves in integrated planning that aims to conserve the region's unique biodiversity and to serve the needs of the growing urban population.

5.7 Ethics approval and consent to participate

The study proposal was approved by the Research Ethics Committee of Stellenbosch University. Participation was voluntary - all participants were informed of their right to refuse to answer any questions and to withdraw from participation at any time. Informed consent was obtained, anonymity and confidentiality were explicitly granted, and questionnaires included no information that could be used to identify individual respondents. All data was thus anonymised prior to analysis.

5.8 Competing interest

The authors declare that they have no conflict of interest.

5.9 Acknowledgements

Funding for this work was provided by the DST-NRF Centre of Excellence for Invasion Biology and the Working for Water Programme through their collaborative research project on "Integrated Management of invasive alien species in South Africa" and the National Research Foundation, South Africa (grant 85417 to DMR). We thank the City of Cape Town's Invasive Species Unit for providing invasive plant density data, Julia Wood for her insights on safety and security issues in Cape Town's nature reserves, Elrena van der Spuy for useful insights on the dynamics of crime in Cape Town, and Simon Pooley and Brian van Wilgen for comments on an early draft.

5.10 References

Abrahams B (2013) A socio-ecological study of the Wolfgat Nature Reserve and the neighbouring Mitchells Plain community. Unpublished Honours thesis, Stellenbosch University (Stellenbosch, South Africa)

Aguilar J (2016) State Scrambles to Fund Border Security Project. The Texas Tribune, 15 June 2016. https://www.texastribune.org/2016/06/15/state-scrambles-fund-border-security-project/

Allsopp N, Anderson PML, Holmes PM, Melin A, Farrell PJO (2014) People, the Cape Floristic Region, and sustainability. In: Allsopp N, Colville JF, Verboom GA (eds) Fynbos Ecology, Evolution and Conservation of a Megadiverse Region. Oxford: Oxford University Press.

Alston KP, Richardson DM (2006) The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol Conserv 132:183–198. https://doi.org/10.1016/j.biocon.2006.03.023

Anderson PML, O'Farrell PJ (2012) An ecological view of the history of the establishment of the City of Cape Town. Ecol Soc 17:28. http://dx.doi.org/10.5751/ ES-04970-170328

Aronson MFJ, La Sorte FA, Nilon CH, et al. (2014) A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc R Soc Lond [Biol] 281:8. doi: 10.1098/rspb.2013.3330

Bailey C (2005) Revisiting the Station Strangler cases. 16 August 2005. https://www.iol.co.za/news/south-africa/revisiting-the-station-strangler-cases-250970

Bogar S, Beyer KM (2015) Green space, violence, and crime: A systematic review. Trauma, Violence, and Abus 17:160-171

Brantingham PJ, Brantingham PL (1991) Environmental Criminology. Waveland Press

Brantingham PL, Brantingham PJ (1978) A topological technique for regionalization. Environ Behav 10:335-353

Brantingham PL, Brantingham PJ (1993) Nodes, paths and edges: Considerations on the complexity of crime and the physical environment. J Environ Psychol 13:3-28

Brearley G, Bradley A, Bell S, McAlpine C (2010) Influence of contrasting urban edges on the abundance of arboreal mammals: A study of squirrel gliders (*Petaurus norfolcensis*) in southeast Queensland, Australia. Biol Conserv 143:60-71. doi: 10.1016/j.biocon.2009.09.003

Brownlow A (2005) An archaeology of fear and environmental change in Philadelphia. Geoforum 37:227–245

Cape Argus (2008) City accused of neglecting its nature reserves. 14 July 2008

City of Cape Town (CoCT) (2018) Biodiversity Report. [Online]. [Accessed 18 May 2018]. Available at: http://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/CCT_Biodiversity_Report_2018-07-27.pdf

City of Cape Town (CoCT) (2010) Biodiversity safety and security audit report (unpublished).

City of Cape Town (CoCT) (2014) Design and management guidelines for a safer city. https://goo.gl/kNvEfC

City of Cape Town (CoCT) (2016a) State of Cape Town Report. https://goo.gl/p8DKjT

City of Cape Town (CoCT) (2016b) Crime in Cape Town: Selected crime types – comparison with selected Metros from 2011/12 to 2014/15. Development Information and GIS Department

Cowling RM, Macdonald IAW, Simmons MT (1996) The Cape Peninsula, South Africa. Biodiver Conserv 5:527–50

Crime Stats SA (2017) Crime Stats Simplified. http://www.crimestatssa.com/index.php

de Neergaard A et al. (2005) Australian wattle species in the Drakensberg region of South Africa—an invasive alien or a natural resource? Agric Syst 85:216–233

de Swardt C, Puoane T, Chopra M, du Toit A (2005) Urban poverty in Cape Town. Environ Urban 17:101-111

Die Burger (1994) Ontbossing in Plain sal raad R5,8 M kos Nasorgsentrums vir kinders oorweeg. 16 February 1994, 7

Donaldson JE, Hui C, Richardson DM, Wilson JRU, Robertson MP Webber BL (2014) Invasion trajectory of alien trees: the role of introduction pathway and planting history. Glob Chang Biol 20:1527–1537

Donovan GH, Prestemon JP (2012) The effect of trees on crime in Portland, Oregon. Environ Behav 44:3–30

Dye PJ, Poulter AG (1995) A field demonstration of the effect on streamflow of clearing invasive pine and wattle trees from a riparian zone. S Afr For J 173:27–30

Eck JE, Weisburd D (1995) Crime places in crime theory. In: Eck JE, Weisburd D (Eds) Crime and place, Crime Prevention Studies. New York: Willow Tree Press

Fisher BS, Nasar JL (1992) Fear of crime in relation to three exterior site features: Prospect, refuge, and escape. Environ Behav 24:35-65

Gaertner M, Biggs R, Te Beest M, Hui C, Molofsky J, Richardson DM (2014) Invasive plants as drivers of regime shifts: Identifying high priority invaders that alter feedback relationships. Divers Distrib 20:733-744. doi: 10.1111/ddi.12182

Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landsc Urban Plan 151:1–9. https://doi.org/10.1016/j.landurbplan.2016.03.010

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) Managing urban ecosystems for goods and services. J Appl Ecol 50:830–840

Gaston KJ (2010) Urban ecology. Cambridge: Cambridge University Press

Goodness J, Anderson P (2013) Local assessment of Cape Town: navigating the management complexities of urbanization, Biodiversity, and Ecosystem Services in the Cape Floristic Region. In: Elmqvist T, Fragkias M, Goodness J, et al. (eds) Urbanization, biodiversity and ecosystem services: challenges and opportunities. Dordrecht: Springer

Goolsby J, Moran PJ, Racelis AE, Summy KR, Jimenez MM, Lacewell RD, de Leon AP, Kirk AA (2015) Impact of the biological control agent *Tetramesa romana* (Hymenoptera: Eurytomidae) on *Arundo donax* (Poaceae: Arundinoideae) along the Rio Grande River in Texas. Biocontrol Sci Techn 26:47-60. doi:10.1080/09583157.2015.1074980

Graham M, Ernstson H (2012) Comanagement at the fringes: examining stakeholder perspectives at Macassar Dunes, Cape Town, South Africa - at the intersection of high biodiversity, urban poverty, and inequality. Ecol Soc 17:34

Hall DJ (1993) The ecology and control of *Typha capensis* in the wetlands of the Cape Flats, South Africa. PhD Thesis. Freshwater Research Unit, Zoology Department, University of Cape Town (Cape Town)

Holmes PM, Rebelo AG, Dorse C, Wood J (2012) Can Cape Town's unique biodiversity be saved? Balancing conservation imperatives and development needs. Ecol Soc 17. https://doi.org/org/10.5751/ES-04552-170228

Irlich UM, Potgieter LJ, Stafford L, Gaertner M (2017) Recommendations for municipalities to become compliant with national legislation on biological. Bothalia 47:1–11. https://doi.org/10.4102/abc.v47i2.2156

Jansson M, Fors H, Lindgren T, Wiström B (2013) Perceived personal safety in relation to urban woodland vegetation—a review. Urban Fore Urban Green 12:127–33

Jeffery CR (1977) Crime Prevention Through Environmental Design. Sage Publications, Beverly Hills.

Jorgensen A (2004) The social and cultural context of ecological plantings. In: Dunnett N, Hitchmough J (eds) The Dynamic Landscape. London: Taylor and Francis

Jorgensen A, Hitchmough J, Dunnett N (2007) Woodland as a setting for housing-appreciation and fear and the contribution to residential satisfaction and place identity in Warrington New Town, UK. Landsc Urban Plan 79:273-287. doi: 10.1016/j.landurbplan.2006.02.015

Jorgensen A, Hitchmough J, Dunnett N (2005) Living in the urban wildwoods: A case study of Birchwood, Warrington New Town, UK. In: Kowarik I, Korner S (Eds) Wild Urban Woodlands: New Perspectives on Urban Forestry. Berlin: Springer-Verlag

Kruger T, Landman K (2008) Crime and the physical environment in South Africa: Contextualising international crime prevention experiences. Built Environ 34:75–87

Kull CA, Shackleton CM, Cunningham PJ, Ducatillon, et al. (2011) Adoption, use and perception of Australian acacias around the world. Divers Distrib 17:822-836

Kuo FE, (2003) The role of arboriculture in a healthy social ecology. J Arboric 29:148-155

Kuo FE, Sullivan WC (2001) Environment and crime in the inner city: Does vegetation reduce crime? Environ Behav 33:343-367. doi: 10.1177/0013916501333002

Kuo FE, Bacaicoa M, Sullivan W (1998) Transforming inner-city landscapes: Trees, sense of safety, and preference. Environ Behav 30:28-59. doi: 10.1177/0013916598301002

Le Maitre DC, Gaertner M, Marchante E, Ens EJ. Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J, Richardson DM (2011) Impacts of invasive Australian acacias: implications for management and restoration. Divers Distrib 17:1015-1029

Le Maitre DC, van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA, Nel JA (2002) Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. For Ecol Manage 160:143–159

Lemanski C (2004) A new apartheid? The spatial implications of fear of crime in Cape Town, South Africa. Environ Urban 16:101–112

Lersch KM (2007) Space, Time, and Crime (Second ed.). Durham: Carolina Academic Press

Madge C (1997) Public parks and the geography of fear. Tijdschrift voor Economische en Sociale Geografie 88:237-250. doi: 10.1111/j.1467-9663.1997.tb01601.x

Majiet L (2012) City beating about bush. Peoples Post, 18 September: 5

Manuel TL (2006) Responses of different community user groups to biodiversity conservation of protected areas in lowland fynbos: The case of the Wolfgat Nature Reserve. PhD thesis. University of Cape Town (Cape Town)

Michael SE, Hull RB, Zahm DL (2001) Environmental factors influencing auto burglary: A case study. Environ Behav 33:375–382

Nasar JL, Fisher BS (1993) Hot spots of fear and crime: A multi-method investigation. Journal of Environ Psychol 13:187–206

Nasar JL, Fisher B, Grannis M (1993) Proximate physical cues to fear of crime. Landsc Urban Plan 26:161-178

O'Connell M (1999) Is Irish public opinion towards crime distorted by media bias? Eur J Comm 14:191-212

Papier M (2011) Residents 'take back' Wolfgat Reserve. Peoples Post, 15 March: 3. https://issuu.com/thepeoplespost/docs/peoples_post_mitchels_palin_edition_15-03-2011/3

Papier M (2012) Bush becomes a criminal haven. Peoples Post, 31 January: 1

Phelan J, Thornhill H (2010) Comprehensive Security Audit of the Biodiversity Management Branch of the City of Cape Town. Biodiversity Management Branch, City of Cape Town

Pooley S (2018) The long and entangled history of humans and invasive introduced plants on South Africa's Cape Peninsula. In: Queiroz AI, Pooley S (eds) Histories of bioinvasions in the Mediterranean. Berlin: Springer

Potgieter LJ, Gaertner M, Irlich UM, O'Farrell PJ, Stafford L, Vogt H, Richardson DM (2018) Managing urban plant invasions: a multi-criteria prioritization approach. Environ Manage. https://doi.org/10.1007/s00267-018-1088-4

Potgieter LJ, Gaertner M, Kueffer C, Larson BMH, Livingston S, O'Farrell PJ, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588.

RADAR (Research Alliance for Disaster and Risk Reduction) (2016) Los Angeles community risk assessment. Department of Geography and Environmental Studies, University of Stellenbosch (Stellenbosch).

Rebelo AG, Holmes PM, Dorse C, Wood J (2011) Impacts of urbanization in a biodiversity hotspot: Conservation challenges in Metropolitan Cape Town. S Afr J Bot 77:20–35. https://doi.org/10.1016/j.sajb.2010.04.006

Richardson DM, Cowling RM (1992) Why is mountain fynbos invasible and which species invade? In: van Wilgen BW, Richardson DM, Kruger FJ, van Hensbergen HJ (eds) Fire in South African mountain fynbos. Berlin: Springer-Verlag

Richardson DM, van Wilgen BW, Higgins SI, Trinder-Smith TH, Cowling RM, McKelly DH (1996) Current and future threats to biodiversity on the Cape Peninsula. Biodivers Conserv 5:607-647

SACN (2017) The State of Urban Safety in South Africa. A report of the Urban Safety Reference Group. South African Cities Network (Johannesburg). www.saferspaces.org.za

Serra G (2017) Raped and murdered teen: Accused's secret lair uncovered. IOL News, 5 July 2017. https://www.iol.co.za/news/south-africa/western-cape/raped-and-murdered-teen-accuseds-secret-lair-uncovered-10136313

Shackleton CM et al. (2006) Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. Human Ecol 35:113–127

Shackleton CM, McGarry D, Fourie S, Gambiza J, Shackleton SE, Fabricius C (2007) Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. Human Ecol 35:113–127

Shackleton RT, Le Maitre DC, Richardson DM (2015) Stakeholder perceptions and practices regarding Prosopis (mesquite) invasions and management in South Africa. Ambio 44:569-581

Shanahan DF, Lin BB, Gaston K, Bush R, Fuller RA (2015) What is the role of trees and remnant vegetation in attracting people to urban parks? Landsc Ecol 30:153–165

Shaw M, Louw A (1998) Environmental design for safer communities: preventing crime in South Africa's cities and towns. Institute for Security Studies (Pretoria)

Sullivan WC (2005) Urban place: reconnecting with the natural world. In: Bartlette P (ed) Forest, Savanna, City: Evolutionary Landscapes and Human Functioning. Cambridge: MIT Press

Swilling M (2010) Sustainability, poverty and municipal services: the case of Cape Town, South Africa. Sustain Dev 18:194-201. http://dx.doi.org/10.1002/sd.489

Thamm M (2011) What becomes of the broken-hearted: Parents of murdered Stellenbosch student vow to plough back. Daily Maverick, 11 September 2011. https://www.dailymaverick.co.za/article/2017-09-11-what-becomes-of-the-broken-hearted-parents-of-murdered-stellenbosch-student-vow-to-plough-back/#.WyoR66czaUk

van Wilgen BW (1981) Some effects of fire frequency on fynbos plant community composition and structure at Jonkershoek, Stellenbosch. S Afr For J 118:42–55

van Wilgen BW (2012) Evidence, perceptions, and trade-offs associated with invasive alien plant control in the Table Mountain National Park, South Africa. Ecol Soc 17:23. https://doi.org/10.5751/ES-04590-170223

van Wilgen BW (2009) The evolution of fire and invasive alien plant management practices in fynbos. S Afr J Sci 105:335–342

van Wilgen BW, Forsyth GG, de Klerk H, Das S, Khuluse S, Schmitz P (2010) Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. J Appl Ecol 47:631-638

van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L (2008) A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manage 89:336–349. https://doi.org/10.1016/j.jenvman.2007.06.015

van Wilgen BW, Richardson DM (1985) The effects of alien shrub invasions on vegetation structure and fire behaviour in south African fynbos shrublands: a simulation study. J Appl Ecol 22:955–966

van Wilgen BW, Scott DF (2001) Managing fires on the Cape Peninsula: dealing with the inevitable. J Mediterr Ecol 2:197-208

Walters L (2011) Management Plan for Wolfgat Nature Reserve. City of Cape Town, Biodiversity Branch (Cape Town)

Wilson J, Kelling G (1982) The police and neighborhood safety Broken windows. Atl Mon 127:29-38

Wolfe MK, Mennis J (2012) Does vegetation encourage or suppress urban crime? Evidence from Philadelphia, PA. Landsc Urban Plan 108:112-122. http://dx.doi.org/10.1016/j.landurbplan.2012.08.006

Yeld J (1994) Strangler's killing field to be cleared if 'Plain residents agree. The Argus, 8 February: 12

Zhou Y, Smith SJ, Zhao K, et al. (2015) A global map of urban extent from nightlights. Environ Res Lett 10:54011. https://doi.org/10.1088/1748-9326/10/5/054011

5.11 Supplementary material

Appendix H. Examples of vegetation associated with criminal activity. (a) The scene of a violent crime incident where the victim's body was discovered in dense native fynbos vegetation (Photo: Leon Knipe); (b) Illegal dumping of waste in dense *Acacia saligna* stands (Photo: L.J. Potgieter); (c) Abalone poachers hide their catch the native fynbos vegetation (Photo: W. Witte); (d) The alien tree *Quercus robur* L. (Fagaceae) used to gain access to a first-floor parking lot where vehicles are regularly broken into (Photo: L.J. Potgieter); (e) *Acacia saligna* stands are used as cover for prostitution (Photo: L.J. Potgieter).

Appendix I. Questionnaire.

1) What is your current employment position?

   Please specify your area of responsibility.

2) Are you responsible (either directly or indirectly) for managing invasive alien plants?

   Yes / No

3) Are you aware of any safety and/or security risks associated with <u>invasive alien plants</u> in your area of responsibility (e.g. criminal activity or illegal dumping)?

   Yes / No

   If yes, please specify the type of activity and the associated species. (If possible, please describe the location at which the activity(ies) occur).

4) Are you aware of any safety and/or security risks associated with <u>native plants</u> in your area of responsibility (e.g. criminal activity or illegal dumping)?

   Yes / No

   If yes, please specify the type of activity and the associated species. (If possible, please describe the location at which the activity(ies) occur).

5) Are you aware of any changes in human activity after invasive alien plants have been cleared (e.g. drop in criminal activity)?

   Yes / No

   If yes, please specify.

6) Criminal activity occurs in both native and invasive vegetation. It's the habitat structure that is important. Do you…

   Strongly agree; Agree; Neutral; Disagree; Strongly disagree

   Please explain why.

Chapter 6. A fine-scale assessment of the ecosystem service-disservice dichotomy in the context of urban ecosystems affected by alien plant invasions

This chapter has been submitted to the journal *Urban Ecosystems*.

Luke Potgieter[1], Mirijam Gaertner[1,2], Patrick J. O'Farrell[3,4], David M. Richardson[1]

[1] Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa.

[2] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

[3] Natural Resources and Environment CSIR, Biodiversity and ES Research Group, P.O. Box 320, Stellenbosch, 7599, South Africa.

[4] Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa.

6.1 Abstract

Management efforts aimed at ensuring the sustainable provision of ecosystem services (ES) are an important response to ongoing urbanization that is placing enormous pressures on natural resources within and around urban landscapes. Given the limited resources available for assessing urban ES in many cities, practical approaches for integrating ES in decision-making process are needed.

We apply remote sensing techniques (integrating LiDAR data with high-resolution multispectral imagery) and supplementary spatial data to develop a replicable approach for assessing the role of urban vegetation (including invasive alien plants) in providing ES and ecosystem disservices (EDS) at a local scale. We identify areas denoting potential management trade-offs based on the spatial distribution of ES and EDS using a local-scale case study in the city of Cape Town, South Africa. Situated within a global biodiversity hotspot, Cape Town must contend with widespread invasions of alien plants (especially trees and shrubs) amid complex socio-political challenges. This represents a useful system to examine the challenges in managing ES and EDS in the context of urban plant invasions.

Areas of high ES provision such as residential gardens and urban green spaces are characterized by the presence of large trees (for example carbon sequestration, shade and visual amenity). However, many of these areas also result in numerous EDS due to invasions of alien trees and shrubs –

particularly along rivers, in wetlands and along the urban edge where tall alien trees have established and spread into the natural vegetation (for example increased water consumption, increased fire risk and reduced soil quality). This suggests significant trade-offs regarding the management of species and the ES and EDS they provide.

The approach applied here can be used to provide recommendations and to guide city planners and managers to fine-tune management interventions at local scales to maximise the provision of ES.

Keywords: • Biodiversity • Biological invasions • Ecosystem disservices • Ecosystem services • Remote sensing • Trade-offs • Urban plant invasions

6.2 Introduction

The continuous growth in the number and size of urban areas and the increasing demand on resources and energy, poses great challenges for both ensuring human well-being in cities, and preventing the accelerating loss of biodiversity (Haase et al. 2014). Information on where different ES are being produced (i.e. the location of the production unit), is important for determining how vulnerable or resilient a city and its inhabitants are to potential disruptions in the generation of ES when exposed to change (Gómez-Baggethun et al. 2013).

Urban vegetation, particularly trees, provides numerous benefits that can improve environmental quality and human well-being in and around urban areas (Jim and Chen 2008; Nowak et al. 2008; Escobedo et al. 2010). However, urban ecosystems also generate functions, processes and attributes that result in perceived or actual negative impacts on human well-being (such as environmental, social, economic, health, visual and aesthetic problems), termed ecosystem disservices (EDS) (Roy et al. 2012; Shackleton et al. 2016; Potgieter et al. 2017; Vaz et al. 2017).

Mapping urban vegetation and the ES and EDS they provide is important for decision makers and managers, as it enables them to identify areas that should be prioritised for management. However, mapping plant species in urban environments presents numerous challenges due to their fine-scale spatial variation (Welch 1982) and high species diversity (native and non-native), often representing novel ecosystems in terms of their composition (Wu 2014). Urban ecological studies investigating the potential of high-resolution images for detection of urban ecosystems and their functions and services are rare. Global and regional studies, although useful for international policy and science have been conducted at too coarse a resolution to be very useful for the management of services at local planning levels. With the simultaneous development of more reliable analytical tools and freely accessible remotely sensed data at higher resolutions, remote sensing technology can make an important contribution in addressing the challenges of future urbanization growth through multiscale analyses of urban change patterns. Land cover information from remote sensing is an appropriate starting point. By augmenting these features with additional data, the state of ecosystems and their capacities to supply ES can be assessed and transferred to maps of different spatial and temporal scales.

Urban floras comprise a high proportion of alien plant species, many of which were intentionally introduced to provide, supplement or restore ES (Potgieter et al. 2017). Many of these species have subsequently spread and become invasive, in some cases negatively impacting on biodiversity and ES, or creating novel EDS (Potgieter et al. 2017; Vaz et al. 2017). Understanding the ES-EDS dichotomy in the context of urban landscapes is important for promoting the development of sustainable cities (Carpenter et al. 2006, Liu et al. 2007). Arguments for and against managing invasive alien plants (IAPs) in urban areas increasingly hinge on the contributions of IAPs to the delivery of ES and EDS (Vaz et al. 2017; Potgieter et al. 2018a). Managing urban ecosystems to enhance the provisioning of ES while reducing EDS is a major challenge. Approaches aimed at optimising specific ES exclusively may exacerbate associated EDS, and those aimed solely at reducing EDS may reduce ES (Shackleton et al. 2016). Given the limited resources available for assessing urban ES and EDS in many cities, practical approaches that integrate ES and EDS in the decision-making process are needed.

Predicting the effect of IAPs on ES is challenging as our knowledge of the mechanisms by which IAPs affect ES remain limited (Charles and Dukes 2007, Pejchar and Mooney 2009), and the metrics used to quantify ES are still crude (Naidoo et al. 2008; Bennett et al. 2009). This lack of understanding on how to predict, manage and measure the effects of IAPs on ES limits our ability to effectively prioritize and manage invasions. Remotely sensed maps of vegetation may be used to inform ES assessments and are increasingly applied in urban contexts. Although many methods have been proposed for quantifying ES (e.g. Gómez-Baggethun and Barton 2013), most are intended for quantifying ES at regional or national scales and focus on natural and rural landscapes.

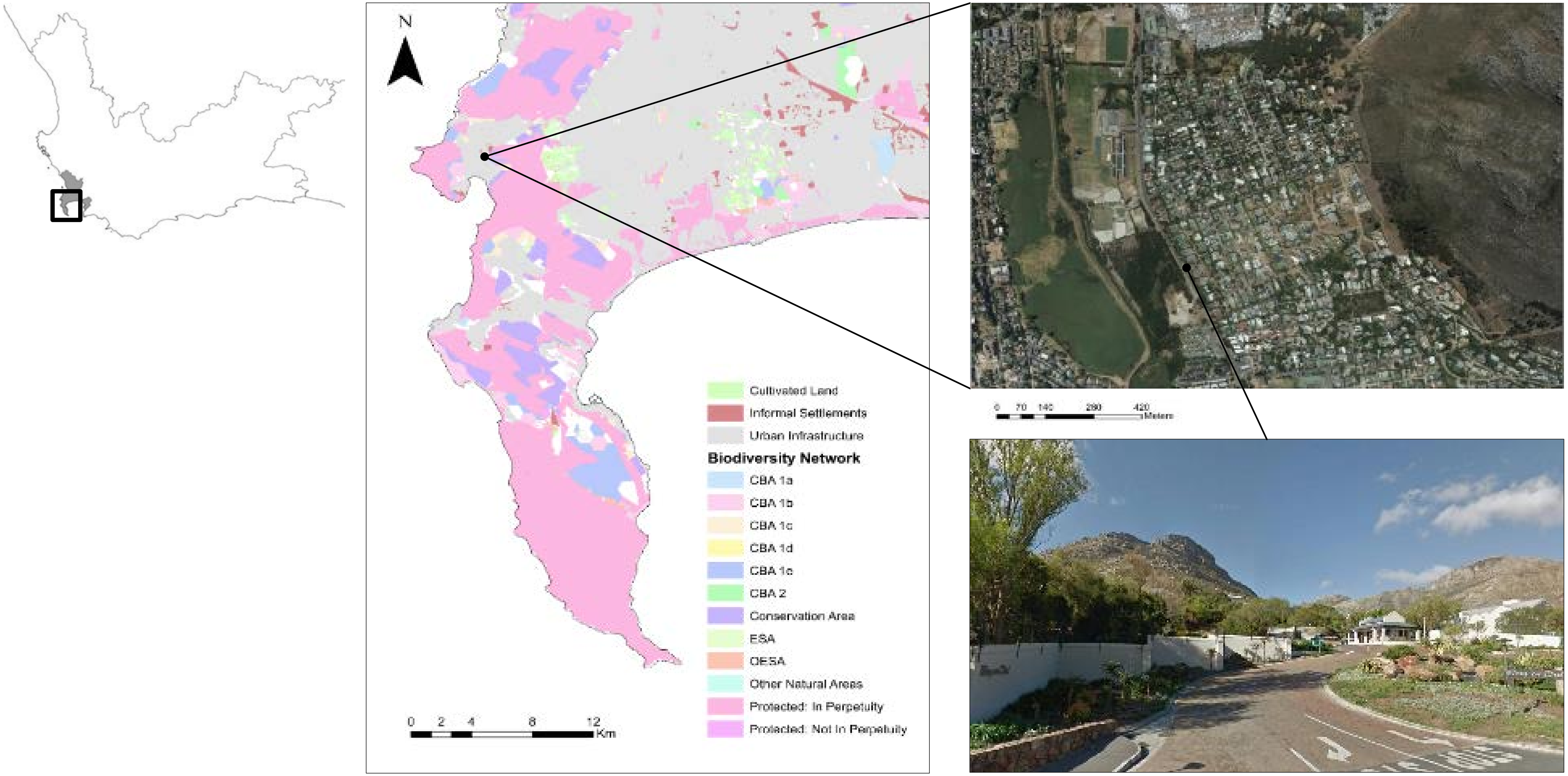
This study aims to develop a replicable approach to assess the role of urban vegetation (including IAPs) in providing ES and EDS at a local-scale, using the city of Cape Town as a case study. We apply remote sensing techniques (integrating LiDAR data with high resolution multispectral imagery) and supplementary spatial data to identify areas of high ES (and EDS) provision. We discuss the trade-offs associated with managing ES and EDS and the challenges in developing and implementing IAP management in urban areas. The approach applied in this study can be adopted by managers in all urban settings to guide the selection and prioritization of areas for ES management and this neglected local scale.

6.3 Methods

6.3.1 Study area

The study site comprises an area (± 2km^2 in extent) in the residential suburb of Hout Bay, located in the city of Cape Town, South Africa (Fig. 6.1). It is bordered by Table Mountain National Park in the east and by the Atlantic Ocean to the south. The dominant natural vegetation in the City is fynbos, a short shrubland vegetation type which forms part of the Cape Floristic Region and holds exceptionally high diversity and endemism. The fynbos biome is characteristically depauperate of native trees while widespread invasions of alien trees and shrubs such as Australian acacias, hakeas and pines dominate many parts of the landscape (Richardson and Cowling 1992), threatening the delivery of ES (van Wilgen et al. 2008; van Wilgen 2012). For example, *Acacia saligna* which was introduced to stabilise mobile sands has spread significantly beyond the borders of formal plantings; it now impacts negatively on biodiversity, surface water runoff, and exacerbates the problem of wildfires (van Wilgen and Richardson 1985; Le Maitre et al. 2002; Yelenik et al. 2004; 2007). However, despite the negative impacts of IAPs, some species still provide benefits to many city residents (Gaertner et al. 2016; Potgieter et al. 2018b) such as recreation, shade and visual amenity. This situation provides a unique opportunity to examine the applicability of remote sensing techniques for the spatially-explicit assessment of the role of urban vegetation (especially alien trees) in providing ES (and EDS) within this fine scale urban context.

Following the spatially entrenched apartheid form of South African cities, Cape Town remains highly divided, socially and spatially (Watson 2009). Rapid growth in "informal settlements" (shanty towns) is a feature of urbanisation in South Africa - a vestige of apartheid policies and practices. While most informal settlements are located on the urban peripheries or in and around areas of low-cost housing, some have developed in middle- and upper-class neighbourhoods, such as Hout Bay (see Ballard 2004). Three very disparate communities presently reside within Hout Bay. The largely white middle- to upper income residents live in the valley and along the mountain slopes in homes that reflect a high socio-economic position. The harbour community consists of both lower-income coloured residents who reside in hostels and flats, and middle-income white and coloured residents, who are located higher up the slopes of Hangberg in an area known as Hout Bay Heights. The third community, which has developed most recently, is the informal settlement of Imizamo Yethu. Established on an old forestry site in 1991 to accommodate people who were illegally occupying land elsewhere in Hout Bay, Imizamo Yethu is characterized by poor service provision, declining living conditions, environmental unsustainability, and poverty.



*CBA – Critical Biodiverse Areas; ESA – Ecological Support Areas; OESA – Other Ecological Support Areas.

Figure 6.1. Location of the study area (±2km^2) within the city of Cape Town municipal boundary in the Western Cape, South Africa.

The study site has several key features that make it a useful study system: a) a range of land cover/land uses; b) significant socio-economic stratification; c) the urban-wildland interface; d) diversity and abundance of alien and native vegetation; and e) different plant invasion densities within the urban fabric and outside the urban edge.

6.3.2 LiDAR data and multispectral imagery

The LiDAR (Light Detection and Ranging) system is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. It provides three-dimensional data with high levels of horizontal and vertical accuracy. A key advantage of LiDAR over traditional optical sensors is its ability to estimate the heights of trees and shrubs with a high vertical accuracy. There are, however, difficulties in accurately classifying vegetation from other land cover features such as buildings based solely on height information. One therefore needs to combine both multispectral satellite imagery and height information obtained from LiDAR data for classification of detailed vegetation components. The airborne LiDAR data collected in February 2014 was provided by the Centre for Geographic Analysis and SPOT-7 images (consisting of red, green, blue and near-infrared image bands) were acquired from the South African Space Agency (SANSA) (image acquisition: 11 November 2016).

Using ArcGIS 10.4, a normalized digital surface model (nDSM) was generated from LiDAR cloud point data (with a spatial resolution of 1.5m) to extract absolute height information by subtracting the digital surface model (DSM) from the digital terrain model (DTM). The nDSM represents the relative object height information for features i.e. the LiDAR data has been corrected relative to the bare earth terrain. The next step involved calculating the normalized difference vegetation index (NDVI) on the near-infrared band and red band of the SPOT-7 image. All pixels with NDVI greater than 0.25 were considered to have significant amounts of vegetation and were included in the analysis. The methodology followed to develop the land classification and final ecosystem service-disservice maps is outlined in Figure 6.2.

For the segmentation and classification of the LiDAR-derived nDSM and SPOT-7 imagery, the object-based image analysis software eCognition® Developer 8.7 (Definiens 2005) was used. We first used multiresolution segmentation to identify objects with correlated characteristics in terms of reflectance and height. In this step, we fuse the nDSM and the NDVI derived from the SPOT-7 imagery for the segmentation process. This method identifies geographical features using scale homogeneity parameters obtained from the spectral reflectance and the height value in the nDSM. Segments were classified into the following six classes based on the mean nDSM height and NDVI in each object: 'Bare ground': nDSM < 0.25m, NDVI < 0.25; 'Grass': nDSM < 0.25m, NDVI >= 0.25; 'Shrubs': nDSM >= 0.25m

< 3m, NDVI >= 0.25; 'Infrastructure': nDSM >= 0.25m, NDVI < 0.25; 'Trees': nDSM >= 3.0m < 10m, NDVI >= 0.25; 'Tall trees': nDSM >=10m, NDVI >=0.25. The final land classifications are detailed in Figure 3a.

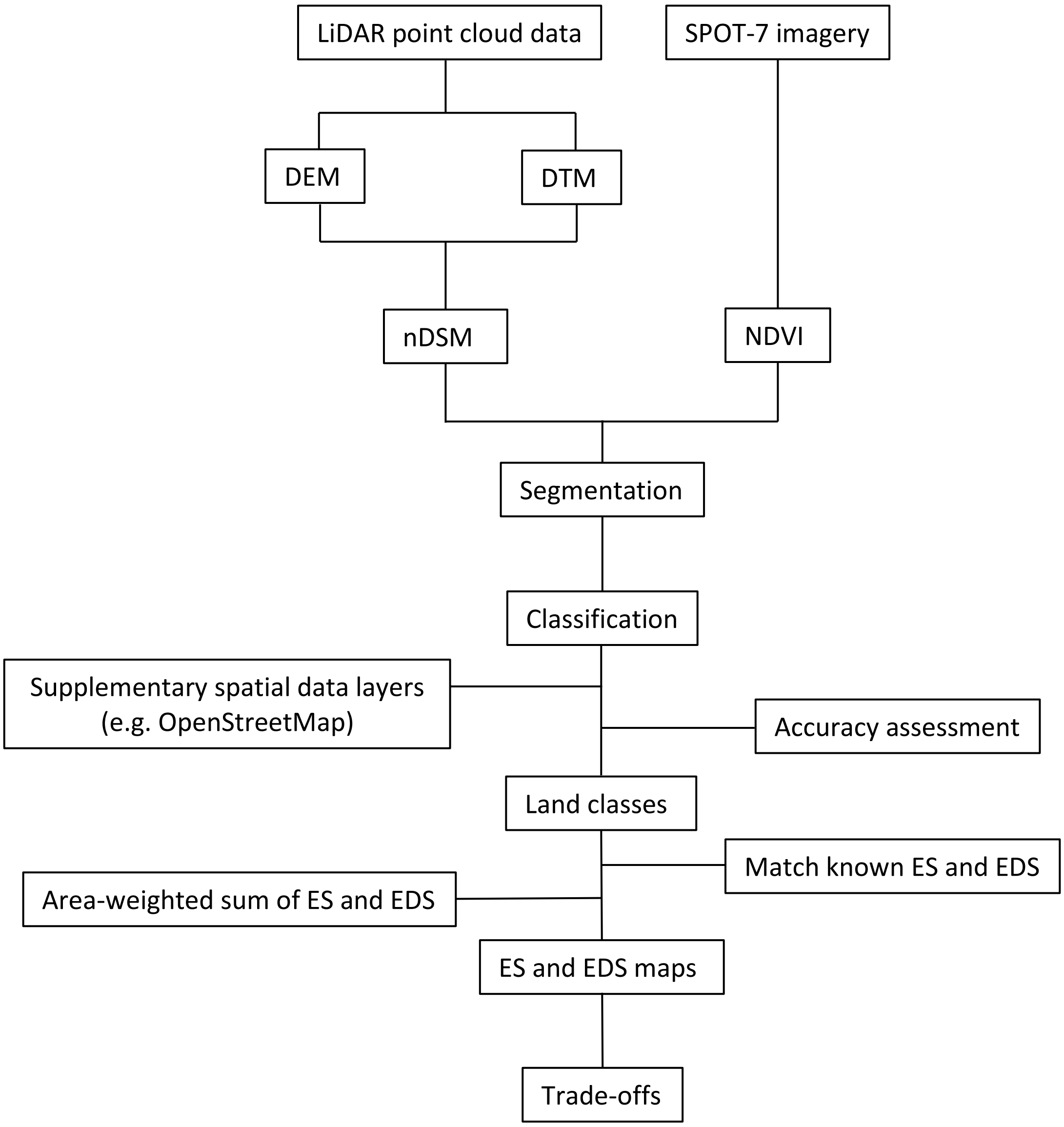


Figure 6.2. Schematic representation of the methodology followed to develop the land classification and final ecosystem service-disservice map.

A classification accuracy assessment was carried out using a class area-weighted, stratified random sample of 168 points and validated using ground truthing. The points selected for each class were spatially dispersed and proportional to their importance in terms of area covered. The final land classification map was adjusted to account for the classification errors. A confusion matrix was computed followed by the estimation of the overall accuracy and the kappa coefficient.

6.3.3 Ecosystem service and disservices

Among the main effects of human activities on the environment are land use and resulting land cover changes. Such changes impact the capacity of ecosystems to provide services to the urban residents. Land cover was used as a proxy measure of ES - the type of land cover, use, and access determines whether a specific ES can be provided or reduced. The mapping of land cover gives a first assessment basis for the potential ES and EDS provision or reduction. Remote sensing provides useful data for land use/land cover classification.

ES and EDS were matched with our final land classification (described in Section 6.3.2) derived from the remotely sensed LiDAR and multispectral image classification, aerial photographs, and supplementary spatial data (OpenStreetMap). ES and EDS were categorised according to Potgieter et al. (2017) and those associated with each respective land class applicable to the study area are detailed in Table 6.1. A grid comprising 100 by 100 m cells was laid over the study area. The area covered by each land class within each grid cell was calculated and weighted based on the sum of corresponding ES and EDS detailed in Table 6.1. As no information was available on the importance of the different ES or EDS they were weighted equally in the assessment (Wainger et al. 2010). For example, a grid cell may comprise tall trees in a residential garden which provide a range of ES: recreation, spiritual interaction, visual amenity, provision of sense-of-place, increased property value, shade provision, climate regulation, improved air quality, carban sequestration, stormwater runoff mitigation, habitat provision, increased nutrient cycling, pollination, primary production and soil formation. Conversely, they may also result in EDS: increased maintenance costs, generation of green waste, increased water consumption, pollen allergies, infrastructural damage and safety hazard. Such ES and EDS were acquired from the literature and cited in Table 6.1 accordingly. The area-weighted sum of ES and EDS per land class within the grid cell is calculated.

Separate maps detailing areas of low to high provision of ES and EDS were developed and combined to form an overall depiction of ES-EDS provision i.e. areas with high provision of both ES and EDS are likely to result in trade-offs regarding the management of species and the ES and EDS they provide. This was achieved by subtracting the overall (net) area-weighted EDS from the net area-weighted ES for each grid cell.

While the relationship between biodiversity and the provision of ES remains contested (e.g. Egoh et al. 2009), most studies associate high species richness with a high levels of ES provision (Balvanera et al. 2006; Benayas et al. 2009). Maintaining biodiversity is considered as an efficient way to enhance ES. Our study area comprises key biodiversity areas (Fig. 6.1) and these were included in the ES-EDS spatial assessment i.e. areas of high biodiversity correspond to areas of high ES provision.

6.3.4 Additional information and tools

We incorporated supplementary spatial data from different sources to improve the accuracy of our classification (see Table 6.2). These included spatial data from OpenStreetMap (OSM), invasive alien plant (IAP) density data from the City of Cape Town Invasive Species Unit (Biodiversity Management Branch; hereafter ISU), and multiple spatial data layers obtained from the City of Cape Town's open data portal.

Table 6.1. Ecosystem services and disservices associated with urban vegetation within the study area.

Ecosystem Service Category	Ecosystem Services	Example	Reference
Cultural	Recreation	Picnicking under tall shade-providing trees (e.g. *Pinus pinea*)	Potgieter et al. (2018b)
	Physical, intellectual and spiritual interactions with nature, including aesthetic values, inspiration and cognitive development, and spiritual enrichment	Well managed urban green spaces with abundant vegetation	Bastian et al. (2012); Dobbs et al. (2011)
	Visual amenity, ornamental purposes and landscape re-greening	Private residential gardens	Carruthers et al. (2011); Dickie et al. (2014); Kull et al. (2011); Le Maitre et al. (2011); Shackleton et al. (2007)
	Provision of a 'sense of place'		Dickie et al. (2014)
	Heritage	*Pinus pinea* trees planted in the 17th century by the early settlers, have significant heritage value	
	Increased property values		Soares et al. (2011)
Provisioning	Firewood	Trees such as *Acacia* sp., *Eucalyptus* sp. or *Pinus* sp. can be used for firewood	Dickie et al. (2014)
	Construction material	Trees such as *Eucalyptus* sp. or *Pinus* sp. can be used for poles	Dickie et al. (2014)
	Medicinal value	Essential oils provided by *Eucalyptus* spp.	
	Fodder	*Eucalyptus camaldulensis* used as fodder	Bernholt et al. (2009)
	Food	*Eucalyptus* spp. (especially *E. cladocalyx*) are important for honey production	
Regulating	Shade	Shade from tall trees with wide canopy such as *Pinus pinea*	Pooley (2014); Potgieter et al. (2018b)

	Climate regulation	Cooling effects (by transpiration) of street trees such as *Platanus x acerifolia*	Jim and Chen (2009)
	Air quality	Reduced emissions of air pollutants by *Platanus x acerifolia*	McPherson (2003)
	Flood attenuation	Wetlands	
	Barrier	*Pinus* spp. used as a barrier plant	
	Carbon sequestration	Trees such as *Platanus x acerifolia* sequester carbon	Potgieter et al. (2017)
	Nitrogen fixation	*Acacia* sp. fix nitrogen, enriching the soil	de Wit et al. (2001); Dickie et al. (2014); Qiu, (2015); van Wilgen and Richardson (2014)
	Erosion control	Erosion control by trees such *Ailanthus altissima*	Kowarik and Saumel (2007); Sladonja et al. (2015)
	Energy saving	Changes in building energy use from shade trees such as *Platanus x acerifolia*	McPherson (2003)
	Stormwater runoff mitigation		
Supporting	Habitat provision	Tall alien trees such as eucalypts and pines provide nesting sites for birds with which many urban dwellers can enjoy encounters.	McPherson et al. (2011)
	Nutrient cycling		
	Pollination		
	Primary production		
	Soil formation		

Ecosystem Disservice Category	**Ecosystem Disservice**	**Example**	**Reference**
Cultural and Aesthetic	Loss of sense of place and aesthetic values*	Loss of sense of place and aesthetic values due to the presence of invasive alien plant species	de Wit et al. (2001); Le Maitre et al. (2011)
	Unattractive species or landscapes	Ugly’ landscapes dominated by *Acacia* species. Neglected vacant lots overgrown with ‘weedy’ vegetation	Carruthers et al. (2011)
	Obscuring good views	Tall trees such as *Pinus* sp. can block good views	
Economic Problem	Increased maintenance costs	Grooming of street trees or sweeping up of leaf litter in streets	Roy et al. (2012)
	Cost of irrigation	Alien plants in gardens require supplementary irrigation during the dry season	
	Reduced property value*	Invasive plants blocking good views can reduce property prices	
Environmental Problem	Generating green waste	Increased green waste from gardens	

	Increased water consumption	Increased water consumption by alien and invasive trees such as *Acacia* spp. and *Eucalyptus* spp.	Carruthers et al. (2011); Kull et al. (2011); Le Maitre et al. (2002), (2011); van Wilgen and Richardson (2014)
	Reduced soil quality*	Modification of soil quality and promotion of soil erosion	de Wit et al. (2001); Shackleton et al. (2014)
	Disruption of soil-nutrient cycling, carbon and nitrogen fixation*	Invasive alien trees and shrubs such as *Acacia* spp. fix nitrogen	Yelenik (2004); Gaertner et al. (2014); Qiu (2015)
	Displacement of native plant species / Reduced species richness*	Invasive alien trees and shrubs spreading into natural areas can disrupt native fynbos plant species and continued spread may reduce native species richness	Carruthers et al. (2011); Dickie et al. (2014); Kull et al. (2011); Le Maitre et al. (2011); Shackleton et al. (2016); van Wilgen and Richardson (2014); Vicente et al. (2013)
Health	Reduced air quality*	Emissions of Biogenic Volatile Organic Compounds reducing air quality	Potgieter et al. (2017)
	Increasing attack by associated insects and other animals	Areas with dense vegetation can harbour potentially dangerous animals such as venomous snakes	Roy et al. (2012)
	Pollen allergies	Pollen allergy and/or dermatitis caused by *A. altissima*, *Acacia dealbata*, *Cortaderia selloana*, and *Schinus terebinthifolius*	Pyšek and Richardson (2010)
	Poisoning	Cardiac problems and poisoning from *Echium plantagineum*	Pyšek and Richardson (2010)
Leisure and Recreation	Reduced recreation*	Presence of invasive species considered unpleasant for recreation	
	Physical injury	Physical injury through contact with plant spines or thorns	Pyšek and Richardson (2010); Shackleton et al. (2007), (2014)
Material	Infrastructural damage	Roots of *Ailanthus altissima* damaging paved surfaces and boundary walls	Celesti-Grapow and Blasi (2004)
Safety and Security	Fears of insects and other animals	Areas with dense vegetation can be invoke fear due to the possible presence of distasteful animals such as insects or snakes	Vaz et al. (2017)
	Increased crime risk	Criminal activity in dense vegetation close to informal settlement	Potgieter et al. (2018a)
Safety and Security / Environmental Problem	Increased fire risk (safety risk to infrastructure, but also impacting on native plants due to increased frequency and intensity of fires)	Increased fire risk due to trees invasions along the urban edge	Gaertner et al. (2014); Le Maitre et al. (2011); van Wilgen and Richardson (2014); Potgieter et al. (2018b)
Safety and Security / Material	Safety hazard	Tall trees blown over in strong winds	Potgieter et al. (2018a)

*Ecosystem disservices resulting from a reduction in ecosystem services.

Table 6.2. Supplementary spatial data and corresponding sources included in the classification process.

Spatial Data	Data Source
Indigenous vegetation remnants	City of Cape Town data portal; South African National Biodiversity Institute (SANBI) BGIS data portal
Biodiversity Network (CBA Rank)	SANBI BGIS data portal
Dams, aquifers, rivers, wetlands	City of Cape Town data portal; Invasive Species Unit (August 2016)
Flood prone areas	Directorate: Disaster Risk Reduction; Invasive Species Unit (August 2016)
Roads, buildings, points of interest	OpenStreetMap
Urban edge	City of Cape Town data portal
Community parks	City of Cape Town data portal
Greenbelts	City of Cape Town data portal
IAP density data	Invasive Species Unit (August 2016)

6.3.4.1 OpenStreetMap

Volunteered geographic information (VGI) is geographic data collection primarily acquired through the voluntary efforts of citizens. One of the most utilized and popular VGI-platforms is OpenStreetMap (OSM) (http://www.osmfoundation.org), a project providing freely exportable maps of cities worldwide. Data in OSM are sourced from a community of volunteers that create spatial data by tracing on non-copyrighted, aerial imagery or generating data directly using GPS. Maps include information on roads, railways, buildings, waterways and points of interests such as parks, commercial centres, leisure centres and commercial activities. Although it is likely that the coverage and quality of such data will vary across locations it has the potential to provide an important research tool, particularly where data from more traditional sources are limited or non-existent.

The OSM vector data for the study area was downloaded in July 2018 using the ArcGIS Editor for OSM in ArcGIS 10.4. All relevant OSM thematic layers were included in the classification process.

6.3.4.2 Invasive alien plants

We obtained spatial data (acquisition date April 2018) on IAP density from the ISU; such data is used to inform invasive species management across the City (Gaertner et al. 2016). The ISU conducts clearing operations in areas managed by multiple departments within the City, including many conservation areas. At each area identified as a priority for control operations, the ISU conducts a site assessment in which management units (MU) are delineated and surveyed and baseline information captured (see Potgieter et al. 2018). All IAPs present within each MU are listed and categorised according to predefined size categories used to describe the age of plants. The density of alien plant cover (% cover) is also estimated for each MU.

IAP cover was delineated using 1) density data from ISU site assessments and 2) the total area of trees and tall trees (>3 m) outside of the urban edge (as per our land classification) - fynbos is typically depauperate of trees (Rundel et al. 2014) and plant species taller than 3 m are likely to be alien (Richardson et al. 1996). The area covered by these delineations within each grid cell was calculated and weighted based on the sum of corresponding ES and EDS detailed in Table 6.1.

6.4 Results

An accuracy assessment of the land classification map yielded an accuracy of 85.71% and a Kappa coefficient of 0.826 (Table 6.3). The 'Bare ground' class yielded the lowest accuracy with a user's accuracy of 75.86%, followed by 'Grass' at 76.92%. The discrimination of bare ground proved problematic at times as it was confused with dry or patchy grass. Furthermore, there were several tree-covered areas that were confused with shrubs or tall trees, largely due to minor height discrepancies.

Table 6.3. Accuracy matrix for the land classification.

Class	Ground truth						User accuracy (%)
	Bare Ground	Grass	Shrubs	Trees	Tall Trees	Infrastructure	
Bare Ground	22	2	1	1	0	3	75,86
Grass	4	20	2	0	0	0	76,92
Shrubs	0	2	36	1	0	0	92,31
Trees	0	0	1	31	1	0	93,94
Tall Trees	0	0	0	2	17	0	89,47
Infrastructure	3	0	1	0	0	18	81,82
Producer's accuracy (%)	75,86	83,33	87,80	88,57	94,44	85,71	

Total accuracy: 85.71%; kappa coefficient: 0.826

Figure 6.3. a) Land classification following LiDAR data and SPOT-7 image fusion; b) Areas of high to low ecosystem service provision (per 100 m grid cell); c) Areas of high to low ecosystem disservice provision (per 100 m grid cell); d) Ecosystem service-disservice dichotomy showing areas of high to low ecosystem service-disservice provision - denoting potential management trade-offs.

6.4.1 Ecosystem services

Areas of high provision of ES were characterized by the presence of large trees, which can sequester and store more carbon, provide more shade for people, and habitat for fauna (Table 6.1). These areas occur predominantly along the urban edge (comprising invasive alien trees which have established and spread into the natural vegetation) and in the gardens of (affluent) residential properties (Fig. 6.3b). Other areas of high ES provision include urban green spaces such as community parks, river networks and wetlands. Such areas are important in creating recreational spaces, reducing flood risk and cooling urban micro-climates (Table 6.1).

Areas of lowest ES provision occur in the township and informal settlement of Imizamo Yethu which is characterised by little to no vegetation, dense informal structures, and bare ground. Other areas of low ES provision included infrastructure such as large building surrounded by impervious surfaces and bare ground (Fig. 6.3b).

6.4.2 Ecosystem disservices

Areas resulting in high EDS coincide with areas densely invaded by IAPs – particularly where alien plants invade along rivers and within wetlands (Fig. 6.3c). Other areas with high EDS occur along the urban edge where tall alien trees have established and started to spread into the natural vegetation. EDS include increased water consumption (environmental problems), increase fire and crime risk (safety and security), reduced soil quality (environmental problems), or a loss of sense of place and aesthetic values (cultural and aesthetic) (Table 6.1).

Moderate EDS are associate with areas comprising trees and shrubs (native or alien) such as private gardens, public open space and vacant lots. This is due to EDS such as increased water consumption (environmental problems), increased maintenance costs (economic problems), safety hazard (safety and security), infrastructural damage (material) or obscuring good views (cultural and aesthetic) (Table 6.1).

Areas associated with low EDS occur outside the urban edge in uninvaded natural vegetation. Areas comprising dense infrastructure (such as the informal settlement of Imizamo Yethu), impervious surfaces or bare ground resulted in moderate EDS. Such areas are more acutely associated with low ES provision (e.g. lack of shade, recreation and sense of place) than high EDS, however, characteristics of such an environment can create EDS (e.g. bare compacted ground or impervious surfaces can enable flooding and increase the ambient temperature).

6.4.3 Trade-offs

Areas with high provision of both ES and EDS are likely to result in trade-offs regarding the management of species and the ES and EDS they provide (Fig. 6.3d). Many of the associated EDS are due to the presence of IAPs - several grid cells identified as important for the provision of ES, comprise IAPs. For example, grid cell 68 contains a river and wetland (vital for ES such as water provision, groundwater recharge and flood attenuation), but is densely invaded by alien aquatic plants, such as *Nasturtium officinale* and *Myriophyllum aquaticum*, which can reduce stream flows and water quality (Fig. 6.3d). Grid cell 108 comprises many alien trees and shrubs such as *Acacia* sp., *Eucalyptus* sp. and *Pinus* sp., which provide ES such as carbon sequestration, firewood, habitat provision and shade. However, these taxa are invasive and create EDS such as increased water consumption, increased fire risk and the displacement of native plant species.

Residential gardens represent areas of moderate ES-EDS provision i.e. there is moderate provision of both ES and EDS (Fig. 6.3d). A high proportion of urban vegetation provides many key ES such as carbon sequestration, shade, and visual amenity. However, there are several associated EDS such as increased water consumption, production of green waste, and increase maintenance and clean-up costs.

6.5 Discussion

Developing approaches that can holistically map ES (and EDS) have been identified as a major research gap (de Groot et al. 2010). We assessed multiple ES and EDS, fusing LiDAR data with high resolution multispectral imagery, and applying supplementary spatially explicit data proxies at a local scale to identify areas of high and low ES and EDS provision. In doing so, we also identified areas denoting potential management trade-offs. This approach can be applied to different urban areas where baseline information on urban vegetation is available and can be used to prioritise the conservation of areas of high provision of ES to maintain human well-being. Conversely, areas of high EDS or low ES provision could be prioritised for management interventions that restore and improve human well-being.

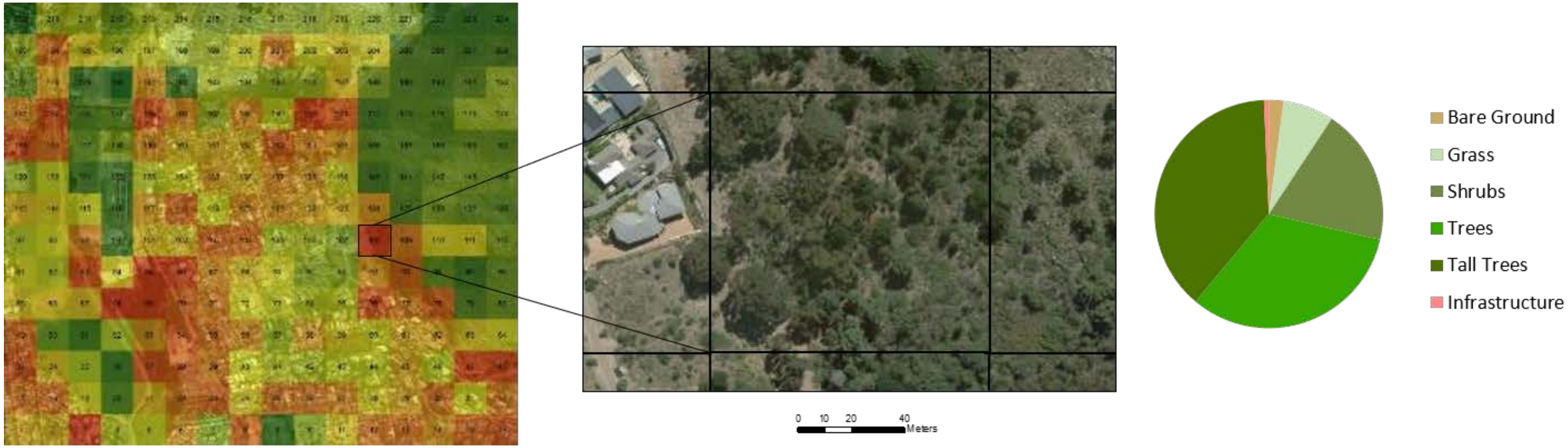
6.5.1 Ecosystem service – disservice dichotomy

Areas of high ES provision such as residential property gardens and urban green spaces are characterized by the presence of large trees (Fig. 6.3). Urban trees provide diverse aesthetic, economic, health, psychological and social benefits for urban residents (Dwyer et al. 1992; Burden 2006; Good 2008) including: mitigating carbon pollution, improving urban air quality, attenuating storm-water flooding, conserving energy, and reducing noise, among others (Table 6.1). However, many of these areas also result in numerous EDS (e.g. increased fire risk and water consumption) due to invasions of alien trees and shrubs – particularly along rivers and within wetlands and along the urban edge where tall alien trees have established and started to spread into the natural vegetation. This suggests significant trade-offs regarding the management of species and the ES and EDS they provide.

6.5.2 Trade-offs and invasive alien plants

Urban planners and managers face many trade-offs in the decision-making process as each area (regional or local) is governed by different ecological, economic, and social elements. Trade-offs exist when the real or perceived benefits associated with a species are weighed against its potential to generate significant negative impacts. Stakeholders in cities often have strongly divergent views about the impacts and benefits of IAPs, and as a result, significant conflicts over the management of IAPs are emerging (Dickie et al. 2014; Gaertner et al. 2017). IAPs may provide provisioning ES (e.g. firewood), but at the expense of biodiversity, which can lead to conflicts over whether to manage for the former or the latter (van Wilgen, 2012). Consequently, many IAPs within urban areas may need to be tolerated at specific sites for a combination of social and pragmatic reasons (Gaertner et al. 2016). Careful evaluation of ES and EDS provided by IAPs may allow conflicts to be mitigated and managed in more efficient ways using ES as a conceptual framework for debate and decision (Dickie et al. 2014; Potgieter et al. 2017).

Several grid cells identified as important for the provision of ES, comprise IAPs which can in turn result in numerous EDS (Fig. 6.4). Residential properties along the urban edge share a border with fynbos vegetation here (Alston and Richardson 2006), and these properties are a regular source of alien plant propagules, which disperse, establish and spread into the natural vegetation, posing a risk to biodiversity. While providing several ES such as firewood and carbon sequestration, the increase in biomass resulting from alien plant invasions close to urban infrastructure represents a substantial fire risk (Fig. 6.5), threatening property and the safety of people (van Wilgen and Scott 2001; van Wilgen et al. 2012). Furthermore, invasive alien trees and shrubs alter the vegetation structure (forming dense stands and growing taller than the surrounding fynbos vegetation; van Wilgen and Richardson, 1985), providing cover for vagrants and those engage in criminal activity. Potgieter et al. (2018a) found that factors related to safety and security are most important for setting spatially-explicit management priorities in Cape Town. Accordingly, invaded areas along the urban edge (e.g. Fig. 6.5) should receive a high priority for management. Areas identified as important in the provision of ES (e.g. urban green spaces and surrounding natural vegetation) should be monitored to ensure the continued provision of ES and maintenance of biodiversity.



Ecosystem services			**Ecosystem disservices**	
Heritage	Firewood**	Energy saving	Reduced species richness	Pollen allergies*
Visual amenity	Medicine*(**)	Runoff mitigation	Increased water consumption	Reduced air quality (bVOC emissions)*
Sense of place	Climate regulation	Shade	Disruption of soil-nutrient cycling	Increased attacks from animals
Recreation	Air quality	Nitrogen fixation*	Increased maintenance costs	Reduced recreation
Spiritual enrichment	Flood attenuation	Habitat provision	Increased clean-up costs	Leaf litter/debris*
Construction material**	Barrier/windbreak	Nutrient cycling	Reduced property value	Increased crime risk
Fodder*(**)	Carbon sequestration	Pollination*	Loss of sense of place and aesthetic values**	Increased fire risk
Food*(**)	Erosion control	Primary production	Unattractive species or landscapes**	Safety hazard
		Soil formation	Obscuring mountain views**	Fear of animals**

*Species level information is required to confirm ecosystem service / ecosystem disservice provision (bVOC = Biogenic Volatile Organic Compound).
**Stakeholder engagement is required to determine ecosystem service provision.

Figure 6.4. An example of the ecosystem service-disservice trade-offs associated with invasive alien plant species at the urban-wildland interface.

Figure 6.5. Google Street View can be used to determine key vegetation characteristics and associated ecosystem services and disservices at specific locations. Tall, dense stands of invasive *Acacia* sp., *Eucalyptus* sp. and *Pinus* sp. behind a residential property on the urban edge are visible; these present a substantial fire risk (imagery date: 09/2009). A pile of wood (likely to be used as firewood) collected from these invasive stands is also clearly visible, highlighting an ecosystem service provided by the invasive alien trees.

6.5.3 Decision-making and management

The nature of people and their discount rates that favour immediate over delayed gratification may be driving decisions about ES, even when such decisions might interfere with ES that are necessary for the long-term sustainability of human well-being (Foley et al. 2005). The emphasis on provisioning ES could be the consequence of their importance being more tangible and identifiable by societies, whereas the importance of cultural, regulating, and supporting services are more difficult to quantify (Potgieter et al. 2017). Particularly, research on cultural ES are generally subjective and socially value-laden (related more to the observer than to ecosystem conditions) as each individual or each group of individuals has different value systems and demands (MA 2005). Various aspects like experience, habits, belief systems, behavioural traditions, and general political and socio-economic status should be considered (Shackleton et al. 2018; Vaz et al. 2017). Social values relate to preferences, importance, measures and principles and assessment need to be plural, participatory and best embedded within transdisciplinary research. Indeed, community engagement is crucial, and quantifications based on interviews, questionnaires or additional information sources can strengthen ES assessments and better inform management strategies (Sherrouse et al. 2010).

Each urban area presents a unique set of challenges requiring city-specific management approaches (Irlich et al. 2017). The challenge in prioritising areas for management at the local scale is to weigh considerations relating to biodiversity conservation, social trade-offs, and ES (and EDS). For example, managers must decide whether to prioritise areas which have negative indirect long-term impacts on biodiversity and regulating and supporting services (such as increased soil erosion and reduced soil quality) or to prioritise areas based on the negative direct short-term impacts on provisioning services (such as water supply).

Decisions must be made on whether to manage to enhance ES provision, or to minimise EDS - high priority areas for management include those which result in EDS and a reduction in ES provision. For example, areas along the urban edge invaded with alien trees and shrubs which negatively impact on biodiversity and ES (such as the displacement of native plant species and reduced soil quality) and result in EDS such as increase fire and crime risk (Potgieter et al. 2018a, b). Such decisions are largely context-specific, and managers need to consider the knock-on effects when reducing EDS or enhancing specific ES, as other ES may be indirectly disrupted, or novel EDS created. For example, planting trees in the informal settlement of Imizamo Yethu with the intention of providing ES (such as shade) and enhancing human well-being may have the opposite effect as trees may blow over in high winds and increase the risk of fires. Such decisions need to be transparent and must consider opinions of a wide range of stakeholders including the public and those involved in urban land-use and ecosystem management decisions (Novoa et al. 2018).

Careful consideration must also be given to the existing supply and demand of ES beneficiaries and their perceptions of ecosystem components (Burkhard et al. 2012; Shackleton et al. 2018). Stakeholder engagement is needed to gauge the ES demand and this information can be aligned with spatial assessments of ES provision to identify areas that have the potential to unlock the required ES to meet this demand. Importantly, however, ES demand is likely to be highly variable and context-specific (e.g. along the socio-economic gradient) (Syrbe and Grunewald 2017). Understanding the ways in which people perceive nature is also crucial for developing effective management strategies to conserve and maintain biodiversity, ES and human well-being (Shackleton et al. 2018). This is especially important in urban areas which typically have a greater number and diversity of stakeholders compared to rural areas (Gaston et al. 2013). Indeed, perceptions of urban vegetation and the ES and EDS they provide can differ markedly between individuals or groups of people (Shackleton et al. 2016; Kueffer and Kull 2017; Potgieter et al. 2018). For example, one person may find a tall pine tree to be aesthetically pleasing and a source of shade whereas another person may regard it as a source of unwanted debris, and obstructed views. Such divergent views complicate management efforts.

6.5.4 Socio-economic context

Spatial heterogeneity in the provision of ES is not only a result of the physical environment, but also of the socio-economic conditions that exist within urban centres (de Groot et al. 2010). Areas of lowest ES provision occur in the township and informal settlement of Imizamo Yethu which is characterised by little to no vegetation, dense informal structures, impervious surfaces and bare ground (Fig. 6.3b). These features result in low ES provision and can facilitate flooding and increase the ambient temperature.

Affluent areas have the capacity and resources to invest in green infrastructure such as plantings in private gardens. In so doing they can contribute to the provision of additional ES such as carbon sequestration, improved air quality and stormwater runoff mitigation (from which other residents may benefit). However, lower income areas such as informal settlements do not have the same capacity or resources and rely solely on existing ES provided by the immediate environment. Indeed, this is a common theme in many rapidly urbanising African cities in which many people are still highly reliant on natural resources (including IAPs). The urban poor lack an adequate supply of basic services like electricity, healthcare, sanitation, waste disposal, and water (Goodness and Anderson 2013). Additional measures are needed to improve the supply of ES to these areas. However, careful evaluation of the demands of the communities is required as there are likely to be divergent viewpoints and competing objectives. Engaging with the community is therefore a key part of the process. Similarly, managing to reduce EDS in the surrounding areas requires rigorous social assessments to avoid potential conflicts of interest. For example, clearing invasive alien trees nearby may affect the livelihoods of Imizamo Yethu residents as they may utilize these species for firewood or construction material.

6.5.5 Methodological considerations

6.5.5.1 Google Earth Street View

Some online resources enable a range of new remote sensing possibilities, including the use of interactive on-the-ground virtual views. Foremost among these is Google's Street View (GSV) - a free-access web technology featured in Google Maps and Google Earth. GSV allows users to conduct virtual travels along roads using georeferenced panoramic photographs regularly taken at short intervals by high-resolution cameras placed on the roof of a moving car. This provides on-the-ground imagery for sites close to roads, most extensively in urban areas.

GSV can serve as a useful supplementary tool in ES assessments (e.g. Richards and Edwards 2017), particularly in urban areas. For example, once an ES or EDS providing area has been identified, GSV images of the site can be examined to determine accessibility, characteristics of street vegetation such as the proportion of streetscape 'green' coverage, and in some cases individual plant species. In some cases, a direct link between surrounding vegetation and ES can be detected (Fig. 6.5).

6.5.5.2 Limitations

Direct remote sensing of ES is challenging as ES are often intangible in that they are defined by ecosystem functions and processes that involve a temporal component. Biodiversity and habitat functions are particularly difficult to map remotely as they depend largely on species composition which must be measured using inventories and ground data collection (Gillespie et al. 2008). Regulating services, characterized as being of indirect use, provide the conditions that allow other directly used ES (e.g. provision of firewood) to exist (Abson and Termansen 2011). Similarly, supporting services do not directly benefit people, but are essential to the functioning of ecosystems and are therefore indirectly responsible for all other services (Haines-Young and Potschin 2010). Consequently, these services are more difficult to quantify (Rodriguez et al. 2006), particularly in urban settings.

Many ES are difficult to effectively conform to land cover as an ES proxy, as genus- or species-level information is required. For example, food (provisioning), nitrogen fixation (regulating) and pollination (supporting) require detailed information on the species traits facilitating the provision of ES (Table 6.1). As a result, such ES may be overrepresented in this approach. The diversity of species in urban areas makes species-level image classification particularly challenging. Coarse spatial and spectral resolutions make it difficult to separate native and alien species in mixed species assemblages. Species mapping efforts are usually limited to a small subset of species that are canopy dominants and that are sufficiently distinct to enable remote detection. The presence of many alien species (mainly herbaceous plants) may not be discernible even using the newest high-resolution sensors (e.g. GeoEye-1). In addition, phenological changes of vegetation due to the presence of alien species might not be recognizable if there is no distinct flowering pattern because of the coarse spectral resolution of high spatial resolution images.

Some ES are more significant than others (McPherson et al. 2005; Stoffberg et al. 2010; Soares et al. 2011). For example, while the value of energy savings, carbon dioxide reduction and air pollutant deposition in Lisbon were comparable to several other USA cities, the large values associated with stormwater runoff reduction and increased property value were considerably greater than values obtained in US cities (Soares et al. 2011). There is no information on the importance of different ES and EDS for our study area and are consequently not weighted in our assessment. It is important to assign priorities to specific ES and EDS prior to performing spatial assessments.

6.6 Conclusions

Efficient management of IAPs in urban landscapes is especially complicated, because of the multiple interacting environmental and socio-economic factors. IAP managers in urban areas across all geographic regions need to overcome the barriers characteristic of urban areas to effectively manage urban plant invasions and ensure the continued provision of ES that are essential for human well-being. However, management decisions need to carefully consider the socio-economic ties associated with IAPs and such decisions need to be plural, participatory and rooted within transdisciplinary research.

This study presents a reproducible spatially-explicit assessment of ES and EDS and demonstrates an effective approach for guiding urban planners and managers to improve ES provision at the local-scale. The study also unpacks potential management trade-offs and conflicts of interest resulting from the complexities of the ES and EDS dichotomy.

Improving resilience through urban policy and planning requires the dynamic interactions between urban vegetation and the provision of ES to be considered. A focus on cities as socio-ecological systems requires the recognition that resilience of and through ES are aims that have the potential to restructure urban spaces towards a more sustainable future.

6.7 Acknowledgements

Funding for this work was provided by the DST-NRF Centre of Excellence for Invasion Biology, the Working for Water Programme through their collaborative research project on "Integrated Management of invasive alien species in South Africa", and the National Research Foundation, South Africa (grant 85417 to DMR). We thank the Invasive Species Unit for providing invasive plant density data. We also thank Divan Vermeulen from the Centre for Geographical Analysis, Stellenbosch University, for providing LiDAR data and additional guidance.

6.8 References

Abson DJ, Termansen M (2011) Valuing ecosystem services in terms of ecological risks and returns. Conserv Biol 25, 250-258

Alston KP, Richardson DM (2006) The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol Conserv 132:183–198. https://doi.org/10.1016/j.biocon.2006.03.023

Ballard R (2004) Middle class neighbourhoods or 'African kraals'? The impact of informal settlements and vagrants on post-Apartheid white identity. Urban Forum 15:48-73

Balvanera P, Pfisterer AB, Buchmann N, He JS, Nakashizuka T, Raffaelli D, et al, (2006) Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol Lett 9:1146–1156

Benayas JMR, Newton AC, Diaz A, Bullock JM (2009) Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. Science 325:1121-1124

Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. Ecol Lett 12:1394–1404

Bernholt H, Kehlenbeck K, Gebauer J, Buerkert A (2009) Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. Agrofor Syst 77:159–179. doi: 10.1007/s10457-009-9236-8

Burkhard B, Kroll F, Nedkov S, Muller F (2012) Mapping ecosystem service supply, demand and budgets. Ecol Indic 21:17–29

Carpenter SR, De Fries R, Dietz T, Mooney HA, Polasky S, Reid WV, Scholes RJ (2006) Millennium Ecosystem Assessment: research needs. Science 257–258

Carruthers J, Robin L, Hattingh JP, Kull CA, Rangan H, van Wilgen BW (2011) A native at home and abroad: the history, politics, ethics and aesthetics of acacias. Divers Distrib 17:810–821

Celesti-Grapow L, Blasi C (2004) The role of alien and native weeds in the deterioration of archaeological remains in Italy. Weed Technol 18:1508–1513. doi: 10.1614/0890-037X(2004)018[1508:TROAAN]2.0.CO;2

Charles H, Dukes JS (2007) Impacts of invasive species on ecosystem services. In: Nentwig W (ed.) Biological Invasions. Berlin: Springer, pp. 217–38

Cowling R, Richardson D (1995) Fynbos: South Africa's unique floral kingdom. Fernwood Press, Cape Town

Cowling RM, Macdonald IAW, Simmons MT (1996) The Cape Peninsula, South Africa. Biodivers Conserv 5:527–50

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol Complex 7:260–272

de Groot RS, Fisher B, Christie M, Aronson J, Braat L, Gowdy J, Haines-Young R, Maltby E, Neuville A, Polasky S, Portela R, Ring I (2010). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In: Kumar P (ed) The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. London: Earthscan

de Wit MP, Crookes DJ, van Wilgen BW (2001) Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. Biol Invasions 3:167–178

Definiens (2005). eCognition Professional, Munich

Dickie I, Bennett B, Burrows L, Nuñez M, Peltzer D, Porté A, Richardson DM, Rejmánek M, Rundel P, van Wilgen BW (2014) Conflicting values: ecosystem services and invasive tree management. Biol Invasions 16:705–719

Dobbs C, Escobedo FJ, Zipperer WC (2011) A framework for developing urban forest ecosystem services and goods indicators. Landsc Urban Plan 99:196–206

Dobbs C, Kendal D, Nitschke CR (2014) Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics. Ecol Indic 43:44–55

Egoh B, Reyers B, Rouget M, Bode M, Richardson DM (2009) Spatial congruence between biodiversity and ecosystem services in South Africa. Biol Conserv 142:553 –562

Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC, Wilkinson C (2013) Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities. Europe: Springer

Escobedo F, Varela S, Zhao M, Wagner JE, Zipperer W (2010) Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. Environ Sci Policy 13:362–372

Gaertner M, Novoa A, Fried J, Richardson DM (2017) Managing invasive species in cities: A decision support framework applied to Cape Town. Biol Invasions 19:3707-3723

Gaertner M, Biggs R, Te Beest M, Hui C, Molofsky J, Richardson DM (2014) Invasive plants as drivers of regime shifts: identifying high-priority invaders that alter feedback relationships. Divers Distrib 20:733–744

Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landsc Urban Plan 151:1–9

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) Managing urban ecosystems for goods and services. J Appl Ecol 50:830–40

Gillespie TW, Foody GM, Rocchini D, Giorgi AP, Saatchi S (2008) Measuring and modeling biodiversity from space. Prog Phys Geogr 32:203–221

Gómez-Baggethun E, Barton DN (2013). Classifying and valuing ecosystem services for urban planning. Ecol Econ 83:235–245

Goodness J, Anderson P (2013) Local assessment of Cape Town: navigating the management complexities of urbanization, Biodiversity, and Ecosystem Services in the Cape Floristic Region. In: Elmqvist T, Fragkias M, Goodness J, et al. (eds) Urbanization, biodiversity and ecosystem services: challenges and opportunities. Dordrecht: Springer, pp. 461- 484

Haase J, Jacob A, Ban Y (2014) Urban ecosystems mapping from spaceborne high-resolution optical data. Proceedings of Dragon 3 Mid-Term Results Symposium, Chengdu, P. R. China, 26-29 May 2014 (ESA SP-724, November 2014) ISBN - 978-92-9221-288-9

Haase D, Schwarz N, Strohbach M, Kroll F, Seppelt R (2012) Synergies, Trade-offs, and Losses of Ecosystem Services in Urban Regions: an Integrated Multiscale Framework Applied to the Leipzig- Halle Region, Germany. Ecol Soc 17:102–123

Haines-Young RH, Potschin M (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D, Frid C (eds) Ecosystem ecology: a new synthesis. BES Ecological Reviews Series, CUP. Cambridge: Cambridge University Press

Jim CY, Chen WY (2009) Ecosystem services and valuation of urban forests in China. Cities 26:187–194. doi: 10.1016/j.cities.2009.03.003

Jim CY, Chen WY (2008) Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J Environ Manage 88:665–676

Kowarik I, Säumel I (2007) Biological flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. Perspect Plant Ecol Evol Syst 8:207–237. doi: 10.1016/j.ppees.2007.03.002

Kueffer C, Kull CA (2017) Non-native species and the aesthetics of nature. In: Vilà M, Hulme PE, Ruiz G (eds) Impact of Biological Invasions on Ecosystem Services. Springer, pp. 311-324

Kull CA, Shackleton CM, Cunningham PJ, Ducatillon C, Dufour-Dror J-M, Esler KJ, Friday JB, Gouveia AC, Griffin AR, Marchante E, Midgley SJ, Pauchard A, Rangan H, Richardson DM, Rinaudo T, Tassin J, Urgenson LS, von Maltitz GP, Zenni RD, Zylstra MJ (2011) Adoption, use and perception of Australian acacias around the world. Divers Distrib 17:822–836

Le Maitre DC, Gaertner M, Marchante E, Ens EJ, Holmes PM, Pauchard A, O'Farrell PJ, Rogers AM, Blanchard R, Blignaut J, Richardson DM (2011) Impacts of invasive Australian acacias: implications for management and restoration. Divers Distrib 17:1015–1029

Le Maitre DC, van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA, Nel JA (2002) Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecol Manage 160:143–159

Le Maitre DC, Versfeld DB, Chapman RA (2000) The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. Water South Africa 26:397–408

Liu J, Dietz T, Carpenter SR, Alberti M, Folke C, Moran E, Pell AN, Deadman P, Kratz T, Lubchenco J, Ostrom E, Ouyang Z, Provencher W, Redman CL, Schneider SH, Taylor WW (2007) Complexity of coupled human and natural systems. Science 317:1513–1516

Luck GW, Smallbone LT, Brien RO (2009) Socio-economics and vegetation change in urban ecosystems: patterns in space and time. Ecosystems 12:604–620

McPherson EG (2003) A benefit-cost analysis of ten street tree species in Modesto, California, U.S. J Arboric 29:1–8

Mcpherson G, Simpson JR, Peper PJ, Maco SE, Xiao Q (2005) Municipal Forest Benefits and Costs in Five US Cities. J For 103:411-416

Millennium Ecosystem Assessment (MA) (2005) Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press

Naidoo R, Balmford A, Costanza R, Fisher B, Green RE, Lehner B, Malcolm TR, Ricketts TH (20080 Global mapping of ecosystem services and conservation priorities. Proc Natl Acad Sci USA 105:9495–9500

Novoa A, Shackleton RT, Canavan S, Cybèle C, Davies SJ, Dehnen-Schmutz K, Fried J, Gaertner M, Geerts S, Griffiths C, Kaplan H, Kumschick S, Le Maitre DC, Measey GJ, Nunes AL, Richardson DM, Robinson TB, Touza J, Wilson JRU (2018) A framework for engaging stakeholders on the management of alien species. J Environ Manage 205:286-297

Nowak DJ, Crane DE, Stevens JC, Hoehn RE, Walton JT, Bond J (2008) A ground-based method of assessing urban forest structure and ecosystem services. Arboric Urban For 34:347–358

O'Farrell P, et al. (2012) Insights and opportunities offered by a rapid ecosystem service assessment in promoting a conservation agenda in an urban biodiversity hotspot. Ecol Soc 17:1–25

Open Street Map (2015) http://www.openstreetmap.org/#map=5/51.500/-0.100 (Accessed 13 August 2018)

Pejchar L, Mooney HA (2009) Invasive species, ecosystem services and human wellbeing. Trends Ecol Evol 24:497–504

Potgieter LJ, Gaertner M, Irlich UM, O'Farrell PJ, Stafford L, Vogt H, Richardson DM (2018a) Managing urban plant invasions: a multi-criteria prioritization approach. Environ Manage. https://doi.org/10.1007/s00267-018-1088-4

Potgieter LJ, Gaertner M, O'Farrell PJ Richardson DM (2018b) Perceptions of impact: Invasive alien plants in the urban environment. J Environ Manage. doi:10.1016/j.jenvman.2018.05.080

Potgieter LJ, Kueffer C, Larson BMH, Livingston S, O'Farrell P, Gaertner M, Richardson DM (2017) Alien plants as mediators of ecosystem services and disservices in urban systems: A global review. Biol Invasions 19:3571-3588

Pyšek P, Richardson DM (2010) Invasive species, environmental change and management, and health. Annu Rev Environ Resour 35:25–55

Qiu J (2015) A global synthesis of the effects of biological invasions on greenhouse gas emissions. Glob Ecol Biogeogr 24:1351–1362

Richards DR, Edwards PJ (2017) Quantifying street tree regulating ecosystem services using Google Street View. Ecol Indic 77:31–40

Richardson DM, Cowling RM (1992) Why is mountain fynbos invasible and which species invade? In: van Wilgen BW, Richardson DM, Kruger FJ, van Hensbergen HJ (Eds) Fire in South African mountain fynbos. Berlin: Springer-Verlag

Richardson DM, van Wilgen BW, Higgins SI, Trinder-Smith TH, Cowling RM, McKelly DH (1996) Current and future threats to biodiversity on the Cape Peninsula. Biodivers Conserv 5:607-647

Rodriguez JP, et al. (2006) Trade-offs across space, time, and ecosystem services. Ecol Soc 11:28

Roy S, Byrne J, Pickering C (2012) A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban For Urban Green 11:351–363

Rundel PW, Dickie IA, Richardson DM (2014) Tree invasions into treeless areas: Mechanisms and ecosystem processes. Biol Invasions 16:663–675. doi:10.1007/s10530-013-0614-9

Shackleton CM, Ruwanza S, Sinasson Sanni GK, Bennett S, Lacy P, Modipa R, Mtati N, Sachikonye M, Thondhlana G (2016) Unpacking Pandora's Box: understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems 19:587–600

Shackleton RT, Richardson DM, Shackleton CM, Bennett B, Crowley S, Dehnen-Schmutz K, Estévez R, Fischer A, Kueffer C, Kull C, Marchante E, Novoa A, Potgieter LJ, Vaas J, Vaz AS, Larson BHM (2018) Explaining people's perceptions of invasive alien species: A conceptual framework. J Environ Manage. https://doi.org/10.1016/j.jenvman.2018.04.045

Sherrouse BC, Clement JM, Semmens DJ (2011) A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. Appl Geogr 31:748-760. doi:10.1016/j.apgeog.2010.08.002

Sladonja B, Sušek M, Guillermic J (2015) Review on invasive tree of heaven (*Ailanthus altissima* (Mill.) Swingle) conflicting values: assessment of its ecosystem services and potential biological threat. Environ Manage 56:1009–1034. doi: 10.1007/s00267-015-0546-5

Soares AL, Rego FC, Mcpherson EG, Simpson JR, Peper PJ, Xiao Q (2011) Benefits and costs of street trees in Lisbon, Portugal. Urban For Urban Green 10:69-78

Stoffberg GH, Van Rooyen MW, Van Der Linde MJ, Groeneveld HT (2010) Carbon sequestration estimates of indigenous street trees in the City of Tshwane, South Africa. Urban For Urban Green 9:9-14

Swetnam RD, Marshall AD, Burgess ND (2010) Valuing Ecosystem Services in the Eastern Arc Mountains of Tanzania. Bull Br Ecol Soc 41:7-8

Syrbe RU, Grunewald K (2017) Ecosystem service supply and demand - the challenge to balance spatial mismatches. Int J Biodivers Sci Manage 13:148–161

van Wilgen BW (2009) The evolution of fire and invasive alien plant management practices in fynbos. S Afr J Sci 105:335–342

van Wilgen BW (2012) Evidence, perceptions, and trade-offs associated with invasive alien plant control in the Table Mountain National Park, South Africa. Ecol Soc 17:23. http://dx.doi.org/10.5751/ES-04590-170223

van Wilgen BW, Forsyth GG, Prins P (2012). The management of fire-adapted ecosystems in an urban setting: the case of Table Mountain National Park, South Africa. Ecol Soc 17:8. https://doi.org/10.5751/ES-04526-170108

van Wilgen BW, Reyers B, Le Maitre DC, Richardson DM, Schonegevel L (2008) A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J Environ Manage 89:336–349. https://doi.org/10.1016/j.jenvman.2007.06.015

van Wilgen BW, Richardson DM (1985) The effects of alien shrub invasions on vegetation structure and fire behaviour in South African fynbos shrublands: A simulation study. J Appl Ecol 22:955-966

van Wilgen BW, Richardson DM (2014) Challenges and trade-offs in the management of invasive alien trees. Biol Invasions 16:721–734

van Wilgen BW, Scott DF (2001) Managing fires on the Cape Peninsula: dealing with the inevitable. J Mediterr Ecol 2:197e208

Vaz AS, Kueffer C, Kull CA, et al. (2017) Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst Serv 23:94–107. doi: 10.1016/j.ecoser.2016.11.017

Vicente JR, Pinto AT, Araújo MB, Verburg PH, Lomba A, Randin CF, Guisan A, Honrado JP (2013) Using life strategies to explore the vulnerability of ecosystem services to invasion by alien plants. Ecosystems 16:678–693

Wainger LA, King DM, Mack RN, Price EW, Maslin T (2010) Can the concept of ecosystem services be practically applied to improve natural resource management decisions? Ecol Econ 69:978–987

Watson V (2009) The planned city sweeps the poor away… Urban planning and 21st century urbanism. Prog Plan 72:151–193

Welch R (1982) Spatial resolution requirements for urban studies. Int J Remote Sens 2:139–146

Wu J (2014) Urban ecology and sustainability: The state-of-the-science and future directions. Landsc Urban Plan 125:209-221

Yelenik SG, Stock WD, Richardson DM (2004) Ecosystem-level impacts of invasive alien nitrogen-fixing plants. Ecosystem and community-level impacts of invasive alien *Acacia saligna* in the fynbos vegetation of South Africa. Restor Ecol 12:44-51

Yelenik SG, Stock WD, Richardson DM (2007) Functional group identity does not predict invader impacts: differential effects of nitrogen-fixing exotic plants on ecosystem function. Biol Invasions 9:117-125

Chapter 7. Conclusions

Urban areas are highly susceptible to biological invasions - they are foci for the introduction of alien species; they have very high levels of propagule pressure increase the likelihood of establishment and persistence of many species; they provide abundant and diverse sets of dispersal pathways and vectors; they have unique disturbance regimes; and profoundly altered abiotic and biotic conditions. These features enable alien species to invade a wide range of urban habitats (e.g. road verges, urban green spaces) and spread into surrounding natural areas. Conversely, there is some "overflow" of natural-area invaders into urban settings. Urban IAS can cause negative effects on existing ES or creating novel ES or EDS. The high number of people in urban areas means these impacts are felt more acutely. Standard impacts associated with IAS (such as pollen allergies) are amplified and complex human-nature interactions allows unique threats to arise (such as crime). A greater number of stakeholders leads to a larger diversity of views about IAPs that may disproportionately complicate management.

This thesis charts a new course for understanding the ways in which urban plant invasions affect people and the environment. The chapters apply a range of ecological and sociological approaches and techniques to gain a holistic understanding of the effects of alien and invasive plants on ES and to identify fundamental requirements for effective management to enhance ES and human well-being. The respective chapters contribute new information on many aspects of the emerging problem of urban plant invasions, and in particular the role of IAPs in Cape Town, South Africa. Despite the advances made through this work, much remains to be done to improve our knowledge and control of invasive species in urban areas, especially regarding the management of those that are beneficial in some ways, and harmful in others. Using interdisciplinary multi-scale approaches, this thesis addresses key research questions regarding the links between alien plants, ES and human well-being in urban areas. My findings are presented below in relation to each of these key questions.

What role do alien plants have in providing ecosystem services in urban areas?

Insights from the global review (Chapter 2), revealed that knowledge about ES and EDS provided by alien plant species in urban areas is still relatively limited and is biased in several ways. Overall, few alien species have been comprehensively studied in terms of ES and EDS provision. For many species, only data on either ES or EDS is available. The role of alien plants in providing ES in developed countries has received the greatest research attention, and more work is needed to elucidate the importance of alien plants in developing countries. There is also an imbalance in the study of different ES and EDS; while provisioning services have been relatively well studied, little information is available on regulating services. Among cultural services, mostly visual amenity (aesthetics) issues have been comprehensively studied, while other cultural services such as psychological, spiritual, social and symbolic roles that are known to be important for the perception of alien species have received little attention. Among EDS, many studies have focused on a few mechanisms such as pollen allergies affecting human health and emissions of BVOCs reducing air quality.

Elucidating the role of alien plants in providing ES and EDS in urban areas can guide management prioritization and facilitate communication with various stakeholders. This review shows that alien plants can provide key ES and EDS in urban landscapes. Urban planners and managers therefore need to consider both the positive and negative effects of alien plant species.

How do alien and invasive plants negatively impact on ecosystem services and human well-being and do these impacts manifest in novel ways?

Using questionnaire-based surveys, analysing criminal court cases, and searching the grey literature, the link between urban vegetation and criminal activity was assessed using the city of Cape Town, South Africa as a case study (Chapter 5). Results showed that the association between vegetation and criminal activity may not always be determined by the biogeographical status of dominant plants (i.e. whether vegetation is dominated by native, alien, or invasive alien species), but rather on the structure/habitat they provide. However, a stronger link between crime and vegetation is likely to occur in areas (such as the Cape Floristic Region) where plant invasions have drastically altered vegetation structure. By drawing attention to a novel interaction between humans and vegetation, this study highlights the need for context-specific management approaches when managing plant invasions, particularly in urban areas and will be useful for urban managers in Cape Town and worldwide to guide the selection and prioritization of areas for vegetation management.

How do urban residents perceive invasive alien plants and which factors drive these perceptions?

The use of social approaches and stakeholder engagement when investigating invasive species is still emerging, but recognition of the importance of understanding the human dimensions of invasions is growing rapidly – especially for conflict-generating species (Shackleton et al. 2018a). Socio-ecological approaches were applied to elucidate the perceived roles of IAPs in providing ES and EDS and the implications of such perceptions for management (Chapter 3). The analysis showed that conflicts of interest are likely to arise when attempting to control and eradicate IAPs - residents perceived IAPs both negatively and positively and the management of plant invasions is not given as high a priority as some other environmental problems. Socio-demographic variables such as age, education, environmental awareness, and ethnicity shaped the perceptions of urban residents regarding IAPs.

This study provides insights into the perceived ES and EDS associated with IAPs and highlights the potential for conflicts of interest that are inherent in IAP management in urban environments. This work highlights the need to integrate public perceptions into the planning and management of IAPs and emphasises the importance of involving stakeholders in the decision-making process, particularly in urban areas.

What approaches can be used to streamline decision-making and management regarding invasive alien plants in urban areas? What are the major barriers to effective management of alien and invasive plants in urban areas and how can these be overcome?

Multi-criteria decision tools were used to develop a prioritisation framework for managing IAPs in urban areas at landscape and local scales (Chapter 4). A stakeholder workshop was held to develop and rank criteria for prioritising land parcels for IAP management in the city of Cape Town, South Africa. By matching spatial data with selected criteria and applying the multi-criteria decision analysis in a Geographic Information System, a strategic landscape-scale prioritisation map was developed. An existing IAP management framework was also modified to develop a tactical (site-level) prioritisation scheme for guiding on-the-ground control operations. The analysis showed that factors related to safety and security (such as fire risk to infrastructure, risk of flooding, and areas at risk of being illegally occupied) emerged as key features for setting spatially-explicit priorities for IAP management. Accordingly, this study identified high-priority land parcels for IAP management at landscape- and local scales across Cape Town. The overall approach resulted in an intuitive framework for dealing with the complexities involved in decision-making processes in urban environments and can be useful for managers in all urban settings to guide the selection and prioritization of land parcels for IAP management.

Given the limited resources available for assessing ES in many cities, practical approaches for integrating ES and EDS in decision-making process are needed, especially at local scales. Remote sensing techniques and supplementary spatial data were applied to develop a replicable approach for assessing the role of urban vegetation (including IAPs) in providing ES and EDS at a local-scale using a case study in the city of Cape Town, South Africa (Chapter 6). This study found that areas of high ES provision such as gardens in residential properties and urban green spaces are characterized by the presence of large trees. However, many of these areas also result in numerous EDS due to invasions of alien trees and shrubs – particularly along rivers, in wetlands and along the urban edge where tall alien trees have established and spread into the natural vegetation. This suggests significant trade-offs regarding the management of species and the ES and EDS they provide. The approach applied here can be used to provide recommendations and to guide city planners and managers to fine-tune management interventions at local scales to maximise the provision of ES.

The frameworks and approaches developed in this thesis contribute to understanding the complexities of the ES-EDS dichotomy and ways to manages IAPs in complex urban settings. This has practical implications for invasion biologists, conservation managers, urban planners and managers. It also highlights the importance of including ES assessments (and stakeholders) into the decision-making process, particularly in urban areas — an approach that is becoming increasingly important as the demand for the sustainable provision of urban ES grows.

Difficulties in quantifying ES (and EDS) in the context of biological invasions remains challenging particularly in complex urban environmentas. Our ability to address key questions on the role of IAPs in mediating ES provision in urban areas is considerably hampered by the lack of data (e.g. the link between vegetation and crime, and ES and EDS associated with individual species). For management to be effective, more research on particular areas and better facilitating mechanisms are required, and conflicts of interest have to be discussed and resolved. Some key issues that require further research are listed below.

- There remains a significant lack of information on the role of alien plants in mediating ES and EDS in urban areas around the world. Indeed, many of the impacts (both positive and negative) of alien and invasive plants are described qualitatively rather than quantitatively. More work is therefore required to elucidate these impacts and their effects on human well-being.
- There is an urgent need to further our understanding of the role of alien plants on ES in urban areas in developing countries, especially given the importance of effective ES delivery in such nations.
- Much more work is needed to compare the role of native and alien plant species and their capacity to provide ES and EDS in urban environments. Such research might become more pertinent in the context of the adaptation of cities to climate change.
- To streamline management interventions, additional (cost effective) tools are needed to efficiently assess the role of alien and invasive species in mediating ES and EDS in urban areas, particularly at local scales.