Cities as hotspots for invasions: the case of the eThekwini municipality

Ashlyn Levadia Padayachee

Submitted in fulfilment of academic requirements for the degree of Doctorate in Philosophy in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville Campus

UNIVERSITY OF KWAZULU-NATAL

As the candidates supervisor I have approved this thesis for submission

Signed: _____________ Name: Şerban Procheş Date:_________________

Abstract

Increased anthropogenic activities (trade and travel) have caused an increase in the introduction of biological organisms outside of their native range. Biological invasions result in serious negative ecological, economic and social impacts in their invaded range and are responsible for a decline in native biodiversity. These negative impacts become more prominent in highly transformed environments, such as those found in cities which are often the first points of introduction for alien species. Durban (eThekwini) is situated on the east coast of South Africa and is one of the largest port cities on the African continent, making it an important economic centre for the country. It is the third most populated city in South Africa and is a major contributor towards tourism. Additionally, Durban is located in the Maputaland-Pondoland Albany, one of thirty-four global hotspots of biodiversity. This study focuses on the patterns, processes and drivers of biological invasions in Durban. I investigated three important aspects of alien species responses in urban environments: 1) precaution through the prevention of alien species introduction; 2) prioritisation through using a combination of early warning systems and techniques to identify potentially high-risk alien species; and 3) preparedness and response for a potential incursion event of *Solenopsis invicta* in Durban. I investigated the importance of preventing alien species introductions by identifying the pathways which facilitate the highest number of introductions for prioritisation for prevention efforts. Furthermore, I identified vectors responsible for secondary spread of alien species in cities. The majority of alien species were either released into nature or escaped from captivity and spread within cities through unaided dispersal. It is difficult to control the natural spread of species, therefore preventing alien species introductions is paramount. However, preventing the introduction of all alien species to a new area is difficult to achieve. Therefore, prioritising alien species for prevention efforts is an essential component of responding to biological invasions which will allow decision makers to more carefully allocate limited resources and time to species with the potential to result in severely negative impacts. Incorporating a holistic prioritisation approach based not only on alien species with a high-risk of invading new areas, but also the pathways which facilitate their introduction and the areas which are most at risk of being invaded is beneficial for decision makers in targeting priority species for prevention efforts. I developed a methodology, integrating these three aspects (species, pathways and sites), to select priority species to target for prevention efforts and identified areas most at risk of being invaded by these species using climatic suitability modelling to select priority targets for prevention efforts. Additionally, I used climatic models and pathway information to identify potential points of first introduction and sites of first naturalisation to target for active and passive surveillance endeavours. *Solenopsis invicta* Buren (the red imported fire ant) was identified as a potentially high-risk species posing serious ecological and socio-economic threats for Durban. I then explored opportunities for strategic response planning for *Solenopsis invicta* for Durban, South Africa. In doing so, I identified key priorities to help decision makers initiate strategic response planning for a potential incursion of this species to Durban. The research presented in this study outlines approaches that can assist with the prevention, prioritisation, and preparedness in responding to alien species in urban environments.

Preface

The work conducted in the compilation of this thesis was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Westville Campus from January 2016 to March 2019, under the supervision of Professor Şerban Procheş, and co-supervision of Professor John R. Wilson.

I hereby declare that the complete work comprised in this thesis is my own, original work, that I am the sole author thereof (unless otherwise, explicitly stated) and that I have not previously, as a whole or in part, submitted for the purpose of obtaining any degree or diploma to any other tertiary institute.

___________________________ __________________________

Ashlyn Levadia Padayachee Date

Declaration 1 – Plagiarism

I, Ashlyn Levadia Padayachee, declare that:

1. The research reported in this thesis, except where otherwise stated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other person's writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written but the general information attributed to them has been referenced.
    b. Where their exact words have been used, then their writing has been italicised and placed between quotation marks, and referenced.
5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and source being detailed in thesis and references.

Signed: ________________________________

Declaration 2 – Publications

Chapter 2 (Publication 1): Padayachee AL, Irlich UM, Faulkner KT, Gaertner M, Procheş Ş, Wilson JRU, Rouget MR (2017) How do invasive species move to and through urban environments? Biol Invasions 19: 3557-3570. https://doi.org/10.1007/s10530-017-1596-9

Contribution of authors:

ALP, UMI, GM, ŞP and JRUW: Planning and discussion of the study

ALP and UMI: compilation of databases

KTF: statistical analyses

ALP: led the writing

UMI, KTF, MG, ŞP, JRUW and MR: Provided comments on the manuscript

Chapter 3 (Publication 2): Padayachee AL, Procheş Ş, Wilson JR (2019) Prioritising potential incursions for contingency planning: pathways, species, and sites in Durban (eThekwini), South Africa as an example. Neobiota 47: 1-21. https://doi.org/10.3897/neobiota.47.31959

Contribution of authors:

ALP, ŞP and JRUW: Planning and discussion of the study

ALP: compilation of database, statistical analyses, led the writing

ŞP and JRUW: Provided comments on the manuscript

Chapter 4 (Manuscript 3): Strategic response planning for the Red Imported Fire Ant (RIFA), *Solenopsis invicta* Buren in eThekwini (Durban), South Africa

Contribution of authors:

ALP, ŞP, JRUW and ED: Planning and discussion of the study

ALP: led the writing

ŞP, JRUW and ED: provided comments on the manuscript

Signed: ________________________________

Dedication

To my late grandparents -

Sonny and Panjali Padayachee

"Do not go gentle into that good night,
Old age should burn and rave at the dose of day;
Rage, rage against the dying of the light.

Though wise men at their end know dark is right,
Because their words has forked no lightning they
Do not go gentle into that good night.

Good men, the last wave by, crying how bright
Their frail deeds might have danced in a green bay,
Rage, rage against the dying of the light.

Wild men who caught and sang the sun in flight,
And learn, too late, they grieved it on its way,
Do not go gentle into that good night.

Grave men, near death, who see with blinding sight
Blind eyes could blaze like meteors and be gay,
Rage, rage against the dying of the light.

And you, my father, there on the sad height,
Curse, bless, me now with your fierce tears, I pray,
Do not go gentle into that good night.
Rage, rage against the dying of the light."

- Dylan Thomas, 1952

Acknowledgements

Deciding to undertake a PhD is like embarking on an enthralling, exciting and sometimes perilous journey, that some would say is not worth the risk. I strongly disagree, the "views" along the road are simply breathtaking and worth the risk. We can't get by without help along the way. So now, as my journey comes to an end, I would like to acknowledge everyone who has helped along the way.

First and foremost, I express my eternal gratitude to the Lord Almighty, my constant source of comfort, wisdom and guidance. *Psalms 28:7 "The Lord is my strength and my shield, my heart trusts in him, and he helps me."*

I am forever grateful to my parents and sister for always encouraging and supporting me in my academic pursuits. Thank you dad and mum for always being available whenever I needed advice, guidance or just someone to talk to.

Thank you to my family and friends for your love and friendship. Thank you for being my source of laughter and light when the days felt darkest.

Thank you to my supervisors Prof. Şerban Procheş and Prof. John Wilson, for your invaluable academic guidance and advice throughout these four years. The help you have given me is sincerely appreciated.

Thank you to Prof. Şerban Procheş for taking me under your wing and helping me achieve all of my academic pursuits. My sincerest gratitude for mentoring me these last seven years and helping me become a better scientist.

I acknowledge the financial support of the South African National Department of Environment Affairs through its funding of the South African National Biodiversity Institute Invasive Species Programme.

For detailed acknowledgements see Chapters 2 and 3.

Table of contents

Chapter 1: Introduction

Over the course of time, human-related activities have modified earth's landscapes and provided mechanisms for the transfer of species beyond their native ranges. In recent times, the rate of human-related activities has increased, thus increasing the rate of exotic species introductions to new regions (Pimentel et al. 2001; Pyšek et al. 2010). Alien species (*sensu* Richardson et al. 2000) do not always successfully establish in their introduced range. Blackburn et al. (2011) proposed a framework describing the "barriers" alien species must overcome to successfully pass through different "stages" to establish and become invasive in their introduced range (the Introduction-Naturalisation-Invasion - "INI" continuum). Some alien species are introduced to provide ecosystem services, for example pine trees (*Pinus* spp.) were introduced for erosion control in South Africa (Richardson 1998). Other alien species, such as the red imported fire ant (*Solenopsis invicta* Buren – introduced to the United States via the shipping industry), were accidentally introduced through human-related activities (Wetterer 2013). Regardless of the intention of introducing alien species (Hulme et al. 2008), the consequent detrimental impacts from alien species ensuing spread and establishment are substantial (Gaertner et al. 2017a). Alien species threaten native species through increased predation, competitive abilities and hybridisation with natives in introduced ranges, having been removed from their natural enemies and competitors (Pimentel et al. 2001; Faeth et al. 2005; Alberti 2015). Some native species are sensitive to ecosystem changes. Moreover, economic losses through the destruction of infrastructure, agriculture and forestry are potentially extensive (Pimentel et al. 2001, Kenis et al. 2009; Vilá et al. 2010). These negative impacts are a cause for concern (Blackburn et al. 2014).

Alien species in urban landscapes

Urban environments (i.e. cities) are susceptible to alien species invasions because of the unique characteristic conditions observed in these environments (e.g. high environmental heterogeneity, high transport intensity, high levels of disturbance, changes in ecological functions, such as fire regimes and hydrological dynamics) rendering them heterogeneous and anthropogenically altered (Rebele 1994; Ricotta et al. 2009; Pyšek et al. 2010; Cadotte et al. 2017; Gaertner et al. 2017a; Novoa et al. 2017). Urban ecosystems are characteristic of continuous, rapid non-linear expansion (Grimm et al. 2008; Ramalho and Hobbs 2012); this means landscapes within these environments will indefinitely be transformed and natural habitats will be lost (Pimentel et al. 2001; Kowarik 2011). Cities present a combination of these distinctive conditions which are not observed in natural environments, making these environments key landscapes in the study of biological invasions (Ricotta et al. 2009). The concentration of human-activities (i.e. trade and travel) guarantees consistent immigration of alien species to cities (Pyšek et al. 2010). In their introduced environments, alien species are removed from their natural enemies and competitors; hence they have an increased likelihood of successful establishment (Alberti 2015). Alien species move with ease because of the high intensity of human movement, not only around cities (Wilson et al. 2009; Essl et al. 2015; Gotzek et al. 2015), but also into surrounding natural areas (von der Lippe and Kowarik 2008; McLean et al. 2017). Managing these species in cities is a sensitive issue because management efforts should not obstruct economic growth and development (Mumford 2002; Simberloff 2006).

There are a number of international frameworks and polices which address the threats posed by alien species with the goal of ensuring economic growth. For example, the Convention on Biological Diversity (CBD) addresses the threats of biodiversity loss with the primary objective of conserving biological diversity (SCBD 2012). The CBD’s 20 “Aichi Targets” tackle different causes of biodiversity loss (SCBD 2012). Aichi Target 9 deals with minimising the threat posed by invasive alien species (Scalera et al. 2016). The primary objective of Aichi Target 9 is the prevention of alien species introduction. While this is an ideal objective, preventing the introduction of all alien species is somewhat impractical. Therefore, early detection of incursions and rapid response is recommended. Furthermore, long-term containment and control plans are also recommended when eradication is infeasible (SCBD 2012).

In South Africa, the National Environmental Management: Biodiversity Act – NEM:BA - (No.10 of 2004) is responsible for protecting biological welfare, including dealing with invasive alien species. NEM:BA requires prevention, eradication or control efforts to be the least environmentally detrimental options (NEM:BA 2004). Under NEM:BA the development of plans to monitor, eradicate and control invasive alien species is a legal requirement for all organs of state (including municipalities) for land which is under their control, with the intention of incorporating these plans into integrated development plans (NEM:BA 2004).

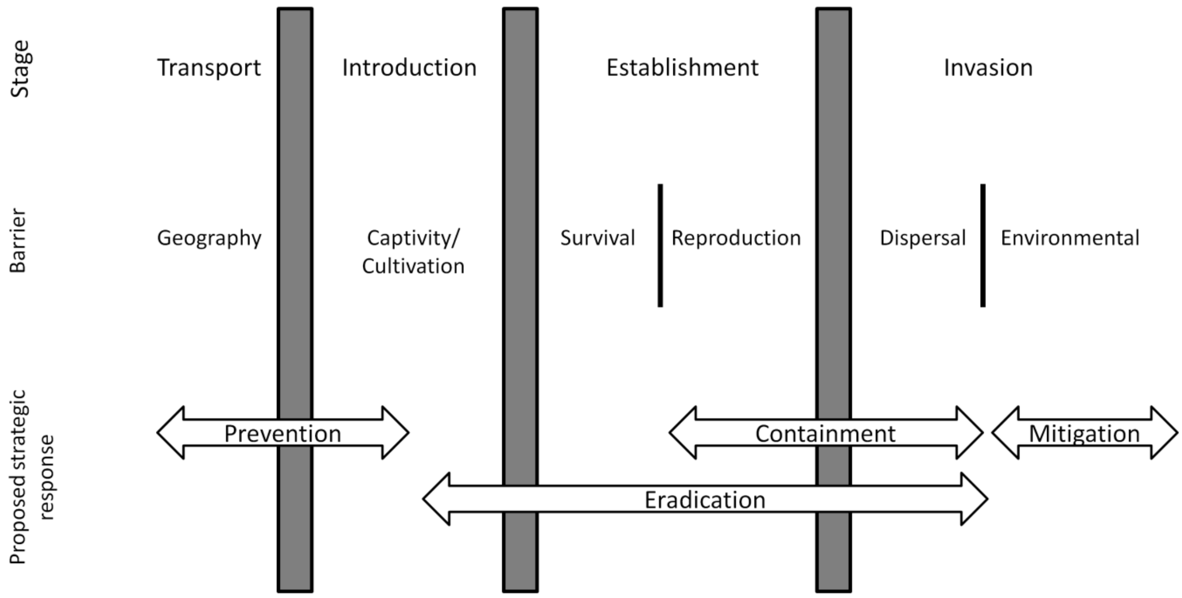

Figure 1.1: adaptation of the framework proposed by Blackburn et al. (2011) which describes the stages (i.e. transport, introduction, establishment and invasion) which an alien species must surpass to become invasive. Proposed strategic responses (i.e. prevention, eradication, containment and mitigation) are also indicated for alien species at different stages of invasion.

The primary objective of alien species frameworks is preventing alien species introductions. Prevention is generally the most cost effective approach for alien species management (Hulme 2006; Faulkner et al. 2016a). The INI continuum proposed by Blackburn et al. (2011) proposes strategies to deal with alien species at various stages in the continuum. The initial stages of the invasion continuum refer to the transport and introduction of alien species to new locations and are essential as the following stages are conditional upon this (Puth and Post 2005; Blackburn et al. 2011). The opportunities to prevent the initial dispersal of alien species to new locations far outweigh the options to respond to invasions (Figure 1.1) (Hulme 2006; Pyšek and Richardson 2010; Kumschick and Richardson 2013; Faulkner et al. 2016a). The processes resulting in the transfer of alien species to new locations are referred to as dispersal pathways, managing these pathways is the most promising approach to prevent alien species introductions (Hulme et al. 2008). Human-mediated transportation of alien species form a subset of dispersal pathways referred to as pathways of introduction (Richardson et al. 2011). Targeting pathways of introduction is advantageous in preventing multiple species from being introduced (Katsanevakis et al. 2013; Woodford et al. 2016). This approach is dependent on identification and assessment of pathways of introduction with the goal of reducing colonisation and propagule pressure (Hulme et al. 2008; Reaser et al. 2008; Katsanevakis et al. 2013). While this is a cost-effective approach, implementation is impeded by the voluminous nature these economically important pathways. Hulme et al. (2008) devised a framework to minimise the challenges in implementing the pathways approach by categorising pathways of introduction into six principle pathways based on varying levels of human mediation (Hulme et al. 2008). While this approach is useful, it is inevitable that some alien species introductions will occur. The pathways approach deals with preventing introductions but does not address the spread of alien species within new locations prior to introduction. The modes of transport or carriers (i.e. vectors of spread) which facilitate the spread of alien species within introduced environments are equally important to target for management efforts. Even though pathways of introduction have been the focus of recent studies (Hulme et al. 2008; Essl et al. 2015; Faulkner et al. 2016a), many of these studies have focused on natural environments (Hansen and Clevenger 2005; Katsanevakis et al. 2013). Urban invasions have received less attention although there are pathways and vectors unique to these environments. This gap in the body of literature presents an opportunity to study how these pathways and vectors influence the movement of alien species to and within urban environments, as well as the implications for alien species management.

It is, however, impractical to prevent all alien species from being introduced into a new region, particularly as the capacity to respond is limited (Grice et al. 2011; Early et al. 2016). For this reason, prioritising efforts to prevent alien species introduction and establishment is important. Ideally, species which pose the greatest risk of invading new regions, the pathways that facilitate their introduction, and the sites most at risk of being invaded should be prioritised for prevention efforts (McGeoch et al. 2016). In order to achieve these goals, it is important to identify threats before incursions occur. Prioritisation efforts usually focus on these three aspects (alien species, pathways, and sites of risk) separately of each other. For example, species watch lists, based on pre-border risk assessments, are used to identify high-risk species but do not address the sites which are at risk of being invaded or the pathways which facilitate the species introduction (Genovesi and Shine 2004; Nehring and

Klingenstein 2008, Parrot et al. 2009; Faulkner et al. 2014). It is important to prioritise not only high-risk species, but also high-risk pathways (Pergl et al. 2017) as well as sites with the highest risk of being invaded. Sites which are the most susceptible (i.e. exposure to incursions and likelihood of incursions establishing and become invasions) and sensitive (i.e. most vulnerable to the impacts of invasions) to incursions should be given priority for surveillance of new alien species (Wilson et al. 2017). As a result of the unique conditions observed in cities, cities can be considered as sites where invasions are highly likely to occur (Pyšek et al. 2010; Cadotte et al. 2017; Gaertner et al. 2017a). Furthermore, cities are potentially sensitive to the impacts of alien species which directly affect ecosystem services or humans (Hansen and Clevenger 2005; Potgieter et al. 2017). For these reasons, prioritisation efforts should incorporate all three aspects (alien species, pathways, and sites of risk) in assigning priorities for prevention efforts.

Ricciardi et al. (2011) argue that invasions should be treated as natural disasters by developing preparedness and rapid response strategies for incursion events. The development of strategic response plans will aid decision makers in achieving preparedness for potential alien species incursion events, and should ideally comprise of prevention, early detection and rapid response (i.e. eradication) and long-term (i.e. control and mitigation) strategies for responding to alien species (see Figure 1.1) (NEM:BA 2004; Blackburn et al. 2011; SCBD 2012). Strategic response plans will not only aid in rapid intervention of alien species incursions, but will also allow decision makers to identify key issues regarding response strategies (i.e. determining the capacity to respond to incursions and appropriate response techniques) and how best to allocate limited funds (Grice et al. 2011; Early et al. 2016) to response efforts. Developing strategic response plans is a time-consuming process and should therefore be conducted prior to an incursion event. For this reason, strategic response plans are dependent on tools which identify threats prior to incursion events. Furthermore, strategic response plans should not only take into account the threats alien species pose to the environment and economy, but also the social issues regarding the management of alien species (Gaertner et al. 2017a). The abundance of stakeholders (i.e. business owners, private enterprises and general public) present in cities produces unique challenges and conflicts for decision makers tasked with managing alien species (Dickie et al. 2014; Crowley et al. 2017; Gaertner et al. 2017a; Novoa et al. 2017). The management of alien species is hampered by human perception of alien species in urban environments. In addition to providing ecosystem services (*Cinnamomum camphora* – shade trees in Australia), the human population establishes connections (i.e. cultural, spiritual or aesthetic) with alien species (e.g. *Jacaranda mimosifolia* and *Anas platyrhynchos* in South Africa) thus preventing the management of these species (Novoa et al. 2017). Including stakeholders in the development of strategic response plans is important for successful management of alien species in urban environments (Gaertner et al. 2017a; Novoa et al. 2017; Shackleton et al. 2018; Wald et al. 2018). Risk communication is vital to successful response strategies by reducing public opposition to response efforts, especially where human health risks associated with alien species is significant (e.g. *Solenopsis invicta* Buren – red imported fire ant) (Glen et al. 2013). Furthermore, citizen science is a potentially beneficial tool in aiding the management of alien species by directing active surveillance efforts to target alien species incursions (Hoffmann et al. 2011).

eThekwini (Durban) Municipality

The eThekwini municipality, also known as Durban and hereafter referred to, is situated in the KwaZulu-Natal province of South Africa and spans a land area of approximately 2 300km^2 (Roberts 2008). Durban is one of the most populated cities in the country (approximately 3.4 million – STATSSA, 2017). In addition to being a vital economic centre in South Africa with the largest port on the east coast of Africa, this city also has a significant tourism industry (Roberts 2008). Biodiversity conservation is a key issue of contention in this growing city which is located within one of the world's biodiversity hotspots (The Maputaland-Pondoland Albany - Myers et al. 2000). Biodiversity hotspots are unique because of their relatively small size coupled with high levels of species richness and endemism (Malcolm et al. 2006). The distinctive biodiversity found in these areas is threatened by the transformation of landscapes through urbanisation, the increased demand on ecosystem services by the growing human population, as well as by the introduction and establishment of alien species (Myers et al. 2000; Seto et al. 2012; Di Minin et al. 2013). Hence, biodiversity conservation, including responding to the threat of alien species, is paramount. However, the resources available to target conservation and respond to alien species are severely limited (Cowling et al. 2003). For these reasons, incursions of alien species in Durban have the potential to cause serious negative ecological, economic and social impacts.

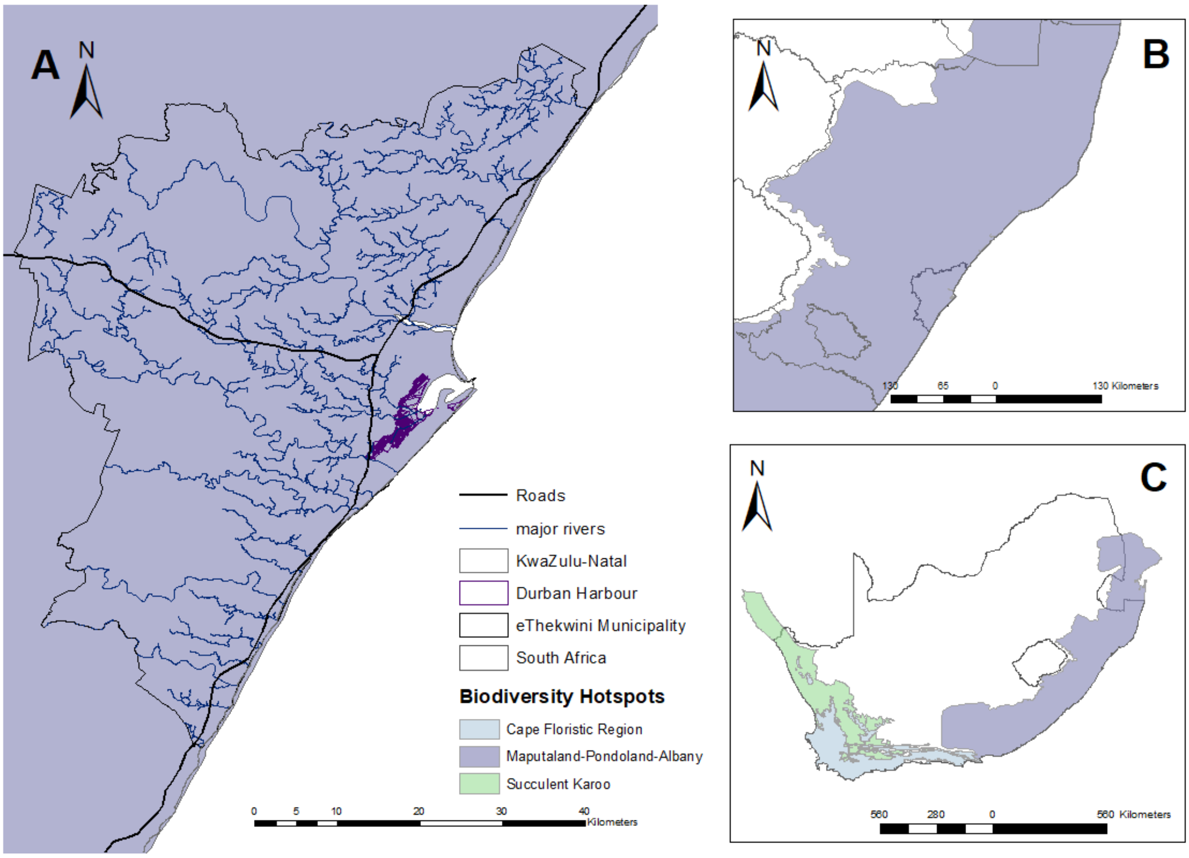

Figure 1.2: eThekwini Municipality, located within the KwaZulu-Natal province is a hub of activity, hosting the largest port on the eastern coast of Africa (Durban Harbour), a primary South African airport (King Shaka International) and major roads linking the city to other important economic centres in the country. The city is located in the B) KwaZulu-Natal province which hosts the Maputaland-Pondoland-Albany biodiversity hotspots (Myers et al. 2000), one of the three hotspots found in B) South Africa.

The hub of activities within cities makes managing alien species a complicated task for decision makers. Responding to alien species can be problematic when considering the ownership of land parcels within the city (e.g. municipal land versus privately owned land or national owned land such as ports and roads). Enforcing the prevention, eradication or control of alien species, in this regard, is an enormous task. Access to privately owned land is an impediment for decision makers who may be unable to respond to alien species within these parcels of land, leading to the spread of alien species within and beyond the city (von der Lippe and Kowarik 2008). The Environmental Planning and Climate Protection department (EPCPD) of the eThekwini municipality (Figure 1.2A) is responsible for responding to the threat of invasive alien plants within the city. In addition to the EPCPD, there are numerous organisations working towards alien species management, each with different goals and targets. One such example is the South African National Biodiversity Institute's Biological Invasions Directorate (SANBI BID) which NEM:BA has been tasked by DEA to work on detecting new incursions, assessing their risks, and facilitating nation-wide eradications (i.e. species categorised as 1a on NEM:BA's Alien and Invasive Species Lists – DEA 2016) within South Africa (Figure 1.2C). Additionally, Ezemvelo KZN Wildlife, the provincial conservation agency, is mandated by the KwaZulu-Natal Nature Conservation Management Act (No. 9 of 1997) to ensure conservation within the province, including the management of protected areas (Figure 1.2B) (EKZNW 2019). In addition to these organisations, there are numerous conservancies that operate within the municipality and respond to alien species on land which they manage (e.g. Duzi Umgeni Conservation Trust [DUCT] and the Kloof Conservancy). While communication between the many organisations operating within the municipality can be difficult, it is not impossible. The "Durban Invasives" website (www.durbaninvasives.org.za) is a good example of the potential for collaboration between the different organisations responding to alien species. This project, which was initiated by several of these organisations (including the SANBI BID, the DUCT, Kloof Conservancy, and eThekwini Municipality), targets known invasive alien plants in the greater Durban area through a citizen science endeavour. This initiative is beneficial for guiding control efforts, research and planning operations through the capture of data on selected invasive alien plants present in the city. Additionally, this approach allows decision makers to deploy teams to implement response strategies in real-time. Even more so, it encourages the regular collaboration of different organisations operating within the municipality through data sharing and information regarding ongoing alien species response efforts. The KwaZulu-Natal Invasive Alien Species Forum, held four times a year, also facilitates information dissemination regarding ongoing invasive alien species between relevant stakeholders in the province.

In this study I investigate three important components of alien species responses: preventing the introduction of alien species; prioritising alien species with the highest risks of invasion and impacts; and preparing for potential incursion events (see Figure 1.3 for aims and objectives of each chapter) within an extremely important economic and ecological urban environment (Durban). This study aimed to investigate these three components of biological invasions in an urban context, which previously had not been attempted. Preventing, prioritising and preparing for invasions in urban environments differ from natural environments due to the differences in the demographic, geographical and ecological conditions between these environments. While there is a depth of literature regarding invasions in natural environments, the urban context is somewhat sparesly covered. This study undertakes to added to the study of invasions in the urban context. Chapter two tackles the identification of the most important pathways of introduction and subsequent vectors of spread, which has not previously been attempted for cities. Additionally, I discussed the importance of targeting high-risk pathways of alien species introductions. Due to the limitations of resources for responding to alien species introductions and incursions, I investigated the importance of pro-active planning tools to aid with assigning priorities for prevention targets for urban environments in chapter three. Preparedness is a vital component of an effective response to alien species incursions. Chapter four focused on the opportunities for strategic response planning for the high-risk ant species *Solenopsis invicta* Buren (red imported fire ant) in Durban, South Africa. Finally, I consolidate the findings of this study and discuss the management implications of the results for alien species management in cities.

Thesis structure and outline

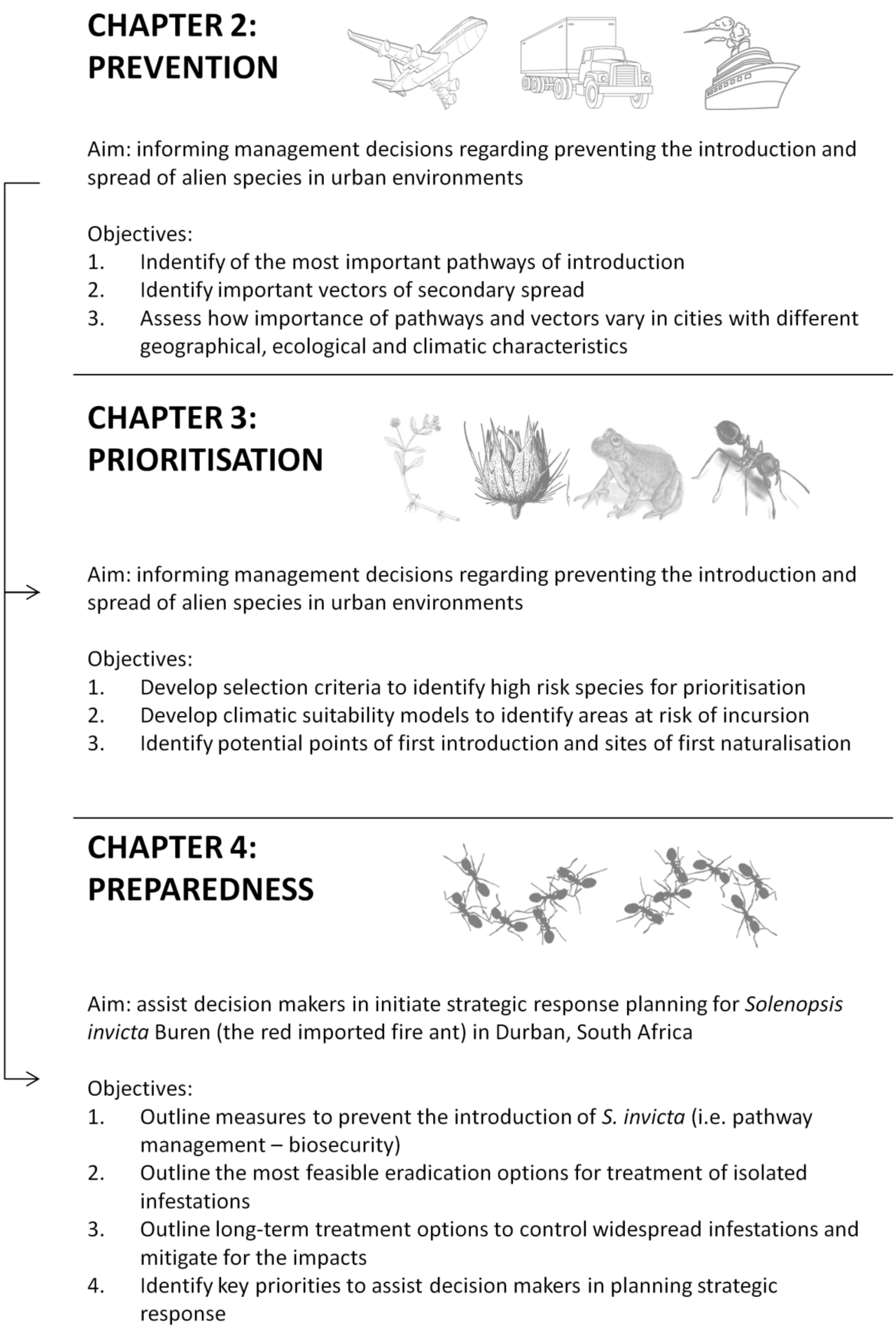

Figure 1.3: outline of aims and objectives of each of the chapters presented in this study. This study is centred on three important aspects of alien species responses: prevention,

prioritisation and preparedness. The overall aim of the study was to provide decision makers with potentially beneficial tools that will help with responding to alien species in cities.

Chapter 2: How do invasive species travel to and through urban environments?

Abstract

Globalisation has resulted in the movement of organisms outside their natural range, often with negative ecological and economic consequences. In particular, cities are hubs of anthropogenic activities, often with both highly transformed and disturbed environments, and the first point of entry for most alien introductions. I compiled a global database of cities using selected demographic, ecological and geographic factors. I then identified the most important pathways of introduction and vectors of spread of non-native species for cities with diverse geographical, ecological and climatic characteristics. Most species were intentionally introduced to cities and were released or escaped from confinement. The majority of alien species then spread within cities through natural means (unaided dispersal, water currents, endozoochory and exozoochory). Pathway importance varied across the taxonomic groups of alien species (for plants and vertebrates, the most important pathway was the escape pathway, for invertebrates, the stowaway and contaminant pathways), and for some organisms depended on the geographical, ecological and climatic characteristics of the city. The characteristics of cities also influenced the importance of vectors of spread of alien species. The most important vector of spread was unaided dispersal. To prevent invasions, both intentional and unintentional introduction of alien species to cities must be prevented. Preventing the natural spread of alien species prior to introduction within cities, as well as into adjacent natural environments will be, at best, difficult. However, the pathways that should be prioritised depend on the taxonomic group of target species, the location of the city, its geographical, ecological and climatic characteristics. The important pathways identified here provide a starting point for decision makers to prioritise pathways for management.

Keywords

Biological invasions, pathways of introduction, vectors of spread, prioritisation

Introduction

The increase in world trade, travel and tourism has resulted in a plethora of mechanisms for organisms to be transported outside of their natural ranges (Wilson et al. 2009; Blackburn et al. 2011; Gallardo and Aldridge 2013; Essl et al. 2015; Gotzek et al. 2015). The negative ecological, economic and social implications of the establishment of introduced alien species are widely recognised (Pimentel et al. 2001; Kenis et al. 2009; Vilá et al. 2010). Once introduced to a new location, alien species (*sensu* Richardson et al. 2000) need to effectively overcome certain barriers before successfully invading these new environments (Blackburn et al. 2011). The framework proposed by Blackburn et al. (2011) depicts this invasion continuum. The "transport" and "introduction" stages of the invasion continuum refer to the initial dispersal of an alien species to a new location (Puth and Post 2005; Blackburn et al. 2011). Initial dispersal is imperative as the sequential stages of the invasion continuum are contingent upon this stage (Puth and Post 2005; Blackburn et al. 2011), and the opportunities to prevent invasions are often greatest and most cost-effective when preventing the initial dispersal of alien species to new locations. Additionally, strategies that prevent the introduction of alien species often prove to be more cost effective than those that respond to incursions (Hulme 2006; Pyšek and Richardson 2010; Kumschick and Richardson 2013; Faulkner et al. 2016a). McGeoch et al. (2016) suggest that to effectively manage invasions, the prioritisation of species, their pathways of introduction, and the sites which are most at risk of invasions is essential. Pathways of introduction are the processes that lead to the introduction of an alien species from one geographical location to another (Richardson et al. 2011), in this study I refer to these processes as the introduction of an alien species to a city.

The most prevalent and well-developed prioritisation approach is one which focuses prevention and management efforts on single species. This approach identifies alien species (often using traits that may be related to invasion success) which are likely to have negative environmental and socio-economic impacts where introduced (McGeoch et al. 2016). However, for unintentional introductions, this approach is not feasible. This is because it is difficult to predict which species will arrive, as the biology and life history of species are sometimes poorly known (Leung et al. 2014; McGeoch et al. 2016) and as there is a vast number of species that could be unintentionally introduced.

Site-based prioritisation focuses on susceptible (sites which are most exposed to invasions) and sensitive (sites which are most vulnerable to impacts of invasions) sites (McGeoch et al. 2016). The designation of “susceptible” and “sensitive” sites is dependent on the perceived importance of their geographical, ecological and climatic characteristics (McGeoch et al. 2016). Cities can be deemed as susceptible and sensitive sites due to their highly disturbed and transformed nature.

The pathway approach focuses on identifying the pathways of introduction which facilitate the introduction of alien species, therefore specific taxa do not need to be identified in order for prevention and management efforts to be conducted (Katsanevakis et al. 2013). Therefore, this approach is particularly valuable where taxon-specific control efforts are not possible, for example, for unintentional introductions (Woodford et al. 2016). This approach focuses on identifying those pathways which have the highest likelihood of introducing alien species, enabling decision makers to prioritise interventions, and reduce the number of alien species (i.e. colonisation pressure) and individuals (i.e. propagule pressure) introduced (Hulme et al. 2008; Reaser et al. 2008; Katsanevakis et al. 2013; Pergl et al. 2017). However, due to the voluminous nature of the pathways and their economic importance, implementation can be legislatively and practically difficult. Therefore, to successfully implement this approach, the prioritisation of pathways of introduction is fundamental. Furthermore, the Convention on Biological Diversity (CBD) which assigns global priorities and guidelines regarding invasive alien species, through Aichi Target 9 require parties (countries) to identify and prioritise pathways of introduction by 2020 (Blackie and Sunderland 2015; Scalera et al 2016). As a result of concentrated anthropogenic activities cities are characterised by high levels of disturbance, high transport intensity and high environmental heterogeneity (Hansen and Clevenger 2005), often providing pathways for alien species to move.

While many recent studies have described and categorised the pathways of introduction (Hulme et al. 2008; Essl et al. 2015; Faulkner et al. 2016a), most of these studies have either focused on how alien species are introduced to natural systems or evaluated pathways at larger scales (globally or nationally) (Hansen and Clevenger 2005; Katsanevakis et al. 2013), and far less attention has been given to urban invasions and their pathways of introduction and vectors of spread. Cities present a complex network of vectors which facilitate alien species movement - both within these environments, and to subsequently invade natural and surrounding areas (von der Lippe and Kowarik 2008) with the possibility of resulting in serious negative impacts. In this study I refer to vectors of spread as the processes through which alien species spread after being introduction to a city.

Here I identify the important pathways of introduction and vectors of spread for cities and evaluate whether these pathways and vectors vary across 1) taxonomic groups, and for cities with different 2) geographical 3) ecological (biodiversity hotspots) and 4) climatic characteristics. By identifying the most important pathways and vectors in urban environments I hope to inform management decisions concerning the prevention of introduction and spread of alien species.

Methods

Data Collection:

In order to evaluate the importance of the pathways of introduction and the vectors of spread in cities, I: 1) selected cities to use as study sites, 2) obtained information on the geography, ecological and climatic characteristics of the cities, 3) identified the alien species present in each city, and 4) determined the pathways of introduction and vectors of spread of these species.

Selection of cities:

Human population affects the pressures exerted on cities to provide natural and economic resources for inhabitants. Therefore, we selected cities based on estimates of human population (only cities with ≥1,000,000 populations were selected) (Demographia 2014; UN 2014). Furthermore, to maintain data quality, I excluded cities in countries which were not affiliated to the Global Biodiversity Information Facility (GBIF) (GBIF 2016 – Accessed 1 December 2016). Lastly, I excluded all cities with no alien species records. A total of 167 cities were selected based on these characteristics (Figure 2.1).

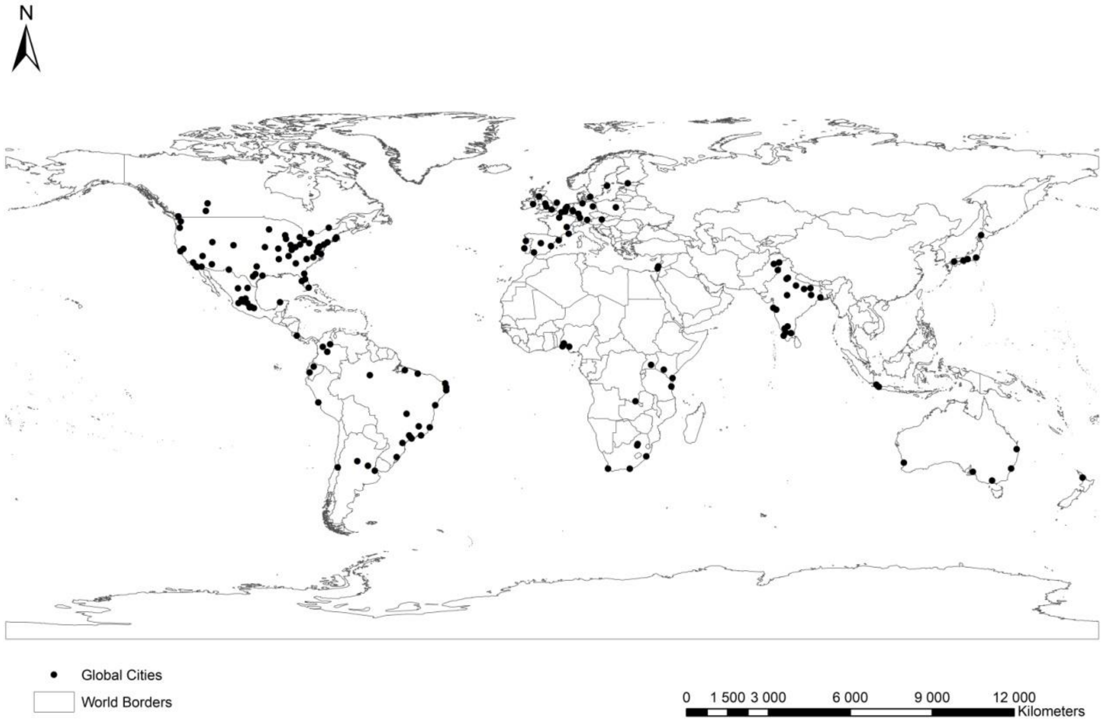

Figure 2.1: Map of the global cities selected based on climatic, ecological and geographic characteristics of cities, overlain with the recognised Biodiversity Hotspots for conservation (Meyers et al. 2000)

City characteristics:

I collected geographical, ecological and climatic data for the selected cities. Coastal and inland cities were identified to ascertain the differences in the importance of pathways of introduction in cities with ports as opposed to cities without ports. Climate affects the establishment of alien species in new locations (Ficetola et al. 2009), therefore I categorised cities into broad climate zones (equatorial, arid, warm temperate and snow climates) according to the Köppen-Geiger climate classification (Kottek et al. 2006). Cities in ecologically significant regions of the world, such as biodiversity hotspots, are expected to implement stricter conservation practices (Butchart et al. 2010). Alien species are one of the major threats to biodiversity conservation in these ecologically significant regions (Foxcroft et al. 2017); therefore, I recorded whether cities are located in biodiversity hotspots or not to determine the importance of pathways of introduction (Myers et al. 2000).

Alien species identification:

The Global Invasive Species Database (GISD) is an online inventory of invasive alien species providing information regarding the pathways of introduction utilised by these species, categorised using a standardised classification system (GISD 2016 - accessed 8 June 2016). Invasive alien species records were extracted from GISD (1124). Additionally, information regarding the introduction location of alien species was recorded for only a portion (282 records) of the species recorded in GISD; however, this information was inconsistently recorded (i.e. in some cases locations were listed as countries, but in other cases cities or provinces). To ascertain the introduced range of the species records extracted from GISD, I searched for each of these species in the Global Register of Introduced and Invasive Species (GRIIS) (GRIIS, 2016 – accessed 15 November 2016). I then downloaded occurrence data for each species' introduced range from the Global Biodiversity Information Facility (GBIF, 2016 – accessed 1 December 2016). I mapped the occurrence of alien species using ArcGIS ArcMap 9.3 to locate alien species presence in the preselected cities.

Pathway and vector data collection:

Hulme et al. (2008) developed a framework for the initial pathways of introduction, outlining six principal pathways (release, escape, transport-contaminant, transport-stowaway, corridor and unaided) for alien species, based on varying levels of human mediation. Pathways included in GISD were classified using the hierarchical categorisation system developed by Hulme et al. (2008), modified and adopted by the CBD (Scalera et al. 2016) (Table 2.1).

Table 2.1: List of the six principal pathways of introduction and the sub-categories within each pathway category as categorised in the CBD scheme (Hulme et al. 2008; Scalera et al. 2016).

Pathway Abbreviation:	Pathway Name
R	**Release**
Release.nature	Release in use for nature
Biol.control	Biological control
Eros.dune.stab	Erosion control and dune stabilisation
Fishery.wild	Fishery in the wild
Hunting.wild	Hunting in the wild
Lands.floral.faunal	Landscape; floral and faunal improvement
E	**Escape**
Agriculture	Agriculture
Aqua.mariculture	Aquaculture or mariculture
Bot.zoo.aquaria	Botanical gardens; zoos or aquaria
Farmed animals	Farmed Animals
Forestry	Forestry
Fur farms	Fur Farms
Horticulture	Horticulture
Ornamental.purp	Ornamental purposes
Pet.terr.species	Pet; aquarium; or terrarium species
Other.contam	Other escape from confinement
Research	Research (in facilities)
Live.food.bait	Live food and live bait
S	**Transport – Stowaway**
Container.bulk	Container or bulk
Hitchhikers.plane	Hitchhikers on a plane
Hitchhikers.boat	Hitchhikers on a ship or boat
Machinery.equip	Machinery or equipment
People.luggage	People and their luggage
Ballast.water	Ship or boat ballast water
Hull.fouling	Ship or boat hull fouling
Vehicles	Vehicles
Other.transport	Other means of transport
Fish.aqauculture	Angling, fishing, aquaculture equipment
Org.pack.mat	Organic packing material
C	**Corridors**
Waterways.seas	Interconnected waterways; basins or seas
Unknown	Unknown

Additionally, GISD provides information regarding vectors of spread (local dispersal methods) of alien species in invaded locations (GISD 2016). Some pathway sub-category names in the GISD data overlapped with those of the listed vectors; however, here I dealt with pathway data and vector data separately. I renamed vectors for ecologically accurate interpretation (e.g. natural dispersal, water currents, endo- and exozoochory can all be considered as natural dispersal, therefore I renamed natural dispersal to unaided dispersal – see Table 2.2).

Table 2.2: List of the vectors of spread and codes used in statistical analysis of vectors. I listed the names of vectors which were changed for ecologically accurate interpretation including the original names as these appear on GISD (2016). Vectors were classified as "intentional", "unintentional" and "natural" based on human-mediation.

Vector Abbreviations	Vector Name (original name)	Classification
Ornament	Ornamental	Intentional
Unaided	Unaided (natural dispersal)	natural
Water.curr	Water currents	natural
Wind.disp	Wind dispersed	natural
Road.veh	Road vehicles	Unintentional
Hab.mater	Transportation of habitat material	Unintentional
Agriculture	Agriculture	Intentional
Boats	Boats	Unintentional
Other	Other	Unknown
Mach.equip	Translocation of machinery or equipment	Unintentional
Endozoo	Endozoochory (consumption or excretion)	natural
Gard.esc	Garden escapes or waste	Unintentional
Disturb	Disturbance	Unintentional
Exozoo	Exozoochory (on animals)	natural
Clth.foot	Clothing or footwear	Unintentional
Hike.wear	Hikers clothing or boots	Unintentional
Off-rd.veh	Off-road vehicles	Unintentional
Aquacul	Aquaculture	Intentional
Esc.confin	Escape from confinement	Intentional
Resr.share	Resource sharing	Unintentional
Acclim	Acclimatisation societies	Intentional
Forestry	Forestry	Intentional
Horticul	Horticulture	Intentional
Intentional	Intentional release	Intentional
Veg.rep	Vegetative reproduction	Unintentional
Forg.resor	Foraging for resources	Unintentional
Land.faunal	Landscape and faunal improvement	Intentional
Live.food	Live food trade	Intentional
Nurs.trade	Nursery trade	Intentional

Furthermore, I classified vectors as intentional, unintentional and natural to emphasize the importance of human mediation in relation to vectors of spread (Scalera et al. 2016). Alien species records containing pathway information (1124 records) were extracted from GISD.

Analysis:

I classified species into taxonomic groups (plants, vertebrates, invertebrates) to investigate the variations in the prominence of pathways and vectors with different taxonomic groups (see Appendix 1 for number of alien species in specific classes for each taxonomic group). I then merged the pathways and vectors datasets with climatic and geographic information contained in the cities database (see Appendix 2 for full dataset).

The pathway and vector data extracted were tabulated to yield the counts of pathways and vectors facilitating the introduction of alien species. However, prior to conducting statistical analyses, inconsistent records were removed from the dataset. For example, all records lacking species-level identification were excluded from the analyses (e.g. *Didemnum spp.* and *Pinus spp.* were listed at a genus-level). I also excluded all species which were not present in the GRIIS and GBIF databases, as well as fungi, viruses and other pathogens (only plants and animals were included). Based on the data available in the GISD at the time of data collection, no species had moved through natural dispersal from one non-native region to another (Saul et al. 2016) and, therefore, the unaided pathway was excluded from the statistical analyses. Also, excluded were species for which pathway of introduction was "unknown". Statistical analyses were only performed at the pathway category level and not at the subcategory level. The vectors of spread are not applicable for all taxonomic groups (e.g. nursery trade and vegetative reproduction are only applicable for plants). Therefore, including taxonomic group in the analyses of the vectors of spread led to many zero counts, and resulted in problems with the statistical models (e.g. algorithms did not converge). Taxonomic group was, therefore, not included as a variable in the statistical analyses of the vectors of spread. All statistical analyses were conducted in R 3.2.3 (R Core Team 2015).

Additionally, I used Pearson's Chi-squared tests to determine if the counts of species that were introduced through the pathways, and that dispersed through the vectors of spread varied significantly from what would be expected based on chance alone (Crawley 2007).

To test the association between pathways of introduction (and vectors of spread) and the different factors (i.e. taxonomic groups, location, climate and biodiversity hotspots) or combinations of factors, the counts of species were analysed as contingency tables using log-linear models (Poisson error distribution and log-link, see Crawley 2007).

Supervised machine learning techniques were used to identify the most important pathways of introduction in cities (Mohri et al. 2012). This type of analysis uses binary recursive splitting to identify the most important "differentiators" (variables used to split the data) to split data into subsets, until the tree is fully grown. While other algorithms give preference to this robustness of tree models, in this study I chose to prune pruned the fully grown output tree to minimise over-fitting which would lead to inaccuracy in predictions (Mohri et al. 2012). The advantage of tree models is that the analysis is non-parametric and a variety of options are available for both continuous and categorical data. In this study I used a classification approach for categorical data to produce a decision tree in R 3.2.3 (R Core Team 2015). Furthermore, the output tree is simple and easy to interpret (Mohri et al. 2012).

Results

Data analysis:

The Pearson's Chi-squared tests showed that for both pathways of introduction ($\chi^2 = 2779$, df = 4, $p < 0.001$) and vectors of spread ($\chi^2 = 5749$, df = 28, $p < 0.001$), species counts varied significantly from what would be expected by chance alone, indicating a significant difference in the importance of both pathways and vectors. The escape and release pathways (intentional introductions) were the most important pathways. Most alien species spread through natural means once introduced, with the most important vectors of spread being unaided dispersal, endozoochory, exozoochory and water currents.

Taxonomic groups (plants, vertebrates, invertebrates):

There was a significant difference in the association between pathways and taxonomic group (Table 2.3). Therefore, the importance of the pathways differed for different taxonomic groups. Escape and release were the most important for plants and vertebrates (Figure 2.2).

Table 2.3: The results from the log-linear model testing the differences in the associations between pathways and factors (taxonomic groups – 3 categories, location – 2 categories, climate – 7 categories, biodiversity hotspots – 2 categories), and combinations of factors. The analyses show signification differences in associations between pathways and factors, as well as between pathways and a combination of factors.

Factor:	χ^2	df	p<
Taxonomic group	901.1	8	0.001*
Location, taxonomic group	28.3	8	0.001*
Climate, taxonomic	68.6	48	0.05*

group			
Biodiversity hotspots, taxonomic group	43.5	8	0.001*

*Significant association between pathways and factor

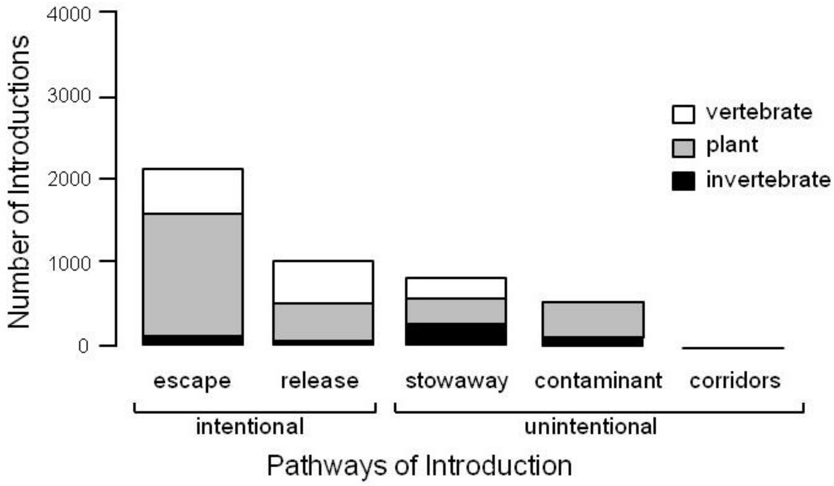

Figure 2.2: The number of alien species introductions through the principal pathways of introduction for different taxonomic groups (plant, invertebrate and vertebrate). Species utilising multiple pathways were counted for all pathways utilised. I found that counts of pathways varied significantly from what was expected based on chance alone ($\chi^2 = 2779$, df = 4, $p < 0.001$).

For invertebrates, the most important pathway was the stowaway pathway. Most plant species were intentionally introduced to cities through horticulture, while most vertebrate species were introduced through the pet trade (Figure 2.3). Most invertebrates were introduced as stowaways on ship or boat hull fouling or ballast water (Figure 2.3).

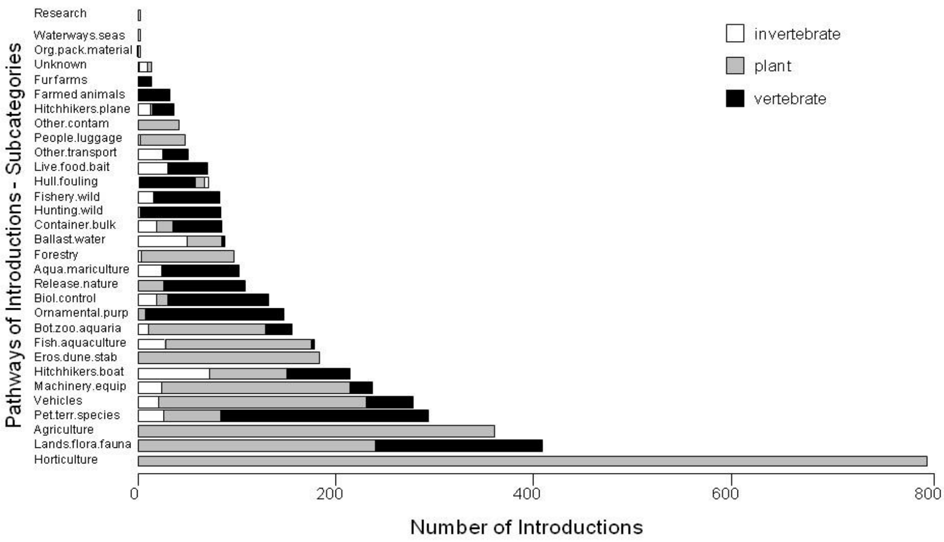

Figure 2.3: The number of alien species introduced to cities through the subcategories of pathways of introduction for different taxonomic groups (plant, invertebrate and vertebrate). Species utilising multiple pathways were counted for all pathways utilised. The full list of subcategory pathway names and codes can be located in Table 2.1.

Although not analysed statistically, unaided dispersal was the most important vector of spread for vertebrates and invertebrates. While unaided was also important, endozoochory and water currents are most important for plants (Figure 2.4).

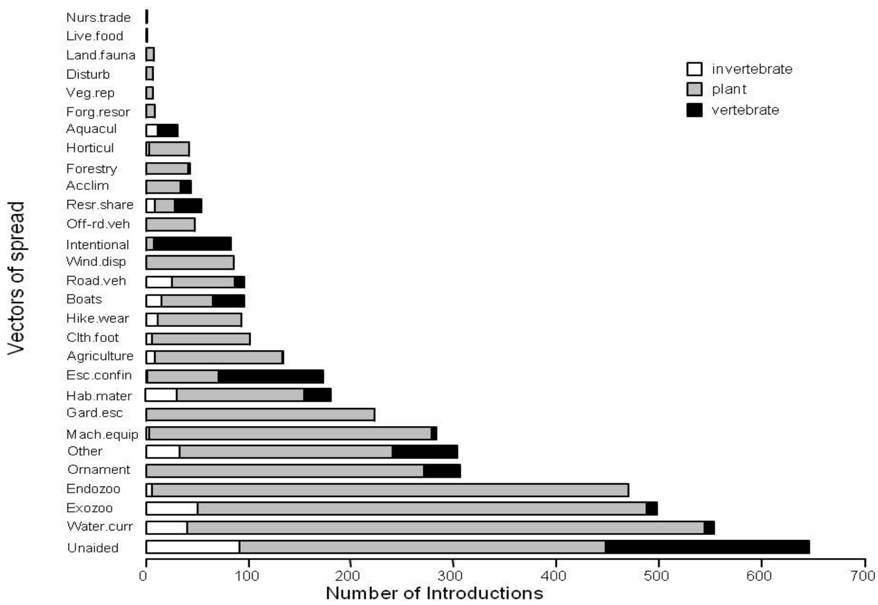

Figure 2.4: The number of alien species spread within coastal and inland cities through different vectors of spread. Species introduced through multiple vectors were counted for all vectors of spread utilised (refer to Table 2.2 for full list of vectors names and codes). I found a significant association between the vectors of spread and whether a city was coastal or inland ($\chi^2 = 5749$, df = 28, $p < 0.001$).

Location (coastal, inland):

I found a significant difference in the association between pathways and city location (coastal and inland) (Table 2.3) but the patterns varied across taxonomic groups. For invertebrates in coastal and inland cities the stowaway pathway was the most important pathway (Figure 2.5).

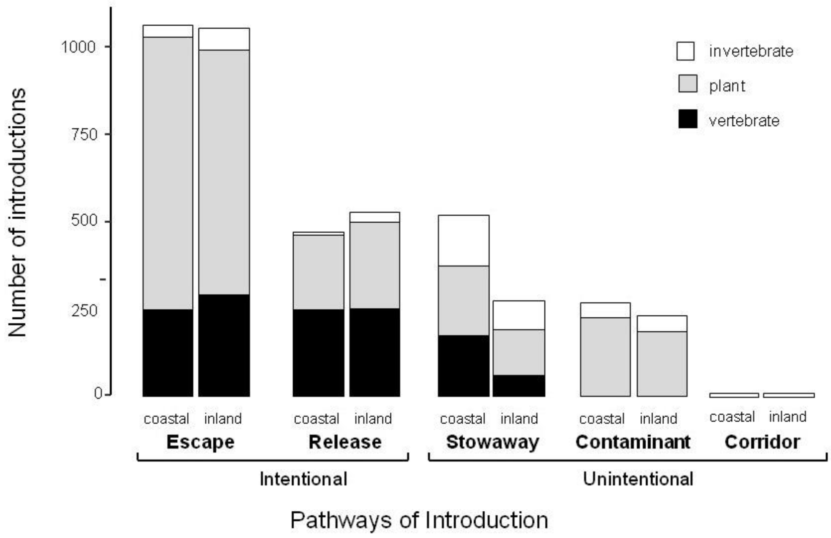

Figure 2.5: The number of alien species introduction through pathways of introduction for different taxonomic groups (plants, invertebrates and vertebrates) to coastal and inland cities. I found a significant association between pathways of introduction, taxonomic groups and whether cities were located along the coast or inland ($\chi^2 = 28$, df = 8, $p < 0.001$).

Most invertebrates were unintentionally introduced to coastal cities as hitchhikers on a ship or boat. The release and escape pathways were both important for vertebrates in coastal cities and inland cities (Figure 2.5). Most vertebrates were introduced through the pet trade and for landscape, floral and faunal improvement. The most important pathway for plants, regardless of the location of a city, was the escape pathway (Figure 2.5). Majority of the plant introductions were through the horticultural industry (Figure 2.3).

There was a significant difference in the association between vectors of spread and whether a city is coastal or inland (Table 2.4). However, regardless of the location of a city, the most important vector of spread was through natural vectors (unaided dispersal) (Figure 2.6).

Table 2.4: The results from the log-linear model testing the association between vectors and factors (taxonomic groups – 3 categories, location – 2 categories, climate – 7 categories, biodiversity hotspots – 2 categories), and combinations of factors. Taxonomic groups were excluded from the analysis. Results from the analysis show significant associations between pathways and factors, as well as between pathways and a combination of factors.

Factor:	χ^2	df	p<
Location	63.6	28	0.001*
Climate	251.4	168	0.001*
Biodiversity hotspots	81.5	28	0.001*

*Significant association between vectors and factors

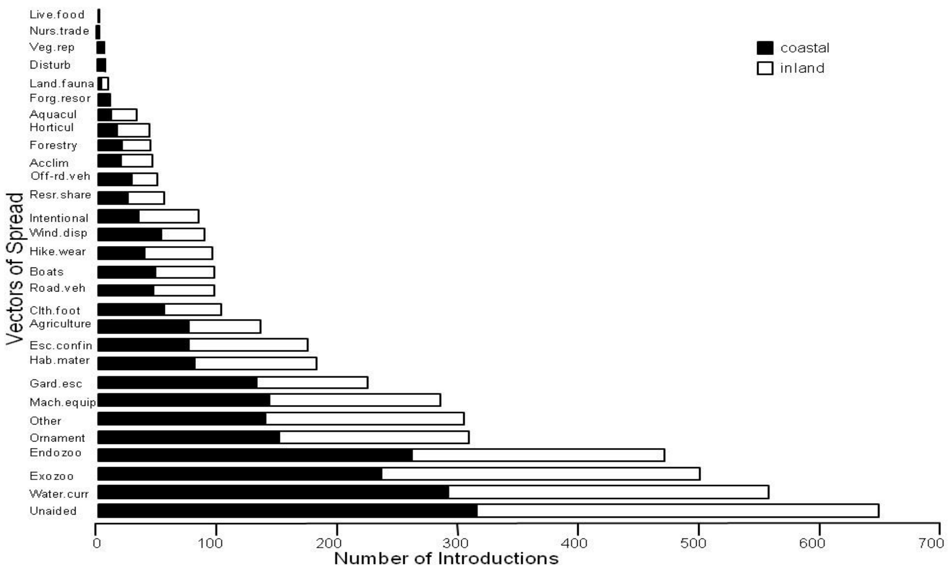

Figure 2.6: The number of alien species spread within coastal and inland cities through different vectors of spread (refer Table 2.2 for full list of vector names and codes). Species introduced through multiple vectors were recorded for all vectors of spread utilised. I found a significant association between the vectors of spread and whether a city was coastal or inland ($\chi^2 = 5749$, df = 28, $p < 0.001$).

Climate:

I found a significant difference in the association between pathways, climate and taxonomic group (Table 2.3). The importance of pathways differed for cities with different climates but the pattern varies depending on the taxonomic group. The escape pathway was the most important pathway of introduction for plants regardless of the climate zone of a city. For vertebrates in cities with different climate zones, the most important pathways of introduction were the escape and release pathways. The patterns observed for invertebrates varied across climate zones, with the stowaway, release and contaminant pathways being most important pathways of introduction

There was a significant difference in the association between vectors and climate (Table 2.4). There was variation in the importance of vectors depending on the climate in which a city is located. The pattern observed showed that in most climate zones unaided dispersal was the most important vector of spread. However, for equatorial climates, endozoochory was the most important vector and for arid-snow climates, ornamental purpose was the most important.

Biodiversity Hotspots:

The analyses showed a significant difference in the association between pathways, taxonomic groups and biodiversity hotspots (Table 2.3). Despite the significant association found between pathways, taxonomic groups and biodiversity hotspots, the importance of pathways for each of the taxonomic groups were the same. The most important pathways of introduction were the escape and release pathways.

Also, I found a significant difference in the association between vectors and biodiversity hotspots (Table 2.4). Regardless of a city's presence within a hotspot or not, the most important vector of spread was unaided dispersal. However, in cities which are not present in hotspots, endozoochory was an important vector of spread.

Importance of pathways based on city characteristics:

The results show that the most important factor in determining the importance of the pathways of introduction is the taxonomic group of alien the species (Figure 2.7).

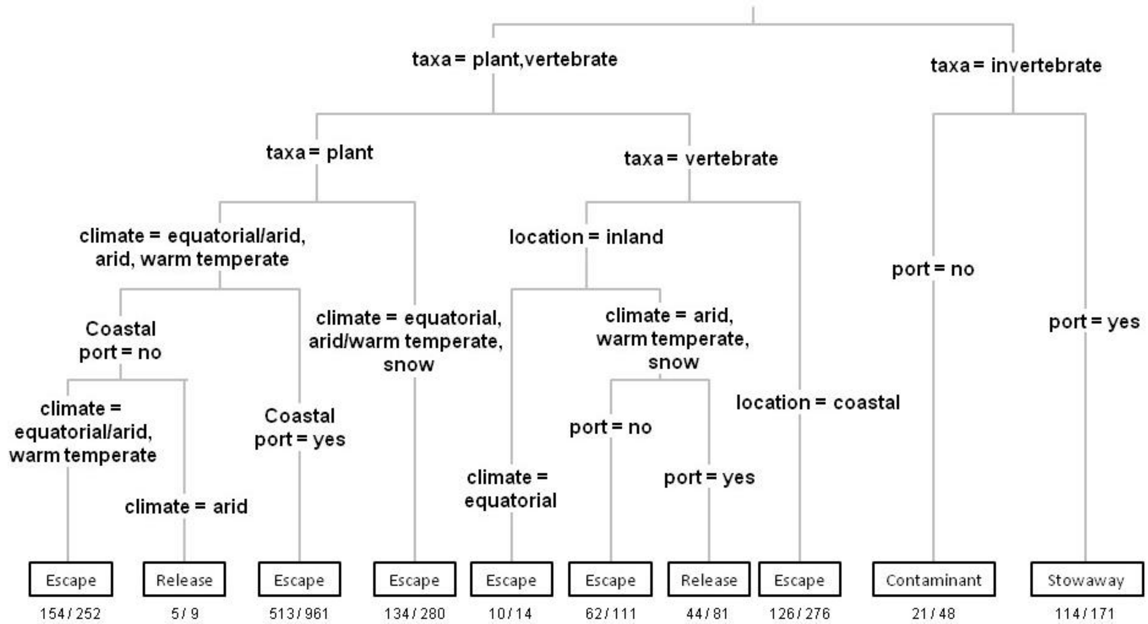

Figure 2.7: The decision tree produced shows, at terminal nodes, the most important pathways of introduction based on the characteristics of cities and taxonomic groups of alien species. The numbers below terminal nodes indicate the number of species recorded for the particular pathway in relation to the total number of species recorded for cities with those particular characteristics across all pathways. The climate zones follow the categorisation system (A = equatorial, B= arid, C = warm temperate and D = snow).

However, for some taxonomic groups, different pathways were important in cities with different geographical, ecological and climatic characteristics. In the case of plants, regardless of the characteristics of the city, escape was the most important pathway. The importance of pathways for invertebrates and vertebrates was more complex and depended on the characteristics of a city. For invertebrates, the importance of pathways differed according to the presence of a port, whether the city was located within a biodiversity hotspot and the climate zone of the city. According to these patterns, the escape, stowaway and contaminant pathways were important for invertebrates (Figure 2.7). The importance of pathways of introduction for vertebrate alien species depended on whether a city was located within a biodiversity hotspot or not, and the climate zone of the city. The escape, release and stowaway pathways were the most important pathways of introduction for vertebrates (Figure 2.7).

Discussion

The identification and prioritisation of pathways that facilitate the introduction of species in cities is essential for an effective response to biological invasions. In this study I focused on identifying the pathways of introduction which facilitate the introduction of alien species to urban environments such as cities. I found that intentional introduction of alien species to cities is more important than unintentional introductions, but subsequently alien species spread through natural mechanisms through the city. Therefore, reducing the number of alien species introduced to cities is pivotal for an effective response to alien species introduction.

In contrast to this study, the one conducted by Pergl et al. (2017) assessed the impacts of alien species in relation to specific pathways and showed that based on the taxonomic groups of alien species, impacts were associated with different pathways. Pergl et al. (2017) show that impacts for alien plant species introductions facilitated through the release, corridor and unaided pathways were more likely to have ecological impacts. However, in this study, the most important pathway of introduction for plants was the escape pathway, regardless of the characteristics of a city. The prominence of the escape pathway is contributed to the horticultural industry, and due to its substantial nature this industry will continue to contribute to the importance of the escape pathway (Burt 2007; Dehnen-Schmutz et al. 2007; Visser et al. 2016; Faulkner et al. 2016a; Cronin et al. 2017). The International Plant Protection Convention (IPPC) and the CBD outline voluntary codes of practice to regulate the horticultural industry (Schrader and Unger 2003), additionally some countries have also legislatively dealt with invasive alien plants (e.g. South Africa undertakes for eradication and management of alien invasive species under the National Environmental: Biodiversity Act No. 10 of 2004) (Reichard and White 2010). However, the lack of awareness regarding invasive alien plants amongst horticulturalists (suppliers and consumers) may result in the continued sale of many invasive plants (Drew et al. 2010; Cronin et al. 2017). The regulation of the horticultural industry lies with national, provincial and state government for particular cities (Burt 2007). In addition to the regulation, creating awareness among horticulturists and consumers is vital to prevent the sale of harmful alien plant species (Drew et al. 2010; Cronin et al. 2017).

Pergl et al. (2017) showed that impacts were not associated for specific pathways of introduction for invertebrates as well as vertebrates. The patterns observed in importance of pathways for invertebrates in this study showed that different pathways should be targeted for management responses based on a city's characteristics. For example, the stowaway pathway should be prioritised for management in cities with ports, while the escape (intentional) and contaminant (unintentional) pathways should be prioritised for cities without ports. Invertebrates (most of which are marine or freshwater introductions) were predominantly introduced as stowaways on ships or boats to cities with ports. In order to effectively respond to aquatic invertebrate introductions, a combination of on-board (i.e. ballast water and hull fouling management) and at-port (i.e. border control strategies) control strategies are essential in prevention measures (Kölzsch and Blasius 2011; Cope et al. 2016). However, it not feasible to inspect every vessel, container or passenger arriving at ports of entry, therefore coordinated strategies need to be implemented to strategically and effectively prevent introductions (Bacon et al. 2012; Faulkner et al. 2016b).

This study shows that for vertebrates, the importance of pathways of introduction is different for cities with different characteristics. Similar to the case of invertebrates, management strategies need to be based on the important pathways of introduction determined by the characteristics of the city. The intentional (escape and release) pathways are most important. Alien vertebrate species are predominantly introduced for the pet trade (Brown 2006; Kraus 2007). The increasing popularity of the pet trade will likely mean that this pathway will continue to be important in the introduction of alien vertebrate species. The management of the pet trade industry hinges on the regulation of species through permits. The problem with permit issuing is that permits centre on voluntary compliance to guidelines and codes of practices (van Wilgen et al. 2010; Essl et al. 2015; Hulme 2015). Permits are only required for owners to be in possession of said species but do not stipulate disposal procedures in the event that the pet owners no longer wish to retain their pets (van Wilgen et al. 2010). Socio-economic factors also play an important role in the escape of pets from confinement. Wealthy pet owners have better resources to adequately care for their pets and ensure that they do not escape from captivity (van Wilgen et al. 2010). But pets owned by a broader section of the consumer spectrum, may be less adequately cared for. In some instances, owners release or dispose of pets if their value decrease, or if they tire of taking care of these pets (van Wilgen et al. 2010). Follow-up procedures regarding the codes of best practice depend on the legislation and implementation of these codes in individual countries. There needs to be stricter traceability and accountability for negligence with regards to the release or disposal of alien vertebrate species kept as pets (Hulme 2006). Alternatively, issuing a tax or levy for the escape of exotics is also an option. However, this can potentially be disadvantageous to the pet trade industry, as the incurred cost could discourage consumers from purchasing exotic pet species. A more definite, rigorous process of permit issuing should be implemented with regards to the possession of ornamental and pet species (Hulme 2015).

Conclusion

This study focused on identifying the most important pathways of introduction. The introduction of alien species is the result of many complex factors. The prioritisation of the pathways of introduction is an essential first step towards an effective response to biological invasions (McGeoch et al. 2016), and even more so is the prioritisation of pathways of introduction to urban environments. I showed that different pathways are more important in cities with different characteristics, based on the taxonomic group of the alien species. In order to curb the introduction of alien species introductions, I recommend prevention strategies consider all of the complex factors resulting in alien species introductions (Pergl et al. 2017). The decision tree presented here provides decision makers with a starting point to prioritise the pathways of introduction for management based on the taxonomic group of interest as well as different characteristics of the city; however, further detailed research will be required for decision makers to assign priorities to alien species and pathways of introduction.

Acknowledgements

This research was funded by the South African National Department of Environmental Affairs through its funding of the South African National Biodiversity Institute's Invasive

Species Programme. I would like to thank The Global Invasive Species Database for the provision of pathways data.

Chapter 3: Prioritising potential incursions for contingency planning: pathways, species, and sites in eThekwini Municipality (Durban), South Africa as an example

Abstract

Increased trade and travel have resulted in an increasing rate of introduction of biological organisms to new regions. Urban environments, such as cities, are hubs for human activities facilitating the introduction of alien species. Additionally, cities are susceptible to invading organisms as a result of the highly altered and transformed nature of these environments. Despite the best efforts at prevention, new incursions of alien species will occur; therefore, prioritising incursion response efforts is essential. This study explores these ideas to identify priorities for strategic prevention planning in a South African city, eThekwini Municipality (Durban), by combining data from alien species watch lists, environmental criteria, and the pathways which facilitate the introduction of alien species in the city. Three species (with known adverse impacts elsewhere in the world) were identified as highly likely to be introduced and establish in Durban (*Alternanthera philoxeroides*, *Lithobates catesbeianus* and *Solenopsis invicta*). These species are most likely to enter at either the Durban Harbour; pet and aquarium stores; or plant nurseries and garden centres—therefore active surveillance should target these sites as well as adjacent major river systems and infrastructure. I suggest that the integrated approach (species, pathways, and sites) demonstrated in this study will help prioritise resources to detecting the most likely and damaging future incursions of alien species.

Keywords

Biological invasions, early detection, incursion response planning, prioritisation, alligator weed, southern sandbur, American bullfrog, red imported fire ant.

Introduction

Human-related activities such as trade and travel have facilitated the increased introduction of biological organisms outside of their native range (Hulme 2009; Tatem 2009; Faulkner et al. 2016b; Hill et al. 2016). Introduction of alien species (sensu Richardson et al. 2000) to regions outside of their native range is a serious problem which can result in the loss of biodiversity and have negative economic and social impacts (Lövei 1997; Pimentel et al. 2001; Kenis et al. 2009; Vilà et al. 2010; Vilà et al. 2011). However, not all alien species pose an unacceptable risk of becoming invasive and many have significant benefits. Moreover, the capacity to respond to the threat of biological invasions is limited, severely so in some cases (Early et al. 2016). It is thus impractical and even undesirable to prevent every alien species from being introduced into a new region. For these reasons, efforts to prevent biological invasions need to be prioritised.

McGeoch et al. (2016) suggest that prioritisation should incorporate three aspects—species, pathways, and sites. Specifically for prevention, priority should be given to species posing the greatest risk of invading new regions, the pathways facilitating their introduction, and sites most at risk of being invaded. For example, species can be assigned to watch lists based on pre-border risk assessments that inform prevention strategies and contingency plans (Genovesi and Shine 2004; Nehring and Klingenstein 2008; Parrot et al. 2009; Faulkner et al. 2014). The German-Austrian Blacklist System (GABLIS), one such example, assigns species to three different categories based on risk assessments: 1) species that are of concern and for which specific intervention is required; 2) species whose risk to biodiversity cannot be ascertained; and 3) species with no risk to biodiversity that can be imported (Essl et al. 2011). GABLIS is a fairly rapid and effective assessment of different taxonomic groups (including plant, vertebrate and invertebrate species) in a variety of environments and illustrates the benefits of using watch lists as an early warning system (Verbrugge et al. 2010; Essl et al. 2011). Similar approaches have been implemented in Germany ('warn list' for aquatic alien species – Nehring and Klingenstein 2008), Belgium (Branquart 2007) and South Africa (NEM:BA prohibited species list – DEA 2016; watch list of alien species - Faulkner et al. 2014).

Similarly, pathways facilitating the introduction of alien species to new regions need to be identified and the risk associated with introductions facilitated through these pathways assessed. Priority should then be given to the pathways of introduction which pose the highest risk of facilitating the introduction of alien species (Padayachee et al. 2017; Pergl et al. 2017). The aim of this approach is to reduce colonisation pressure (i.e. the number of alien species) and propagule pressure (i.e. the number of individuals of a given alien species) facilitated through high-risk pathways of introduction (Hulme et al. 2008; Reaser et al. 2008). This approach is significant in targeting the prevention of multiple taxa being introduced to a variety of environments, and especially in responding to the unintentional introduction of alien species.

Finally, sites are assessed as high-risk based on the likelihood of an invasion (i.e. the exposure to incursions and whether incursions will establish and become invasions) and sensitivity (i.e. most vulnerable to the impacts of invasions) (Wilson et al. 2017). Sites which are most at risk of being invaded and most sensitive to the impacts of invasions are given priority for targeting the surveillance of new alien species. An important consideration in prioritising sites for prevention efforts is to identify where species are likely to first be introduced and establish. In this context, and given the preponderance of introduction pathways, it is important that some biosecurity efforts explicitly focus on cities. Cities can be considered as sites where invasions are likely to occur as a result of the high environmental heterogeneity, high transport intensity and high levels of disturbance present in these environments (Kuhman et al. 2010; Pyšek et al. 2010; Kowarik 2011; Cadotte et al. 2017; Gaertner et al. 2017b). Moreover, cities are potentially sensitive if the impacts affect ecosystem services or humans directly (Hansen and Clevenger 2005; Potgieter et al. 2017). They are also often areas where there are many complex competing demands on natural resource managers (e.g. for South Africa see (Dickie et al. 2014; Gaertner et al. 2017a; Irlich et al. 2017; Zengeya et al. 2017)

In this study I identified potential future incursions in eThekwini (Durban), South Africa, based on selected alien species, the pathways facilitating their introduction, and the sites most at risk of being invaded by these species. By jointly considering species, pathways and sites, I hoped to provide a tool for decision makers to more effectively target surveillance and contingency planning.

Methods

The eThekwini municipality (also referred to as Durban) is one of the largest port cities on the east coast of the African continent and is an important economic centre in South Africa (Roberts 2008). In addition to being a major populated city (approximately 3.4 million – STATSSA 2017), Durban is also a significant contributor towards tourism (Roberts 2008). Resources to target the introduction of alien species are scarce (Grice et al. 2011; Early et al. 2016); therefore, prioritisation is essential to effectively prevent the introduction of alien species.

To develop a methodology for decision makers to assign priorities for prevention strategies I: 1) identified cities with similar climate to Durban; 2) used existing lists of species considered as not present in South Africa that pose an unacceptable risk of invasion; 3) identified which of the selected species are likely to have pathways facilitating their introduction to Durban; 4) developed climatic suitability models for the selected species based on the climate in Durban; and 5) linked the climate and pathway information to identify sites within Durban that should be the focus of contingency planning for particular species (Figure 3.1).

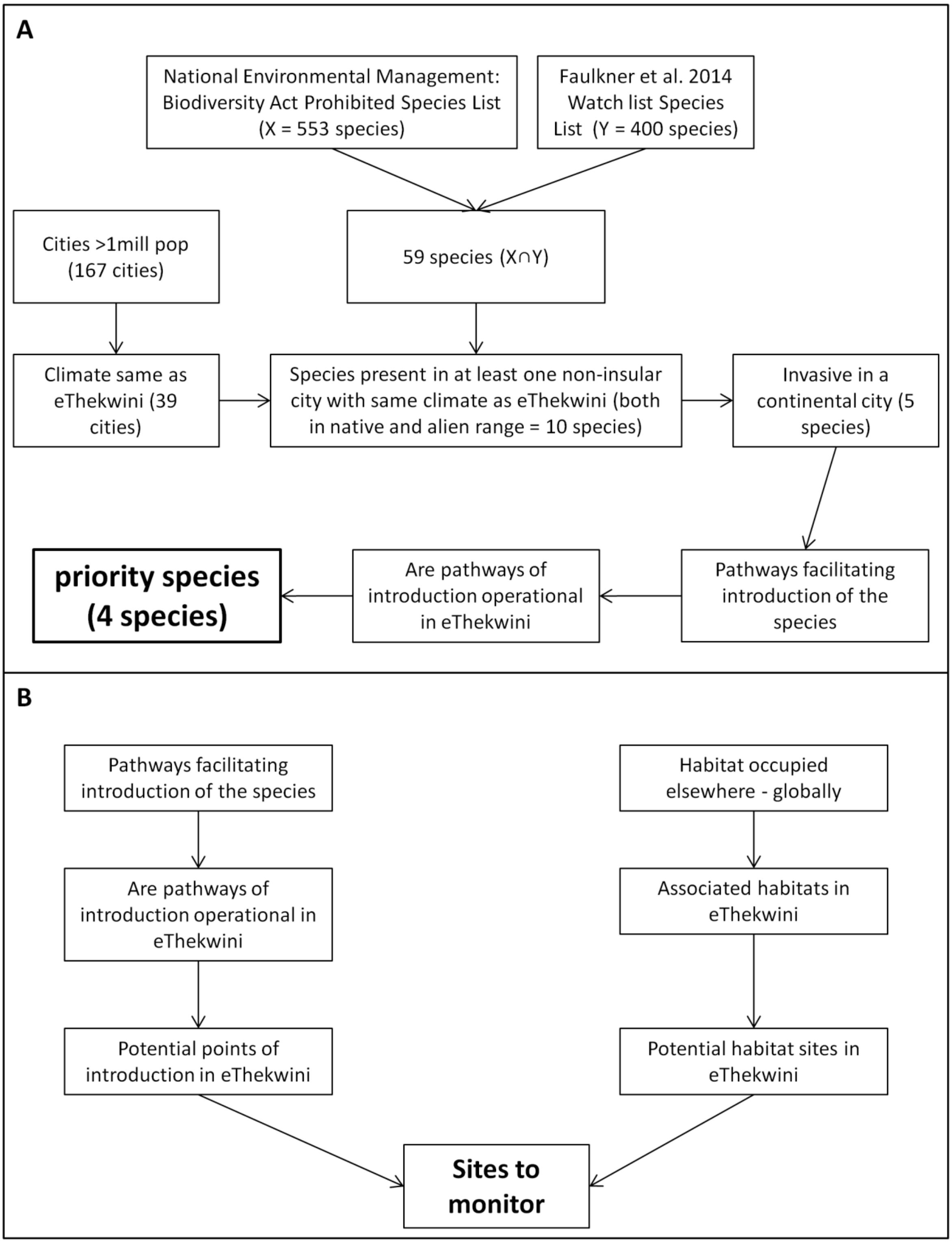

Figure 3.1: A simple and rapid method to prioritise targets for contingency planning to prevent biological invasions. The method identifies priority sites for managing particular high-risk incursions. Figure 3.1A shows the selection criteria used to select target species for climatic suitability analyses, the number of species selected at each stage of selection is

indicated in parentheses. Figure 3.1B shows the criteria used to identify potential points of introduction for the select target species, as well as the criteria used to identify potential points of naturalisation (i.e. priority sites for monitoring in the eThekwini municipality).

Human population, as a result of the associated activities (trade and travel), is one of the main correlates of species introductions into regions outside of their native range (Hulme 2009, Carpio et al. 2016), while climate is one of the main limitations to species establishment in these new regions (Rejmánek and Richardson 1996; Welk et al. 2002; Robertson et al. 2004; Thuiller et al. 2006). The methodology used in this study is required to be easily implementable and adjustable to various urban contexts, therefore I considered cities across countries with varying economic statuses. I selected global cities with populations of ≥1 million people (Padayachee et al. 2017) and used climate matching techniques to select all global cities, from this list, with the same climate type as Durban based on the Köppen-Geiger climate classification (Köttek et al. 2006).

The National Environmental Management: Biodiversity Act (No. 10 of 2004) governs all biodiversity related issues in South Africa, including biological invasions (NEM:BA 2004). In regulations under NEM:BA, a prohibited species list was created, based in part on expert opinion, that lists species that are not believed to be present in South Africa and whose introduction should be prevented (DEA 2016). The implication is that strategic prevention plans should be developed for all species on the prohibited list. Separate to this, Faulkner et al. (2014) created a watch list of alien species whose introduction into South Africa should be regulated (based on likelihood of introduction, likelihood of establishment, and impact elsewhere). In this study I considered species present on both of these lists, as these are species that have been identified as high-risk and the regulations mandate government entities (e.g. municipalities) to manage such species.

I used these national lists and applied my own selection criteria (Figure 3.1) to identify species which should be prioritised for Durban. I ascertained the native and alien range of species using the CABI Invasive Species Compendium database (CABI 2018 - https://www.cabi.org/isc/) and the Global Register of Introduced and Invasive Species database (GRIIS 2017 - http://www.griis.org/). I downloaded occurrence data for all the species in both their native and alien range from the Global Biodiversity Information Facility

(GBIF 2017a; 2017b; 2017c; 2017d). Species occurrences for which sources were not listed or were listed as "unknown" in the GBIF database were removed from the dataset; additionally (for plant species) I removed occurrences based on herbarium records. Species with inconsistent taxonomic classification were also excluded (i.e. species for which variations and subspecies were only listed in GBIF). The occurrence records were then mapped and converted to shapefiles using ESRI ArcMap 10.3.1 software (ESRI 2015). Species occurrence records were then overlaid onto the selected cities. Species which occurred within the topographical boundaries of cities with the same climate as Durban were selected (regardless of whether the species were native or alien to the city). Furthermore, I excluded species which were only found as alien on islands (including Australia). This was on the assumption that biotic resistance is different on islands and continents. I used the CABI Invasive Species Compendium (CABI 2018 – https://www.cabi.org/isc/) and Global Invasive Species Database (GISD 2018 – http://www.iucngisd.org/gisd/) to identify the pathways facilitating the introduction of the remaining species to see if they might be introduced to Durban. The description of the pathways used in this study was as per the Convention of Biological Diversity pathway classification scheme (Hulme et al. 2008; Scalera et al. 2016; Harrower et al. 2017).

Maximum entropy distribution modelling was selected to map the potential geographic distribution and evaluate the risk of invasion of the remaining species (Maxent v3.4.1 - Phillips et al. 2006; Phillips and Dudík 2008). Even though Maxent has limitations in its representation as being a "presence-only data" algorithm, the software by default selects pseudo-absences in the form of background data and hence works well for presence-only datasets, such as the datasets downloaded from GBIF and used in this study (Barbet-Massin et al. 2012). Furthermore, predictions are robust as small sample sizes and irregularly sampled data do not strongly affect the model produced (Pearson et al. 2007; Elith et al. 2011). I chose to primarily utilise the default settings used by Maxent: 1) 10 000 random background points were assumed to be pseudo-absences points, however, I restricted the selection of background points to select points from the species distribution range (native and alien); 2) create response curves to evaluate the species response to individual predictors; 3) use a logistic output to produce continuous maps and 4) perform a jack-knife procedure to assess individual predictor importance to the model. In addition, I also chose to select auto features as these produced smooth response curves. I opted to change the following settings: 1) I controlled over-fitting and clamping by setting the regularisation parameter to 1; 2) I evaluated the model and reduced bias by setting a random seed and selecting a random test percentage of 25 percent (i.e. the model was trained using 75% of the data); 3) I ensured variability by choosing to subsample the data over 10 replicate models; and 4) I allowed the model enough time for convergence by setting the number of iterations to 5000. The importance of individual bioclimatic predictors was assessed using jack-knife procedures and their individual percentage contribution to training the model. I evaluated model performance using a measure of model performance called the area under the curve (AUC) of the receiver operating characteristic, ranging from 0 to 1 (high accuracy = AUC > 0.9; moderate accuracy = 0.9 < AUC > 0.7; poor accuracy = 0.7 < AUC > 0.5; model performance worse than random = AUC < 0.5) (Peterson et al. 2011). I created binary maps of the species predicted climatic suitability using ESRI ArcMap 10.3.1 (ESRI 2015). Climate is one of the main determinants of species growth and establishment in regions outside of their native ranges (Welk et al. 2002; Robertson et al. 2004; Thuiller et al. 2006; Ficetola et al. 2007); therefore I utilised climatic data from the WORLDCLIM database (19 bioclimatic predictors – http://www.worldclim.org/) (Hijmans et al. 2005). I selected bioclimatic predictors which were closely related to the successful growth and establishment of the selected species (e.g. *Lithobates catesbeianus* thrives in wet, hot environments, therefore I selected precipitation of the warmest month as a climatic variable), and those predictors which were least correlated. I tested the multicollinearity of the data for each species using the correlation and summary statistics tool found in the SDM toolbox developed for ESRI ArcMap (Brown 2014). The SDM toolbox was developed to facilitate the pre-processing of data for species distribution modelling, specifically using the Maxent software (Phillips and Dudík 2008; Brown 2014). The correlation between raster layers is measured as the dependency between all of the input layers. Correlation is measured as a ratio of the covariance between the raster layers divided by the product of their standard deviations. I set a correlation cut-off value of 0.60 (i.e. layers with a correlation of 0.60 or higher were considered as being highly correlated) (Snedecor and Cochran 1968; Brown 2014). Layers which were highly correlated were excluded from the climatic models.

Results

Fifty-nine species from different taxonomic groups were on both the NEM:BA prohibited species list and the watch list produced by Faulkner et al. (2014) (invertebrates - 9, plants - 32 and vertebrates - 18). Based on the Köppen-Geiger Climate Classification (Köttek et al. 2006), there are 39 cities of over a million inhabitants which have the same climate type as Durban (see Appendix 5). Ten species, from the initial 59, were present in at least one of the 39 cities. After eliminating species which were only alien or invasive on islands, five species were left (*Alternanthera philoxeroides* – alligator weed, *Cenchrus echinatus* – southern sandbur, *Lithobates catesbeianus* – American bullfrog, *and Solenopsis invicta* – red imported fire ant and *Vulpes vulpes* – red fox).

I identified the pathways of introduction for each of the remaining species. At this stage, I excluded *V. vulpes* (red fox) as it is extremely unlikely to be introduced by the only pathways that have historically led to its introduction to other countries (hunting in the wild and fur farms – GISD 2018). The pathways facilitating the introduction of *C. echinatus* were unknown (GISD 2018). This meant that while it was possible to still build a climatic suitability model for the species, it is not possible, at this stage, to link climate suitability to introduction pathways. *Alternanthera philoxeroides* (Box 3.1) and *S. invicta* (Box 3.4) have previously been introduced through the transport-stowaway and transport-contaminant pathways. The introduction of *L. catesbeianus* (Box 3.3) has been facilitated through the release and escape pathways. Three main potential points of introduction were identified for these species based on the pathways: the Durban Harbour (all four species), pet and aquarium stores (29 within the municipal boundary – *L. catesbeianus*) as well as plant nurseries and garden centres (60 within the municipal boundary – *S. invicta*). I then identified likely points of first naturalisation as sites to monitor for the presence of the four selected species: the Durban Harbour was identified as a site to monitor for the presence of *A. philoxeroides* (Figure B3.1) and *S. invicta* (Figure B3.4). River systems adjacent to points of introduction are also identified for surveillance efforts for *A. philoxeroides* (Figure B3.1), *L. catesbeianus* (Figure B3.3) and *S. invicta* (Figure B3.2) because of these species' dependency on readily available water resources for survival. I also identified the built infrastructure surrounding the Durban Harbour for monitoring for *S. invicta* (Figure B3.4). River systems and wetlands adjacent to pet and aquarium stores were identified for monitoring for the presence of *L. catesbeianus* (Figure B3.3).

Species distribution models:

The climate models developed for the selected species ranged from highly accurate model performance to moderately accurate performance based on the AUC of receiver operating characteristics (see Table 3.1 for details). However, the patterns of predicted climatic suitability varied for each of the species. The *L. catesbeianus* (Figure B3.3) and *C. echinatus* (Figure B3.2) models (moderately accurate performance) showed a uniform climatic suitability for these species across the city, with *C. echinatus* having a higher predicted climatic suitability than *L. catesbeianus*. The *A. philoxeroides* (Figure B3.1 – highly accurate model performance) model showed the highest predicted climate suitability along the coastline of Durban decreasing to the north-west of the city. The *S. invicta* (Figure B3.4 – highly accurate model performance) model showed a relatively low climatic suitability, however, the most important regions for *S. invicta* were the northern regions and the coastline of the city (see Table 3.1 for details).

Box 3.1: Pathways of introduction, preferred habitats, potential entry points, sites to monitor, and climatic suitability for *Alternanthera philoxeroides* (alligator weed)

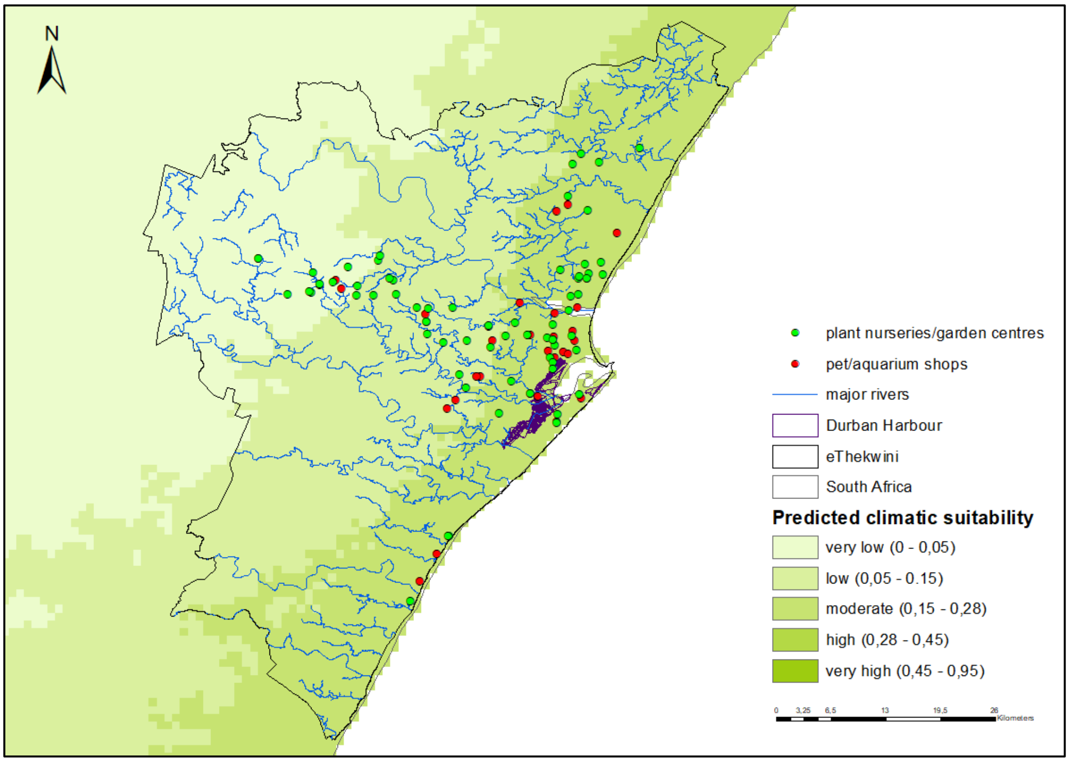

Figure B3.1: predicted climatic suitability *A. philoxeroides* in Durban. The model is highly accurate in predicting climatic suitability (0.929 ± 0.007 - AUC±SD). Predicted suitability is indicated using a colour scale (darker shades indicate higher predicted suitability). Also indicated are the potential points of introduction and potential points of first naturalisation to monitor for *A. philoxeroides* in Durban.

Pathways of introduction: ship ballast (historical), transportation of habitat material, ornamental purposes

Potential points of first introduction: The Durban harbour, plant nurseries and garden centres, pet and aquarium shops

Habitat and Land uses: *Alternanthera philoxeroides* can grow in a variety of habitats but is usually found in aquatic habitats, particularly rivers, lakes, dams, ponds, canals, flood plains and irrigation channels

Habitats present in Durban: Yes

Potential sites of first naturalisation in Durban: The Durban harbour and adjacent river systems (particularly uMhlatuzana and uMbilo river systems).

Box 3.2: Pathways of introduction, preferred habitats, potential entry points, sites to monitor, and climatic suitability for *Cenchrus echinatus* (southern sandbur)

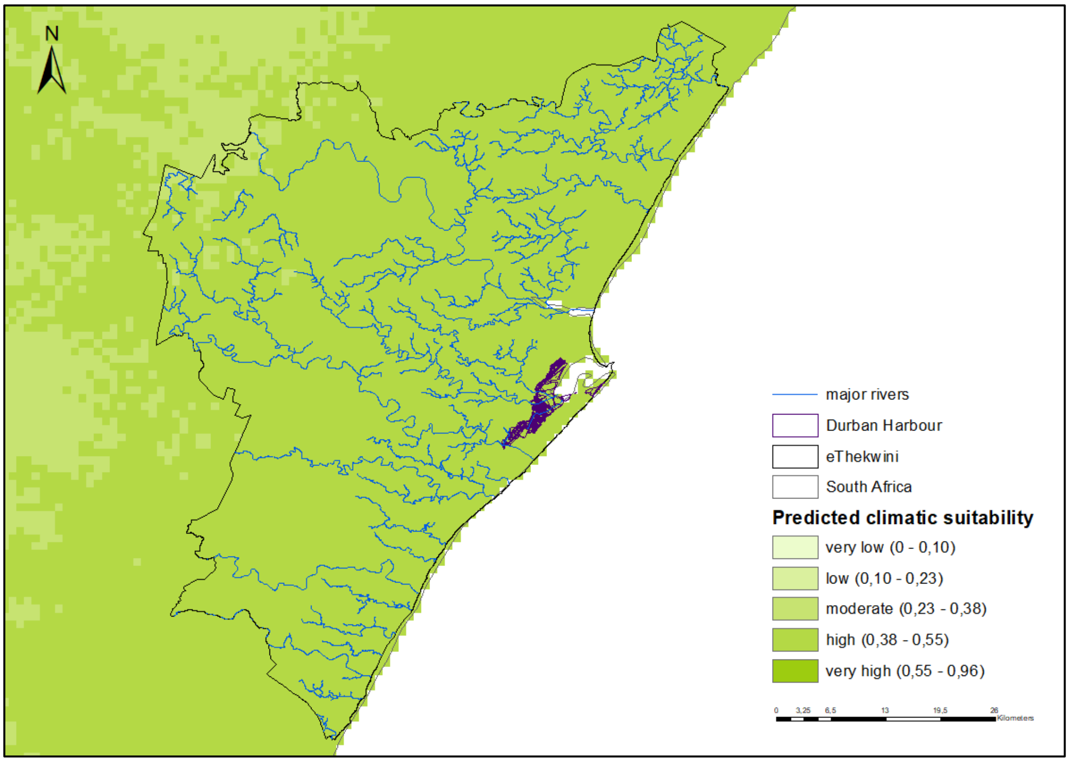

Figure B3.2: predicted climatic suitability for *C. echinatus* in Durban. The model is moderately accurate in predicting climatic suitability (0.812 ± 0.008 - AUC±SD). Predicted climatic suitability is indicated using a colour scale (darker shades indicate higher predicted suitability). Even though pathways of introduction for this species could not be identified with certainty, the potential points of introduction and first naturalisation (i.e. where to monitor) for *C. echinatus* in Durban are indicated

Pathways of introduction: unknown

Potential points of introduction: The Durban harbour

Habitats and Land Use: *Cenchrus echinatus* favours temperate and tropical zones. This species is usually found in open lands, cultivated fields, along roadsides and coastal environments and waste places.

Habitats present in Durban: Yes

Potential sites of first naturalisation: The Durban harbour and adjacent beach environments and sand dunes

Box 3.3: pathways of introduction, preferred habitats, potential entry points, sites to monitor and climatic suitability for *Lithobates catesbeianus* (North American bullfrog)

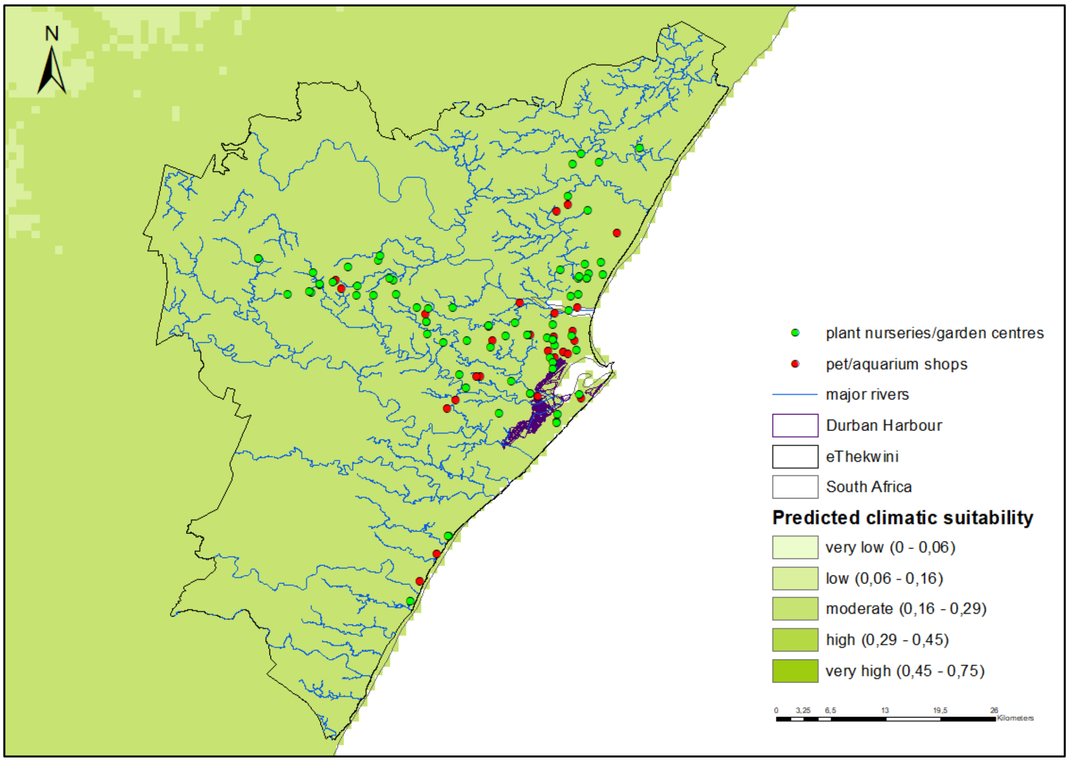

Figure B3.3: predicted climatic suitability of *L. catesbeianus* in Durban. The model is moderately accurate in predicting climatic suitability (0.791 ± 0.005 - AUC±SD). Predicted suitability is indicated using a colour scale (darker shades indicate higher predicted suitability). Also indicated are the potential points of first naturalisation (i.e. priorities for monitoring) for *C.echinatus* in Durban.

Pathways of introduction biological control, landscape; floral and faunal improvement, release in use for nature, aquaculture (food source), ornamental purposes

Potential points of introduction: The Durban harbour, pet and aquarium shops

Habitats and Land Use: *Lithobates catesbeianus* prefers warm, moist environments and requires permanent, shallow and still bodies of water. This frog species usually occupies ponds, swamps, streams and irrigation ditches

Habitats present in Durban: Yes

Potential sites of first naturalisation: major river systems, especially those adjacent to potential points of introduction (pet and aquarium shops)

Box 3.4: pathways of introduction, preferred habitats, potential entry points, sites to monitor and climatic suitability for *Solenopsis invicta* (red imported fire ant).

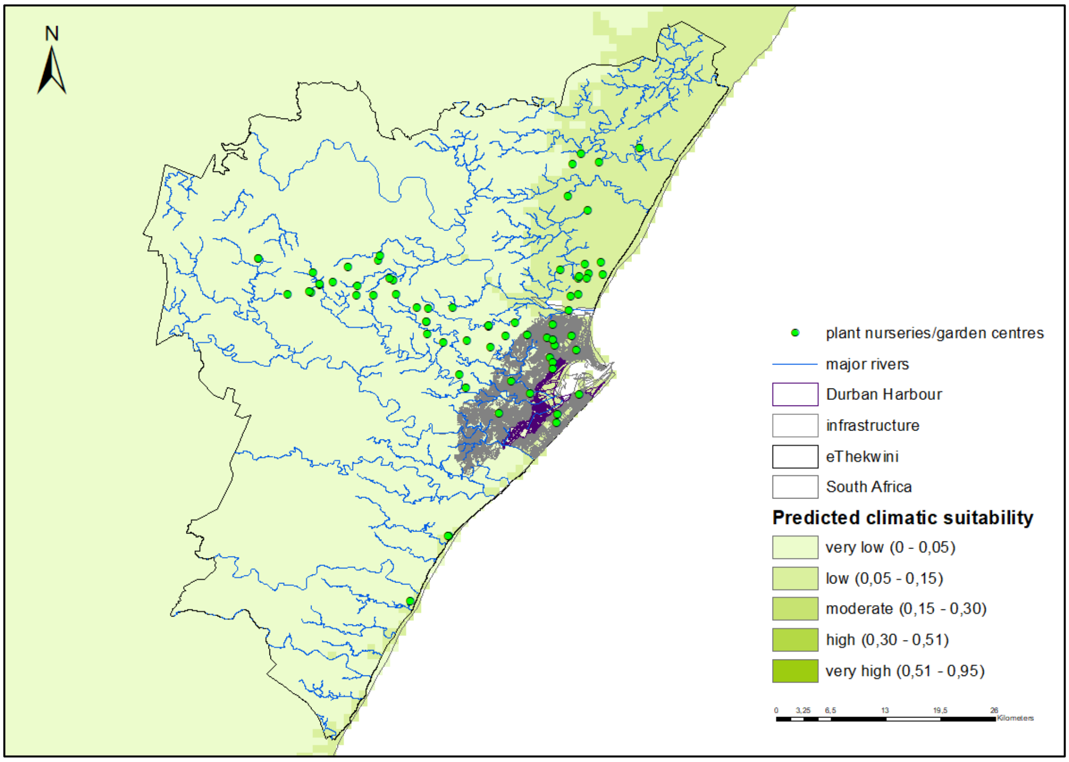

Figure B3.4: predicted climatic suitability of *S. invicta* in Durban. The model is highly accurate in predicting climatic suitability (0.961 ± 0.006 – AUC±SD). Predicted suitability is indicated using a colour scale (darker shades indicated higher predicted suitability). Also indicated are the potential points of introduction and fist naturalisation to monitor for *S. invicta* in Durban.

Pathways of introduction: contaminated nursery material, translocation of machinery and equipment, organic wood packaging

Potential points of introduction: The Durban harbour, plant and nursery material

Habitats and Land Use: *Solenopsis invicta* can occupy a wide variety of habitats and can become dominant in altered habitats. This ant species is found in disturbed or developed forests or on trails near buildings

Habitats present in Durban: Yes

Potential sites of first naturalisation: The Durban harbour and adjacent built infrastructure, plant nurseries and garden centres and surrounding natural environments linked to major river systems.

Table 3.1: List of species for which predictive models were developed, the bioclimatic predictors used to develop each model, and the percentage contribution of each predictor to the model

Species	Bioclimatic Predictors selected (% contribution to model)	Model Performace (AUC ± Standard Deviation)
Alternanthera philoxeroides	Mean diurnal range (10), Mean temperature of the warmest month (17), Precipitation seasonality (21), Precipitation of the warmest quarter (9), Precipitation of the coldest quarter (54)	High accuracy (0.929 ± 0.007)
Cenchrus echinatus	Mean temperature of the warmest quarter (25), Precipitation of seasonality (34), Precipitation of the wettest quarter (44), Precipitation of the driest quarter (7)	Moderate accuracy (0.812 ± 0.008)
Lithobates catesbeianus	Mean diurnal range (4), Temperature seasonality (44), Maximum temperature of the warmest month (21), Precipitation of the warmest quarter (3), Precipitation of the coldest quarter (38)	Moderate accuracy (0.791 ± 0.005)
Solenopsis invicta	Mean diurnal range (13), Maximum temperature of the warmest month (28), Precipitation of the wettest month (20), Precipitation of the driest month (45), Precipitation seasonality (4)	High accuracy (0.961 ± 0.006)

Additionally, I superimposed pet and aquarium shops, nurseries and garden centres, the major river systems and the Durban Harbour data with the climatic suitability models (see Boxes 3.1-3.4). From the sixty plant nurseries and garden centres in Durban, eighteen were located adjacent to major rivers, while seven were located adjacent to the Durban Harbour. Climatic suitability for *C. echinatus* and *L. catesbeianus* (Boxes 3.2-3.3) was found to be uniform across the city; therefore, all points of introduction are likely to be sites of first naturalisation. The highest predicted climatic suitability for *A. philoxeroides* (Box 3.1) was found along the coast of Durban in which 34 plant nurseries and garden centres were located. I found 23 plant nurseries and garden centres located in low climate suitability regions for *S. invicta* (Box 3.4). I found 29 pet and aquarium shops within Durban, 13 of which were located near the major river systems while eight were located near the harbour. Nineteen pet and aquarium shops were located in the regions of highest predicted suitability for *A. philoxeroides*, while 17 were located in the highest predicted suitability for *S. invicta*. One pet and aquarium shop was located within the built infrastructure adjacent to the Durban Harbour; hence this was highlighted as an important potential point of introduction for *A. philoxeroides*, *L. catesbeianus* and *S. invicta*.

Discussion

While watch lists and prohibited lists are beneficial in highlighting species to monitor, the lists often consist of numerous species, across a variety of taxa (e.g. the NEM:BA prohibited species list – 553 targeted species, DEA 2016; Faulkner et al. 2014 – 400 watch list species). The selection criteria used in this study (Figure 3.1) allow for these lists to be narrowed down in the context of a specific urban setting, to provide priority targets for incursion response. I recommend that three of the species identified (*Alternanthera philoxeroides*, *Lithobates catesbeianus* and *Solenopsis invicta*) be targeted for contingency planning in Durban, e.g. through the production of awareness material to improve passive surveillance, consideration of active surveillance through a monitoring scheme, and the development of incursion response plans so that if they are detected, there is no delay before action is taken (Wilson et al. 2017). Consideration should also be given to planning for the fourth species, *Cenchrus echinatus*, although a priority will be to first identify if and where it is likely to be introduced to.

The Convention on Biological Diversity (CBD) Aichi Target 9 requires that pathways of introduction be identified and prioritised for management efforts (UNEP 2011). In this study, I identified likely sites of first naturalisation as priorities for incursion response efforts. I identified three important potential introduction points: the Durban Harbour, pet and aquarium stores and nursery and garden centres. Each of the species used in this study were linked to one of these potential introduction points. The potential sites of first naturalisation identified in this study were all found to be in close proximity to the Durban harbour and the major river systems in the city, indicating that these sites are important for monitoring efforts.

Identifying the pathways facilitating the introduction of alien species is important for preventing alien species introductions. However, not all pathways of introduction are operational in all cities. By identifying the pathways which facilitate alien species introductions, priorities can be assigned to species with the potential of being introduced to the particular region of interest. In this study I was able to eliminate the species *Vulpes vulpes* (red fox) because the pathways facilitating its introduction (hunting in the wild and fur farms) are not operational in Durban. By contrast, the pathways which facilitate the introduction of *C. echinatus* are unknown. Therefore, determining if, how, and where the species is likely to be introduced to the city should be a key area for future applied research.

The Durban Harbour was identified as an important potential introduction point as well as a site to monitor for the introduction of *A. philoxeroides* and *S. invicta*. The pathways facilitating the introduction of these species are linked to the harbour. *Alternanthera philoxeroides* is primarily introduced through ship ballast and as a stowaway on ship cargo (Burgin et al. 2010), while *S. invicta* is introduced on organic wood packaging. These species can thrive in highly transformed habitats; therefore, I also recommend the adjacent infrastructure to the harbour as sites for monitoring efforts. *S. invicta* is known to have negative ecological, economic and social impacts (Tang et al. 2013). Ecologically, this species is known to reduce native invertebrate and vertebrate communities through predation (McGlynn 1999; Holway et al. 2002; Allen et al. 2004). Furthermore, this species dominates altered habitats such as those present in cities, where *S. invicta* has an affinity to electrical equipment (Morrison et al. 2004). This ant is considered to be one of the most destructive invasive ant species (Lowe et al. 2000; Ascune et al. 2011). *S. invicta* also has negative social impacts and poses a threat to the human population. The venom from *S. invicta* stings is known to result in allergic reactions for humans and animals (Solley et al. 2002). Box 3.4 shows that predicted climatic suitability for *S. invicta* coincides with land use in the city; this is potentially problematic for the human population. Therefore, I recommend that this species should be a priority target for strategic prevention efforts.

The river systems adjacent to potential point of introduction in the municipality were also identified as important sites to monitor. *Alternanthera philoxeroides* (Julien et al. 1995) and *Lithobates catesbeianus* (Silva and Filho 2009) are found in aquatic habitats such as rivers, along flood plains, in lakes and dams. *Alternanthera philoxeroides* is primarily an aquatic plant but can invade terrestrial environments such as agricultural areas (Burgin et al. 2010). *Alternanthera philoxeroides* can reproduce vegetatively to form new infestations from broken plant material and often forms fragile mats covering water bodies. *Lithobates catesbeianus* is introduced primarily through intentional introductions for faunal improvement to landscapes, ornamental purposes and through the aquaculture as a food source (Measey et al. 2017). *Lithobates catesbeianus* has high fecundity and environmental plasticity and is known to grow relatively large in size, ensuring their survival in a variety of habitats including disturbed environments (Silva and Filho 2009; Akmentins and Cardozo 2010). Furthermore, bullfrogs are potential vectors of diseases to native amphibians (Ficetola et al. 2007; Eskew et al. 2015). Box 3.1 (*A. philoxeroides*) and Box 3.3 (*L. catesbeianus*) both show potential points of introduction in close proximity to the major river systems in the city. Both of these species are considered to be prolific invaders with potentially devastating impacts (*A. philoxeroides* - Burgin and Norris 2008; Chen et al. 2013; *L. catesbeianus* - Lowe et al. 2000). Both *A. philoxeroides* (Burgin and Norris 2008; Burgin et al. 2010; Basset et al. 2010; Clements et al. 2011) and *L. catesbeianus* (Ficetola et al. 2007; Silva and Filho 2009; Silva et al. 2009) are capable of spread via natural dispersal once introduced and will be at best difficult to manage (Padayachee et al. 2017), especially because the likelihood of these species establishing throughout the city is high (Boxes 3.1-3. 2). I recommend both of these species as targets for strategic prevention efforts in Durban.

Invasions are, of course, often unpredictable and context dependent. Therefore, the prioritisation here should only be one small part of an overall biosecurity strategy (Wilson et al. 2017). The most effective methods for detection (e.g. traps or visual inspections) and the mix between passive and active surveillance (Hester and Cacho 2017) will depend on the biology of the organism. Similarly, it is important to understand the context of the invasion, going beyond whether pathways still operate to consider factors that might limit invasions (e.g. is there a strong mechanistic reason, such as biotic resistance, for expecting that the uniquely insular invasions discounted here will not become invasive in Durban). It will be vitally important to continue general surveillance efforts and create and maintain capacity to respond to surprises. However, by identifying species that are known to be problematic elsewhere in the world, that are likely to establish in Durban, and that are likely to be introduced, at least part of the detection and response efforts can be prioritised. It also helps Durban meet its legal requirements to address the threat posed by future biological invasions.

Even though this study focuses on Durban, the procedures used here represent a practical method in which to assign priorities for preventing the introduction of alien species. The methodology used in this study has merit for assigning priorities to a variety of taxa, such as this study (invertebrates, plants and vertebrates), or single taxa studies. Online databases such as CABI ISC, GBIF, GISD and GRIIS makes alien species information required for utilising this methodology readily accessible. The accessibility of information and adaptability of the methodology used in this study makes the protocol feasible. However, there are many ways in which things can be improved. For example, occurrence data sourced from online databases are often plagued with inconsistencies (e.g. validity of location points and taxonomy). The use of expert opinion in determining the validity of these data is a potentially beneficial improvement to this prioritisation tool. The procedures used in this study can further be improved quantitatively through additional analyses which will assess how pathways of introduction contribute to invasiveness (e.g. frequency analysis tests) of the target species as well as the contribution of potential introduction points to invasiveness (e.g. landscape level analysis) of target species. The advantage of the technique presented here, is that it focuses on likely known threats and ensures that appropriate measures are put in place to deal with them.

Conclusion

Prioritisation is a fundamental component of effective strategic prevention strategies targeting the introduction of alien species to new regions (Reaser et al. 2008; Essl et al. 2011; McGeoch et al. 2016; Padayachee et al. 2017; Pergl et al. 2017). The selection criteria used in this study provide decision makers with an easy way to identify where to focus resources to target incursions that have a high likelihood of occurring and resulting in substantial negative impacts. Implementing prioritisation schemes that consider all three aspects (species, pathways, and sites) (Wilson et al. 2017) allows decision makers to target monitoring efforts where the risk of particular invasions is highest. Additionally, integrating prioritisation schemes, such as in this study, allows decision makers to focus resources on species which poses a greater risk of invasion and impact.

Acknowledgements

This research was funded by the South African National Department of Environmental Affairs through its funding of the South African National Biodiversity Institute, Biological Invasions Directorate.

Chapter 4: Strategic response planning for the Red Imported Fire Ant (RIFA), *Solenopsis invicta* Buren in eThekwini (Durban), South Africa

Abstract

It has been argued that decision makers should treat biological invasions in the same manner as natural disasters by developing strategic response plans to facilitate preparedness and emergency response to alien species incursions. In this study I discuss key elements of strategic response planning and recommend priorities to help decision makers plan for a potential incursion of *Solenopsis invicta* Buren (the red imported fire ant) in Durban, South Africa where it has not yet been introduced. This species is known for its detrimental ecological, economic and social impacts in its invaded range and was identified as a high-risk threat. Hence, planning for a potential incursion is required. Pathway management, through the implementation of biosecurity measures (i.e. border control and precautionary treatments of goods), could help reduce the risk of introduction. Early detection of the presence of *S. invicta* will facilitate rapid response to incursions. Expansion and development of citizen science tools (e.g. The Durban Invasives project) are beneficial in achieving this goal. In the case of incursion, I recommend chemical treatment of infestations using existing approved products to extirpate infestations and hopefully prevent establishment. Long-term control responses, however, should focus on less ecologically damaging treatment options such as biological control and modifying environments through changes in disturbance regimes to decrease habitat suitability for establishment of *S. invicta*. Ultimately, the success of strategic response hinges on the participation and co-operation between all relevant stakeholders in the city. I recommend the municipality prioritises: 1) development of an action task team comprising of relevant stakeholders (national, provincial and municipal agencies, private and non-governmental organisations) to address potential incursion events of *S. invicta*; 2) capacity building through the training and development of personnel to actively monitoring for *S. invicta* and implement treatments should the species be identified; 3) passive surveillance endeavours through the production of awareness materials and expansion of citizen science tools to aid detection; and 4) research and investment in testing of biological control agents (*Pseudacteon* spp. and *Thelohania solenopsae*) for *S. invicta* in South Africa.

Key words

Strategic response planning, prioritisation, stakeholder engagement, eradication, prevention, control, mitigation

Introduction

The movement of biological organisms beyond their native ranges is greatly assisted by human-related activities (i.e. trade of goods and travel) (Wilson et al. 2009; Essl et al. 2015; Gotzek et al. 2015) often resulting in negative ecological and socio-economic impacts (Pimentel et al. 2001; Kenis et al. 2009; Vilà et al. 2010). Responding to alien species is contentious for decision makers and managers, who are tasked with managing these species (*sensu* Richardson et al. 2000) without hindering economic growth (Mumford 2002; Simberloff 2006). Preparedness and emergency response are important mechanisms which will aid decision makers in responding to alien species without restricting economic activities. Ricciardi et al. (2011) argue that biological invasions are similar in nature to natural disasters and as such should be treated in a similar manner regarding preparedness and response. Developing strategic response plans will allow decision makers to implement early detection techniques for high-risk species, assess feasibility of treatment options for response strategies, the capacity to implement response strategies, and assess the feasibility of, and prioritise, treatment options to optimally utilise the limited funds available (Grice et al. 2011; Early et al. 2016). Neglecting to develop strategic response plans for alien species will render countries, provinces and municipalities unprepared for incursions while the impacts of invasions will be exacerbated by the lack of rapid intervention and response. The polyphagous shot hole borer (PSHB) invasion in South Africa is an ideal example of the need for preparedness and emergency responses for high-risk alien species. PSHB, one of three cryptic species in the *Euwallacea fornicatus* species complex, was detected in Pietermaritzburg, South Africa in 2017 during surveys forming part of a sentinel project (Paap et al. 2018), though noted it was previously detected as part of DNA barcoding work, without triggering a response. While the PSHB does not directly result in the death of trees, its fungal symbiont, *Fusarium euwallaceae*, causes Fusarium die-back in trees (Paap et al. 2018). This example highlights the potential detrimental impacts incurred from a lack of preparedness and emergency response. First, the taxon has not been included as a predicted invader [e.g. the National Environmental Management Biodiversity Act (No. 10 of

2004) prohibited species listing, DEA 2016; the watch list of alien species produced by Faulkner et al. 2014] due to its uncertain taxonomic status (Padayachee et al. 2019). Taxonomic uncertainties hamper decision makers from detecting potentially high-risk species and implementing rapid response techniques to eradicate incursions. Furthermore, the lack of advanced planning makes determining the capacity (i.e. legal, financial, infrastructural and human resource) required for responses difficult. While scientists and decision makers attempt to develop an effective strategy to respond to, determine capacity, assign roles and responsibilities and allocate funding to the PSHB invasion, the species continues to spread exacerbating the impacts.

Social insects, such as ants, have the potential to become problematic alien species. Response strategies targeting these insects are complicated by their complex interactions with invaded environments as well as with each other in these environments, even more so in highly disturbed and transformed environments, such as cities (Gentz 2009; Hoffmann et al. 2016). Alien ants are among the most cosmopolitan invasive insect taxa (Suarez et al. 2010) known for their detrimental impacts and are closely associated with human-assisted transport, often found in close proximity to human habitats (Mikheyev and Mueller 2006). Among the most detrimental tramp ant species is *Solenopsis invicta* Buren, the red imported fire ant native to sub-Amazonian South America (Lowe et al. 2000; Morrison et al. 2004; Ascune et al. 2011; Tang et al. 2013; Wetterer 2013). S. *invicta* is known to out-compete native species resulting in declines of native invertebrate and even vertebrate fauna (Schmitz et al. 2000; Holway et al. 2002; Allen et al. 2004; Grover et al. 2007; Trager et al. 2010). Altered habitats such as those present in cities, are ideal environments for the successful establishment of *S. invicta* which has an affinity to human-made structures, such as electrical equipment, resulting in major damage (Morrison et al. 2004). Moreover, there is serious human and animal health risks associated with *S. invicta* due to the painful stings often causing burning sensations and, in some cases, allergic reactions (Solley et al. 2002; Wetterer 2013). The risks associated with impacts resulting from an incursion of *S. invicta* are potentially serious; therefore, preparedness and emergency responses for this species should be prioritised (Ricciardi et al. 2011).

The eThekwini municipality (Durban) is a vital economic centre of South Africa, hosting one of the largest port cities on the east coast of Africa (Roberts 2008). Durban is not only a significant tourist destination (Roberts 2008), but also one of the most populous cities in South Africa (approximately 3.4 million – STATSSA 2017). Conservation is a central issue of concern for this expanding city which is located within the Maputaland-Pondoland-Albany biodiversity hotspot (Myers et al. 2000). An incursion of *S. invicta* in Durban has the potential to cause serious negative impacts. Besides posing serious health risks for humans and animals, this species will also result in detrimentally negative impacts in natural environments present in the city, but also contribute to major economic losses through the destruction of infrastructure (Morrison et al. 2004). Due to the fact that *S. invicta* has not yet been introduced in Durban; there is the advantage for decision makers to save time and efficiently utilise the limited resources available (Early et al. 2016) to target alien species incursions by developing strategic responses.

Responding to alien species can become a complicated task for decision makers. The framework proposed by Backburn et al. (2011) describes the transition of an alien species from introduction to naturalisation and invasion (the introduction-naturalisation-invasion "INI" continuum). These authors further proposed response strategies (prevention, eradication and long-term control and mitigation) which should be implemented for alien species at various stages of the continuum. The proposed response strategies are also recommended by the Convention on Biological Diversity (CBD) and the National Environmental Management: Biodiversity Act - NEM:BA - (No.10 of 2004) (NEM:BA 2004). The CBD's primary goal is to conserve biological diversity by addressing the causes of biodiversity loss including the threat posed by alien species (SCBD 2012). This framework recommends a three-tiered response to alien species introduction with the primary goal of preventing introductions. Early detection and rapid response (eradication) is prescribed in the event of failing to prevent introductions. In cases for which eradication is deemed infeasible, containment and mitigation are recommended (SCBD 2012; Scalera et al. 2016). NEM:BA is responsible for ensuring the biological welfare of South Africa, including responding to the threats posed by alien species. Similarly to the CBD, NEM:BA makes provisions for prevention, eradication or containment and mitigation of invasive alien species (NEM:BA 2004). Under NEM:BA, landowners (state, municipal and private) are responsible for responding to alien species found on their land. Furthermore, all organs of state are legally required to develop monitoring, eradication or control plans for invasive alien species and incorporate these plans into mandatory integrated development plans (NEM:BA 2004). Strategic response plans are a necessity in achieving this goal and should ideally incorporate these recommended response strategies.

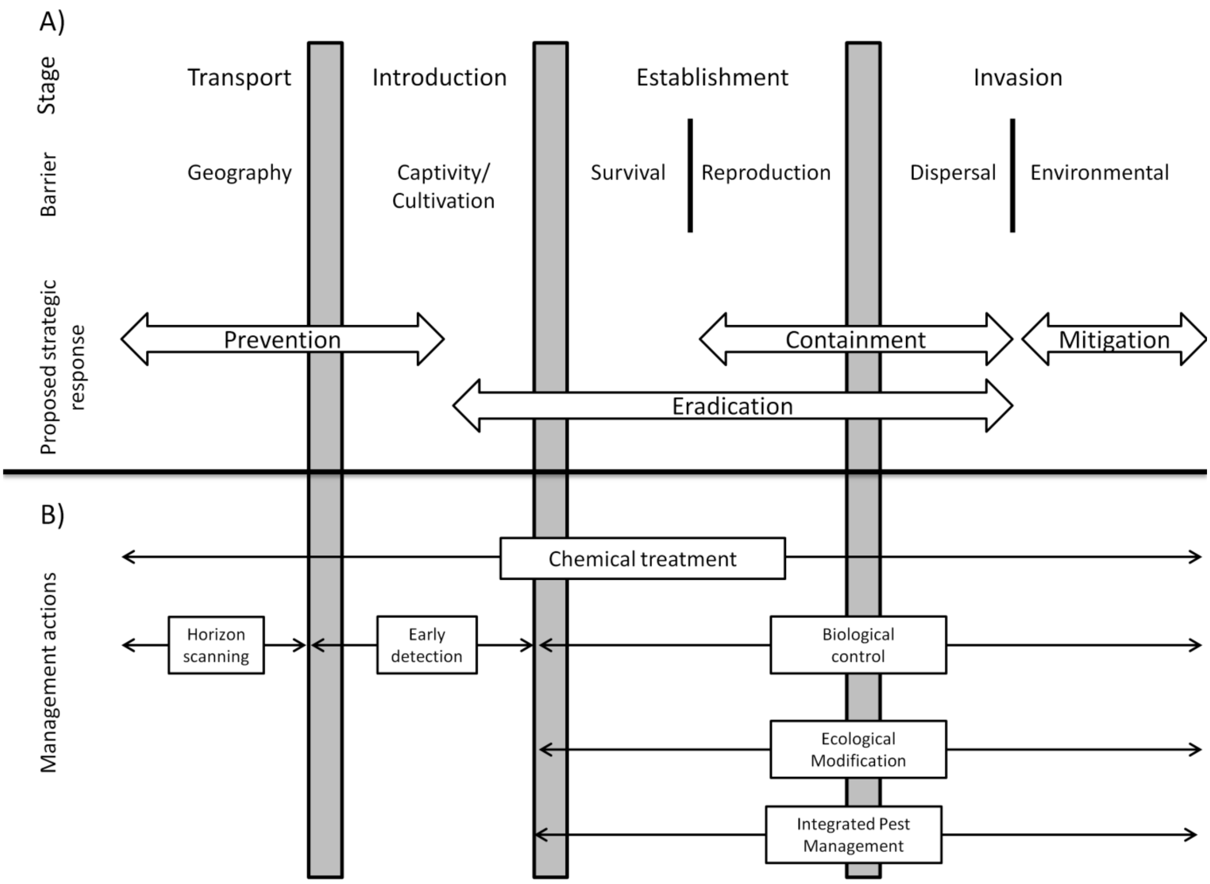

Figure 4.1: A) The unified framework adapted from Blackburn et al (2011) showing the proposed response strategies for alien species at different stages of the introduction-naturalisation-invasion "INI" continuum. Prevention is proposed for alien species which are either not yet introduced or newly introduced into new regions. Eradication is the ultimate goal for both, species at which are newly introduced as well as those which have become established and invasive. Containment and mitigation is proposed for species with self-sustaining population and those which are propagating into new locations. B) Chemical treatments can be used at all stages of invasions for different goals. Identifying high-risk species is important during the transport stage of invasion. Detecting the presence of high-risk species is important in the introduction stage of invasions to target eradication. Biological control, ecological modification or integrated pest management responses can be

used as options for long-term control of widespread infestations to mitigate the impacts of *S. invicta*.

In this study I look at the options for proposed strategic responses (using the INI continuum) for *S. invicta* in Durban (Figure 4.1) as an example to investigate the capacities to implement strategic response for a high-risk alien species. Key priorities are identified to assist decision makers in developing strategic responses and prepare for a potential incursion of *S. invicta* (Table 4.1).

Preventing the introduction of *Solenopsis invicta* Buren

Identifying potentially high-risk species

The identification of potentially high-risk alien species before they are introduced to particular regions of interest is important for planning appropriate strategic responses. Alien species watch lists are one such example in which pre-border pest risk assessments can be used to assign species to watch lists that inform strategic response efforts (i.e. prevention strategies and contingency plans) (Genovesi and Shine 2004; Nehring and Klingenstein 2008, Parrot et al. 2009; Faulkner et al. 2014). Identifying threats prior to introduction assists with risk assessment, risk communication and in determining whether response efforts are required (Leung et al. 2002; Hoffmann et al. 2011). A prohibited species list was created (based in part on expert opinion) in regulations under NEM:BA, listing species which are not yet present in South Africa and whose introduction should be prevented (DEA 2016). Independent to this, a watch list of alien species whose introduction into South Africa should be regulated (based on likelihood of introduction, likelihood of establishment, and impact elsewhere) was created by Faulkner et al. (2014). Developing strategic responses for species present on alien species watch lists is suggested as precautionary approach in the case of an incursion event. In Chapter 3, I used a combination of these two lists in conjunction with specific criteria to identify potentially high-risk alien species for Durban (Padayachee et al. 2019). *S. invicta* was listed on the prohibited species list and Faulkner et al. (2014) watch list of alien species (see Table 1). Furthermore, in chapter 3, I identified *S. invicta* as a potentially high-risk species and developed a climatic suitability model for *S. invicta* in Durban (Figure 4.2). I combined pathway information for this species with the climatic model to identify potential points of first introduction and first naturalisation in Durban to aid decision makers for targeted active surveillance efforts (Figure 4.2).

Pathway management

S. invicta is introduced as a stowaway in contaminated nursery material, on organic wood packaging or translocated with machinery and equipment (GISD 2018). These pathways are associated with the Durban Harbour, which was identified as an important potential point of first introduction for this species; as such biosecurity strategies should target this focal point (Figure 4.2).

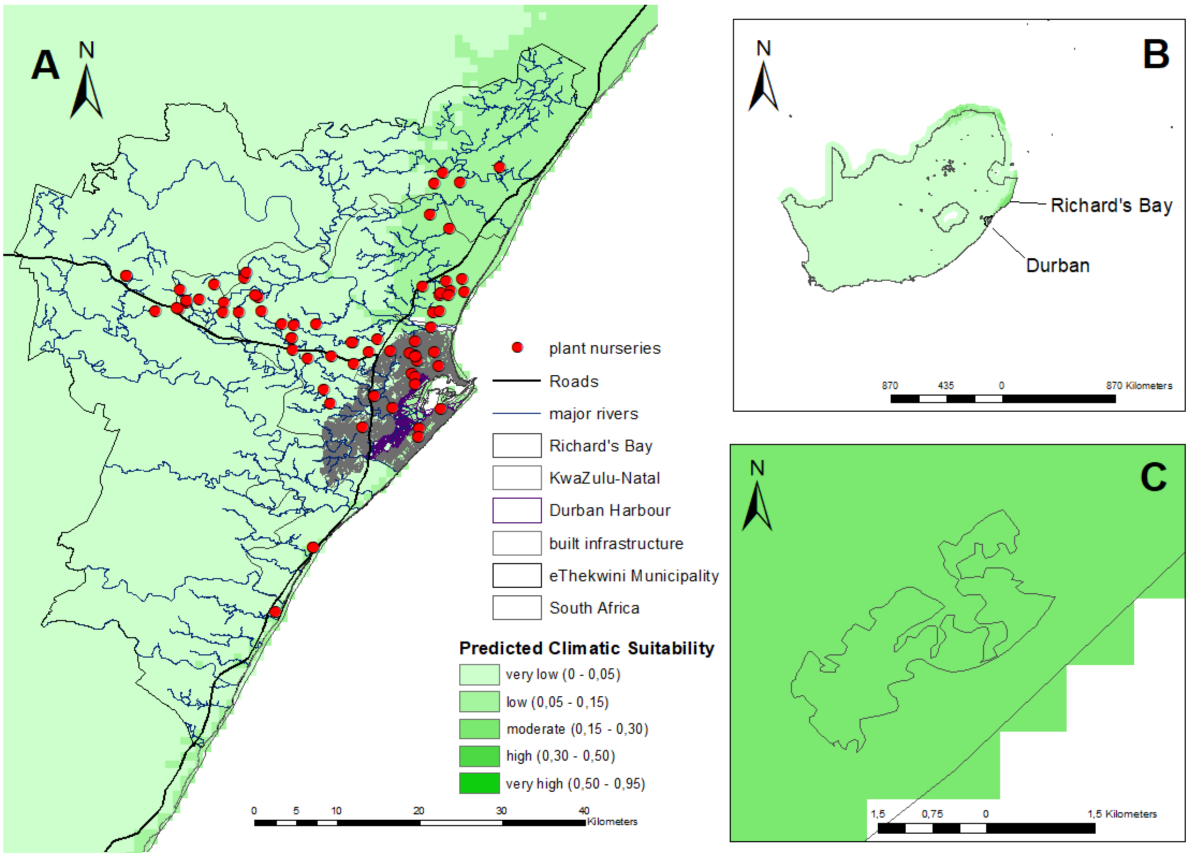

Figure 4.2: the predicted climatic suitability model (0.961 ± 0.006 – AUC±SD) developed for *S. invicta* overlayed with the potential points of first introduction (Durban Harbour and plant nurseries and garden centres) and the potential points of first naturalisation (built infrastructure and points of introduction in close proximity to major rivers) identified for *Solenopsis invicta* Buren in A) Durban in Chapter 3. The climatic suitability coincides with human activities (built infrastructure) in the city which is a cause of concern because of the human health risks the species pose as a result of envenomated stings. Predicted climatic

suitability was found to be the high in northern and north-eastern South Africa (B), peaking in the C) Richard's Bay Municipality (darker shades indicate higher predicted climatic suitability).

Biosecurity efforts should focus on the treatment (e.g. chemical fumigation) of incoming and outgoing goods, to not only prevent the introduction of *S. invicta* to Durban but also prevent its translocation to trading partner countries (Stanaway et al. 2001). Implementing strategic responses at the Durban Harbour are complicated by the intricacies of landownership at this port. The Durban Harbour is one of numerous ports in South Africa managed by Transnet (Transnet 2019). However, there are many privately owned enterprises operating out of the port. Random search strategies are employed to assess incoming goods, ensuring these are free of pests. Compliance of treating goods and packaging is only enforced by the requirement of trading partners for exporters to declare that goods are pest free. This form of voluntary compliance may not be the best possible way to ensure goods are free of pests. It would be more appropriate for compliance to be enforced by legal entities which would ensure compliance to a greater extent. In addition to pathway management, the secondary spread of *S. invicta* should also be prevented through the treatment of storage facilities housing imported goods (Hoffmann et al. 2011). However, goods are stored at facilities which belong to the companies responsible for importation, thus the responsibility of treating these facilities lies with the company to which the storage facility belongs. There is no competent authority designated to ensure biosecurity measures are being implemented at the port. This provides an opportunity for the municipality to initiate cooperation with Transnet as well as private companies for the development of personnel tasked with targeting alien species prevention through pathway management and storage facility treatment. This would entail training personnel operating within the Durban Harbour to inspect and treat goods for *S. invicta*, as well as storage facilities housing goods. Additionally, personnel should be trained to install active surveillance measures (i.e. setting baits and traps) and collect data for early detection of *S. invicta* and conduct post-treatment monitoring to assist early detection and rapid response efforts (Hoffmann et al. 2011). The Pacific Ant Prevention Program, aimed at preventing the introduction of *Solenopsis invicta* Buren (red imported fire ant) and *Wasmannia auropunctata* (little fire ant), is one example where quarantine and custom staff operating in ports in the Pacific Region were trained to conducted inspections, treatments and active surveillance measures (PAPP 2005). This proved to be a useful investment even though the target species were not detected at ports. Furthermore, the training manual developed by PAPP to equip quarantine and customs staff (available at: http://piat.org.nz/uploads/PIAT_content/pdfs/PAPP_TRAINING_MANUAL.pdf) is potentially beneficial for the municipality to use as a guideline in developing personnel for targeting the prevention *S. invicta* in Durban and response to incursions.

Stakeholder engagement and co-operation

Stakeholder engagement is a fundamental component in successful strategic response efforts to target invasive alien species (Shackleton et al. 2018; Wald et al. 2018). Engaging stakeholders is especially important for land which is not owned or managed by the municipality (e.g. ports managed by Transnet or reserves managed by Ezemvelo KZN Wildlife – EKZNW) to access and implement strategic responses, especially where incursions are detected (Gardener et al. 2010; Hoffmann et al. 2011).

From the predicted climatic suitability models and pathways of introduction information collected for *S. invicta* Buren, The Richards Bay Harbour can be inferred as a potential first point of introduction. This harbour is also one of the ports managed by Transnet. Co-operation between the municipality, Transnet and private enterprises operating out of these ports (i.e The Durban and Richard's Bay Harbours) would greatly enhance facilitatating the implementation of strategic responses conducted by trained personnel. Moreover, *S. invicta* can easily spread throughout the landscape; therefore, installing active surveillance at both of these ports is beneficial to both municipalities for early detection and prevention of subsequent spread of *S. invicta*. In the event of detecting the species at either of these ports, the municipality in which it has not been detected can then employ strategic response measures to prevent subsequent spread.

In addition, there are numerous agencies and organisations operating within the municipality with the purpose of responding to invasive alien species (e.g. the South African National Biodiversity Institute's Biological Invasions Directorate [SANBI BID]), Ezemvelo KZN Wildlife, Duzi Umgeni Conservation Trust [DUCT], various conservancies as well as various departments within the municipality). Due to the vast number of stakeholders operating within the municipality, it is important to assign specific roles and responsibilities for the prevention of *S. invicta*. The initiation of an action team, comprised of representative stakeholders, tasked with the duty of ensuring prevention of *S. invicta* and implementing strategic responses should the species be detected, is one option to promote collaboration and co-operation between stakeholders (Anderson 2005; Kaplan et al. 2017). An example of the benefits of such an action team is highlighted in the establishment of the Southern California Caulerpa Action Team (SCCAT) tasked with responding to an incursion of *Caulerpa taxifolia* (M. Vahl) C. Agardth in Southern California, United States of America (Anderson 2005). This action team comprised of relevant stakeholders whose primary goal was to eradicate the infestations of *C. taxifolia*. This group functioned not only as a technical advisory committee, but also targeted outreach and education campaigns to raise awareness of the impacts of an invasion by *C. taxifolia* (Anderson 2005). The establishment of such a group for the red imported fire ant in Durban will allow decision makers to not only develop best practices for eradicating potential infestations but also conduction awareness and education campaigns to alert the general public of the impacts of a potential invasion by *S. invicta* in Durban. The value of such a team is immeasurable, which can be seen from the example of the PSHB invasion in South Africa (Paap et al. 2018). If such a team were established prior to the invasion of PSHB, the impacts of this invasion could potentially be far less than the current situation.

Public awareness and citizen science

Creating awareness around target species prior to implementing strategic responses is important for informing the public about the risks and potential impacts (especially economic) that may be incurred as a result of the successful establishment of the target species and will help encourage public support of biosecurity (Hoffmann et al. 2011; Dickie et al. 2014; Crowley et al. 2017; Gaertner et al. 2017a; Novoa et al. 2017). Moreover, emphasizing human health risks from alien species introductions will help to reduce the likelihood of public opposition to strategic responses (Glen et al. 2013). This can be achieved through the production of awareness materials such as pamphlets, leaflets, fact sheets and pictures of the species, targeted at points of first naturalisation for *S. invicta* (plant nurseries and garden centres; within the Durban Harbour). Additionally, public awareness can facilitate early detection of *S. invicta* through reporting sightings through citizen science tools such as spotters networks (Hoffmann et al. 2011). Developing a "network of spotters" can help to focus searches where potential sightings of this species may have occurred. The eThekwini Municipality has developed the 'Durban Invasives' website (www.durbaninvasives.org.za) as a collaborative project, initiated by several organisations that operate within the broader Durban area (including the SANBI, DUCT, Kloof Conservancy, and eThekwini Municipality). The website allows organisations to report on targeted invasive alien plant species. Data captured on the website is then used to guide targeted IAP control efforts, as well as for research and planning for future operations. The real-time sharing of field observation data coupled with the option to simultaneously deploy teams is one of the novel aspects of this approach. It has also allowed collaboration of different organisations that previously may not have collaborated regularly, to immediately know what activities are underway. Even though this project focuses on known invasive plants, there is potential for expanding this intiative to include different taxonomic group. Such an expansion could incorporate *S. invicta* as one of the target species. While this project focuses on Durban specifically, other examples of such tools are the iNaturalist (https://www.inaturalist.org/) and iSpot (https://www.ispotnature.org/) websites which also provide the public with reporting structures for sightings of invasive alien species. To ensure a comprehensive early detection strategy, these websites need to be regular monitored for reported sightings of target species in Durban. This would require personnel dedicated to monitor and verify the validity of reported sightings. This will promote early detection of high-risk species such as *S. invicta*, as well as allow the municipality to test the efficacy of citizen science tools in aiding the detection of species which are not as yet present in Durban.

Controlling incursions of *S. invicta* in Durban

Chemical control

Preventing the introduction of all alien species in often impractical and infeasible, therefore proactive strategies are required to respond to incursions once they occur (Simberloff 2003; Lodge et al. 2006; Wilson et al. 2017). The goal of eradication is ensuring the complete extirpation of invasive alien species populations (Hoffmann et al. 2011). Targeting *S. invicta* while in the early stages of invasion (transport and introduction – see Figure 4.1) is important as the species will be restricted to the point of introduction, making responses cost-effective (Gardener et al. 2010). Chemical treatments are fast working and generally more efficient, therefore this should be the first option to eradicate incursions of invasive alien species (including *S. invicta* – see Table 4.1) (Gentz 2009; Rabitsch 2011). Synthetic compounds (i.e. fipronil, hydramethylnon and juvenile hormone mimics – JHMs - (pyriporoxyfen, methoprene and fenoxycarb) are most commonly used to treat incursions of *S. invicta* (Hoffmann et al. 2016). Fipronil and hydramethylnon are the most used compounds, either individually or combined to successfully eradicate *S. invicta* incursions (see Hoffmann et al. 2011 for examples of *S. invicta* eradication). For example, a combination of treatment methods was successful for the eradication *S. invicta* in Yarwun, Queensland where fipronil was directly injected into nests and hydramethylnon was broadcast with granular bait (Hoffmann et al. 2011). The chemicals used to treat *S. invicta* incursions (fipronil, hydramethylnon, fenoxycarb and juvenile hormone mimics) are available for purchase in South African as these are used as broad-spectrum insecticides or to treat other pests. The responsibility of rapidly responding to incursion should ideally be allocated to personnel operating at potential first points of introduction (Table 4.1). These individuals should be trained to deploy and deliver chemical treatments in sites where incursions are detected. While chemical treatment provides a rapid response, this is not a long-term solution because of the resultant negative environmental impacts (e.g. accumulation of chemical compounds in water systems and food chains as well as the associated non-target species effects) from usage of these compounds (Gentz 2009; Gardener et al. 2010; Rabitsch 2011).

Containing widespread infestations of *S. invicta* and mitigating the impacts of establishment

Biological control

Biological control is generally more environmentally desirable and involves locating natural enemies of a species from their native range to control the species in the invaded range (Williams et al. 1999). This treatment option is generally preferred for controlling widespread infestations (Figure 4.1) and could potentially reduce the need for insecticides and pesticides, minimising the environmental risks of using chemical treatments (Drees et al. 2013). Phorid flies in the genus *Pseudacteon* and the microsporidium *Thelohania solenopsae* are two examples of biological control agents that have been successfully used to control populations of *S. invicta* (see Table 4.1). In laboratory and field studies these biological control agents were found to be host specific for *Solenopsis invicta* (*Pseudacteon* spp. - Morrison and Gilbert 1999; Porter 2000; Cônsoli et al. 2001; Morrison and Porter 2005a; Morrison and Porter 2005b; Gilbert et al. 2008; *Thelohania solenopsae* - Oi et al. 2001; Valles et al. 2002; Oi et al. 2019). Currently there are no biological control agents for *S. invicta* in South Africa. *Pseudacteon* spp. and *Thelohania solenopsae* have proven to be successful biological control agents for *S. invicta* in the United States where it is invasive. As such as risk assessments, host-specificity testing (in laboratories) and trail fielding testing studies for suitability of these species as biological control agents in South Africa should be the focus of research and investment. Assessing biological control agents for hig-risk invasive alien species is benefical for decision makers to gain a head start in developing reponse strategies for potential incursion events. Testing and approving biological control agents can be a long and rigorous process. In the case of *S. invica* which has not yet been introduced to Durban, the advantage of commencing testing and approval of these biological control agents would promote the development of strategic response and save time in responding to potential incursions should they occur.

Ecological modification

Ecological modifications are a long-term control and mitigation response to reduce the likelihood of invasive alien species establishment in new locations (i.e. changes in fire regimes and drainage restrictions – see Table 4.1 for examples of ecological modifications for *S. invicta*) (Hoffmann and O'Connor 2004; Holway and Suarez 2006; Hoffmann et al. 2016). *S. invicta* thrives in environments with poor disturbance regimes; therefore, increasing the frequency of disturbances to invaded environments will decrease habitat suitability for the species (Hoffmann et al. 2016). For example, changing fire regimes in natural environments invaded by *S. invicta* will temporarily reduce food sources (i.e. sap-sucking scale insects) of this species providing a good response to control *S. invicta* populations. Modification of fire regimes in urban environmentsmay not be possible. However, *S. invicta* is dependent on readily available water resources; therefore, restricting water supply (e.g. run-off) will create unsuitable environments for the establishment of this species in urban environments (Holway et al. 2002; Menke and Holway 2006). This response strategy is useful in both, natural and urban environments. Moreover, a potential benefit of this response strategy is the restoration of biotic resistance from native species which will aid in further reducing the likelihood of *S. invicta* establishment (Menke et al. 2007). While the benefits of using ecological modifications are evident, this is an explorative response strategy and ideally requires further research and testing to assess the benefits (e.g. biotic resistance) or negative impacts (e.g. non-target effects) that may arise with ecological modification.

Integrated pest management

Integrated pest management (IPM) is an alternative response strategy incorporating the previously discussed response strategies (i.e. chemical control, biological and ecological response strategies) to suppress widespread infestations of *S. invicta* (see Table 4.1 - Drees et al. 2013). In addition to these strategies, public awareness and citizen science are important components of this response strategy by aiding in the detection of new, unreported infestation for response (Drees et al. 2013). This is why it is important for the current citizen science initiative ("Durban Invasives") to be expanded to incorporate high-risk species such as *S. invicta* as these initiatives will direct response efforts where new and previously unknown infestations are detected..

Table 4.1: The proposed strategic responses for different stages of invasions outlined in Blackburn et al. (2011), with the available management actions, treatment options and opportunities for capacity building for *Solenopsis invicta* Buren (the red imported fire ant) in Durban, South Africa. These management actions, treatment options and opportunities for capacity building are detailed below.

	Response			
Stages of invasion	Management goal	Management approach	Tools / Management actions	Resource required
Transport/ Introduction	Prevention	Identification of threats	Alien species watch lists[1,2]	Expertise scientific support; regulatory revision of lists
			Identification of threats for prioritisation	Climatic and habitat suitability modelling
		Pathway management (Biosecurity)	Inspecting and treating goods and storage facilities[4] Active surveillance at points of first introduction and naturalisation[3] (i.e. baiting and trapping)	Development and training of personnel to carry out these functions[5]
		Co-ordination	Proposed chain of command tasked with prevention and management of *S. invicta* in Durban[6]	Establishment of an action team for response efforts
		Awareness raising	Action team (as above)	Produce and distribute awareness raising material (pamphlets, leaflets etc.)
		Citizen science	Durban Invasives project[7]	Development of reporting structures for the presence of *S. invicta*
Introduction/ Invasion	Eradication	Chemical control	Synthetic chemical compounds (fipronil, hydramethylnon and junvenile hormone mimics)[8;9]	All of these compounds are used as insecticides for other pests, and are available in South Africa for purchase
Establishment/ Invasion	Containment/ Mitigation	Biological control	Research should focus on testing agents shown to be effective elsewhere for suitability in SA, aim of getting pre-approval for release (i.e. *Pseudacteon* spp. and *Thelohania solenopsae*[10; 11; 12; 13; 14; 15; 16; 17; 18; 19])	Development of testing protocols for South Africa, Host lists for testing, facilities to conduct testing, international collaboration

			with host species native countries for in field testing
	Ecological modification	Changes to disturbance regimes (i.e. fire regimes and drainage systems)[4]	Testing for the feasibility of these options
	Integrated Pest Management	Combining chemical, biological and ecological control with public awareness and citizen science endeavours to suppress widespread infestations[20]	Development of plans targeted at combining these strategies for long-term control and mitigation is required

[1]DEA (2016); [2]Faulkner et al. (2014); [3]Padayachee et al. (2019); [4]Hoffmann et al. (2016); [5]PAPP (2005); [6]Kaplan et al. (2017); [7]Durban Invasives; [8]Gentz (2009); [9]Rabitsch (2011); [10]Cônsoli et al. (2001); [11]Gilbert et al. (2008); [12]Morrison and Gilbert (1999); [13]Morrison and Porter (2005a); [14]Morrison and Porter (2005b); [15]Oi et al. (2001); [16]Oi et al. (2019); [17]Porter et al. (2000); [18]Valles et al. (2002); [19]Morrison and Porter (2006); [20]Drees et al. (2013)

Recommendations

Targeting high-risk alien species prior to their introduction is paramount in the development of strategic responses for potential incursion events (e.g. *Solenopsis invicta* Buren is not yet present in Durban but is known to be a high-risk alien species - Lowe et al. 2000; Morrison et al. 2004; Ascune et al. 2011; Tang et al. 2013; Wetterer 2013). This means there is an opportunity to prepare for potential incursion events of high-risk invasive alien species. In order to target prevention and preparedness of high-risk alien species (using *S. invicta* as an example), I recommend the following:

Firstly, the establishment of an action teams, such as the SCCAT established for *C. taxifolia* in Southern California, comprising of all relevant stakeholders involved in research, policy and management for high-risk invasive alien species is paramount. This will facilitate the assignment ofroles and responsibilities to team members for targeting prevention and management efforts for invasive alien species. The establishment of such a team would be extremely benefical for *S. invicta* which is not yet present in Durban, thus facilitating the development of strategic responses for potential incursion events. Furthermore, establishing an action team would help to determine the parties responsible for the various strategic response discussed in this paper.

Secondly, capacity building is essential. The development and training of personnel to conduct inspections and chemical treatments at ports and storage facilities and install active surveillance measures and post-treatment monitoring efforts should be implemented. The PAPP should be used as a guideline for such capacity building in the event of an introduction of *S. invicta*.

Third, implementing education and awareness campaigns are important for early detection efforts. The production of awareness materials (e.g. pamphlets and leaflets) targeted at points of first naturalisation for high-risk alien species can be benefical to this regard (e.g. plant nurseries and garden centres were identified as points of first naturalisation for *S. invicta*). Also, expansion and further development of citizen science measures would also assist in early detection efforts (e.g. Durban Invasives project should be expanded to include high-risk alien species by including *S. invicta* in this project).

Lastly, further research testing for the use of ecologically sustainable response strategies such as ecological modification and biological control agents need to be established for high-risk invasive alien species. Ecological modifications are an exploratory strategic response and should be further investigated to assess the potential impacts that may arise from changes to ecological regimes. In the case of *S. invicta*, two potential biological control agents (i.e. *Pseudacteon* spp. and *Thelohania solenopsae*) were identified. These biological control agents have not yet been tested for South Africa and should be given priority especially since the species is not yet present in the country.

Chapter 5: Consolidation

Biological invasions have increased with the increase in the rate of human-related activities (Wilson et al. 2009; Blackburn et al. 2011; Gallardo and Aldridge 2013; Essl et al. 2015; Gotzek et al. 2015). This study explored the patterns, processes and drivers of biological invasions unique to urban environments. The focus of this study was to evaluate cities as hotspots for invasions by investigating the opportunities to respond to alien species introductions in cities. These intricate landscapes are hubs of human-related activities, such as the trade of goods and tourism, and are often considered the first point of introduction for many alien species. The complexities observed in the environmental conditions within cities make these environments, both, susceptible to invasions and sensitive to the impacts of these invasions (ecological, economic and social - Pimentel et al. 2001; Kenis et al. 2009; Pyšek et al. 2010; Vilá et al. 2010). The management of biological invasions in these environments is contentious because of the limited resources available to respond to incursions (Early et al. 2016). Additionally, the vast number of stakeholders and organisations dealing with alien species also complicates the implementation of strategic responses (Gaertner et al. 2017a; Novoa et al. 2017). Implementation is further complicated by the requirement that response strategies should not restrict economic growth (Mumford 2002; Simberloff 2006).

Three important components of responding to alien species introductions were investigated (i.e. prevention, prioritisation and preparedness). These are discussed below in detail.

Global scale analysis (Chapter 2)

Preventing the introduction of alien species is often the most cost-effective approach to respond to the threats posed by alien species. Furthermore, responding to alien species introductions will in turn prevent their subsequent spread within as well as out of cities into surrounding natural environments. Prioritising which pathways of introduction and vectors of spread to target for response efforts is important for ensuring funds are efficiently used. I assessed how the observed patterns in the importance of pathways of introduction and vectors of spread could potentially aid management decisions to prevent the introduction and spread of alien species in urban environments (see Chapter 1, Figure 1.3).

The importance of pathways of introduction varied with the taxonomic groups of alien species in cities with varying geographical, ecological and climatic characteristics. Intentional pathways (release and escape) were the most important pathway facilitating the introduction of alien plants and vertebrates to cities. The horticultural trade was found to be one of the most significant contributors to the introduction of alien plants. The sheer substantial nature of this industry will, in all likelihood, continue to facilitate the introduction of alien plants through the escape pathway (Burt 2007; Dehnen-Schmutz et al. 2007; Visser et al. 2016; Faulkner et al. 2016a; Cronin et al. 2017). The most important pathways for the introduction of alien vertebrate species were found to be the release and escape pathways (intentional releases), many of which were introduced through the pet trade (Brown 2006; Kraus 2007). This growing trade will likely imply the continued importance of this pathway in introduction of alien vertebrate species. In the case of invertebrates, the importance of pathways varied on whether ports were located within cities or not. Invertebrates, many of which are marine or freshwater introductions, were mainly introduced as stowaways on ships or boats to cities with ports.

Prioritising at a local scale (Chapter 3)

Preventing the introduction of all alien species to cities is impractical, therefore prioritising which alien species to target is important. I identified potential future incursions based on selected alien species, the pathways facilitating their introduction, and the sites most at risk of being invaded. The aim was to provide an effective tool for decision makers to more carefully target surveillance and strategic response planning in Durban, South Africa (see Chapter 1, Figure 1.3).

The methodologies used to identify high-risk alien species is effective for assigning priorities to a variety of taxa, (e.g. invertebrates, plants and vertebrates – as done in this study), or single taxa studies. The selection criteria chosen allowed for watch lists to be narrowed down in the context of a specific urban setting (Durban), to provide priority targets for incursion response. Three species were identified (*Alternanthera philoxeroides*, *Lithobates catesbeianus* and *Solenopsis invicta*) as targets for strategic response planning endeavours. Due to the uncertainty in determining pathways facilitating the introduction of *Cenchrus echinatus*, priority should first focus on identifying if and where it is likely to be introduced to. Additionally, through the combination of climatic modelling and pathway information, potential points of first introduction and sits of first naturalisation were identified as priorities for strategic response planning efforts. The Durban Harbour, pet and aquarium stores and nursery and garden centres were identified as important potential points of first introduction for the three target species identified as priorities. The potential sites of first naturalisation identified were all found to be in close proximity to the Durban Harbour and the major river systems in the city, indicating that these sites are important for monitoring efforts. The Durban Harbour was identified as an important potential introduction point as well as a site to monitor for the introduction of *A. philoxeroides* and *S. invicta*. The pathways facilitating the introduction of these species are linked to the harbour (i.e. *A. philoxeroides* – ship ballast and ship cargo and *S. invicta* – organic wood packaging). The river systems adjacent to potential point of introduction were also identified as important sites to monitor for the presence of these water dependent target species. *A. philoxeroides* (Burgin and Norris 2008; Basset et al. 2010;Burgin et al. 2010; Clements et al. 2011) and *L. catesbeianus* (Ficetola et al. 2007; Silva and Filho 2009; Silva et al. 2009) are capable of dispersal via natural mechanism once introduced, therefore will be difficult to respond to if introduced (Padayachee et al. 2017), particularly because the likelihood of these species establishing throughout the city is high. Therefore, these species should be considered as targets for strategic response efforts in Durban.

Developing strategic response plans for specific high-risk invasions (Chapter 4)

Lastly, being prepared for potential incursions is necessary for rapidly responding to alien species introductions. I discussed the significance of strategic response planning for alien ant species (the red imported fire ant - *Solenopsis invicta* Buren), and identified key priorities to help decision makers plan strategic responses in preparation for a potential incursion event (see Chapter 1, Figure 1.3). The red imported fire ant was selected as an example to explore the opportunities for strategic response planning because this species was identified as a potentially high-risk species with the potential of result in detrimental impacts in Durban, South Africa.

Solenopsis invicta Buren is a high-risk alien species which has the potential to result in negative ecological, economic and social impacts (Lowe et al. 2000; Morrison et al. 2004;

Ascune et al. 2011; Tang et al. 2013; Wetterer 2013) and has not been introduced to Durban. In addition to being identified as potentially problematic species (NEM:BA prohibited species list – DEA 2016; alien species watch list – Faulkner et al. 2014; Padayachee et al. 2019) climatic suitability modelling showed predicted climatic suitability for *S. invicta* in Durban coincides with land use in the city; which is problematic for the human population. Preventative pathway management through the implementation of biosecurity measures (i.e. border control and precautionary treatments of goods) is important for preventing *S. invicta* from being introduced to Durban. Early detection is an important component of rapid responses strategies to prevent establishment of alien species. Active surveillance and public vigilance through the use of citizen science reporting tools target at potential points of first introduction (The Durban Harbour and plant nurseries and garden centres) is important for early detection of *S. invicta*. Short term control efforts involve chemical treatments to effectively eradicated isolated infestations, however, these treatments are unsuitable for long term responses (Gentz 2009; Gardener et al. 2010; Rabitsch 2011; Hoffmann et al. 2016). Biological control and ecological modifications to decrease habitat suitability are less ecologically damaging options for long term control of *S. invicta* (Hoffmann et al. 2016). However, these strategic responses will not be successful without the stakeholder participation and co-operation from the general public (Dickie et al. 2014; Crowley et al. 2017; Gaertner et al. 2017a; Novoa et al. 2017). In Durban, there is a wealth of stakeholder who will be affected by the incursion of *S. invicta*. It is important for these stakeholders to be incorporated into planning strategic responses to prevent the introduction and respond to a potential incursion of *S. invicta*. A starting point for the decision makers to target, not only a potential incursion of *S.invicta*, but other high-risk invasive alien species as well, would be to prioritise the following actions: 1) the development of an action team comprising of relevant stakeholders; 2) capacity building through development of biosecurity agents trained to actively monitoring and implement treatments for high-risk invasive alien species; 3) passive surveillance through the production of awareness materials and expansion of citizen science assisting early detection; 4) and 5) research focused on testing suitable biological control agents forhigh-risk alien invasive species in South Africa, such as *S. invicta*.

Overall implications

Ultimately, the most pertinent goal for decision makers is to prevent alien species introductions and prepare for incursion events if these species are introduced. This study identified urban environments, such as cities, as important landscapes for the study of biological invasions especially because cities are often the first point of introduction of alien species and a source of secondary spread to adjacent natural environments. Preventing alien species introductions is contingent on pathway management. The pathways operating in urban environments differ from those operating in natural environments, predominantly due to the high human population present in cities. Intentional pathways were identified as the major contributors to alien species introductions in cities (e.g. horticultural and pet trade industries – Padayachee et al. 2017). Strategies to manage intentional pathways differ from the management of unintentional pathways (Hulme et al. 2008). Regulation of industries contributing to introductions through issuing permits for alien species is one potential pathway management strategy (van Wilgen et al. 2010; Essl et al. 2015; Hulme 2015). However, this is problematic in that compliance to codes of best practice is voluntary. There is an evident need for follow-up procedures to ensure compliance to guidelines and codes of best practice, as well a stricter traceability and accountability regarding the disposal of unwanted ornamental and pet species (Hulme 2006). More definite, rigorous processes in permit issuing with regards to the possession of ornamental and pet species are required (Hulme 2015). Taxes or levies for the escape of exotics is also an option but may be disadvantageous by discouraging consumers from purchasing exotic species because of the added costs incurred. Moreover, education and awareness campaigns are important for preventing the sale or exchange these exotic species by sellers that may be unaware of these species (Drew et al. 2010; Cronin et al. 2017).

The methodologies used in Chapter 2 highlighted the importance of intentional pathways (release and escape) in an urban context. These pathways are especially important in the urban environment because of the dependence on human populations introducing species through these pathways. Decision makers are provided with a easy methodology to identify pathways of introduction and subsequent vectors of spread prove unique to the particular urban conditions of cities targeting pathway management to prevent the introduction of alien species.

Preparing for incursion events means that decision makers need to identify threats before they occur. In Chapter 3 I show that using a combination of early warning systems (Genovesi and Shine 2004; Nehring and Klingenstein 2008, Parrot et al. 2009; Faulkner et al. 2014) and climatic suitability modelling will allow decision makers to identify threats. The integrated (species, pathways and sites) approach used to identify threats in this study, which has previously not been attempted, allows decision makers to effectively refine early warning systems (i.e. watch lists consisting of numerous species spanning a variety of taxa) and assign priorities to species most likely to invade with the most detrimental impacts. The methodology used here proved to be an easily implementable and adjustable approach for identifying potentially high-risk alien species. It is necessary for decision makers to implement a predicative methodology such as the one used in this study as this will assist with risk assessment, risk communication and in determining whether response efforts are required should the species be introduced (Leung et al. 2002; Hoffmann et al. 2011).

Strategic response planning is important to not only prepare responses for potential incursions but also effectively allocate limited financial resources to ensure implementation is possible (Grice et al. 2011; Early et al. 2016). Building on this in Chapter 4 I explored the opportunities for strategic response planning of high-risk invasive alien species using the potential incursion *S. invicta* in Durban, South Africa as an example for exploring these opportiunities. The development of strategic responses should ideally consider options for preventing introductions, early detection and eradication of incursions and long-term control of widespread infestations of the target species. The benefit of planning ahead is that decision makers can identify if responses are required, and if so, whether the city has the capacity to respond to incursions of the target species. In Chapter 4 I outlined certain key issues that need to be addressed to effectively respond to a potential incursion of alien species. For example, the vast number of stakeholder present in cities can be problematic for managing alien species (Shackleton et al. 2018; Wald et al. 2018). The establishment of co-operative task teams and action committees is one way to resolve this issue which will promote co-operation between stakeholders (Kaplan et al. 2017). Awareness and education campaigns are also important in securing public co-operation for managing invasive alien species in cities. These endeavours need to be implemented and should target raising awareness for high-risk alien species which are not yet present in cities to alert the public to potential impacts that may be incurred from an incursion (e.g. the case of *S. invicta*). The lack of capacity to implement biosecurity measures is problematic for rapid response in cities. Resources should be invested in the training of personnel tasked with implementing and actively monitoring for high-risk species in cities. The responses required to target high-risk alien species in urban environments differ from the response for natural environments. While there has been a depth of literature regarding responding to alien species in natural environments, the urban context is not dealth with in such depth. The exploration of strategic response opportunities and recommendations to target hih-risk alien species in an urban environment aimed to combat this issue. The recommendations outlined in Chapter 4 provide a good foundation for decision makers to build strategic response plans.

Conclusions

Cities are often the first point of entry for alien species and as such are a central setting in the study of biological invasions. Responding to- and managing alien species in cities can be a complicated and contentious for decision makers who are tasked with addressing the threats posed by these species without impeding economic growth. In addition, the resources available for responding to alien species are limited. Therefore, preventing the introduction of these species is favoured as the most cost-effective response strategy. Even though prevention is the ultimate goal, decision makers should invest in preparing for potential incursions and developing rapid response strategies to eradicate infestations should these occur.

The research presented in this study enhances our understanding of prevention, prioritisation and prepardeness for alien species in urban environments. The methodologies and techniques presented in this study provide decision makers with robust, easily implementable tools to help prevent introductions, identify threats and respond timeously to incursions.

References

Akmentins MS, Cardozo DE (2010) American bullfrog *Lithobates catesbeianus* (Shaw, 1802) invasion in Argentina. Biological Invasions 12: 735-737. https://doi.org/10.1007/s10530-009-9515-3

Alberti M (2015). Eco-evolutionary dynamics in an urbanizing planet. Trends in Ecology and Evolution 30: 114-126. https://doi.org/10.1016/j.tree.2014.11.007

Allen CR et al. (2004) Red Imported Fire Ant impact on wildlife: A decade of research. The American Midland Naturalist 152: 88-103. https://doi.org/10.1674/00030031(2004)152[0088:RIFAIO]2.0CO;2

Anderson LWJ (2005) California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. Biological Invasions 7: 1003-1016. https://doi.org/10.1007/s10530-004-3123-z

Ascune MS et al. (2011) Global invasion history of the Fire Ant *Solenopsis invicta*. Science 331: 1066-1068. https://doi.org/10.1126/science.1198734

Bacon SJ, Bacher S, Aebi A (2012) Gaps in Border Controls Are Related to Quarantine Alien Insect Invasions in Europe. PLoS ONE 7: e47689. https://doi.org/10.1371/journal.pone.0047689

Barbet-Massin M et al. (2012) Selecting pseudo-absences for species distribution models: how, where and how many? Methods in Ecology and Evolution 3:327-338. https://doi.org/10.1111/j.2041-210X.2011.00172.x

Basset IE et al. (2010) Decomposition dynamics of invasive alligator weed compared with native sedges in a Northland lake. New Zealand Journal of Ecology 34:3 24-331. http://www.newzealandecology.org/nzje/

Blackburn TM et al. (2011) A proposed unified framework for biological invasions. Trends in Ecology and Evolution 26: 333-339. https://doi.org/10.1016/j.tree.2011.03.023

Blackburn TM et al. (2014) A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12: e1001850. https://doi.org/10.1371/journal.pbio.1001850

Blackie RR, Sunderland TC (2015) Mapping landscape guidelines and principles to the Aichi targets. CIFOR 123, pp.1-4

Branquart E (2007) Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium. Version 2.4. Harmonia. Belgium Forum on Invasive Species. https://ias/biodiversity.be/ias/documents/ISEIA_protocol.pdf

Brown R (2006) Exotic Pets Invade United States Ecosystems: Legislative Failure and a Proposed Solution. Indiana Law Journal 81: 713-731

Brown J (2014) SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. Methods in Ecology and Evolution 5: 694-700. https://doi.org/10.1111/2041-210X.12200

Burgin S, Norris A (2008) Alligator weed (*Alternanthera philoxeroides*) in New South Wales, Australia: A status report. Weed Biology and Management 8: 284-290. https://doi.org/10.1111/j.1445-6664.2008.00306.x

Burgin S et al. (2010) *Alternanthera philoxeroides* in New South Wales, Australia: Are we closer to control of alligator weed? Weed Technology 24: 121-126. https://doi.org/10.1614/WT-08-059.1

Burt JW et al. (2007). Preventing horticultural introductions of invasive plants: potential efficacy of voluntary initiatives. Biological Invasions 9: 909-923. https://doi.org/10.1007/s10530-007-9090-4

Butchart SHM et al. (2010) Global Biodiversity: Indicators of Recent Decline. Science 328: 1164-1168. https://doi.org/10.1126/science.1187512

CABI (2018) Invasive Species Compendium. CAB International. http://www.cabi.org/isc Accessed 16 February 2018

Cadotte MW et al. (2017). Are urban systems beneficial, detrimental, or indifferent for biological invasion? Biological Invasions 19: 3489-3503. https://doi.org/10.1007/s10530-017-1586-y

Carpio et al. (2016) An assessment of conflict areas between alien and native species richness of terrestrial vertebrates on a macro-ecological scale in a Mediterranean hotspot. Animal Conservation 20: 433-443. https://doi.org/10.1111/acv.12330

Chen Y et al. (2013) The invasive wetland plant *Alternanthera philoxeroides* shows a higher tolerance to waterlogging than its native congener *Alternanthera sessilis*. PLoS ONE 8: e81456. https://doi.org/10.1371/journal.pone.0081456

Clements D et al. (2011) Growth of alligator weed (*Alternanthera philoxeroides*) over 5 years in South-east Australia. Aquatic Invasions 6: 77-88. https://doi.org/10.3391/ai.2011.6.1.09

Cônsoli FL et al. (2001) Immature development of *Pseudacteon tricuspis* (Diptera: Phoridae), an endoparasitoid of the red imported fire ant (Hymenoptera: Formicidae). Annals of the Entomological Society of America 94:97-109. https://doi.org/10.1603/0013-8746(2001)094[0097:IDOPTD]2.0.CO;2

Cope RC et al. (2016) Intergrative Analysis of the Physical Transport Network Into Australia. PloS ONE 11: e0148831. https://doi.org/10.1371/journal.pone.0148831

Cowling RM et al. (2003) A conservation plan for a global biodiversity hotspot – the Cape Florisitc Region, South Africa. Biological Conservation 112: 191-216. https://doi.org/10.1016/S0006-3207(02)00425-1

Crawley M (2007) The R book. Imperial College London at Silwood Park. UK, pp.527-528

Cronin K et al. (2017) Aliens in the nursery: assessing the attitudes of nursery managers to invasive species regulations. Biological Invasions 19: 925-937. https://doi.org/10.1007/s10530-016-1363-3

Crowley SL, Hinchliffe S, McDonald RA (2017) Conflict in invasive species management. Frontiers in Ecology and the Environment 15: 133-141. https://doi.org/10.1002/fee.1471

DEA (2016) National Environmental Management: Biodiversity Act 2004 (Act No. 10 of 2004) Alien and Invasive species lists. Government Gazette 40166(864): 31-104

Dehnen-Schmutz K et al. (2007) The Horticultural Trade and Ornamental Plant Invasions in Britain. Conservation Biology 21: 224-231. https://doi.org/10.1111/j.1523-1739.2006.00538.x

Demographia (2014) Demographia World Urban Areas (Built-up Urban Areas or World Agglomerations) 10th Annual Edition. http://www.demographia.com/ Accesssed 23 August 2015

Dickie IA et al. (2014) Conflicting values: ecosystem services and invasive tree management. Biological Invasions 16: 705-719. https://doi.org/10.1007/s10530-013-0609-6

Di Minin E et al. (2013). Creating larger and better connected protected areas enhances the persistence of big game species in the Maputaland-Pondoland-Albany Biodiversity Hotspot. PloS One 8:e71788. https://doi.org/10.1371/journal.pone.0071788

Drees BM, Calixto AA, Nester PR (2013) Integrated pest management concepts for red imported fire ants *Solenopsis invicta* (Hymenoptera: Formicidae). Insect Science 20:429-438. https://doi.org/10.1111/j.1744-7917-2012.01552.x

Drew J, Anderson N, Andow D (2010) Conundrums of a complex vector for invasive species control: a detailed examination of the horticultural industry. Biological Invasions 12: 2837-2851. https://doi.org/10.1007/s10530-010-9689-8

Early R et al. (2016) Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications 7:1-9. https://doi.org/10.1038/ncomms12485

EKZNW (2019) Ezemvelo KZN Wildlife. Available at: http://www.kznwildlife.com/index.html

Elith J et al. (2011) A statistical explanation of MaxEnt for ecologists. Diversity and Distribution 17: 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

Eskew EA et al. (2015) American bullfrogs (*Lithobates catesbeianus*) resists infection by multiple isolates of Batrachochytrium dendrobatidis including one implicated in wild mass mortality. Ecohealth 12: 513-518. https://doi.org/10.1007/s10393-015-1035-2

ESRI (2015) ArcGIS ArcMap v10.3.1.4959. Environmental Systems Research Institute. Redlands, California, USA

Essl F et al. (2011) Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). Journal of Nature Conservation 19: 339-350 https://doi.org/10.1016/j.jnc.2011.08.005

Essl F et al. (2015) Crossing frontiers in tackling pathways of biological invasions. BioScience 65: 769-782. https://doi.org/10.1093/biosci/biv082

Faeth SH et al. (2005). Trophic dynamics in urban communities. BioScience 55: 399-407. https://doi.org/10.1641/0006-3568(2005)055[0399:TDIUC]2.0.CO;2

Faulkner KT et al. (2014) A simple, rapid methodology for developing invasive species watchlists. Biological Conservation 179: 25-32. https://doi.org/10.1016/j.biocon.2014.08.014

Faulkner KT et al. (2016a) Understanding and managing the introduction pathways of alien taxa: South Africa as a case study. Biological Invasions 18: 73-87. https://doi.org/10.1007/s10530-015-0990-4

Faulkner KT et al. (2016b) Border control for stowaway alien species should be prioritised based on variations in establishment debt. Journal of Environmental Management 180: 301-309. https://doi.org/10.1016/j.jenvman.2016.05.023

Ficetola GF, Thuiller W, Miaud C (2007) Prediction and validation of the potential global distribution of a problematic alien invasive species – the American bullfrog. Diversity and Distribution 13: 467-485. https://doi.org/10.1111/j.1472-4642.2007.00377.x

Ficetola GF, Thuiller W, Padoa-Schioppa E (2009) From introduction to the establishment of alien species: bioclimatic differences between presence and reproduction localities in the slider turtle. Diversity and Distributions 15: 108-16. https://doi.org/10.1111/j.1472-4642.2008.00516.x

Foxcroft LC et al. (2017) Plant invasion science in protected areas: Progress and priorities. Biological Invasions 19: 1353-78. https://doi.org/10.1007/s10530-016-1367-z

Gaertner M et al. (2017a) Non-native species in urban environments: patterns, processes, impacts and challenges. Biological Invasions 19: 3461-3470. https://doi.org/s10530-017-1598-7

Gaertner M et al. (2017b) Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape and Urban Planning 151: 1-9. https://doi.org/10.1016/j.landurbplan.2016.03.010

Gallardo B, Aldridge DC (2013) The 'dirty dozen': socio-economic factors amplify the invasion potential of 12 high-risk aquatic invasive species in Great Britain and Ireland. Journal of Applied Ecology 50: 757-766. https://doi.org/10.1111/1365-2664.12079

Gardener MR et al. (2010) Eradications and people: lessons from the plant eradication program in Galapagos. Restoration Ecology 18:20-29. https://doi.org/10.1111/j.1526-100X.2009.00614.x

GBIF (2016) Global Biodiversity Information Facility. http://www.gbif.org/ Accessed 01 December 2016

GBIF (2017) Global Biodiversity Information Facility. https://www.gbif.org/ Accessed 05 May 2017

GBIF (2017a) GBIF Occurrence download *Alternanthera philoxeroides*. https://doi.org/10.15468/dl.fay5de [Accessed 21 November 2017]

GBIF (2017b) GBIF Occurrence download *Cenchrus echinatus*. https://doi.org/10.15468/dl.g5wqi0 [Accessed 21 November 2017]

GBIF (2017c) GBIF Occurrence download *Lithobates catesbeianus*. https://doi.org/10.15468/dl.0xqd2c [Accessed 21 November 2017]

GBIF (2017d) GBIF Occurrence download *Solenopsis invicta*. https://doi.org/10.15468/dl.i6nsbc [Accessed 21 November 2017]

Gentz MC (2009) A review of chemical control options for invasive social insects in island ecosystems. Journal of Applied Entomology 133:229-235. https://doi.org/10.1111/j.1439-0418.2008.01326.x

Genovesi P, Shine C (2004) European Strategy on Invasive Alien Species. Council of Europe (Nature and environment), No. 137, Council of Europe Publishing, Strasbourgh, 66pp.

Gilbert LE et al. (2008) Introducing Phorid fly parasitoids of red imported fire ant workers from South America to Texas: outcomes vary by region and by *Pseudacteon* species released. Southwestern Entomologist 33:15-29. https://doi.org/10.3958/0147-1724-33.1.15

GISD (2016) Global Invasive Species Database. Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission. http://www.issg.org/database Accessed 09 June 2016

GISD (2018) Global Invasive Species Database. Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission. http://www.issg.org/database Accessed 16 February 2018

Glen As et al. (2013) Eradicating multiple invasive species on inhabited islands: the next big step in island restoration? Biological Invasions 15:2589-2603. https://doi.org/10.1007/s10530-013-0495-y

Gotzek D et al (2015) Global invasion history of the tropical fire ant: a stowaway on the first global trade routes. Molecular Ecology 24: 374-388. https://doi.org/10.1111/mec.13040

Grice AC, Clarkson JR, Calvert M (2011) Geographic differentiation of management objectives for invasive species: a case study of *Hymenachne amplexicaulis* in Australia. Environmental Science and Policy 14: 986-997. https://doi.org/10.1016/j.envsci.2011.07.006

GRIIS (2016) Global Register of Introduced and Invasive Species. http://www.griis.org/ Accessed 15 November 2016

GRIIS (2017) Global Register of Introduced and Invasive Species. https://www.griis.org/ Accessed 05 May 2017

Grimm NB et al. (2008) Global change and the ecology of cities. Science 319: 756-760. https://doi.org/10.1126/science.1150195

Grover CD et al. (2007) Linking nutrition and behaviourial dominance: carbohydrate scarcity limits aggression and activity in Argentine ants. Proceedings of the Royal Society B 274:2951-2957. https://doi.org/10.1098/rspb.2007.1065

Hansen MJ, Clevenger AP (2005) The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. Biological Conservation 125: 249-259. https://doi.org/10.1016/j.biocon.2005.03.024

Harrower CA et al. (2017) Guidance for interpretation of CBD categories on introduction pathways. Technical note prepared by IUCN for the European Commission.

Hester SM, Cacho OJ (2017) The contribution of passive surveillance to invasive species management. Biological Invasions 19: 737-748. https://doi.org/s10530-016-1362-4

Hill MP et al. (2016) Drivers, impacts, mechanisms and adaptations in insect invasions. Biological Invasions 18: 883-891. https://doi.org/10.1007/s10530-016-1088-3

Hijmans RJ et al. (2005) Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. https://doi.org/10.1002/joc.1276

Hoffmann BD and O'Connor S (2004). The eradication of two exotic ants from Kakadu National Park. Ecological Management and Restoration 5:98-105. https://doi.org/10.1111/j.1442-8903.2004.00182.x

Hoffmann BD et al. (2011) Improving ant eradications: details of more success, a global synthesis and recommendations. Aliens: The Invasive Species Bulletin 31:16-23. http://www.issg.org/publications.htm

Hoffmann BD et al. (2016) Improving invasive ant eradication as a conservation tool: A review. Biological Conservation 198:37-49. https://doi.org/10.1016/j.biocon.2016.03.036

Holway DA et al. (2002) The causes and consequences of ant invasions. Annual Review of Ecology and Systematics 33: 181-233. https://doi.org/10.1146/annurev.ecolsys.33.010802.150444

Holway DA and Suarez AV (2006) Homogenisation of ant communities and invasion. Biological Conversation 127:317-326. https://doi.org/10.1016/j.biocon.2005.05.016

Hulme PE (2006) Beyond control: wider implications for the management of biological invasions. Journal of Applied Ecology 43:835-847. https://doi.org/10.1111/j.1365-2664.2006.01227.x

Hulme PE et al. (2008). Grasping at the routes of biological invasions: a framework for integrating pathways into policy. Journal of Applied Ecology 45: 403414. https://doi.org/10.1111/j.1365-2664.2007.01442.x

Hulme PE (2009) Trade, transport and trouble: managing invasive pathways in an era of globalization. Journal of Applied Ecology 46: 10-18. https://doi.org/10.1111/j.1365-2664.2008.01600.x

Hulme PE (2015) Invasion pathways at a crossroads: policy and research challenges for managing alien species introductions. Journal of Applied Ecology 52: 1418-1424. https://doi.org/10.1111/j.1365-2664.2007.01442.x

Irlich UM et al. (2017) Recommendations for municipalities to become compliant with National legislation on biological invasions. Bothalia: African Biodiversity and Conservation 47: 1-11. https://dx.doi.org/10.4102/abc.v47i2.2156

Julien MH, Skarratt B, Maywald GF (1995) Potential geographic distribution of Alligator weed and its biological control by *Agasicles hygrophila*. Journal of Aquatic Plant Management 33: 55-60.

Kaplan H et al. (2017) A proposed strategic national framework for the management of Cactaceae in South Africa. Bothalia 47: a2149. https://doi.org/10.4102/abc. v47i2.2149

Katsanevakis S et al. (2013) Invading European Seas: Assesing pathways of introduction of marine aliens. Ocean & Coastal Management 76: 64-74. https://doi.org/10.1016/j.ocecoaman.2013.02.024

Kenis M et al. (2009) Ecological effects of invasive alien insects. Biological Invasions 11: 21-45. https://doi.org/10.1007/s10530-008-9318-y

Kölzsch A, Blasius B (2011) Indications of marine bioinvasion from network theory. European Physical Journal B 84: 601-612. https://doi.org/10.1140/epjb/e2011-20228-5

Köttek M et al. (2006) World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15: 259-263. https://doi.org/10.1127/0941-2948/2006/0130

Kowarik I (2011) Novel urban ecosystems, biodiversity and conservation. Environmental Pollution 159: 1974-1983. https://doi.org/10.1016/j.envpol.2011.02.022

Kraus F (2007) Using pathway analysis to inform prevention strategies for alien reptiles and amphibians. In: Witmer GW, Pitt WC, Fagerstone KA (eds) Managing vertebrate invasive species. USDA/APHIS Wildlife Services, National Wildlife Research Centre, Fort Collins, Colorado, USA, pp.94-103

Kuhman TR et al. (2010) Effects of land-use history and the contemporary landscape on non-native plant invasions at local and regional scales in the forest dominated southern Appalachains. Landscape Ecology 25: 1433-1445. https://doi.org/10.1007/s10980-01-9500-3

Kumschick S, Richardson DM (2013) Species-based risk assessments for biological invasions: advances and challenges. Diversity and Distributions 19: 1095-1105. https://doi.org/10.1111/ddi.12110

Leung B et al. (2002) An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London B 269:2407-2413. https://doi.org/10.1098/rspb.2002.2179

Leung B et al. (2014) Pathway-level risk analysis: the net present value of an invasive species policy in the US. Frontiers in Ecology and the Environment 12: 273-279. https://doi.org/10.1890/130311

Lövei GL (1997) Biodiversity: global change through invasion. Nature 388: 627-628. https://doi.org/10.1038/41665

Lodge DM et al. (2006) Biological Invasions: Recommendations for U.S. policy and management. Ecological Applications 16:2035-2054. https://doi.org/10.1890/1051-0761(2006)016[2035:BIRFUP]2.0.CO;2

Lowe S et al. (2000) 100 of the World's Worst Invasive Alien Species: A selection from the Global Invasive Species Database. The Invasive Species Specialist Group, New Zealand. http://www.issg.org/booklet.pdf

Malcolm JR et al. (2006). Global warming and extinction of species from biodiversity hotspots. Conservation Biology 20: 538-548. https://doi.org/10.1111/j.1523-1739.2006.00364.x

McLean P et al. (2017) Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa. Biological Invasions 19: 3451-3555. https://doi.org/10.1007/s10530-017-1600-4

McGeoch MA et al. (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasions. Biological Invasions 18: 299-314. https://doi.org/10.1007/s10530-015-1013-1

McGlynn TP (1999) The worldwide transfer of ants: geographical distribution and ecological invasions. Journal of Biogeography 26: 535-548. https://doi.org/10.1046/j.1365-2699.1999.00310.x

Measey J et al. (2017) Invasive amphibians in southern Africa: A review of invasion pathways. Bothalia 47: 1-12. https://doi.org/10.4102/abc.v47i2.2117

Menke SB and Holway DA (2006) Abiotic factors control invasion by Argentine ants at the community scale. Journal of Animal Ecology 75:368-376. https://doi.org/10.1111/j.1365-2656-2006.01056.x

Menke S et al. (2007) Biotic and biotic controls of Argentine ant invasion success at local and landscape scales. Ecology 88:3164-3173. https://doi.org/10.1890/07-0122.1

Mikheyev AS and Mueller UG (2006). Invasive species: customs intercepts reveal what makes a good ant stowaway. Current Biology 16:129-131. https://doi.org/10.1016/j.cub.2006.02.001

Mohri M, Rostamizadeh A, Talwalkar A (2012) The Foundations of Machine Learning. The MIT Press.

Moles AT et al. (2012) Invasions: the trail behind, the path ahead, and a test of a disturbing idea. Journal of Ecology 100: 116-127. https://doi.org/10.1111/j.1365-2745.2011.01915.x

Morrison LW and Gilbert LE (1999) Host-specificity in two additional *Pseudacteon* spp. (Diptera: Phoridae), parasitoids of *Solenopsis* fire ants (Hymenoptera: Formicidae). The Florida Entomologist 82:404-409. https://doi.org/10.2307/3496867

Morrison LW et al. (2004) Potential global range expansion of the invasive fire ant (*Solenopsis invicta*). Biological Invasions 6: 183-191. https://doi.org/10.1023/B.BINV.0000022135.96042.90

Morrison LW and Porter SD (2005a) Phenology and parasitism rates in introduced populations of *Pseudacteon tricuspis*, a parasitoid of *Solenopsis invicta*. BioControl 50:127-141. https://doi.org/10.1007/s40526-004-0551-8

Morrison LW and Porter SD (2005b) Testing for population-level impacts of introduced *Pseudacteon tricuspis* flies, phorid parasitoids of *Solenopsis invicta* fire ants. Biological Control 33:9-19. https://doi.org/10.1016/j.biocontrol.2005.01.004

Morrison LW and Porter SD (2006) Post-release host-specificity testing of *Pseudacteon tricuspis*,a phorid parasitoid of *Solenopsis invicta* fire ants. BioControl 51:195. https://doi.org/10.1007/s10526-004-4655-y

Mumford JD (2002). Economic issues related to quarantine in international trade. European Review of Agricultural Economics 29: 329-348. https://doi.org/10.1093/eurrag/29.3.329

Myers N et al. (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853-858. http://dx.doi.org/10.1038/35002501

Nehring S, Klingenstein F (2008) Aquatic alien species in Germany – listing system and options for action. Neobiota 7: 19-33

NEM:BA (2004) National Environmental Management: Biodiveristy Act No.10 of 2004, Government Gazette No. 26436. Available at: https://www.environment.gov.za/files

Novoa A et al. (2017). Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. Biological Invasions 19: 3691-3705. https://doi.org/10.1007/s10530-07-1592-0

Oi DH et al. (2001) Evidence of intracolony transmission of *Thelohania solenopsae* (Microsporidia: Thelohaniidae) in red imported fire ants (Hymenoptera: Formicidae) and the first report of spores from pupae. Journal of Invertebrate Pathology 78:128-134. https://doi.org/10.1006/jipa.2001.5053

Oi DH et al. (2019) Introduction of fire ant biological control agents into the Coachella Valley of California. Florida Entomologist 102:284-286. https://doi.org/10.1653/024.102.0156

Paap T et al. (2018) The ployphagous shot hole borer (PSHB) and its fungal symbiont *Fusarium euwallaceae*: a new invasion in South Africa. Australasian Plant Pathology 47:231-237. https://doi.org?10.1007/s13313-018-0545-0

Padayachee AL et al. (2017) How do invasive species travel to and through the urban environment? Biological Invasions 19: 3557-3570 https://doi.org/10.1007/s10530-017-1596-9

Padayachee AL, Procheş Ş, Wilson JR (2019) Prioritising potential incursions for contingency planning: pathways, species, and sites in Durban (eThekwini), South Africa as an example. Neobiota 47: 1-21. https://doi.org/10.3897/neobiota.47.31959

PAPP (2005) Pacific Ant Prevention Programme. Pacifica Invasive Ant Group (PIAG) on behalf of the IUCN/SCC Invasice Species Specialist Group (ISSG). Available at: https://www.issg.org/papp

Parrot D et al. (2009) Horizon scanning for new invasive non-native animal species in England. Natural England Commissioned Report NECR009, Sheffield, UK

Pearson RG et al. (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34: 102-117. https://doi.org/10.1111/j.1365-2699.2006.01594.x

Pergl J et al. (2017). Troubling travellers: are economically harmful alien species associated with particular introduction pathways? Neobiota 32: 1-20. http://dx.doi.org/10.3897/neobiota.32.10199

Peterson AT et al. (2011) Ecological niches and geographic distributions. Princeton University Press, Princeton, New Jersey

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modelling of species geographic distribution. Ecological Modelling 190: 231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: new extensions and comprehensive evaluation. Ecography 31: 161-175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Pimentel D et al. (2001) Economic and environmental threats of alien plant, animal and microbe invasions. Agriculture, Ecosystems and Environment 84: 1-20. https://doi.org/10.1016/S0167-8809(00)00178-X

Porter SD (2000) Host specificity and risk assessment of releasing the decapitating fly *Pseudacteon curvatus* as a classical biocontrol agent for imported fire ants 19:35-47. https://doi.org/bcon.2000.0843

Potgieter L et al. (2017) Alien plants as mediators of ecosystems and disservices in urban systems: a global review. Biological Invasions 19: 3571-3558. https://doi.org/10.1007/s10530-017-1589-8

Puth LM, Post DM (2005) Studying invasion: have we missed the boat? Ecology Letters 8: 715-721. https://doi.org/10.1111/j.1461-0248.2005.00774.x

Pyšek P, Richardson DM (2010) Invasive species, environmental change and management, and health. Annual Review of Environment and Resources 35: 25-55. https://doi.org/10.1146/annurev-environ-033009-095548

Pyšek P et al. (2010) Disentangling the role of environmental and human pressures on biological invasions across Europe. Proceedings of the National Academy of Science 107: 12157-12162. https://doi.org/10.1073/pnas.1002314107

R Core Team (2014) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org/

Rabitsch W (2011) The hitchhiker's guide to alien ant invasions. BioControl 56:551-572. https://doi.org/10.1007/s10526-011-9370-x

Ramalho CE, Hobbs RJ (2012) Time for a change: dynamic urban ecology. Trends in Ecology and Evolution 27: 179-188. https://doi.org/10.1016/j.tree.2011.10.008

Reaser JK, Meyerson LA, Von Holle B (2008) Saving camels from straws: how propagule pressure-based prevention policies can reduce the risk of biological invasions. Biological Invasions 10:1085-1098. https://doi.org/10.1007/s10530-007-9186-x

Rebele F (1994) Urban ecology and spatial features of urban ecosystems. Global Ecology and Biogeography Letters 4: 173-187. https://doi.org/10.2307/2997649

Reichard SH, White P (2001) Horticulture as a pathway of invasive plant introductions in the United States: most invasive plants have been introduced for horticultural use by nurseries, botanical gardens, and individuals. BioScience 51: 103-13. https://doi.org/10.1641/0006-3568(2001)051[0103:HAAPOI]2.0.CO;2

Rejmánek M, Richardson DM (1996) What attributes make some plant species more invasive? Ecology 77: 1655-1661. https://doi.org/10.2307/2265768

Ricciardi A, Palmer ME, Yan ND (2011) Should biological invasions be managed as natural disasters? BioScience 61: 312-317. https://doi.org/10.1525/bio.2011.61.4.11

Ricotta C et al. (2009). Phyloecology of urban alien floras. Journal of Ecology 97: 1243-1251. https://doi.org/10.1111/j.1365-2745.2009.01548.x

Richardson DM (1998) Forestry trees as invasive aliens. Conservation Biology 12: 18-26. https://doi.org/10.1111/j.1523-1739.1998.96392.x

Richardson DM et al. (2000) Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6: 93-107. https://doi.org/10.1046/j.1472-4642.2000.00083.x

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

Roberts D (2008) Thinking globally, acting locally – institutionalizing climate change at the local government level in Durban, South Africa. Environment and Urbanization 20:521-537. https://doi.org/10.117/0956247808096126

Robertson MP, Villet MH, Palmer AR (2004) A fuzzy classification technique for predicting species distributions: applications using invasive alien plants and indigenous insects. Diversity and Distribution 10: 461-474. https://doi.org/10.1111/j.1366-9516.2004.00108.x

Saul W-C et al. (2016) Assessing patterns in introduction pathways of alien species by linking major invasion databases. Journal of Applied Ecology 54: 657-669. https://doi.org/10.1111/1365-2664.12819

Scalera R et al. (2016) Technical Report: Progress towards pathways prioritization in compliance to Aichi Target 9. Information documented presented at SBSTTA 20 UNEP/CBD/SBSTTA/20/INF/5, the twentieth meeting of the CBD's Subsidiary Body on Scientific, Technical and Technological Advice, Montreal, Cananda, 25-30 April 2016

SCBD (2012) Report on the high-level panel on global assessment of resources for implementing the strategic plan for biodiversity 2011-2020 (No.: UNEP/CBD/COP/11/INF/20). Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available at: https://www.cbd.int/doc/meetings/cop/cop-11/information/cop-11-inf-20-en.pdf

Schmitz OJ, Hamback PA, Beckerman AP (2000) Trophic cascades in terrestrial systems: a review of the effects of carnivore removal on plants. American Naturalist 155:141-153. https://doi.org/10.1086/303311

Schrader G, Unger J-G (2003) Plant quarantine as a measure against invasive alien species: the framework of the International Plant Protection Convention and the plant health regulations in the European Union. Biological Invasions 5: 357-364. https://doi.org/10.1023/B:BINV.0000005567.58234.b9

Seto KC, Güneralp B, Hutyra LR (2012) Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Science 109:16083-16088. https://doi.org/10.1079/pnas.1211658109/-/DCSupplemental

Shackleton R et al. (2018) Explaining people's perceptions of invasive alien species: A conceptual framework. Journal of Environmental Management 229:10-26. https://doi.org/10.1016/j.jenvman.2018.04.045

Silva ET, Filho OPR (2009) Predation on juveniles of the invasive American bullfrog *Lithobates catesbeianus* (Anura: Ranidae) by native frog and snake species in South-eastern Brazil. Herpetology Notes 2: 215-218.

Silva ET et al. (2009) Diet of the invasive frog Lithobates catesbeianus (Shaw, 1802) (AnuraL Ranidae) in Viçosa, Minas Gerais State, Brazil. South American Journal of Herpetology 4: 286-294. https://doi.org/10.2994/057.004.0312

Simberloff D (2003) How much information on population biology is needed to manage introduced species? Conservation Biology 17:83-92. http://www.jstor.org/stable/3095275

Simberloff D (2006). Risk assessments, blacklists, and white lists for introduced species: are predictions good enough to be useful? Agricultural and Resource Economics 35: 1-10. https://doi.org/10.1017/S1068280500010005

Snedecor GW, Cochran WG (1968) Statistical Methods, 6th eds. Ames Iowa, The Iowa State University Press

Solley GO, Vanderwoude C, Knight GK (2002) Anaphylaxis due to red imported fire ant sting. Medical Journal of Australia 176: 521-523

Stanaway MA wt al. (2001) Pest risk assessment of insects in sea cargo containers. Australian Journal of Entomology 40:180-192. https://doi.org/10.1046/j.1440-6055.2001.00215.x

STATSSA (2017). Statistics South Africa. http://www.statssa.gov.za/?page_id=1021&id=ethekwini-municipality. Accessed 15 October 2018

Suarez AV, McGlynn TP, Tsutsui ND (2010) Biogeographic and taxonomic patterns of introduced ants. In: Lach L, Parr CL, Abbott KL (Eds.) Ant Ecology. Oxford University Press, Oxford pp. 233–244.

Tang L et al. (2013) Fumigant acitivity of eight plant essential oils against workers of red imported fire ant, *Solenopsis invicta*. Sociobiology 60: 35-40. http://periodicos.uefs.br/ojs/index.php/sociobiology

Tatem AJ (2009) The worldwide airline network and the dispersal of exotic species: 2007-2010. Ecography 32: 94-102. https://doi.org/10.1111/j.1600-058702008.05588.x

Trager MD et al. (2010) Benefits for plants in ant-plant mutualisms: a meta-analysis. PLoS One, e14308. https://doi.org/10.1371/journal.pone.0014308

Transnet 2019. Transnet. Available at: https://www.transnet.net/Pages/Home.aspx

Thuiller W et al. (2006) Interactions between environment, species traits and human uses describe patterns of plant invasions. Ecology 87: 1755-1769. https://doi.org/10.1890/0012-9658(2006)87[1755:IBESTA]2.0.CO;2

UNEP (2011) The strategic plan for biodiversity 2011-2020 and the Aichi biodiversity targets. COP CBD tenth meeting, Nagoya (Japan), October 2010. www.cbd.int/decisions/cop/?m=cop-10

United Nations, Department of Economic and Social Affairs, Population Division (2014) World Urbanization Prospects: The 2014 Revision, CD-ROM Edition https://esa.un.org/unpd/wup/cd-rom/ Accessed 23 August 2015

Valles SM et al. (2002) Detection of *Thelohania solenopsae* (Microsporidia: Thelohaniidae) in *Solenopsis invicta* (Hymenoptera: Formicidae) by multiplex PCR. Journal of Invertebrate Pathology 81:196-201. https://doi.org/10.1016/S0022-2011(02)00175-1

van Wilgen NJ et al. (2010) Alien invaders and reptile traders: what drivers the live animal trade in South Africa? Animal Conservation 13:24-32. https://doi.org/10.1111/j.1469-1795.2009.00298.x

Verbrugge LNH, Lueven RSEW, van der Velde G (2010) Evaluation of international risk assessment protocols for exotic species. Final Report. University Nijmegen, Netherlands

Vilá M et al. (2010) How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Frontiers in Ecology and Environment 8: 135-144. https://doi.org/10.1890/080083

Vilá M et al. (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters 14: 702-708. https://doi.org/10.1111/j.1461-0248.2011.01628.x

Visser V et al. (2016) Much more give than take: South Afica as a major donor but infrequent reciepient of invasive non-native grasses. Global Ecology and Biogeography 25:679-692. https://doi.org/10.1111/geb.12445

von der Lippe M, Kowarik I (2008) Do cities export biodiversity? Traffic as a dispersal vector across urban-rural gradients. Diversity and Distributions 14: 18-25. https://doi.org/10.1111/j.1472-4642.2007.00401.x

Wald DM et al (2018). The Role of Trust in Public Attitudes toward Invasive Species Management on Guam: A Case Study. Hunt KP (Ed.) Understanding the Role of Trust and Credibility in Science Communication. https://doi.org/10.31274/sciencecommunication-181114-14

Welk E, Schubert K, Hoffmann MH (2002) Present and potential distribution of invasive garlic mustard (*Alliaria petiolata*) in North America. Diversity and Distribution 8:219-233. https://doi.org/10.1046/j.1472-4642.2002.00144.x

Wetterer JK (2013) Exotic spread of *Solenopsis invicta* Buren (Hymenoptera: Formicidae) beyond North America. Sociobiology 60: 50-55. http://dx.doi.org/10.13102/sociobiology.v60i1.50-55

Wilson JRU et al. (2009). Something in the way you move: dispersal pathways affect invasion success. Trends in Ecology and Evolution 24: 136-144. https://doi.org/10.1016/j.tree.2008.10.007

Wilson JR, Panetta FD, Lindgren C (2017) Detecting and responding to alien plant incursions. Cambridge University Press—Ecology, Biodiversity and Conservation Series. pp.286. ISBN: 9781107095601. www.cambridge.org/9781107095601

Woodford DJ et al. (2016) Confronting the wicked problem of managing biological invasions. NeoBiota 31: 63-86. https://doi.org/10.3897/neobiota.31.10038

Zengeya T et al. (2017) Managing conflict-generating invasive species in South Africa: Challenges and trade-offs. Bothalia 47:a2160. https://doi.org/10.4102/abc.v7i2.2160

Appendices

Appendix 1 (Chapter 1)

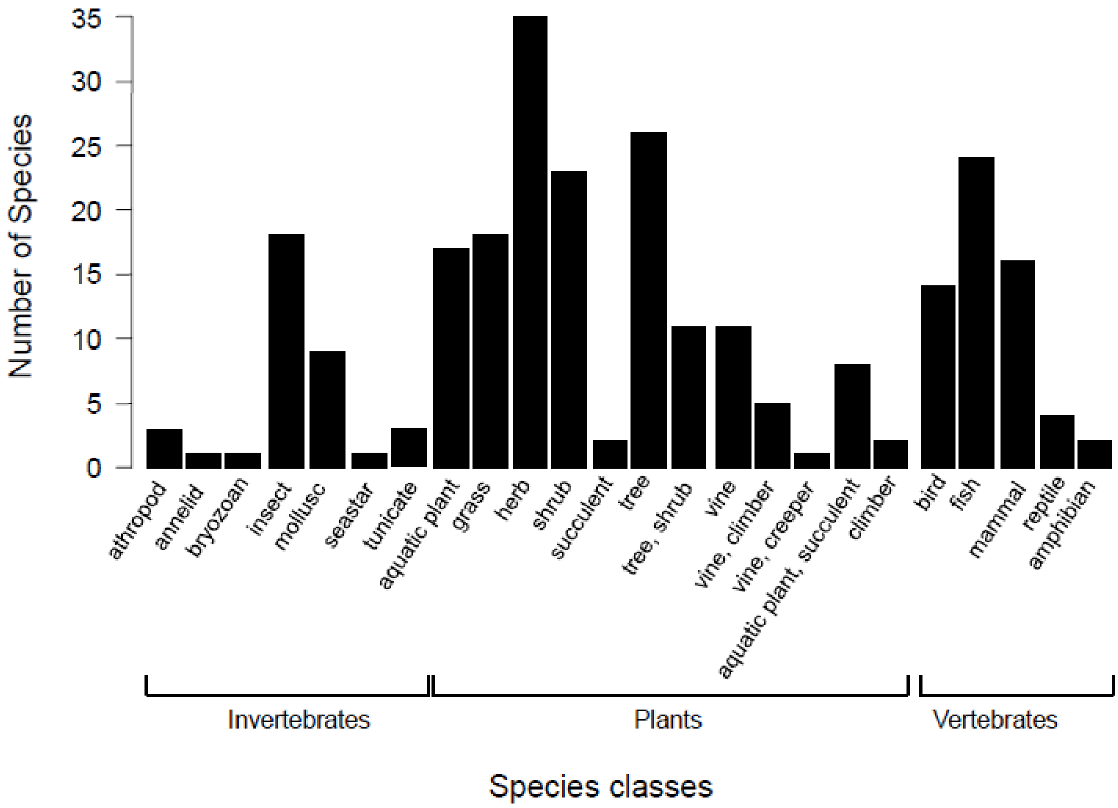

Figure 1: The number of species within each sub-group for the taxonomic groups (arthropod=8, annelid=3, bryozoan=1, insect=18, mollusc=9, seastar=1, tunicate=3, aquatic plant=17, grass=18, herb=35, shrub=23, succulent=2, tree=26, tree-shrub=11, vine=11, vine-climber=5, aquatic plant-succulent=1, climber=2, bird=14, fish=24, mammal=16, reptile=4, amphibian=2).

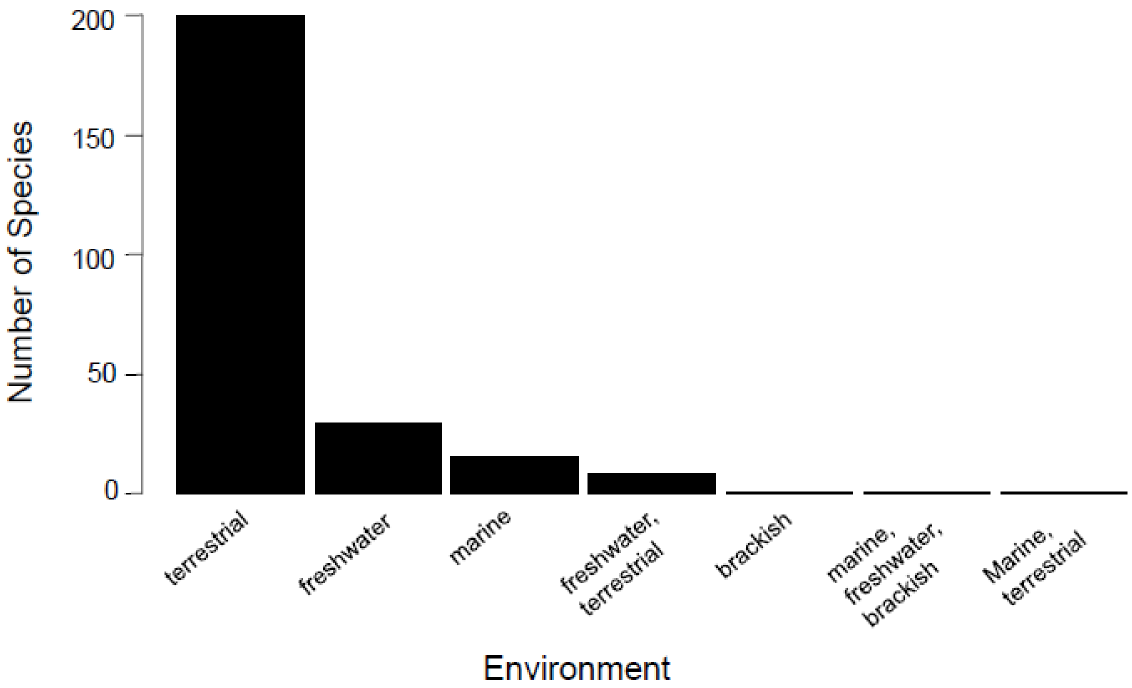

Figure 2: The number of alien species occupying different environments (terrestrial=20, freshwater=6, marine=14, freshwater-terrestrial=8, marine-brackish-freshwater=1, marine-terrestrial=1).

CART analysis – supplementary statistics

Table 1: The results of the confusion matrix produced in the CART analysis showing the prediction accuracy of the model produced. Prediction accuracy was calculated as the percentage of correct prediction in relation to the total number of observations for each pathway.

Predicted results	True observations				Prediction Accuracy (%)
	Contaminant	Escape	Release	Stowaway	
Contaminant	8	10	12	18	16.7
Escape	178	926	423	367	48.9
Release	5	38	42	5	46.7
Stowaway	32	64	26	49	28.7

*all records for "unknown" pathways were removed prior to analysis
*corridor pathway was excluded from analysis as there was only 1 record

Appendix 2 (Chapter 1): List of global cities with human population ≥ 1 million

	Country	City	Population Estimate	Year	Land Area (km²)	Density	Köppen Classification	Location	Harbour/ Port	Airport
1.	Argentina	Buenos Aires	14 122 000	2015	2 681	5 300	C	Coastal	Yes	Yes
2.	Argentina	Córdoba	1 585 000	2015	363	4 400	C	Inland	No	Yes
3.	Argentina	Rosario	1 338 000	2015	233	5 700	C	Inland	Yes	Yes
4.	Australia	Adelaide	1 140 000	2015	852	1 300	C	Coastal	Yes	Yes
5.	Australia	Brisbane	1 999 000	2015	1 972	1 000	C	Coastal	Yes	Yes
6.	Australia	Melbourne	3 906 000	2015	2 543	1 500	C	Coastal	Yes	Yes
7.	Australia	Perth	1 751 000	2015	1 566	1 100	C	Coastal	Yes	Yes
8.	Australia	Sydney	4 063 000	2015	2 037	2 000	C	Coastal	Yes	Yes
9.	Austria	Vienna	1 763 000	2015	453	3 900	C	Inland	No	Yes
10.	Belgium	Antwerpen	1 008 000	2015	635	1 600	C	Inland	Yes	Yes
11.	Belgium	Bruxelles-Brussel	2 089 000	2015	803	2 600	C	Inland	Yes	Yes
12.	Brazil	Belém	1 979 000	2015	259	7 600	A	Inland	Yes	Yes
13.	Brazil	Belo Horizonte	4 517 000	2015	1 088	4 200	A	Inland	Yes	Yes
14.	Brazil	Brasilia	2 536 000	2015	673	3 800	A	Inland	No	Yes
15.	Brazil	Campinas	2 645 000	2015	932	2 800	C	Inland	No	Yes
16.	Brazil	Curitiba	3 102 000	2015	842	3 700	C	Inland	No	Yes
17.	Brazil	João Pessoa	1 052 000	2015	194	5 400	A	Coastal	Yes	Yes
18.	Brazil	Manaus	1 893 000	2015	324	5 800	A	Inland	Yes	Yes
19.	Brazil	Natal	1 064 000	2015	246	4 300	A	Inland	Yes	Yes
20.	Brazil	Pôrto Alegre	3 413 000	2015	803	4 300	C	Inland	Yes	Yes
21.	Brazil	Recife	3 347 000	2015	414	8 100	A	Coastal	Yes	Yes
22.	Brazil	Rio de Janeiro	11 727 000	2015	2 020	5 800	A	Coastal	Yes	Yes
23.	Brazil	Salvador	3 190 000	2015	350	9 100	A	Coastal	Yes	Yes
24.	Brazil	Santos	1 653 000	2015	298	5 500		Coastal	Yes	Yes
25.	Brazil	Sao Luis	1 717 000	2015	427	2 700		Coastal	Yes	Yes
26.	Brazil	São Paulo	20 365 000	2015	2 707	7 500	C	Inland	No	Yes
27.	Brazil	Vittoria	1 172 000	2015	337	3 500		Coastal	Yes	Yes
28.	Canada	Calgary	1 189 000	2015	704	1 700	D	Inland	No	Yes
29.	Canada	Edmonton	1 040 000	2015	855	1 200	D	Inland	No	Yes
30.	Canada	Montréal	3 536 000	2015	1 546	2 300	D	Inland	Yes	Yes
31.	Canada	Toronto	6 456 000	2015	2 287	2 800	D	Inland	Yes	Yes
32.	Canada	Vancouver	2 273 000	2015	1 150	2 000	C	Inland	Yes	Yes
33.	Chile	Santiago	6 225 000	2015	984	6 300	C	Inland	No	Yes
34.	Colombia	Bogotá	8 991 000	2015	492	18 300	C	Inland	No	Yes
35.	Colombia	Bucaramanga	1 029 000	2015	60	17 300	A	Inland	No	Yes
36.	Colombia	Medellín	3 568 000	2015	228	15 700	A	Inland	No	Yes
37.	Democratic Republic of Congo	Lumbumbashi	2 000 000	2015	155	12 900	C	Inland	No	Yes
38.	Costa Rica	San José	1 170 000	2015	337	3 500	A	Inland	No	Yes
39.	Denmark	Copenhagen	1 248 000	2015	453	2 800	C	Coastal	Yes	Yes
40.	Ecuador	Guayaquil	2 700 000	2015	220	12 300	A	Inland	Yes	Yes

41.	Ecuador	Quito	1 720 000	2015	479	3 600	C	Inland	No	Yes
42.	Finland	Helsinki	1 208 000	2015	641	1 900	D	Coastal	Yes	Yes
43.	France	Lille	1 018 000	2015	280	3 600	C	Inland	No	Yes
44.	France	Lyon	1 583 000	2015	1 178	1 300	C	Inland	No	Yes
45.	France	Marseille	1 397 000	2015	453	3 100	C	Coastal	Yes	Yes
46.	France	Paris	10 858 000	2015	2 845	3 800	C	Inland	No	Yes
47.	Germany	Berlin	4 096 000	2015	1 347	3 000	C	Inland	No	Yes
48.	Germany	Cologne-Bonn	2 104 000	2015	932	2 300	C	Inland	No	Yes
49.	Germany	Essen-Dusseldorf	6 679 000	2015	2 655	2 500	C	Inland	No	Yes
50.	Germany	Frankfurt	1 915 000	2015	648	3 000	C	Inland	No	Yes
51.	Germany	Hamburg	2 087 000	2015	777	2 700	C	Inland	No	Yes
52.	Germany	Munich	1 981 000	2015	466	4 200	C	Inland	No	Yes
53.	Germany	Stuttgart	1 379 000	2015	479	2 900	C	Inland	No	Yes
54.	India	Bangalore	9 807 000	2015	1 166	8 400	A	Inland	No	Yes
55.	India	Bhopal	2 075 000	2015	181	11 400	A	Inland	No	Yes
56.	India	Coimbatore	2 481 000	2015	285	8 700	A	Inland	No	Yes
57.	India	Delhi	24 998 000	2015	2 072	12 100	B	Inland	No	Yes
58.	India	Kanpur	3 037 000	2015	207	14 700	C	Inland	No	Yes
59.	India	Kochi	2 374 000	2015	440	5 400	A	Coastal	Yes	Yes
60.	India	Kolkata	14 667 000	2015	1 240	12 200	A	Inland	Yes	Yes
61.	India	Meerut	1 541 000	2015	104	14 900	C	Inland	No	Yes
62.	India	Mumbai	17 712 000	2015	546	32 400	A	Coastal	Yes	Yes
63.	India	Mysore	1 078 000	2015	91	11 900	A	Inland	No	Yes
64.	India	Patna	2 200 000	2015	142	15 400	C	Inland	No	Yes
65.	India	Pune	5 631 000	2015	479	11 800	A	Inland	No	Yes
66.	India	Ranchi	1 246 000	2015	57	21 900	C	Inland	No	Yes
67.	India	Srinagar	1 409 000	2015	127	11 100	C	Inland	No	Yes
68.	India	Tiruchirappali	1 101 000	2015	85	12 900	A	Inland	No	Yes
69.	India	Varanasi	1 536 000	2015	101	15 200	C	Inland	No	Yes
70.	Indonesia	Bandung	5 695 000	2015	466	12 200	A	Inland	No	Yes
71.	Indonesia	Jakarta	30 539 000	2015	3 225	9 500	A	Coastal	Yes	Yes
72.	Ireland	Dublin	1 160 000	2015	453	2 600	C	Coastal	Yes	Yes
73.	Israel	Hefa	1 090 000	2015	228	4 800	C	Coastal	Yes	Yes
74.	Israel	Tel Aviv-Yafo	2 979 000	2015	479	6 200	C	Coastal	Yes	Yes
75.	Japan	Hiroshima	1 377 000	2015	285	4 800	C	Coastal	Yes	Yes
76.	Japan	Nagoya	10 177 000	2015	3 885	2 600		Coastal	Yes	Yes
77.	Japan	Osaka-Kobe-Kyoto	17 444 000	2015	3 212	5 400		Coastal	Yes	Yes
78.	Japan	Sapporo	2 570 000	2015	622	4 100	D	Coastal	Yes	Yes
79.	Japan	Tokyo	37 843 000	2015	8 547	4 400	C	Coastal	Yes	Yes
80.	Kenya	Mombasa	1 116 000	2015	85	13 100	A	Inland	Yes	Yes
81.	Kenya	Nairobi	4 738 000	2015	557	8 500	C	Inland	No	Yes
82.	Mexico	Aguascalientes	1 020 000	2015	106	9 600	B	Inland	No	Yes
83.	Mexico	Ciudad de Mexico	20 063 000	2015	2 072	9 700	C	Inland	No	Yes
84.	Mexico	Ciudad Juárez	1 391 000	2015	324	4 300	B	Inland	No	Yes
85.	Mexico	Guadalajara	4 603 000	2015	751	6 100	C	Inland	No	Yes
86.	Mexico	León de le Aldamas	1 469 000	2015	233	6 300	B	Inland	No	Yes

87.	Mexico	Mérida	1 111 000	2015	207	5 400	A	Inland	No	Yes
88.	Mexico	Mexicali	1 018 000	2015	202	5 000	B	Inland	No	Yes
89.	Mexico	Monterrey	4 083 000	2015	894	4 600	B	Inland	No	Yes
90.	Mexico	Puebla	2 088 000	2015	440	4 700	C	Inland	No	Yes
91.	Mexico	Querétaro	1 249 000	2015	150	8 300	B	Inland	No	Yes
92.	Mexico	San Luis Postosí	1 137 000	2015	132	8 600	B	Inland	No	Yes
93.	Mexico	Tijuana	1 986 000	2015	466	4 200	B	Coastal	No	Yes
94.	Mexico	Toluca de Lerdo	1 878 000	2015	272	6 900	C	Inland	No	Yes
95.	Mexico	Torreón	1 327 000	2015	168	7 900	B	Inland	No	Yes
96.	Netherlands	Amsterdam	1 624 000	2015	505	3 200	C	Inland	Yes	Yes
97.	Netherlands	Rotterdam	2 660 000	2015	984	2 700	C	Inland	Yes	Yes
98.	New Zealand	Auckland	1 356 000	2015	544	2 500	C	Coastal	Yes	Yes
99.	Nigeria	Benin City	1 490 000	2015	228	6 500	A	Inland	No	Yes
100.	Nigeria	Ibadan	3 160 000	2015	466	6 800	A	Inland	No	Yes
101.	Nigeria	Lagos	13 123 000	2015	907	14 500	A	Coastal	Yes	Yes
102.	Pakistan	Lahore	10 052 000	2015	790	12 700	B	Inland	No	Yes
103.	Pakistan	Rawalpindi	2 510 000	2015	427	5 900	C	Inland	No	Yes
104.	Peru	Lima	10 750 000	2015	919	11 700	B	Inland	No	Yes
105.	Poland	Warsaw	1 720 000	2015	544	3 200	C	Inland	No	Yes
106.	Portugal	Lisbon	2 666 000	2015	958	2 800	C	Coastal	Yes	Yes
107.	Portugal	Porto	1 474 000	2015	777	1 900	C	Coastal	Yes	Yes
108.	South Africa	Cape Town	3 812 000	2015	816	4 700	C	Coastal	Yes	Yes
109.	South Africa	Durban	3 421 000	2015	1 062	3 200	C	Coastal	Yes	Yes
110.	South Africa	Johannesburg	8 432 000	2015	2 590	3 300	C	Inland	No	Yes
111.	South Africa	Port Elizabeth	1 212 000	2015	389	3 100	C	Coastal	Yes	Yes
112.	South Africa	Pretoria	2 927 000	2015	1 230	2 400	C	Inland	No	Yes
113.	Spain	Barcelona	4 693 000	2015	1 075	4 400	C	Coastal	Yes	Yes
114.	Spain	Madrid	6 171 000	2015	1 321	4 700	B	Inland	No	Yes
115.	Spain	Sevilla	1 107 000	2015	272	4 100	C	Inland	Yes	Yes
116.	Spain	Valencia	1 561 000	2015	272	5 700	B	Coastal	Yes	Yes
117.	Sweden	Stockholm	1 484 000	2015	382	3 900	C	Coastal	Yes	Yes
118.	Tanzania	Dar es Salaam	4 219 000	2015	570	7 400	A	Coastal	Yes	Yes
119.	Uganda	Kampala	1 930 000	2015	492	3 900	A	Inland	No	Yes
120.	United Kingdom	Birmingham	2 512 000	2015	599	4 200	C	Inland	No	Yes
121.	United Kingdom	Glasgow	1 220 000	2015	368	3 300	C	Inland	Yes	Yes
122.	United Kingdom	Leeds-Bradford	1 893 000	2015	488	3 900	C	Inland	No	
123.	United Kingdom	London	10 236 000	2015	1 738	5 900	C	Inland	Yes	Yes
124.	United Kingdom	Manchester	2 639 000	2015	630	4 200	C	Inland	Yes	Yes
125.	United States	Atlanta	5 015 000	2015	6 851	700	C	Inland	No	Yes
126.	United States	Austin	1 616 000	2015	1 355	1 200	C	Inland	No	Yes
127.	United States	Baltimore	2 263 000	2015	1 857	1 200	C	Coastal	Yes	Yes
128.	United States	Boston	4 478 000	2015	5 325	800	C	Coastal	Yes	Yes
129.	United States	Charlotte	1 535 000	2015	1 919	800	C	Inland	No	Yes
130.	United States	Chicago	9 156 000	2015	6 856	1 300	C	Inland	Yes	Yes
131.	United States	Cincinnati	1 682 000	2015	2 041	800	C	Inland	No	Yes
132.	United States	Cleveland	1 783 000	2015	1 999	900	C	Inland	Yes	Yes

133.	United States	Columbus, Ohio	1 481 000	2015	1 321	1 100	C	Inland	No	Yes
134.	United States	Dallas-Fort Worth	6 174 000	2015	5 175	1 200	C	Inland	No	Yes
135.	United States	Denver-Aurora	2 559 000	2015	1 730	1 500	B	Inland	No	Yes
136.	United States	Detroit	3 672 000	2015	3 463	1 100	C	Inland	Yes	Yes
137.	United States	Houston	5 764 000	2015	4 644	1 200	C	Coastal	Yes	Yes
138.	United States	Indianapolis	1 617 000	2015	1 829	900	C	Inland	No	Yes
139.	United States	Jacksonville, Florida	1 154 000	2015	1 373	800	C	Coastal	Yes	Yes
140.	United States	Kansas City	1 593 000	2015	1 756	900	C	Inland	No	Yes
141.	United States	Las Vegas	2 191 000	2015	1 080	2 000	B	Inland	No	Yes
142.	United States	Los Angeles-Long Beach-Santa Ana	15 058 000	2015	6 299	2 400	B	Coastal	Yes	Yes
143.	United States	Louisville	1 025 000	2015	1 235	800	C	Inland	No	Yes
144.	United States	Memphis	1 102 000	2015	1 287	900	C	Inland	Yes	Yes
145.	United States	Miami	5 764 000	2015	3 209	1 800	A	Coastal	Yes	Yes
146.	United States	Milwaukee	1 408 000	2015	1 414	1 000	D	Inland	Yes	Yes
147.	United States	Minneapolis-St. Paul	2 771 000	2015	2 647	1 000	D	Inland	No	Yes
148.	United States	Nashville-Davidson	1 081 000	2015	1 458	700	C	Inland	No	Yes
149.	United States	New York-Newark	20 630 000	2015	11 642	1 800	C	Coastal	Yes	Yes
150.	United States	Orlando	2 040 000	2015	1 958	1 000	C	Inland	No	Yes
151.	United States	Philadelphia	5 570 000	2015	5 131	1 100	C	Coastal	Yes	Yes
152.	United States	Phoenix-Mesa	4 194 000	2015	3 196	1 300	B	Inland	No	Yes
153.	United States	Pittsburg	1 730 000	2015	2 344	700	C	Inland	No	Yes
154.	United States	Portland	1 976 000	2015	1 357	1 500	C	Inland	Yes	Yes
155.	United States	Providence	1 201 000	2015	1 412	900	C	Coastal	Yes	Yes
156.	United States	Raleigh	1 085 000	2015	1 342	800	C	Inland	No	Yes
157.	United States	Richmond	1 018 000	2015	1 274	800	C	Inland	Yes	Yes
158.	United States	Sacramento	1 885 000	2015	1 220	1 500	C	Inland	Yes	Yes
159.	United States	Salt Lake City	1 085 000	2015	720	1 500	C	Inland	No	Yes
160.	United States	San Antonio	1 976 000	2015	1 546	1 300	C	Inland	No	Yes
161.	United States	San Diego	3 086 000	2015	1 896	1 600	B	Coastal	Yes	Yes
162.	United States	San Francisco-Oakland	5 929 000	2015	2 797	2 100	C	Coastal	Yes	Yes
163.	United States	Seattle	3 218 000	2015	2 616	1 200	C	Inland	Yes	Yes
164.	United States	St. Louis	2 186 000	2015	2 393	900	C	Inland	Yes	Yes
165.	United States	Tampa-St. Petersburg	2 621 000	2015	2 479	1 100	C	Coastal	Yes	Yes
166.	United States	Virginia Beach	1 463 000	2015	1 334	1 100	C	Coastal	Yes	Yes
167.	United States	Washington D.C.	4 889 000	2015	3 424	1 400	C	Inland	Yes	Yes

Köppen Climate Classification:
A – Tropical climates
B – Dry (arid and semi-arid) climates
C – Temperate climates (mild winters)
D – Continental climates (cold winters)
E – Polar and alpine climates (cold winters and summers)

Appendix 3 (Chapter 1): List of invasive alien and the pathways which facilitate their introduction to regions beyond their native ranges extracted from the GISD database.

Species name	Group	Life-form	Environ.	Pathway	Pathway category
Acacia confusa	Plant	Tree, shrub	Terrestrial	Release	Erosion control; dune stabilisation
Acacia longifolia	Plant	Tree, shrub	Terrestrial	Release Escape	Erosion control; dune stabilisation Horticulture
Acacia mearnsii	Plant	Tree	Terrestrial	Escape	Forestry Horticulture
Acacia melanoxylon	Plant	Tree	Terrestrial	Release, Escape	Landscape; floral and faunal improvement Forestry Horticulture
Acacia saligna	Plant	Tree, shrub	Terrestrial	Release Escape	Landscape; floral and faunal improvement Agriculture Horticulture
Acanthogobius flavimanus	vertebrate	fish	Terrestrial	Stowaway	Ship and boat hull fouling
Acanthus mollis	Plant	herb	Terrestrial	Escape	Horticulture
Acer ginnala	Plant	Tree	Terrestrial	Escape	Horticulture
Acer platanoides	Plant	Tree	Terrestrial	Escape	Horticulture
Acridotheres tristis	vertebrate	Bird	Terrestrial	Stowaway Escape Release	Hitchhikers on a ship or boat Pet; aquarium or terrarium species Botanical gardens; zoos or aquaria Landscape; floral and faunal improvement
Adelges piceae	Invertebrate	Insect	Terrestrial	Contaminant	Contaminant on nursery material
Adelges tsguae	Invertebrate	Insect	Terrestrial	Contaminant Escape Unknown	Contaminant on nursery material Forestry Unknown
Aedes albopictus	Invertebrate	Insect	Terrestrial	Contaminant Stowaway	Transportation of habitat material Vehicles
Agapanthus praecox	Plant	Herb	Terrestrial	Escape	Horticulture
Agave americana	Plant	Succulent	Terrestrial	Release Escape	Landscape; floral and faunal improvement Horticulture
Ailanthus altissima	Plant	Tree	Terrestrial	Escape	Horticulture
Akebia quinata	Plant	Vine, climber	Terrestrial	Escape	Horticulture
Albizia lebbeck	Plant	Tree	Terrestrial	Escape	Forestry
Alexandrium minutum	Plant	Aquatic plant	Terrestrial	Stowaway Contaminant	Ship or boat ballast water Transportation of habitat material
Alitta succinea	Invertebrate	Annelid	Marine	Stowaway	Ship or boat ballast water
Alliaria petiolata	Plant	Herb	Terrestrial	Escape	Agriculture
Alnus glutinosa	Plant	Tree	Terrestrial	Release Escape	Erosion control; dune stabilisation Forestry Horticulture
Alosa pseudoharengus	Vertebrate	Fish	Freshwater	Release Corridor	Fishery in the wild Interconnected waterways; basins and seas
Alpinia zerumbet	Plant	Succulent	Terrestrial	Escape	Horticulture
Alternanthera philoxeroides	Plant	Herb	Terrestrial	Stowaway Contaminant	Ship or boat ballast water Transportation of habitat material
Ambrosia artemisiifolia	Plant	Herb	Terrestrial	Contaminant Escape Stowaway	Food contaminant Seed contaminant Transportation of habitat material Agriculture People and their luggage
Ameiurus nebulosus	Vertebrate	Fish	Terrestrial	Stowaway Release	Angling and fishing equipment Fishery in the wild
Ammophila arenaria	Plant	Vine, climber	Terrestrial	Release Stowaway	Erosion control; dune stabilisation Hitchhikers on a ship or boat
Ampelopsis brevipendunculata	Plant	Vine, climber	Terrestrial	Escape	Horticulture
Anas platyrhynchos	Vertebrate	Bird	Freshwater, terrestrial	Release Escape	Hunting in the wild Farmed animals Ornamental purposes
Angiopteris evecta	Plant	Tree	Terrestrial	Escape	Botanical gardens; zoos or aquaria Horticulture Agriculture
Anoplolepis gracilipes	Invertebrate	Insect	Terrestrial	Stowaway Contaminant Release	Vehicles Machinery or equipment Hitchhikers on a plane Organic packaging material Timber trade Transportation of habitat material Contaminant on nursery material Food contaminant

Species name	Group	Life-form	Environ.	Pathway	Pathway category
					Biological control
Anredera cordifolia	Plant	Climber	Terrestrial	Release Escape	Landscape; floral and faunal improvement Horticulture
Antigonon leptopus	Plant	Climber	Terrestrial	Escape	Horticulture
Ardisia elliptica	Plant	Shrub	Terrestrial	Escape	Botanical gardens; zoos or aquaria Horticulture
Arundo donax	Plant	Grass	Terrestrial	Release Escape	Landscape; floral and faunal improvement Agriculture
Ascidiella aspersa	Invertebrate	Turnicate	Marine	Escape Stowaway	Aquaculture or mariculture Angling and fishing equipment Ship or boat ballast water Ship or boat hull fouling
Asparagus densiflorus	Plant	Herb	Terrestrial	Escape	Horticulture
Asterias amurensis	Invertebrate	Seastar	Marine	Stowaway Contaminant Escape	Angling and fishing equipment Hitchhikers on a ship or boat Ship or boat ballast water Ship or boat hull fouling Contaminant on animals Live food and live bait
Azolla pinnata	Plant	Aquatic plant	Terrestrial	Escape Containment	Agriculture Contaminant on animals
Bambusa vulgaris	Plant	Grass	Terrestrial	Release Escape	Erosion control; dune stabilisation Forestry Botanical gardens; zoos or aquaria Other escape from confinement
Berberis thunbergii	Plant	Shrub	Terrestrial	Escape	Botanical gardens; zoos or aquaria
Bidens pilosa	Plant	Herb	Terrestrial	Escape	Agriculture Horticulture
Branta canadensis	Vertebrate	Bird	Freshwater, terrestrial	Release Escape	Ornamental purposes Hunting in the wild
Bromus inermis	Plant	Grass	Terrestrial	Release Escape	Landscape; floral and faunal improvement Agriculture
Bromus rubens	Plant	Grass	Terrestrial	Escape Contaminant	Agriculture Contaminant on animals
Bromus tectorum	Plant	Grass	Terrestrial	Escape	Agriculture
Buddleja davidii	Plant	Shrub	Terrestrial	Escape	Horticulture
Buddleja madagascariensis	Plant	Shrub	Terrestrial	Escape	Agriculture Horticulture
Bugula neritina	Invertebrate	Bryozoan	Marine	Stowaway Contaminant	Ship or boat ballast water Food contaminant
Butomus umbellatus	Plant	Aquatic plant	Terrestrial	Escape Stowaway	Botanical gardens; zoos or aquaria Ship or boat ballast water
Cambomba caroliniana	Plant	Aquatic plant	Terrestrial	Escape Contaminant Stowaway	Botanical gardens; zoos or aquaria Pet; aquarium or terrarium species Contaminated bait Transportation of habitat material Machinery or equipment Ship or boat hull fouling
Caesalpinia decapetala	Plant	Shrub	Terrestrial	Escape Contaminant	Horticulture Other escape from confinement Transportation of habitat material
Canis lupis	Vertebrate	Mammal	Terrestrial	Escape	Farmed animals
Capra hircus	Vertebrate	Mammal	Terrestrial	Release Escape	Release in use for nature Farmed animals
Carassius auratus	Vertebrate	Fish	Freshwater	Escape	Ornamental purposes Pet; aquarium or terrarium species
Carcinus maenas	Invertebrate	Arthropod	Marine, terrestrial	Escape Stowaway	Aquaculture or mariculture Pet; aquarium or terrarium species Live food and live bait Ship or boat ballast water Ship or boat hull fouling
Cardamine flexuosa	Plant	Herb	Terrestrial	Stowaway Contaminant	People and their luggage Machinery or equipment Contaminant on animals
Cardiospermum grandiflorum	Plant	Vine, climber	Terrestrial	Escape	Horticulture
Carduus nutans	Plant	Herb	Terrestrial	Escape Contaminant	Horticulture Seed contaminant
Carpobrotus edulis	Plant	Aquatic plant	Terrestrial	Release Escape	Erosion control; dune stabilisation Horticulture
Casuarinas equisetifolia	Plant	Tree	Terrestrial	Release Escape	Landscape; floral and faunal improvement Erosion control; dune stabilisation Horticulture Forestry
Celastrus orbiculatus	Plant	Vine	Terrestrial	Escape	Horticulture
Cenchrus ciliaris	Plant	Grass	Terrestrial	Release	Erosion control; dune stabilisation Landscape; floral and faunal

Species name	Group	Life-form	Environ.	Pathway	Pathway category
				Escape	improvement
					Agriculture
Cenchrus	Plant	Grass	Terrestrial	Escape	Agriculture
clandestinus					Horticulture
Cenchrus	Plant	Grass	Terrestrial	Escape	Horticulture
macrourus				Stowaway	Machinery or equipment
				Contamin	Contaminant on animals
				ant	
Cenchrus	Plant	Grass	Terrestrial	Escape	Horticulture
setaceus				Stowaway	People and their luggage
				Contamin	Vehicles
				ant	Contaminant on animals
Centaurea	Plant	Herb	Terrestrial	Stowaway	Ship or boat ballast water
biebersteinii				Contamin	Seed contaminant
				ant	
Centaurea	Plant	Herb	Terrestrial	Escape	Agriculture
melitensis				Stowaway	Machinery or equipment
				Contamin	Vehicles
				ant	Transportation of habitat material
					Seed contaminant
Centaurea	Plant	Herb	Terrestrial	Escape	Agriculture
solstitialis				Stowaway	Vehicles
				Contamin	Seed contaminant
				ant	
Ceratitis capitata	Invertebrate	Insect	Terrestrial	Contamin	Parasite on plants
				ant	
Ceratophyllum	Plant	Aquatic	Terrestrial	Escape	Pet; aquarium or terrarium species
demersum		plant		Stowaway	Angling and fishing equipment
Cervus elaphus	Vertebrate	Mammal	Terrestrial	Release	Hunting in the wild
					Landscape; floral and faunal
				Escape	improvement
					Farmed animals
Chamaeleo	Vertebrate	Reptile	Terrestrial	Escape	Pet; aquarium or terrarium species
jacksonii					
Channa argus	Vertebrate	Fish	Freshwater	Release	Release in use for nature
				Escape	Fishery in the wild
					Pet; aquarium or terrarium species
					Live food and live bait
Channa marulius	Vertebrate	Fish	Freshwater	Escape	Pet; aquarium or terrarium species
					Live food and live bait
Chromolaena	Plant	Shrub	Terrestrial	Release	Biological control
ordorata				Escape	Agriculture
					Horticulture
				Stowaway	Botanical gardens, zoos or aquarium
				Contamin	Vehicles

Species name	Group	Life-form	Environ.	Pathway	Pathway category
				ant	Machinery or equipment
					Seed contaminant
					Transportation of habitat material
Chrysanthemoid	Plant	Shrub	Terrestrial	Release	Landscape; floral and faunal
es monilifera				Stowaway	improvement
					Ship or boat ballast water
Cirsium arvense	Plant	Herb	Terrestrial	Stowaway	Ship or boat ballast water
				Contamin	Seed contaminant
				ant	
Clarias batrachus	Vertebrate	Fish	Freshwater	Escape	Pet. Aquarium or terrarium species
					Aquaculture or mariculture
Coccinia grandis	Plant	Vine	Terrestrial	Escape	Agriculture
Columba livia	Vertebrate	Bird	Terrestrial	Release	Release in use for nature
				Escape	Farmed animals
Corbicula	Invertebrate	Mollusc	Freshwater	Stowaway	Ship or boat ballast water
fluminea				Contamin	Ship or boat hull fouling
				ant	Contaminated bait
Coronilla varia	Plant	Herb	Terrestrial	Release	Erosion control; dune stabilisation
				Escape	Agriculture
Cortaderia	Plant	Grass	Terrestrial	Escape	Horticulture
jubata					
Cortaderia	Plant	Grass	Terrestrial	Release	Erosion control; dune stabilisation
selloana				Escape	Agriculture
					Horticulture
Corvus splendens	Vertebrate	Bird	Terrestrial	Release	Release in use for nature
				Stowaway	Hitchhikers on a ship or boat
Continus	Plant	Shrub	Terrestrial	Release	Landscape; floral and faunal
coggygria					improvement
Crassula helmsii	plant	Aquatic	Terrestrial	Escape	Horticulture
		plant,		Contamin	Transportation of habitat material
		succulent		ant	
Cryptostegia	Plant	Vine	Terrestrial	Escape	Horticulture
grandifolra				Stowaway	Agriculture
				Contamin	Vehicles
				ant	Contaminant on animals
				Unknown	Unknown
Culex	Invertebrate	Insect	Terrestrial	Stowaway	Hitchhikers on a ship or boat
quinquefasciatus					Hitchhikers on a plane
Cupaniopsis	Plant	Tree	Terrestrial	Escape	Horticulture
anacardioides					
Cyathea cooperi	Plant	Herb	Terrestrial	Escape	Horticulture
Cygnus olor	Vertebrate	Bird	Freshwater,	Escape	Botanical gardens; zoos or aquaria
			terrestrial		
Cyperus rotundus	Plant	Herb	Terrestrial	Escape	Agriculture
				Stowaway	Ship or boat ballast water

Species name	Group	Life-form	Environ.	Pathway	Pathway category
				Contaminant	Food contaminant Seed contaminant Transportation of habitat material
Cyprinus carpio	Vertebrate	Fish	Freshwater	Release Escape	Release in use for nature Fishery in the wild Landscape; floral or faunal improvement Aquaculture or mariculture Ornamental purposes
Cytisus scoparius	Plant	Shrub	Terrestrial	Escape Stowaway	Horticulture Vehicles
Dioscorea oppositifolia	Plant	Vine	Terrestrial	Escape	Horticulture
Dipogon lignosus	Plant	Vine	Terrestrial	Escape	Horticulture
Dreissena polymorpha	Invertebrate	Mollusc	Marine	Escape Stowaway Contaminant	Botanical gardens; zoos or aquaria Ship or boat ballast water Ship or boat hull fouling Transportation of habitat material
Eichhornia crassipes	Plant	Aquatic plant	Terrestrial	Release Escape Stowaway	Release in use for nature Botanical gardens; zoos or aquaria Horticulture Machinery or equipment Vehicles
Elaeagnus umbellata	Plant	Shrub	Terrestrial	Release Escape	Landscape; floral or faunal improvement Agriculture Horticulture
Erinaceus europaeus	Vertebrate	Mammal	Terrestrial	Release	Landscape; floral or faunal improvement Biological control
Eriocheir sinensis	Invertebrate	Arthropod	Freshwater	Escape Stowaway	Pet; aquarium or terrarium species Live food and live bait Ship or boat ballast water Ship or boat hull fouling
Eugenia uniflora	Plant	Shrub	Terrestrial	Release Escape	Landscape; floral or faunal improvement Horticulture Agriculture
Euonymus fortunei	Plant	Vine	Terrestrial	Escape	Horticulture
Felis catus	Vertebrate	Mammal	Terrestrial	Escape Stowaway	Pet; aquarium terrarium species Hitchhikers on a ship or boat
Ficus rubiginosa	Plant	Tree	Terrestrial	Escape	Botanical gardens; zoos or aquaria Forestry
Gallus gallus	Vertebrate	Bird	Terrestrial	Escape	Farmed animals
Gambusia affinis	Vertebrate	Fish	Freshwater	Release Escape Stowaway	Biological control Botanical gardens; zoos or aquaria Hitchhikers on a ship or boat
Gambusia holbrooki	Vertebrate	Fish	Freshwater	Escape	Pet; aquarium or terrarium species
Geukensia demissa	Invertebrate	mollusc	Marine	Escape Stowaway	Live food and live bait Ship or boat ballast water Ship or boat hull fouling
Glyceria maxima	Plant	Grass	Terrestrial	Contaminant	Contaminant on animals
Gymnorhina tibicen	Vertebrate	Bird	Terrestrial	Release	Biological control
Harmonia axyridis	Invertebrate	Insect	Terrestrial	Escape Stowaway	Horticulture Hitchhikers on a ship or boat
Hedera helix	Plant	Vine	Terrestrial	Release Escape	Landscape; floral and faunal improvement Horticulture
Hedychium flavescens	Plant	Herb	Terrestrial	Escape	Horticulture
Hemidactylus frenatus	Vertebrate	Reptile	Terrestrial	Escape Stowaway	Pet; aquarium or terrarium species Container or bulk
Heracleum mantegazzianum	Plant	Herb	Freshwater	Escape Contaminant	Horticulture Parasite on plants
Herpestes javanicus	Vertebrate	Mammal	Terrestrial	Release	Biological control
Hydrilla verticillata	Plant	Aquatic plant	Terrestrial	Escape Contaminant	Pet; aquarium or terrarium species Contaminant on plants
Hylastes ater	Invertebrate	Insect	Terrestrial	Contaminant	Seed contaminant Parasite on plants
Hypericum perforatum	Plant	Herb	Terrestrial	Escape Stowaway Contaminant	Horticulture Vehicles Seed contaminant
Hypophthalmichthys molitrix	Vertebrate	Fish	Freshwater	Release Escape	Landscape; floral and faunal improvement Release in use for nature Live food and live bait Aquaculture or mariculture
Hypophthalmichthys nobilis	Vertebrate	Fish	Freshwater	Release Escape	Landscape; floral and faunal improvement Fishery in the wild Release in use for nature Aquaculture or mariculture

Species name	Group	Life-form	Environ.	Pathway	Pathway category
Iguana iguana	Vertebrate	Reptile	Terrestrial	Escape	Pet; aquarium or terrarium species
Impatiens glandulifera	Plant	Herb	Terrestrial	Escape Containment	Horticulture Transportation of habitat material
Imperata cylindrica	Plant	Grass	Terrestrial	Escape Stowaway Containment	Agriculture Vehicles Contaminant on nursery material
Iris pseudacorus	Plant	Herb	Terrestrial	Release Escape	Erosion control; dune stabilisation Horticulture
Lantana camara	Plant	Shrub	Terrestrial	Escape	Horticulture
Lasius neglectus	Invertebrate	Insect	Terrestrial	Contaminant	Transportation of habitat material
Lates niloticus	Vertebrate	Fish	Freshwater	Release	Fishery in the wild
Lepidium latifolium	Plant	Herb	Terrestrial	Stowaway Contaminant	Hitchhikers on a ship or boat Seed contaminant
Lepus europaeus	Vertebrate	Mammal	Terrestrial	Release	Hunting in the wild
Lespedeza cuneata	Plant	Herb	Terrestrial	Release Escape	Erosion control; dune stabilisation Landscape; floral and faunal improvement Agriculture
Leucaena leucocephala	Plant	Tree, shrub	Terrestrial	Release Escape	Landscape; floral and faunal improvement Forestry Botanical gardens; zoos or aquaria Agriculture
Ligustrum lucidum	Plant	Tree	Terrestrial	Escape	Horticulture
Ligustrum sinense	Plant	Tree	Terrestrial	Escape	Horticulture
Limnoperna fortunei	Invertebrate	Mollusc	Freshwater	Stowaway	Ship or boat ballast water Ship or boat hull fouling
Linaria vulgaris	Plant	Herb	Terrestrial	Escape	Horticulture Agriculture
Linepithema humile	Invertebrate	Insect	Terrestrial	Release Stowaway Contaminant	Landscape; floral and faunal improvement Hitchhikers on a ship or boat Vehicle Machinery or equipment Timber trade
Lithobates catesbeianus	Vertebrate	Amphibian	Terrestrial	Release Escape	Biological control Landscape; floral and faunal improvement Release in use for nature
					Aquaculture or mariculture Ornamental purposes
Livistona chinensis	Plant	Tree, shrub	Terrestrial	Escape	Horticulture
Lonicera japonica	Plant	Vine	Terrestrial	Escape	Horticulture
Lotus corniculatus	Plant	Herb	Terrestrial	Release Contaminant	Landscape; floral and faunal improvement Contaminant on plants
Ludwigia peruviana	Plant	Shrub	Terrestrial	Contaminant	Seed contaminant
Lumbricus rubellus	Invertebrate	Annelid	Terrestrial	Stowaway	Vehicles Container or bulk
Lygodium japonicum	Plant	Vine, climber	Terrestrial	Escape	Horticulture
Lymantria dispar	Invertebrate	Insect	Terrestrial	Stowaway Containment	Container or bulk Ship or boat hull fouling Organic packing material Contaminant on nursery material
Lythrum salicaria	Plant	Herb	Terrestrial	Release	Landscape; floral or faunal improvement
Melaleuca quinquenerva	Plant	Tree	Terrestrial	Release Escape Stowaway	Landscape; floral and faunal improvement Forestry Horticulture Vehicles
Melia azedarach	Plant	Tree	Terrestrial	Escape	Forestry Agriculture
Miconia calvescens	Plant	Tree	Terrestrial	Escape Stowaway Contaminant	Botanical gardens; zoos or aquaria Machinery or equipment Transportation of habitat material
Micropterus salmoides	Vertebrate	Fish	Freshwater	Release Escape	Fishery in the wild Aquaculture or mariculture
Mimosa pigra	Plant	Shrub	Terrestrial	Release Escape Stowaway Contaminant	Erosion control; dune stabilisation Botanical gardens; zoos or aquaria Horticulture Machinery or equipment Seed contaminant
Monomorium pharaonis	Invertebrate	Insect	Terrestrial	Escape Contaminant	Pet; aquarium or terrarium species Contaminant on plants
Monopetrus alba	Vertebrate	Fish	Freshwater	Release	Release in use for nature
Morus alba	Plant	Tree, shrub	Terrestrial	Escape	Agriculture
Mus musculus	Vertebrate	Mammal	Terrestrial	Stowaway	Hitchhikers on a plane

Species name	Group	Life-form	Environ.	Pathway	Pathway category
					Vehicles Machinery or equipment Container or bulk Hitchhikers on a ship or boat
Musculista senhousia	Invertebrate	Mollusc	Marine	Stowaway Contaminant	Ship or boat ballast water Ship or boat hull fouling Food contaminant
Mya arenaria	Invertebrate	Mollusc	Marine	Stowaway Contaminant	Ship or boat ballast water Ship or boat hull fouling Food contaminant
Myiopsitta monachus	Vertebrate	Bird	Terrestrial	Escape	Pet; aquarium or terrarium species
Myocastor coypus	Vertebrate	Mammal	Freshwater, terrestrial	Escape	Fur farms
Myriophyllum aquaticum	Plant	Aquatic plant	Terrestrial	Escape	Horticulture
Myriophyllum heterophyllum	Plant	Aquatic plant	Terrestrial	Escape Stowaway	Horticulture Pet; aquarium or terrarium species Hitchhikers on a ship or boat
Myriophyllum spicatum	Plant	Aquatic plant	Terrestrial	Escape Stowaway Contaminant Unknown	Pet; aquarium or terrarium species Hitchhikers on a ship or boat Transportation of habitat material unknown
Myrmica rubra	Invertebrate	Insect	Terrestrial	Contaminant	Contaminant on plants Transportation of habitat material
Mytilus galloprovincialis	Invertebrate	Mollusc	Marine	Escape Stowaway	Aquaculture or mariculture Live food and live bait Ship or boat ballast water Ship or boat hull fouling Hitchhikers on a ship or boat
Neovision vison	Vertebrate	Mammal	Terrestrial	Escape	Fur farms
Nymphaea odorata	Plant	Aquatic plant	Terrestrial	Escape	Horticulture
Oncorhynchus mykiss	vertebrate	Fish	Freshwater	Release Escape	Fishery in the wild Aquaculture or mariculture
Onopordum acanthium	Plant	Herb	Terrestrial	Escape	Horticulture
Opuntia monacantha	Plant	Tree, shrub	Terrestrial	Escape	Agriculture
Opuntia stricta	Plant	Tree, shrub	Terrestrial	Escape	Horticulture Other escape from confinement
Orconectes rusticus	Invertebrate	Arthropod	Freshwater	Release Escape	Biological control Pet; aquarium or terrarium species Research (in facilities)
Oreochromis aureus	Vertebrate	Fish	Freshwater	Release	Biological control Fishery in the wild
Oreochromis mossambiscus	Vertebrate	Fish	Freshwater	Escape	Aquaculture or mariculture Botanical gardens; zoos or aquaria
Oreochromis niloticus	Vertebrate	Fish	Freshwater	Release Escape	Fishery in the wild Aquaculture or mariculture Live food and live bait
Oryctolagus cuniculus	Vertebrate	Mammal	Terrestrial	Release Escape	Landscape; floral and faunal improvement Live food and live bait
Oxyura jamaicensis	Vertebrate	Bird	Freshwater	Escape	Botanical gardens; zoos or aquaria Pet; aquarium or terrarium species
Pacifastacus leniusculus	Vertebrate	Arthropod	Freshwater	Release Escape	Release in use for nature Aquaculture or mariculture
Paratrechina longicornis	Invertebrate	Insect	Terrestrial	Stowaway Contaminant	People and their luggage Transportation of habitat material Food contaminant Timber trade Contaminant on nursery material
Parthenium hysterophorus	Plant	Herb	Terrestrial	Contaminant	Seed contaminant Food contaminant
Passer domesticus	Vertebrate	Bird	Terrestrial	Stowaway	Other means of transport
Passiflora tarminiana	Plant	Vine	Terrestrial	Escape	Agriculture Horticulture
Paulownias tormentosa	Plant	Vine	Terrestrial	Release Escape	Landscape; floral and faunal improvement Forestry Horticulture
Perna virdis	Invertebrate	Mollusc	Marine	Stowaway	Ship or boat ballast water Ship or boat hull fouling
Phalaris arundinacea	Plant	Grass	Terrestrial	Escape	Ornamental purposes Agriculture
Pheidole megacephala	Invertebrate	Insect	Terrestrial	Stowaway Unknown	Machinery or equipment Other means of transport Hitchhikers on a ship or boat Container or bulk Unknown
Phragmites australis	Plant	Grass	Terrestrial	Release	Erosion control; dune stabilisation Landscape; floral and faunal improvement
Pistia stratiotes	Plant	Aquatic plant	Terrestrial	Escape Stowaway	Pet; aquarium or terrarium species Angling or fishing equipment Ship or boat hull fouling
Pittosporum	Plant	Tree	Terrestrial	Escape	Botanical gardens; zoos or aquaria

Species name	Group	Life-form	Environ.	Pathway	Pathway category
undulatum					Horticulture
Poecilia reticulata	Vertebrate	Fish	Freshwater	Escape	Pet; aquarium or terrarium species
Polygonum cuspidatum Sieb. & Zucc. (=Fallopia japonica	Plant	Herb	Terrestrial	Release Escape Containment	Erosion control; dune stabilisation Landscape; floral and faunal improvement Botanical gardens; zoos or aquaria Horticulture Agriculture Transportation of habitat material
Populus alba	Plant	Tree	Terrestrial	Escape	Horticulture
Porcellio scaber	Invertebrate	Arthropod	Terrestrial	Contaminant	Transportation of habitat material Contaminant on plants Food contaminant
Potamocorbula amurensis	Invertebrate	Mollusc	Marine	Stowaway	Ship or boat ballast water
Potamopyrgus antipodarum	Invertebrate	Arthropod	Freshwater	Escape Stowaway	Pet; aquarium or terrarium species Ship or boat ballast water Ship or boat hull fouling
Procambarus clarkii	Invertebrate	Arthropod	Freshwater	Release Escape	Biological control Fishery in the wild Aquaculture or mariculture Pet; aquaria or terrarium species Live food and live bait
Psidium guajava	Plant	Tree, shrub	Terrestrial	Escape	Agriculture Horticulture
Psittacula krameri	Vertebrate	Bird	Terrestrial	Escape	Pet; aquarium or terrarium species
Psoralea pinnata	Plant	Shrub	Terrestrial	Escape Stowaway Contaminant	Horticulture Machinery or equipment Transportation of habitat material
Pteris cretica	Plant	Shrub	Terrestrial	Escape	Horticulture
Pterygoplichthys anisitsi	Vertebrate	Fish	Freshwater	Escape	Aquaculture or mariculture Pet; aquaria or terrarium species Live food and live bait
Pueraria montana var. lobata	Plant	Vine, climber	Terrestrial	Escape Stowaway	Horticulture Agriculture Vehicles
Pycnonotus jocosus	Vertebrate	Bird	Terrestrial	Escape	Pet; aquarium or terrarium species
Rattus norvegicus	Vertebrate	Mammal	Terrestrial	Stowaway	Container or bulk Hitchhikers on ship or boat
Rattus rattus	Vertebrate	Mammal	Terrestrial	Stowaway	Container or bulk Vehicles
Rhamnus alaternus	Plant	Tree	Terrestrial	Escape	Horticulture
Rhinella marina	Vertebrate	Amphibian	Terrestrial	Release Stowaway	Biological control Container or bulk Vehicles
Rhithropanopeus harrisii	Invertebrate	Arthropod	Brackish	Stowaway Contaminant	Ship or boat ballast water Ship or boat hull fouling Food contaminant
Rhododendron ponticum	Plant	Shrub	Terrestrial	Release Escape	Landscape; floral and faunal improvement Erosion control; dune stabilisation Horticulture
Ricinus communis	Plant	Tree, shrub	Terrestrial	Escape	Agriculture Horticulture
Robinia pseudoacacia	Plant	Tree	Terrestrial	Release Escape	Erosion control; dune stabilisation Horticulture
Rosa multifolra	Plant	Shrub	Terrestrial	Release Escape	Erosion control; dune stabilisation Other escape from confinement
Rubus ellipticus	Plant	Shrub	Terrestrial	Escape	Agriculture
Rubus phoenicolasius	Plant	Shrub	Terrestrial	Escape	Horticulture
Rumex acetosella	Plant	Herb	Terrestrial	Escape Stowaway Contaminant	Agriculture Machinery or equipment Vehicles Seed contaminant
Sabella spallanzanii	Invertebrate	Annelid	Marine	Contaminant Stowaway	Contaminated bait Hitchhikers on ship or boat Ship or ballast water Ship or boat hull fouling
Sagittaria platyphylla	Plant	Aquatic plant	Terrestrial	Escape	Horticulture
Salmo trutta	vertebrate	Fish	Freshwater	Release Escape	Fishery in the wild Aquaculture or mariculture
Salvelinus fontinalis	Vertebrate	Fish	Freshwater	Escape	Aquaculture or mariculture
Salvinia molesta	Plant	Aquatic plant	Terrestrial	Escape Stowaway	Horticulture Pet; aquarium or terrarium species Botanical gardens, zoos or aquaria Hitchhikers on a ship or boat
Sciurus carolinensis	Vertebrate	Mammal	Terrestrial	Release	Landscape; floral and faunal improvement
Scenecio inaequidens	Plant	Shrub	Terrestrial	Stowaway Contaminant	Machinery or equipment Vehicles Container or bulk Transportation of habitat material

Species name	Group	Life-form	Environ.	Pathway	Pathway category
					Contaminant on animals
Sesbania punicea	Plant	Shrub	Terrestrial	Escape	Horticulture
Solanum mauritianum	Plant	Tree, shrub	Terrestrial	Escape	Horticulture
Solanum sisymbriifolium	Plant	Herb	Terrestrial	Release Containment	Biological control Food contaminant
Solenopsis geminata	Invertebrate	Insect	Terrestrial	Stowaway Contaminant	Hitchhikers on a plane Container or bulk Vehicles Food contaminant Contaminant on plants Transportation of habitat material
Sorghum halepense	Plant	Grass	Terrestrial	Escape Contaminant	Agriculture Contaminant on animals
Spartina alterniflora	Plant	Grass	Terrestrial	Release Contaminant	Landscape; floral and faunal improvement Food contaminant
Spathodea campanulata	Plant	Tree	Terrestrial	Escape	Horticulture
Sphagneticola trilobata	Plant	Herb	Terrestrial	Escape Unknown	Horticulture Unknown
Sporobolus africanus	Plant	Grass	Terrestrial	Stowaway Contaminant	Vehicles People and their luggage Machinery or equipment Contaminant on animals Transportation of habitat material Food contaminant Seed contaminant
Sturnus vulgaris	Vertebrate	Bird	Terrestrial	Release Escape	Biological control Landscape; floral or faunal improvement Ornamental purposes Pet; aquarium or terrarium species
Styela clava	Invertebrate	Turnicate	Marine	Stowaway Contaminant	Ship or boat hull fouling Food contaminant
Styela plicata	Invertebrate	Turnicate	Marine	Stowaway Contaminant	Ship or boat ballast water Ship or boat hull fouling Food contaminant
Sus scrofa	Vertebrate	Mammal	Terrestrial	Release Escape	Hunting in the wild Release in use for nature Farmed animals
Syngonium	Plant	Vine	Terrestrial	Escape	Horticulture

Species name	Group	Life-form	Environ.	Pathway	Pathway category
podophyllum					
Syzygium cumini	Plant	Tree	Terrestrial	Escape	Horticulture
Tamarix ramosissima	Plant	Tree	Terrestrial	Release Escape	Erosion control; dune stabilisation Horticulture
Tapinoma melanocephalum	Invertebrate	Insect	Terrestrial	Stowaway	Other means of transport
Trachemys scripta elegans	Vertebrate	Reptile	Freshwater, terrestrial	Escape	Pet; aquarium or terrarium species
Trachycarpus fortunei	Plant	Tree	Terrestrial	Escape	Horticulture
Tradescantia fluminensis	Plant	Vine, creeper	Terrestrial	Escape	Horticulture
Triadica sebifera	Plant	Tree	Terrestrial	Escape	Horticulture Forestry
Tridentiger trigonocephalus	Vertebrate	Fish	Marine, freshwater	Stowaway Contaminant	Ship or boat ballast water Ship or boat hull fouling Food contaminant
Typha latifolia	Plant	Aquatic plant	Terrestrial	Stowaway	Machinery or equipment People and their luggage
Ulex europaeus	Plant	Shrub	Terrestrial	Escape	Horticulture Other escape from confinement
Vallisneria spirallis	Plant	Herb	Terrestrial	Release	Landscape; floral and faunal improvement
Verbena brasiliensis	Plant	Herb	Terrestrial	Contaminant	Food contaminant
Vespula germanica	Invertebrate	Insect	Terrestrial	Stowaway Contaminant	Container or bulk Hitchhikers on a plane Transportation of habitat material
Vespula vulgaris	Invertebrate	Insect	Terrestrial	Stowaway	Container or bulk Other means of transport
Vulpes vulpes	Vertebrate	Mammal	Terrestrial	Release	Hunting in the wild
Wisteria sinensis	Plant	Vine	Terrestrial	Escape	Horticulture
Xanthium spinosum	Plant	Herb	Terrestrial	Stowaway Contaminant	People and their luggage Contaminant on animals

Appendix 4 (Chapter 1): List of alien species and the vectors facilitating their spread within urban environments extracted from the GISD database.

Species name	Group	Description	Environment	Vectors of spread
Acacia confusa	Plant	Tree, shrub	Terrestrial	Ornamental Forestry
Acacia longifolia	Plant	Tree, shrub	Terrestrial	Ornamental Natural dispersal Water currents Wind dispersal
Acacia mearnsii	Plant	Tree	Terrestrial	Consumption and excretion Ornamental On animals People foraging transportation
Acacia melanoxylon	Plant	Tree	Terrestrial	Consumption and excretion Ornamental On animals Water currents
Acacia saligna	Plant	Tree, shrub	Terrestrial	Consumption or excretion
Acanthogobius flavimanus	vertebrate	fish	Terrestrial	Boats Natural dispersal Water currents Other
Acanthus mollis	Plant	herb	Terrestrial	Garden escape and waste Consumption or excretion Other
Acer ginnala	Plant	Tree	Terrestrial	Ornamental Garden escape and waste Horticulture On animals
Acer platanoides	Plant	Tree	Terrestrial	Natural dispersal On animals
Acridotheres tristis	vertebrate	Bird	Terrestrial	Natural dispersal Escape from confinement
Adelges piceae	Invertebrate	Insect	Terrestrial	Hikers clothing and boots Natural dispersal On animals Road vehicles
Adelges tsguae	Invertebrate	Insect	Terrestrial	Hikers clothing and boots Horticulture On animals

Species name	Group	Description	Environment	Vectors of spread
Aedes albopictus	Invertebrate	Insect	Terrestrial	People sharing resources Road vehicles Natural dispersal Road vehicles Transportation of habitat material
Agapanthus praecox	Plant	Herb	Terrestrial	Vegetative reproduction Water currents Other
Agave americana	Plant	Succulent	Terrestrial	Garden escape and waste Wind dispersal
Ailanthus altissima	Plant	Tree	Terrestrial	Escape from confinement On animals
Akebia quinata	Plant	Vine, climber	Terrestrial	Consumption and excretion Other
Albizia lebbeck	Plant	Tree	Terrestrial	
Alexandrium minutum	Plant	Aquatic plant	Terrestrial	Water currents
Alitta succinea	Invertebrate	Annelid	Marine	
Alliaria petiolata	Plant	Herb	Terrestrial	Water currents
Alnus glutinosa	Plant	Tree	Terrestrial	Consumption and excretion Water currents Other
Alosa pseudoharengus	Vertebrate	Fish	Freshwater	Aquaculture Natural dispersal
Alpinia zerumbet	Plant	Succulent	Terrestrial	Consumption and excretion Water currents
Alternanthera philoxeroides	Plant	Herb	Terrestrial	Horticulture
Ambrosia artemisiifolia	Plant	Herb	Terrestrial	Translocation of machinery and equipment Water currents
Ameiurus nebulosus	Vertebrate	Fish	Terrestrial	Intentional release Natural dispersal Other
Ammophila arenaria	Plant	Vine, climber	Terrestrial	
Ampelopsis brevipendunculata	Plant	Vine, climber	Terrestrial	Consumption and excretion Ornamental Water currents Other
Anas platyrhynchos	Vertebrate	Bird	Freshwater, terrestrial	Natural dispersal
Angiopteris evecta	Plant	Tree	Terrestrial	Ornamental Natural dispersal Wind dispersal
Anoplolepis gracilipes	Invertebrate	Insect	Terrestrial	Agriculture

Species name	Group	Description	Environment	Vectors of spread
				Boats Natural dispersal Road vehicles Translocation of machinery and equipment Other
Anredera cordifolia	Plant	Climber	Terrestrial	Natural dispersal Transportation of habitat material
Antigonon leptopus	Plant	Climber	Terrestrial	Consumption and excretion Garden escape and waste Water currents
Ardisia elliptica	Plant	Shrub	Terrestrial	Consumption and excretion Garden escape and waste
Arundo donax	Plant	Grass	Terrestrial	Garden escape and waste Translocation of machinery and equipment Water currents Wind dispersal
Ascidiella aspersa	Invertebrate	Turnicate	Marine	Water currents
Asparagus densiflorus	Plant	Herb	Terrestrial	Consumption and excretion
Asterias amurensis	Invertebrate	Seastar	Marine	Water currents
Azolla pinnata	Plant	Aquatic plant	Terrestrial	
Bambusa vulgaris	Plant	Grass	Terrestrial	Disturbance Natural dispersal Water currents
Berberis thunbergii	Plant	Shrub	Terrestrial	Consumption and excretion Ornamental Natural dispersal
Bidens pilosa	Plant	Herb	Terrestrial	Ornamental On animals Clothing and footwear Water currents
Branta canadensis	Vertebrate	Bird	Freshwater, terrestrial	Natural dispersal Other
Bromus inermis	Plant	Grass	Terrestrial	Natural dispersal On animals
Bromus rubens	Plant	Grass	Terrestrial	Agriculture Consumption and excretion On animals Water currents
Bromus tectorum	Plant	Grass	Terrestrial	
Buddleja davidii	Plant	Shrub	Terrestrial	Off-road vehicles On animals Road vehicles Translocation of machinery and equipment Water currents
Buddleja madagascariensis	Plant	Shrub	Terrestrial	Garden escape and waste Natural dispersal On animals Translocation of machinery and equipment Water currents Wind dispersal
Bugula neritina	Invertebrate	Bryozoan	Marine	Agriculture
Butomus umbellatus	Plant	Aquatic plant	Terrestrial	Boats Consumption and excretion Ornamental Garden escape and waste Water currents Other
Cambomba caroliniana	Plant	Aquatic plant	Terrestrial	Natural dispersal
Caesalpinia decapetala	Plant	Shrub	Terrestrial	Consumption and excretion Translocation of machinery and equipment Water currents
Canis lupis	Vertebrate	Mammal	Terrestrial	Escape from confinement
Capra hircus	Vertebrate	Mammal	Terrestrial	
Carassius auratus	Vertebrate	Fish	Freshwater	Escape from confinement Ornamental Intentional release
Carcinus maenas	Invertebrate	Arthropod	Marine, terrestrial	Natural dispersal
Cardamine flexuosa	Plant	Herb	Terrestrial	Hikers clothing and boots Natural dispersal Off-road vehicles On animals On clothing and footwear Road vehicles Water currents
Cardiospermum grandiflorum	Plant	Vine, climber	Terrestrial	Water currents
Carduus nutans	Plant	Herb	Terrestrial	On animals
Carpobrotus edulis	Plant	Aquatic plant	Terrestrial	Consumption or excretion
Casuarinas equisetifolia	Plant	Tree	Terrestrial	Consumption or excretion On animals Water currents Wind dispersal
Celastrus orbiculatus	Plant	Vine	Terrestrial	

Species name	Group	Description	Environment	Vectors of spread
Cenchrus ciliaris	Plant	Grass	Terrestrial	Agriculture On animals On clothing and footwear Water currents
Cenchrus clandestinus	Plant	Grass	Terrestrial	Agriculture Consumption and excretion Ornamental Garden escape and waste Natural dispersal Translocation of machinery and equipment
Cenchrus macrourus	Plant	Grass	Terrestrial	Water currents
Cenchrus setaceus	Plant	Grass	Terrestrial	Ornamental Garden escape and waste Off-road vehicles On animals Water currents
Centaurea biebersteinii	Plant	Herb	Terrestrial	Agriculture Consumption and excretion Off-road vehicles On animals Road vehicles Water currents
Centaurea melitensis	Plant	Herb	Terrestrial	Agriculture Consumption and excretion Hikers clothing and boots On animals Road vehicles Translocation of machinery and equipment Transportation of habitat material Water currents
Centaurea solstitialis	Plant	Herb	Terrestrial	Consumption and excretion Hikers clothing and boots On animals Translocation of machinery and equipment
Ceratitis capitata	Invertebrate	Insect	Terrestrial	Agriculture On animals
Ceratophyllum demersum	Plant	Aquatic plant	Terrestrial	Boats Intentional release Natural dispersal Translocation of machinery and equipment

Species name	Group	Description	Environment	Vectors of spread
Cervus elaphus	Vertebrate	Mammal	Terrestrial	Agriculture Forestry Natural dispersal
Chamaeleo jacksonii	Vertebrate	Reptile	Terrestrial	Intentional release
Channa argus	Vertebrate	Fish	Freshwater	Natural dispersal
Channa marulius	Vertebrate	Fish	Freshwater	
Chromolaena ordorata	Plant	Shrub	Terrestrial	Hikers clothing and boots On animals Road vehicles Translocation of machinery and equipment Water currents
Chrysanthemoides monilifera	Plant	Shrub	Terrestrial	Disturbance Natural dispersal Off-road vehicles Water currents
Cirsium arvense	Plant	Herb	Terrestrial	Agriculture Consumption and excretion Natural dispersal On animals Translocation of machinery and equipment Water currents
Clarias batrachus	Vertebrate	Fish	Freshwater	Aquaculture Escape from confinement Water currents Other
Coccinia grandis	Plant	Vine	Terrestrial	Consumption and excretion Garden escape and waste
Columba livia	Vertebrate	Bird	Terrestrial	Escape from confinement Natural dispersal
Corbicula fluminea	Invertebrate	Mollusc	Freshwater	Escape from confinement Water currents
Coronilla varia	Plant	Herb	Terrestrial	Natural dispersal
Cortaderia jubata	Plant	Grass	Terrestrial	On animals Translocation of machinery and equipment Water currents
Cortaderia selloana	Plant	Grass	Terrestrial	Agriculture Ornamental Natural dispersal
Corvus splendens	Vertebrate	Bird	Terrestrial	
Continus coggygria	Plant	Shrub	Terrestrial	
Crassula helmsii	plant	Aquatic plant, succulent	Terrestrial	Consumption and excretion Ornamental

Species name	Group	Description	Environment	Vectors of spread
				Horticulture Water currents
Cryptostegia grandifolra	Plant	Vine	Terrestrial	Escape from confinement Ornamental On animals Translocation of machinery and equipment Water currents
Culex quinquefasciatus	Invertebrate	Insect	Terrestrial	
Cupaniopsis anacardioides	Plant	Tree	Terrestrial	Ornamental Landscape improvement
Cyathea cooperi	Plant	Herb	Terrestrial	
Cygnus olor	Vertebrate	Bird	Freshwater, terrestrial	
Cyperus rotundus	Plant	Herb	Terrestrial	Translocation of machinery and equipment
Cyprinus carpio	Vertebrate	Fish	Freshwater	Boats Escape from confinement Ornamental Natural dispersal People sharing resources Transportation of habitat material Other
Cytisus scoparius	Plant	Shrub	Terrestrial	Consumption and excretion On animals Water currents Other
Dioscorea oppositifolia	Plant	Vine	Terrestrial	Garden escape and waste Natural dispersal On animals Water currents
Dipogon lignosus	Plant	Vine	Terrestrial	Natural dispersal Transportation of habitat material
Dreissena polymorpha	Invertebrate	Mollusc	Marine	Aquaculture Boats Natural dispersal On animals Transportation of habitat material Water currents Other
Eichhornia crassipes	Plant	Aquatic plant	Terrestrial	Boats Hikers clothing and boots On animals Translocation of machinery and equipment Water currents
Elaeagnus umbellata	Plant	Shrub	Terrestrial	Consumption and excretion
Erinaceus europaeus	Vertebrate	Mammal	Terrestrial	Intentional release
Eriocheir sinensis	Invertebrate	Arthropod	Freshwater	
Eugenia uniflora	Plant	Shrub	Terrestrial	Garden escape and waste
Euonymus fortunei	Plant	Vine	Terrestrial	Consumption and excretion Garden escape and waste
Felis catus	Vertebrate	Mammal	Terrestrial	
Ficus rubiginosa	Plant	Tree	Terrestrial	Consumption and excretion Ornamental
Gallus gallus	Vertebrate	Bird	Terrestrial	
Gambusia affinis	Vertebrate	Fish	Freshwater	Other
Gambusia holbrooki	Vertebrate	Fish	Freshwater	Intentional release On animals Other
Geukensia demissa	Invertebrate	mollusc	Marine	
Glyceria maxima	Plant	Grass	Terrestrial	On animals Translocation of machinery and equipment Water currents
Gymnorhina tibicen	Vertebrate	Bird	Terrestrial	Natural dispersal
Harmonia axyridis	Invertebrate	Insect	Terrestrial	Natural dispersal
Hedera helix	Plant	Vine	Terrestrial	Consumption and excretion Ornamental Garden escape and waste
Hedychium flavescens	Plant	Herb	Terrestrial	Ornamental Garden escape and waste Other
Hemidactylus frenatus	Vertebrate	Reptile	Terrestrial	Road vehicles Translocation of machinery and equipment
Heracleum mantegazzianum	Plant	Herb	Freshwater	Consumption and excretion Ornamental Hikers clothing and boots Water currents Other
Herpestes javanicus	Vertebrate	Mammal	Terrestrial	
Hydrilla verticillata	Plant	Aquatic plant	Terrestrial	Boats Consumption and excretion Water currents
Hylastes ater	Invertebrate	Insect	Terrestrial	Natural dispersal Wind dispersal

Species name	Group	Description	Environment	Vectors of spread
Hypericum perforatum	Plant	Herb	Terrestrial	Garden escape and waste On animals Water currents Other
Hypophthalmichthys molitrix	Vertebrate	Fish	Freshwater	Intentional release
Hypophthalmichthys nobilis	Vertebrate	Fish	Freshwater	Live food trade
Iguana iguana	Vertebrate	Reptile	Terrestrial	
Impatiens glandulifera	Plant	Herb	Terrestrial	Natural dispersal On clothing and footwear Translocation of machinery and equipment Transportation of habitat material Water currents
Imperata cylindrica	Plant	Grass	Terrestrial	Natural dispersal On animals Translocation of machinery and equipment Wind dispersal
Iris pseudacorus	Plant	Herb	Terrestrial	Ornamental Natural dispersal Water currents
Lantana camara	Plant	Shrub	Terrestrial	Consumption and excretion
Lasius neglectus	Invertebrate	Insect	Terrestrial	Natural dispersal
Lates niloticus	Vertebrate	Fish	Freshwater	Natural dispersal
Lepidium latifolium	Plant	Herb	Terrestrial	Agriculture
Lepus europaeus	Vertebrate	Mammal	Terrestrial	
Lespedeza cuneata	Plant	Herb	Terrestrial	Agriculture Consumption and excretion Natural dispersal
Leucaena leucocephala	Plant	Tree, shrub	Terrestrial	
Ligustrum lucidum	Plant	Tree	Terrestrial	Agriculture Consumption and excretion Garden escape and waste Other
Ligustrum sinense	Plant	Tree	Terrestrial	Consumption and excretion Escape from confinement Ornamental purposes
Limnoperna fortunei	Invertebrate	Mollusc	Freshwater	Boats On animals Translocation of machinery and equipment Water currents
Linaria vulgaris	Plant	Herb	Terrestrial	Garden escape and waste Intentional release Off-road vehicles On animals Water currents
Linepithema humile	Invertebrate	Insect	Terrestrial	Natural dispersal On animals Road vehicles Transportation of habitat materials Water currents
Lithobates catesbeianus	Vertebrate	Amphibian	Terrestrial	Natural dispersal
Livistona chinensis	Plant	Tree, shrub	Terrestrial	
Lonicera japonica	Plant	Vine	Terrestrial	Consumption and excretion Garden escape and waste Natural dispersal Other
Lotus corniculatus	Plant	Herb	Terrestrial	
Ludwigia peruviana	Plant	Shrub	Terrestrial	Natural dispersal On clothing and footwear Translocation of machinery and equipment Other
Lumbricus rubellus	Invertebrate	Annelid	Terrestrial	Road vehicles Water currents
Lygodium japonicum	Plant	Vine, climber	Terrestrial	Garden escape and waste On animals On clothing and footwear Translocation of machinery and equipment
Lymantria dispar	Invertebrate	Insect	Terrestrial	Hiker clothing and boots Natural dispersal On animals
Lythrum salicaria	Plant	Herb	Terrestrial	
Melaleuca quinquenerva	Plant	Tree	Terrestrial	Ornamental purposes Off-road vehicles On animals Water currents Wind dispersal
Melia azedarach	Plant	Tree	Terrestrial	Consumption and excretion Natural dispersal
Miconia calvescens	Plant	Tree	Terrestrial	Consumption and excretion Garden escape and waste Hikers clothing and boots

Species name	Group	Description	Environment	Vectors of spread
				On animals
				Road vehicles
				Translocation of machinery and equipment
				Water currents
Micropterus salmoides	Vertebrate	Fish	Freshwater	
Mimosa pigra	Plant	Shrub	Terrestrial	Consumption and excretion
				Hikers clothing and boots
				On animals
				Road vehicles
				Transportation of habitat material
				Water currents
Monomorium pharaonis	Invertebrate	Insect	Terrestrial	Natural dispersal
Monopetrus alba	Vertebrate	Fish	Freshwater	Escape from confinement
Morus alba	Plant	Tree, shrub	Terrestrial	Consumption and excretion
Mus musculus	Vertebrate	Mammal	Terrestrial	
Musculista senhousia	Invertebrate	Mollusc	Marine	
Mya arenaria	Invertebrate	Mollusc	Marine	Natural dispersal
Myiopsitta monachus	Vertebrate	Bird	Terrestrial	Escape from confinement
				Intentional release
Myocastor coypus	Vertebrate	Mammal	Freshwater, terrestrial	
Myriophyllum aquaticum	Plant	Aquatic plant	Terrestrial	Ornamental purposes
				Other
Myriophyllum heterophyllum	Plant	Aquatic plant	Terrestrial	Consumption and excretion
				Garden escape and waste
Myriophyllum spicatum	Plant	Aquatic plant	Terrestrial	
Myrmica rubra	Invertebrate	Insect	Terrestrial	Horticulture
Mytilus galloprovincialis	Invertebrate	Mollusc	Marine	Natural dispersal
				On animals
Neovision vison	Vertebrate	Mammal	Terrestrial	Escape from confinement
				Intentional release
				Natural dispersal
Nymphaea odorata	Plant	Aquatic plant	Terrestrial	Intentional release
				Water currents
Oncorhynchus mykiss	vertebrate	Fish	Freshwater	Acclimatisation societies
				Aquaculture
				Natural dispersal
Onopordum acanthium	Plant	Herb	Terrestrial	On animals
Opuntia monacantha	Plant	Tree, shrub	Terrestrial	
Opuntia stricta	Plant	Tree, shrub	Terrestrial	Water currents
				Other

Species name	Group	Description	Environment	Vectors of spread
Orconectes rusticus	Invertebrate	Arthropod	Freshwater	
Oreochromis aureus	Vertebrate	Fish	Freshwater	Escape from confinement
Oreochromis mossambiscus	Vertebrate	Fish	Freshwater	Escape from confinement
Oreochromis niloticus	Vertebrate	Fish	Freshwater	
Oryctolagus cuniculus	Vertebrate	Mammal	Terrestrial	
Oxyura jamaicensis	Vertebrate	Bird	Freshwater	
Pacifastacus leniusculus	Vertebrate	Arthropod	Freshwater	Natural dispersal
Paratrechina longicornis	Invertebrate	Insect	Terrestrial	Natural dispersal
Parthenium hysterophorus	Plant	Herb	Terrestrial	Other
Passer domesticus	Vertebrate	Bird	Terrestrial	
Passiflora tarminiana	Plant	Vine	Terrestrial	Consumption and excretion
Paulownias tormentosa	Plant	Vine	Terrestrial	Ornamental purposes
				Forestry
				Natural dispersal
				On animals
Perna virdis	Invertebrate	Mollusc	Marine	Aquaculture
				Natural dispersal
Phalaris arundinacea	Plant	Grass	Terrestrial	Agriculture
				Other
Pheidole megacephala	Invertebrate	Insect	Terrestrial	People sharing resources
Phragmites australis	Plant	Grass	Terrestrial	On animals
				Translocation of machinery and equipment
				Transportation of habitat material
				Water currents
				Other
Pistia stratiotes	Plant	Aquatic plant	Terrestrial	Boats
				Garden escape and waste
				Water currents
Pittosporum undulatum	Plant	Tree	Terrestrial	Consumption and excretion
				Ornamental purposes
Poecilia reticulata	Vertebrate	Fish	Freshwater	
Polygonum cuspidatum Sieb. & Zucc. (=Fallopia japonica	Plant	Herb	Terrestrial	Escape from confinement
				Natural dispersal
				On animals
				Transportation of habitat material
				Water currents
				Other
Populus alba	Plant	Tree	Terrestrial	On animals

Species name	Group	Description	Environment	Vectors of spread
				Other
Porcellio scaber	Invertebrate	Arthropod	Terrestrial	
Potamocorbula amurensis	Invertebrate	Mollusc	Marine	
Potamopyrgus antipodarum	Invertebrate	Arthropod	Freshwater	Consumption and excretion Hikers clothing and boots On animals On clothing and footwear Water currents
Procambarus clarkii	Invertebrate	Arthropod	Freshwater	Natural dispersal Other
Psidium guajava	Plant	Tree, shrub	Terrestrial	Agriculture Consumption and excretion Garden escape and waste Water currents
Psittacula krameri	Vertebrate	Bird	Terrestrial	
Psoralea pinnata	Plant	Shrub	Terrestrial	Consumption and excretion Garden escape and waste Water currents
Pteris cretica	Plant	Shrub	Terrestrial	Ornamental purposes Nursery trade
Pterygoplichthys anisitsi	Vertebrate	Fish	Freshwater	Intentional release
Pueraria Montana var. lobata	Plant	Vine, climber	Terrestrial	Consumption and excretion Garden escape and waste Road vehicles Translocation of machinery and equipment Water currents
Pycnonotus jocosus	Vertebrate	Bird	Terrestrial	Escape from confinement
Rattus norvegicus	Vertebrate	Mammal	Terrestrial	Natural dispersal
Rattus rattus	Vertebrate	Mammal	Terrestrial	Natural dispersal
Rhamnus alaternus	Plant	Tree	Terrestrial	Consumption and excretion Other
Rhinella marina	Vertebrate	Amphibian	Terrestrial	Natural dispersal Road vehicles Water currents
Rhithropanopeus harrisii	Invertebrate	Arthropod	Brackish	
Rhododendron ponticum	Plant	Shrub	Terrestrial	Ornamental purposes Horticulture Landscape improvement
Ricinus communis	Plant	Tree, shrub	Terrestrial	Consumption and excretion Garden escape and waste Natural dispersal

Species name	Group	Description	Environment	Vectors of spread
				On clothing and footwear Translocation of machinery and equipment Water currents
Robinia pseudoacacia	Plant	Tree	Terrestrial	Natural dispersal
Rosa multifolra	Plant	Shrub	Terrestrial	Agriculture Consumption and excretion Ornamental purposes People sharing resources
Rubus ellipticus	Plant	Shrub	Terrestrial	Consumption and excretion Garden escape and waste Other
Rubus phoenicolasius	Plant	Shrub	Terrestrial	Consumption and excretion
Rumex acetosella	Plant	Herb	Terrestrial	Consumption and excretion On animals Water currents Wind dispersal q
Sabella spallanzanii	Invertebrate	Annelid	Marine	
Sagittaria platyphylla	Plant	Aquatic plant	Terrestrial	Natural dispersal On animals Translocation of machinery and equipment Water currents
Salmo trutta	vertebrate	Fish	Freshwater	Aquaculture
Salvelinus fontinalis	Vertebrate	Fish	Freshwater	Natural dispersal
Salvinia molesta	Plant	Aquatic plant	Terrestrial	Boats Garden escape and waste Off-road vehicles On animals Water currents
Sciurus carolinensis	Vertebrate	Mammal	Terrestrial	
Scenecio inaequidens	Plant	Shrub	Terrestrial	On animals Road vehicles Translocation of machinery and equipment Transportation of habitat material Wind dispersal
Sesbania punicea	Plant	Shrub	Terrestrial	Ornamental purposes Garden escape and waste Water currents
Solanum mauritianum	Plant	Tree, shrub	Terrestrial	Agriculture Consumption and excretion Forestry Garden escape and waste

Species name	Group	Description	Environment	Vectors of spread
Solanum sisymbriifolium	Plant	Herb	Terrestrial	Consumption and excretion
Solenopsis geminata	Invertebrate	Insect	Terrestrial	Agriculture Natural dispersal On animals Water currents Other
Sorghum halepense	Plant	Grass	Terrestrial	Acclimatisation societies Consumption and excretion Natural dispersal On animals Translocation of machinery and equipment Water currents
Spartina alterniflora	Plant	Grass	Terrestrial	Natural dispersal
Spathodea campanulata	Plant	Tree	Terrestrial	On animals Other
Sphagneticola trilobata	Plant	Herb	Terrestrial	Ornamental purposes Garden escape and waste
Sporobolus africanus	Plant	Grass	Terrestrial	Off-road vehicles On animals On clothing and footwear Road vehicles Translocation of machinery and equipment Transportation of habitat material Water currents
Sturnus vulgaris	Vertebrate	Bird	Terrestrial	
Styela clava	Invertebrate	Turnicate	Marine	
Styela plicata	Invertebrate	Turnicate	Marine	Other
Sus scrofa	Vertebrate	Mammal	Terrestrial	Escape from confinement Natural dispersal
Syngonium podophyllum	Plant	Vine	Terrestrial	
Syzygium cumini	Plant	Tree	Terrestrial	Consumption and excretion Ornamental purposes Forestry Horticulture
Tamarix ramosissima	Plant	Tree	Terrestrial	On animals Translocation of machinery and equipment Other
Tapinoma melanocephalum	Invertebrate	Insect	Terrestrial	Natural dispersal

Species name	Group	Description	Environment	Vectors of spread
Trachemys scripta elegans	Vertebrate	Reptile	Freshwater, terrestrial	Intentional release Natural dispersal
Trachycarpus fortunei	Plant	Tree	Terrestrial	Consumption and excretion Ornamental purposes Other
Tradescantia fluminensis	Plant	Vine, creeper	Terrestrial	
Triadica sebifera	Plant	Tree	Terrestrial	Consumption and excretion Ornamental purposes Forestry Water currents
Tridentiger trigonocephalus	Vertebrate	Fish	Marine, freshwater	Boats Natural dispersal
Typha latifolia	Plant	Aquatic plant	Terrestrial	On animals Translocation of machinery and equipment Vegetative reproductive Water currents
Ulex europaeus	Plant	Shrub	Terrestrial	Garden escape and waste Hikers clothing and boots Natural dispersal On animals Translocation of machinery and equipment Transportation of habitat material Water currents Other
Vallisneria spirallis	Plant	Herb	Terrestrial	Aquaculture
Verbena brasiliensis	Plant	Herb	Terrestrial	
Vespula germanica	Invertebrate	Insect	Terrestrial	
Vespula vulgaris	Invertebrate	Insect	Terrestrial	Natural dispersal
Vulpes vulpes	Vertebrate	Mammal	Terrestrial	Natural dispersal
Wisteria sinensis	Plant	Vine	Terrestrial	Agriculture Ornamental purposes Garden escape and waste Water currents
Xanthium spinosum	Plant	Herb	Terrestrial	On animals On clothing and footwear Water currents

Appendix 5 (Chapter 2): List of global cities and their climates, including cities with a climate match to eThekwini municipality (Durban).

	Country	City	Population Estimate	Year	Land Area (km²)	Density	Köppen Classification	Climate match (eThekwini)
1.	Argentina	Buenos Aires	14 122 000	2015	2 681	5 300	C	Yes
2.	Argentina	Córdoba	1 585 000	2015	363	4 400	C	No
3.	Argentina	Rosario	1 338 000	2015	233	5 700	C	Yes
4.	Australia	Adelaide	1 140 000	2015	852	1 300	C	No
5.	Australia	Brisbane	1 999 000	2015	1 972	1 000	C	Yes
6.	Australia	Melbourne	3 906 000	2015	2 543	1 500	C	No
7.	Australia	Perth	1 751 000	2015	1 566	1 100	C	No
8.	Australia	Sydney	4 063 000	2015	2 037	2 000	C	Yes
9.	Austria	Vienna	1 763 000	2015	453	3 900	C	No
10.	Belgium	Antwerpen	1 008 000	2015	635	1 600	C	No
11.	Belgium	Bruxelles-Brussel	2 089 000	2015	803	2 600	C	No
12.	Brazil	Belém	1 979 000	2015	259	7 600	A	No
13.	Brazil	Belo Horizonte	4 517 000	2015	1 088	4 200	A	No
14.	Brazil	Brasilia	2 536 000	2015	673	3 800	A	No
15.	Brazil	Campinas	2 645 000	2015	932	2 800	C	Yes
16.	Brazil	Curitiba	3 102 000	2015	842	3 700	C	No
17.	Brazil	João Pessoa	1 052 000	2015	194	5 400	A	No
18.	Brazil	Manaus	1 893 000	2015	324	5 800	A	No
19.	Brazil	Natal	1 064 000	2015	246	4 300	A	No
20.	Brazil	Pôrto Alegre	3 413 000	2015	803	4 300	C	Yes
21.	Brazil	Recife	3 347 000	2015	414	8 100	A	No
22.	Brazil	Rio de Janeiro	11 727 000	2015	2 020	5 800	A	No
23.	Brazil	Salvador	3 190 000	2015	350	9 100	A	No
24.	Brazil	Santos	1 653 000	2015	298	5 500		Yes
25.	Brazil	Sao Luis	1 717 000	2015	427	2 700		No
26.	Brazil	São Paulo	20 365 000	2015	2 707	7 500	C	Yes
27.	Brazil	Vittoria	1 172 000	2015	337	3 500		No
28.	Canada	Calgary	1 189 000	2015	704	1 700	D	No
29.	Canada	Edmonton	1 040 000	2015	855	1 200	D	No
30.	Canada	Montréal	3 536 000	2015	1 546	2 300	D	No
31.	Canada	Toronto	6 456 000	2015	2 287	2 800	D	No
32.	Canada	Vancouver	2 273 000	2015	1 150	2 000	C	No
33.	Chile	Santiago	6 225 000	2015	984	6 300	C	No
34.	Colombia	Bogotá	8 991 000	2015	492	18 300	C	No
35.	Colombia	Bucaramanga	1 029 000	2015	60	17 300	A	No
36.	Colombia	Medellín	3 568 000	2015	228	15 700	A	No
37.	Democratic Republic of Congo	Lumbumbashi	2 000 000	2015	155	12 900	C	No
38.	Costa Rica	San José	1 170 000	2015	337	3 500	A	No
39.	Denmark	Copenhagen	1 248 000	2015	453	2 800	C	No
40.	Ecuador	Guayaquil	2 700 000	2015	220	12 300	A	No

41.	Ecuador	Quito	1 720 000	2015	479	3 600	C	No
42.	Finland	Helsinki	1 208 000	2015	641	1 900	D	No
43.	France	Lille	1 018 000	2015	280	3 600	C	No
44.	France	Lyon	1 583 000	2015	1 178	1 300	C	No
45.	France	Marseille	1 397 000	2015	453	3 100	C	No
46.	France	Paris	10 858 000	2015	2 845	3 800	C	No
47.	Germany	Berlin	4 096 000	2015	1 347	3 000	C	No
48.	Germany	Cologne-Bonn	2 104 000	2015	932	2 300	C	No
49.	Germany	Essen-Dusseldorf	6 679 000	2015	2 655	2 500	C	No
50.	Germany	Frankfurt	1 915 000	2015	648	3 000	C	No
51.	Germany	Hamburg	2 087 000	2015	777	2 700	C	No
52.	Germany	Munich	1 981 000	2015	466	4 200	C	No
53.	Germany	Stuttgart	1 379 000	2015	479	2 900	C	No
54.	India	Bangalore	9 807 000	2015	1 166	8 400	A	No
55.	India	Bhopal	2 075 000	2015	181	11 400	A	No
56.	India	Coimbatore	2 481 000	2015	285	8 700	A	No
57.	India	Delhi	24 998 000	2015	2 072	12 100	B	No
58.	India	Kanpur	3 037 000	2015	207	14 700	C	No
59.	India	Kochi	2 374 000	2015	440	5 400	A	No
60.	India	Kolkata	14 667 000	2015	1 240	12 200	A	No
61.	India	Meerut	1 541 000	2015	104	14 900	C	No
62.	India	Mumbai	17 712 000	2015	546	32 400	A	No
63.	India	Mysore	1 078 000	2015	91	11 900	A	No
64.	India	Patna	2 200 000	2015	142	15 400	C	No
65.	India	Pune	5 631 000	2015	479	11 800	A	No
66.	India	Ranchi	1 246 000	2015	57	21 900	C	No
67.	India	Srinagar	1 409 000	2015	127	11 100	C	No
68.	India	Tiruchirappali	1 101 000	2015	85	12 900	A	No
69.	India	Varanasi	1 536 000	2015	101	15 200	C	No
70.	Indonesia	Bandung	5 695 000	2015	466	12 200	A	No
71.	Indonesia	Jakarta	30 539 000	2015	3 225	9 500	A	No
72.	Ireland	Dublin	1 160 000	2015	453	2 600	C	No
73.	Israel	Hefa	1 090 000	2015	228	4 800	C	No
74.	Israel	Tel Aviv-Yafo	2 979 000	2015	479	6 200	C	No
75.	Japan	Hiroshima	1 377 000	2015	285	4 800	C	Yes
76.	Japan	Nagoya	10 177 000	2015	3 885	2 600		Yes
77.	Japan	Osaka-Kobe-Kyoto	17 444 000	2015	3 212	5 400		Yes
78.	Japan	Sapporo	2 570 000	2015	622	4 100	D	No
79.	Japan	Tokyo	37 843 000	2015	8 547	4 400	C	Yes
80.	Kenya	Mombasa	1 116 000	2015	85	13 100	A	No
81.	Kenya	Nairobi	4 738 000	2015	557	8 500	C	No
82.	Mexico	Aguascalientes	1 020 000	2015	106	9 600	B	No
83.	Mexico	Ciudad de Mexico	20 063 000	2015	2 072	9 700	C	No
84.	Mexico	Ciudad Juárez	1 391 000	2015	324	4 300	B	No
85.	Mexico	Guadalajara	4 603 000	2015	751	6 100	C	No
86.	Mexico	León de le Aldamas	1 469 000	2015	233	6 300	B	No

87.	Mexico	Mérida	1 111 000	2015	207	5 400	A	No
88.	Mexico	Mexicali	1 018 000	2015	202	5 000	B	No
89.	Mexico	Monterrey	4 083 000	2015	894	4 600	B	No
90.	Mexico	Puebla	2 088 000	2015	440	4 700	C	No
91.	Mexico	Querétaro	1 249 000	2015	150	8 300	B	No
92.	Mexico	San Luis Postosí	1 137 000	2015	132	8 600	B	No
93.	Mexico	Tijuana	1 986 000	2015	466	4 200	B	No
94.	Mexico	Toluca de Lerdo	1 878 000	2015	272	6 900	C	No
95.	Mexico	Torreón	1 327 000	2015	168	7 900	B	No
96.	Netherlands	Amsterdam	1 624 000	2015	505	3 200	C	No
97.	Netherlands	Rotterdam	2 660 000	2015	984	2 700	C	No
98.	New Zealand	Auckland	1 356 000	2015	544	2 500	C	No
99.	Nigeria	Benin City	1 490 000	2015	228	6 500	A	No
100.	Nigeria	Ibadan	3 160 000	2015	466	6 800	A	No
101.	Nigeria	Lagos	13 123 000	2015	907	14 500	A	No
102.	Pakistan	Lahore	10 052 000	2015	790	12 700	B	No
103.	Pakistan	Rawalpindi	2 510 000	2015	427	5 900	C	No
104.	Peru	Lima	10 750 000	2015	919	11 700	B	No
105.	Poland	Warsaw	1 720 000	2015	544	3 200	C	No
106.	Portugal	Lisbon	2 666 000	2015	958	2 800	C	No
107.	Portugal	Porto	1 474 000	2015	777	1 900	C	No
108.	South Africa	Cape Town	3 812 000	2015	816	4 700	C	No
109.	South Africa	Durban	3 421 000	2015	1 062	3 200	C	Yes
110.	South Africa	Johannesburg	8 432 000	2015	2 590	3 300	C	No
111.	South Africa	Port Elizabeth	1 212 000	2015	389	3 100	C	Yes
112.	South Africa	Pretoria	2 927 000	2015	1 230	2 400	C	No
113.	Spain	Barcelona	4 693 000	2015	1 075	4 400	C	No
114.	Spain	Madrid	6 171 000	2015	1 321	4 700	B	No
115.	Spain	Sevilla	1 107 000	2015	272	4 100	C	No
116.	Spain	Valencia	1 561 000	2015	272	5 700	B	No
117.	Sweden	Stockholm	1 484 000	2015	382	3 900	C	No
118.	Tanzania	Dar es Salaam	4 219 000	2015	570	7 400	A	No
119.	Uganda	Kampala	1 930 000	2015	492	3 900	A	No
120.	United Kingdom	Birmingham	2 512 000	2015	599	4 200	C	No
121.	United Kingdom	Glasgow	1 220 000	2015	368	3 300	C	No
122.	United Kingdom	Leeds-Bradford	1 893 000	2015	488	3 900	C	No
123.	United Kingdom	London	10 236 000	2015	1 738	5 900	C	No
124.	United Kingdom	Manchester	2 639 000	2015	630	4 200	C	No
125.	United States	Atlanta	5 015 000	2015	6 851	700	C	Yes
126.	United States	Austin	1 616 000	2015	1 355	1 200	C	Yes
127.	United States	Baltimore	2 263 000	2015	1 857	1 200	C	Yes
128.	United States	Boston	4 478 000	2015	5 325	800	C	No
129.	United States	Charlotte	1 535 000	2015	1 919	800	C	Yes
130.	United States	Chicago	9 156 000	2015	6 856	1 300	C	No
131.	United States	Cincinnati	1 682 000	2015	2 041	800	C	Yes
132.	United States	Cleveland	1 783 000	2015	1 999	900	C	No

133.	United States	Columbus, Ohio	1 481 000	2015	1 321	1 100	C	Yes
134.	United States	Dallas-Fort Worth	6 174 000	2015	5 175	1 200	C	Yes
135.	United States	Denver-Aurora	2 559 000	2015	1 730	1 500	B	No
136.	United States	Detroit	3 672 000	2015	3 463	1 100	C	No
137.	United States	Houston	5 764 000	2015	4 644	1 200	C	Yes
138.	United States	Indianapolis	1 617 000	2015	1 829	900	C	Yes
139.	United States	Jacksonville, Florida	1 154 000	2015	1 373	800	C	Yes
140.	United States	Kansas City	1 593 000	2015	1 756	900	C	Yes
141.	United States	Las Vegas	2 191 000	2015	1 080	2 000	B	No
142.	United States	Los Angeles-Long Beach-Santa Ana	15 058 000	2015	6 299	2 400	B	No
143.	United States	Louisville	1 025 000	2015	1 235	800	C	Yes
144.	United States	Memphis	1 102 000	2015	1 287	900	C	Yes
145.	United States	Miami	5 764 000	2015	3 209	1 800	A	No
146.	United States	Milwaukee	1 408 000	2015	1 414	1 000	D	No
147.	United States	Minneapolis-St. Paul	2 771 000	2015	2 647	1 000	D	No
148.	United States	Nashville-Davidson	1 081 000	2015	1 458	700	C	Yes
149.	United States	New York-Newark	20 630 000	2015	11 642	1 800	C	Yes
150.	United States	Orlando	2 040 000	2015	1 958	1 000	C	No
151.	United States	Philadelphia	5 570 000	2015	5 131	1 100	C	Yes
152.	United States	Phoenix-Mesa	4 194 000	2015	3 196	1 300	B	No
153.	United States	Pittsburg	1 730 000	2015	2 344	700	C	Yes
154.	United States	Portland	1 976 000	2015	1 357	1 500	C	No
155.	United States	Providence	1 201 000	2015	1 412	900	C	No
156.	United States	Raleigh	1 085 000	2015	1 342	800	C	Yes
157.	United States	Richmond	1 018 000	2015	1 274	800	C	Yes
158.	United States	Sacramento	1 885 000	2015	1 220	1 500	C	No
159.	United States	Salt Lake City	1 085 000	2015	720	1 500	C	No
160.	United States	San Antonio	1 976 000	2015	1 546	1 300	C	Yes
161.	United States	San Diego	3 086 000	2015	1 896	1 600	B	No
162.	United States	San Francisco-Oakland	5 929 000	2015	2 797	2 100	C	No
163.	United States	Seattle	3 218 000	2015	2 616	1 200	C	No
164.	United States	St. Louis	2 186 000	2015	2 393	900	C	Yes
165.	United States	Tampa-St. Petersburg	2 621 000	2015	2 479	1 100	C	Yes
166.	United States	Virginia Beach	1 463 000	2015	1 334	1 100	C	Yes
167.	United States	Washington D.C.	4 889 000	2015	3 424	1 400	C	Yes

Appendix 6 (Chapter 2): List of alien species and the selection criteria used to select species for prioritisation

	Species name	Organism type	Description	Environment	NEMBA	Climate match	Pathways	Operational pathway in eThekwini
1.	*Abelmoschus moschatus*	Plant	herb, shrub	Terrestrial	No	No	Not assessed	Not assessed
2.	*Acacia concinna*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
3.	*Acacia confusa*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
4.	*Acacia mangium*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
5.	*Acanthocereus tetragonus*	Plant	succulent	Terrestrial	No	No	Not assessed	Not assessed
6.	*Acanthogobius flavimanus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
7.	*Acer ginnala*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
8.	*Acer platanoides*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
9.	*Acridotheres fuscus*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
10.	*Acromyrmex octospinosus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
11.	*Adelges piceae*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
12.	*Adenanthera pavonina*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
13.	*Aedes aegypti*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
14.	*Aegilops triuncialis*	Plant	grass	Terrestrial	Yes	No	Not assessed	Not assessed
15.	*Agrostis capillaris*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
16.	*Akebia quinata*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
17.	*Alitta succinea*	Animal	annelid	Marine	No	No	Not assessed	Not assessed
18.	*Alliaria petiolata*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
19.	*Alosa pseudoharengus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
20.	*Alternanthera philoxeroides*	Plant	aquatic plant, herb	Terrestrial	Yes	Yes	Ship or boat ballast water Transportation of habitat material	Yes
21.	*Ameiurus nebulosus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
22.	*Ampelopsis brevipedunculata*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
23.	*Andropogon virginicus*	Plant	sedge	Terrestrial	Yes	No	Not assessed	Not assessed
24.	*Angiopteris evecta*	Plant	fern	Terrestrial	No	No	Not assessed	Not assessed
25.	*Annona glabra*	Plant	tree	Terrestrial	Yes	No	Not assessed	Not assessed
26.	*Annona squamosa*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
27.	*Anolis aeneus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
28.	*Anolis carolinensis*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
29.	*Anolis cristatellus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
30.	*Anolis distichus*	Animal	reptile	Terrestrial	Yes	No	Not assessed	Not assessed
31.	*Anolis equestris*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
32.	*Anolis garmani*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
33.	*Anolis lineatus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
34.	*Anolis porcatus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
35.	*Anolis richardii*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
36.	*Anolis trinitatis*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
37.	*Anopheles quadrimaculatus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
38.	*Anoplophora glabripennis*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
39.	*Artemia franciscana*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
40.	*Asparagus officinalis*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
41.	*Asterias amurensis*	Animal	sea star	Marine	No	No	Not assessed	Not assessed
42.	*Austroeupatorium inulifolium*	Plant	herb, shrub	Terrestrial	No	No	Not assessed	Not assessed
43.	*Bactrocera tryoni*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
44.	*Bambusa vulgaris*	Plant	grass, tree	Terrestrial	No	No	Not assessed	Not assessed
45.	*Batillaria attramentaria*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
46.	*Bellis perennis*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
47.	*Berberis buxifolia*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
48.	*Berberis darwinii*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
49.	*Boa constrictor imperator*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
50.	*Boehmeria penduliflora*	Plant	herb, shrub	Terrestrial	No	No	Not assessed	Not assessed
51.	*Boiga irregularis*	Animal	reptile	Terrestrial	Yes	No	Not assessed	Not assessed
52.	*Boonea bisuturalis*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
53.	*Bos taurus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
54.	*Bothriochloa pertusa*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
55.	*Branta canadensis*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
56.	*Bubo virginianus*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
57.	*Butomus umbellatus*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
58.	*Bythotrephes longimanus*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
59.	*Caiman crocodilus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
60.	*Callithrix jacchus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
61.	*Calluna vulgaris*	Plant	herb	Terrestrial	Yes	No	Not assessed	Not assessed
62.	*Camelina sativa*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
63.	*Canis latrans*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
64.	*Canis lupus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
65.	*Cardamine glacialis*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
66.	*Carijoa riisei*	Animal	coral	Marine	No	No	Not assessed	Not assessed
67.	*Carpodacus mexicanus*	Animal	bird	Terrestrial	Yes	No	Not assessed	Not assessed
68.	*Castilla elastica*	Plant	tree	Terrestrial	No	No	Not assessed	Not

								assessed
69.	*Castor canadensis*	Animal	mammal	Terrestrial	Yes	No	Not assessed	Not assessed
70.	*Caulerpa taxifolia*	Plant	alga	Marine	Yes	No	Not assessed	Not assessed
71.	*Cavia porcellus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
72.	*Cecropia peltata*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
73.	*Cecropia schreberiana*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
74.	*Celastrus orbiculatus*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
75.	*Cenchrus echinatus*	Plant	grass	Terrestrial	Yes	Yes	Translocation of machinery/equipment	Uncertain
76.	*Cenchrus polystachios*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
77.	*Centaurea biebersteinii*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
78.	*Centaurea diffusa*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
79.	*Ceratostoma inornatum*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
80.	*Cercopithecus mona*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
81.	*Cestrum nocturnum*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
82.	*Chamaeleo jacksonii*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
83.	*Channa argus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
84.	*Channa marulius*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
85.	*Charybdis japonica*	Animal	crustacean	Marine	No	No	Not assessed	Not assessed
86.	*Chrysobalanus icaco*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
87.	*Chthamalus proteus*	Animal	crustacean	Marine	No	No	Not assessed	Not assessed
88.	*Cichla ocellaris*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
89.	*Cichlasoma urophthalmus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
90.	*Cinara cupressi*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
91.	*Cinchona pubescens*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
92.	*Cinnamomum verum*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
93.	*Circus approximans*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
94.	*Citharexylum spinosum*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
95.	*Clarias batrachus*	Animal	fish	Terrestrial	Yes	No	Not assessed	Not assessed
96.	*Clematis terniflora*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
97.	*Clematis vitalba*	Plant	vine, climber	Terrestrial	Yes	No	Not assessed	Not assessed
98.	*Clidemia hirta*	Plant	shrub	Terrestrial	Yes	No	Not assessed	Not assessed
99.	*Coccinia grandis*	Plant	vine, climber	Terrestrial	Yes	No	Not assessed	Not assessed
100.	*Colubrina asiatica*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
101.	*Compsilura concinnata*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
102.	*Corbicula fluminea*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
103.	*Coronilla varia*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
104.	*Crassula helmsii*	Plant	Aquatic plant,	Terrestrial	Yes	No	Not assessed	Not assessed
			succulent					
105.	*Crepidula fornicata*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
106.	*Crocidura suaveolens*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
107.	*Cryphonectria parasitica*	Other	fungus	Terrestrial	No	No	Not assessed	Not assessed
108.	*Cryptococcus fagisuga*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
109.	*Cryptostegia madagascariensis*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
110.	*Ctenosaura similis*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
111.	*Culex quinquefasciatus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
112.	*Cupaniopsis anacardioides*	Plant	tree	Terrestrial	Yes	No	Not assessed	Not assessed
113.	*Cynanchum rossicum*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
114.	*Cynara cardunculus*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
115.	*Cynoglossum officinale*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
116.	*Cyprinella lutrensis*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
117.	*Cytisus striatus*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
118.	*Dendroctonus valens*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
119.	*Didymosphenia geminata*	Plant	alga	Terrestrial	No	No	Not assessed	Not assessed
120.	*Dioscorea bulbifera*	Plant	herb, vine, climber	Terrestrial	No	No	Not assessed	Not assessed
121.	*Dioscorea oppositifolia*	Plant	herb, vine, climber	Terrestrial	No	No	Not assessed	Not assessed
122.	*Dreissena bugensis*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
123.	*Dreissena polymorpha*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
124.	*Dysdera crocata*	Animal	insect, arachnid	Terrestrial	No	No	Not assessed	Not assessed
125.	*Elaeagnus angustifolia*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
126.	*Elaeagnus pungens*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
127.	*Elaeagnus umbellata*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
128.	*Elaeis guineensis*	Plant	palm	Terrestrial	No	No	Not assessed	Not assessed
129.	*Elephantopus mollis*	Plant	herb	Terrestrial	Yes	No	Not assessed	Not assessed
130.	*Elettaria cardamomum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
131.	*Eleutherodactylus coqui*	Animal	amphibian	Terrestrial	Yes	No	Not assessed	Not assessed
132.	*Eleutherodactylus johnstonei*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
133.	*Eleutherodactylus planirostris*	Animal	amphibian	Terrestrial	Yes	No	Not assessed	Not assessed
134.	*Epipremnum pinnatum*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
135.	*Equus caballus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
136.	*Erinaceus europaeus*	Animal	mammal	Terrestrial	Yes	No	Not assessed	Not assessed
137.	*Eriocheir sinensis*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
138.	*Erythrocebus patas*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
139.	*Esox lucius*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
140.	*Euglandina rosea*	Animal	mollusc	Terrestrial	Yes	No	Not assessed	Not assessed

141.	*Euonymus alata*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
142.	*Euonymus fortunei*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
143.	*Eupatorium cannabinum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
144.	*Falcataria moluccana*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
145.	*Ficus rubiginosa*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
146.	*Flemingia strobilifera*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
147.	*Frangula alnus*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
148.	*Fraxinus floribunda*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
149.	*Fuchsia boliviana*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
150.	*Fuchsia magellanica*	Plant	vine, climber, shrub	Terrestrial	No	No	Not assessed	Not assessed
151.	*Gallus varius*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
152.	*Gambusia holbrooki*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
153.	*Gastrophryne carolinensis*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
154.	*Gemma gemma*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
155.	*Geukensia demissa*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
156.	*Glyptoperichthys gibbiceps*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
157.	*Gunnera manicata*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
158.	*Gunnera tinctoria*	Plant	herb	Terrestrial	No		Not assessed	Not assessed
159.	*Gymnocephalus cernuus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
160.	*Gymnocoronis spilanthoides*	Plant	aquatic plant	Terrestrial	Yes	No	Not assessed	Not assessed
161.	*Gymnodinium catenatum*	Plant	alga	Marine	No	No	Not assessed	Not assessed
162.	*Gymnorhina tibicen*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
163.	*Haematoxylum campechianum*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
164.	*Halophila stipulacea*	Plant	aquatic plant	Marine	No	No	Not assessed	Not assessed
165.	*Heliotropium angiospermum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
166.	*Hemigrapsus sanguineus*	Animal	crustacean	Marine	No	No	Not assessed	Not assessed
167.	*Heracleum mantegazzianum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
168.	*Hieracium aurantiacum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
169.	*Hieracium floribundum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
170.	*Hieracium pilosella*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
171.	*Hiptage benghalensis*	Plant	vine, climber, shrub	Terrestrial	No	No	Not assessed	Not assessed
172.	*Hydrocharis morsus-ranae*	Plant	aquatic plant	Terrestrial	Yes	No	Not assessed	Not assessed
173.	*Hygrophila polysperma*	Plant	aquatic plant	Terrestrial	Yes	No	Not assessed	Not assessed
174.	*Hyphantria cunea*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
175.	*Hypophthalmichthys nobilis*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
176.	*Iguana iguana*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
177.	*Ilyanassa obsoleta*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
178.	*Impatiens glandulifera*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
179.	*Ips typographus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
180.	*Ischaemum polystachyum*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
181.	*Kalanchoe pinnata*	Plant	succulent	Terrestrial	No	No	Not assessed	Not assessed
182.	*Lachnellula willkommii*	Other	fungus	Terrestrial	No	No	Not assessed	Not assessed
183.	*Lama guanicoe*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
184.	*Lates niloticus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
185.	*Leiothrix lutea*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
186.	*Lepidium latifolium*	Plant	herb	Terrestrial	Yes	No	Not assessed	Not assessed
187.	*Lepus americanus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
188.	*Lepus europaeus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
189.	*Leuciscus idus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
190.	*Ligustrum robustum*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
191.	*Limnocharis flava*	Plant	aquatic plant	Terrestrial	Yes	No	Not assessed	Not assessed
192.	*Limnoperna fortunei*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
193.	*Limnophila sessiliflora*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
194.	*Linyphia triangularis*	Animal	arachnid	Terrestrial	No	No	Not assessed	Not assessed
195.	*Lithobates catesbeianus*	Animal	amphibian	Terrestrial	Yes	Yes	Biological control Landscape flora/fauna improvement Release in use for nature Aquaculture/mariculture Ornamental purposes	Yes
196.	*Litoria aurea*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
197.	*Littorina littorea*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
198.	*Lonicera maackii*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
199.	*Lumbricus rubellus*	Animal	annelid	Terrestrial	No	No	Not assessed	Not assessed
200.	*Lumbricus terrestris*	Animal	annelid	Terrestrial	No	No	Not assessed	Not assessed
201.	*Lupinus polyphyllus*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
202.	*Luzula campestris*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
203.	*Lycalopex griseus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
204.	*Lymantria dispar*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
205.	*Lymantria monacha*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
206.	*Macaca fascicularis*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
207.	*Macaca mulatta*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
208.	*Maconellicoccus hirsutus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
209.	*Martes melampus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
210.	*Melastoma candidum*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed

211.	*Merremia peltata*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
212.	*Merremia tuberosa*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
213.	*Miconia calvescens*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
214.	*Microstegium vimineum*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
215.	*Mikania micrantha*	Plant	vine, climber	Terrestrial	Yes	No	Not assessed	Not assessed
216.	*Mimosa diplotricha*	Plant	vine, climber, shrub	Terrestrial	Yes	No	Not assessed	Not assessed
217.	*Miscanthus sinensis*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
218.	*Misgurnus anguillicaudatus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
219.	*Molothrus ater*	Animal	bird	Terrestrial	Yes	No	Not assessed	Not assessed
220.	*Molothrus bonariensis*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
221.	*Monomorium floricola*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
222.	*Monomorium pharaonis*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
223.	*Monopterus albus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
224.	*Montia fontana*	Plant	aquatic, plant	Terrestrial	No	No	Not assessed	Not assessed
225.	*Morella faya*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
226.	*Morone americana*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
227.	*Musculista senhousia*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
228.	*Mustela erminea*	Animal	mammal	Terrestrial	Yes	No	Not assessed	Not assessed
229.	*Mustela furo*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
230.	*Mustela nivalis*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
231.	*Mya arenaria*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
232.	*Myiopsitta monachus*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
233.	*Myriophyllum heterophyllum*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
234.	*Myrmica rubra*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
235.	*Mytilopsis leucophaeata*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
236.	*Mytilopsis sallei*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
237.	*Najas minor*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
238.	*Nasua nasua*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
239.	*Natrix maura*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
240.	*Neogobius melanostomus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
241.	*Neovison vison*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
242.	*Neyraudia reynaudiana*	Plant	grass	Terrestrial	Yes	No	Not assessed	Not assessed
243.	*Norops grahami*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
244.	*Norops sagrei*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
245.	*Nymphaea odorata*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
246.	*Nypa fruticans*	Plant	palm	Terrestrial	No	No	Not assessed	Not assessed
247.	*Ocimum gratissimum*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
248.	*Octolasion tyrtaeum*	Animal	annelid	Terrestrial	No	No	Not assessed	Not assessed
249.	*Odocoileus virginianus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
250.	*Onopordum acanthium*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
251.	*Ophiostoma ulmi*	Other	fungus	Terrestrial	No	No	Not assessed	Not assessed
252.	*Opuntia cochenillifera*	Plant	tree, shrub, succulent	Terrestrial	No	No	Not assessed	Not assessed
253.	*Orconectes rusticus*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
254.	*Orconectes virilis*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
255.	*Oryctes rhinoceros*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
256.	*Osteopilus septentrionalis*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
257.	*Ovis ammon*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
258.	*Ovis aries*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
259.	*Oxyura jamaicensis*	Animal	bird	Terrestrial	Yes	No	Not assessed	Not assessed
260.	*Pachycondyla chinensis*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
261.	*Pacifastacus leniusculus*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
262.	*Paederia foetida*	Plant	vine, climber	Terrestrial	Yes	No	Not assessed	Not assessed
263.	*Passiflora maliformis*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
264.	*Peromyscus fraterculus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
265.	*Peromyscus maniculatus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
266.	*Persicaria perfoliata*	Plant	vine	Terrestrial	No	No	Not assessed	Not assessed
267.	*Petrogale inornata*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
268.	*Petromyzon marinus*	Animal	fish	Terrestrial	Yes	No	Not assessed	Not assessed
269.	*Phalanger orientalis*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
270.	*Phalloceros caudimaculatus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
271.	*Phoxinus phoxinus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
272.	*Phragmites australis*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
273.	*Phyllorhiza punctata*	Animal	jellyfish	Marine	No	No	Not assessed	Not assessed
274.	*Phyllostachys flexuosa*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
275.	*Pimenta dioica*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
276.	*Pinus caribaea*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
277.	*Pinus nigra*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
278.	*Piper aduncum*	Plant	tree, shrub	Terrestrial	Yes	No	Not assessed	Not assessed
279.	*Pitangus sulphuratus*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
280.	*Pittosporum tenuifolium*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
281.	*Pluchea carolinensis*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
282.	*Pluchea indica*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
283.	*Podarcis sicula*	Animal	reptile	Terrestrial	No	No	Not assessed	Not

								assessed
284.	*Polistes chinensis antennalis*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
285.	*Polygala paniculata*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
286.	*Polygonum cuspidatum*	Plant	herb	Terrestrial	Yes	No	Not assessed	Not assessed
287.	*Pomacea canaliculata*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
288.	*Pomacea insularum*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
289.	*Potamocorbula amurensis*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
290.	*Potamogeton crispus*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
291.	*Potamogeton perfoliatus*	Plant	aquatic plant	Terrestrial	Yes	No	Not assessed	Not assessed
292.	*Potamopyrgus antipodarum*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
293.	*Procyon lotor*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
294.	*Prosopis juliflora*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
295.	*Prunus campanulata*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
296.	*Pseudodiaptomus inopinus*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
297.	*Pterois volitans*	Animal	fish	Marine	Yes	No	Not assessed	Not assessed
298.	*Pterygoplichthys anisitsi*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
299.	*Pterygoplichthys multiradiatus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
300.	*Pterygoplichthys pardalis*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
301.	*Puccinia psidii*	Other	fungus	Terrestrial	No	No	Not assessed	Not assessed
302.	*Pycnonotus cafer*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
303.	*Pylodictis olivaris*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
304.	*Pyrus calleryana*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
305.	*Python molurus bivittatus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
306.	*Rangia cuneata*	Animal	mollusc	Terrestrial	No	No	Not assessed	Not assessed
307.	*Rangifer tarandus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
308.	*Ranunculus ficaria*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
309.	*Raoiella indica*	Animal	arachnid	Terrestrial	No	No	Not assessed	Not assessed
310.	*Rapana venosa*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
311.	*Rattus exulans*	Animal	mammal	Terrestrial	Yes	No	Not assessed	Not assessed
312.	*Rauvolfia vomitoria*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
313.	*Rhamnus alaternus*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
314.	*Rhamnus cathartica*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
315.	*Rhinella marina*	Animal	amphibian	Terrestrial	Yes	No	Not assessed	Not assessed
316.	*Rhithropanopeus harrisii*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
317.	*Rhizophora mangle*	Plant	aquatic plant, tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
318.	*Rhododendron ponticum*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
319.	*Rhodomyrtus tomentosa*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
320.	*Rhus longipes*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
321.	*Rosa bracteata*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
322.	*Rubus alceifolius*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
323.	*Rubus ellipticus*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
324.	*Rubus moluccanus*	Plant	vine, climber, shrub	Terrestrial	Yes	No	Not assessed	Not assessed
325.	*Ruellia brevifolia*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
326.	*Rupicapra rupicapra*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
327.	*Rutilus rutilus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
328.	*Sabella spallanzanii*	Animal	annelid	Marine	No	No	Not assessed	Not assessed
329.	*Sagittaria sagittifolia*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
330.	*Salix cinerea*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
331.	*Salix humboldtiana*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
332.	*Salvelinus namaycush*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
333.	*Salvinia minima*	Plant	aquatic plant, fern	Terrestrial	No	No	Not assessed	Not assessed
334.	*Samanea saman*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
335.	*Sansevieria trifasciata*	Plant	succulent	Terrestrial	No	No	Not assessed	Not assessed
336.	*Sargassum fluitans*	Plant	algae	Marine	No	No	Not assessed	Not assessed
337.	*Sargassum muticum*	Plant	aquatic plant	Marine	Yes	No	Not assessed	Not assessed
338.	*Scardinius erythrophthalmus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
339.	*Schismus arabicus*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
340.	*Schizoporella errata*	Animal	bryozoan	Marine	No	No	Not assessed	Not assessed
341.	*Schizoporella unicornis*	Animal	bryozoan	Marine	No	No	Not assessed	Not assessed
342.	*Scinax ruber*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
343.	*Scinax x-signatus*	Animal	amphibian	Terrestrial	No	No	Not assessed	Not assessed
344.	*Scolytus multistriatus*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
345.	*Sechium edule*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
346.	*Senecio squalidus*	Plant	herb	Terrestrial	Yes	No	Not assessed	Not assessed
347.	*Senecio viscosus*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
348.	*Senegalia catechu*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
349.	*Solanum tampicense*	Plant	shrub	Terrestrial	Yes	No	Not assessed	Not assessed
350.	*Solenopsis invicta*	Animal	insect	Terrestrial	Yes	Yes	Contaminated nursery material Translocation of machinery/equipment Organic wood packaging	Yes
351.	*Solenopsis richteri*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
352.	*Spartina anglica*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
353.	*Spartina densiflora*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed

354.	*Sparus aurata*	Animal	fish	Marine	No	No	Not assessed	Not assessed
355.	*Spermacoce verticillata*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
356.	*Sphaeroma quoianum*	Animal	crustacean	Terrestrial	No	No	Not assessed	Not assessed
357.	*Spiraea japonica*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
358.	*Stellaria alsine*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
359.	*Streptopelia decaocto*	Animal	bird	Terrestrial	No	No	Not assessed	Not assessed
360.	*Styela clava*	Animal	tunicate	Marine	No	No	Not assessed	Not assessed
361.	*Tabebuia heterophylla*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
362.	*Tapinoma melanocephalum*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
363.	*Tenrec ecaudatus*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
364.	*Terminalia catappa*	Plant	tree	Terrestrial	No	No	Not assessed	Not assessed
365.	*Tetropium fuscum*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
366.	*Thaumetopoea pityocampa*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
367.	*Thunbergia grandiflora*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
368.	*Tibouchina urvilleana*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
369.	*Tilapia mariae*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
370.	*Tomicus piniperda*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
371.	*Trachycarpus fortunei*	Plant	palm	Terrestrial	No	No	Not assessed	Not assessed
372.	*Tradescantia spathacea*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
373.	*Trichosurus vulpecula*	Animal	mammal	Terrestrial	Yes	No	Not assessed	Not assessed
374.	*Tridentiger trigonocephalus*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
375.	*Trididemnum solidum*	Animal	tunicate	Marine	No	No	Not assessed	Not assessed
376.	*Triphasia trifolia*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
377.	*Tubastraea coccinea*	Animal	coral	Marine	No	No	Not assessed	Not assessed
378.	*Tussilago farfara*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
379.	*Typha latifolia*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
380.	*Undaria pinnatifida*	Plant	aquatic plant, alga	Marine	No	No	Not assessed	Not assessed
381.	*Urochloa mutica*	Plant	grass	Terrestrial	No	No	Not assessed	Not assessed
382.	*Urosalpinx cinerea*	Animal	mollusc	Marine	No	No	Not assessed	Not assessed
383.	*Utricularia gibba*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
384.	*Vallisneria nana*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
385.	*Vallisneria spiralis*	Plant	aquatic plant	Terrestrial	No	No	Not assessed	Not assessed
386.	*Varanus indicus*	Animal	reptile	Terrestrial	No	No	Not assessed	Not assessed
387.	*Verbascum thapsus*	Plant	herb	Terrestrial	No	No	Not assessed	Not assessed
388.	*Vespa velutina nigrithorax*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
389.	*Vespula pensylvanica*	Animal	insect	Terrestrial	No	No	Not assessed	Not assessed
390.	*Vespula vulgaris*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
391.	*Vitex rotundifolia*	Plant	shrub	Terrestrial	No	No	Not assessed	Not assessed
392.	*Viverricula indica*	Animal	mammal	Terrestrial	No	No	Not assessed	Not assessed
393.	*Vulpes vulpes*	Animal	mammal	Terrestrial	Yes	No	Hunting in the wild	No
394.	*Wasmannia auropunctata*	Animal	insect	Terrestrial	Yes	No	Not assessed	Not assessed
395.	*Waterhousea floribunda*	Plant	tree, shrub	Terrestrial	No	No	Not assessed	Not assessed
396.	*Wisteria sinensis*	Plant	vine, climber	Terrestrial	No	No	Not assessed	Not assessed
397.	*Xiphophorus hellerii*	Animal	fish	Terrestrial	No	No	Not assessed	Not assessed
398.	*Zizania latifolia*	Plant	grass	Terrestrial	Yes	No	Not assessed	Not assessed
399.	*Zoobotryon verticillatum*	Animal	bryozoan	Marine	No	No	Not assessed	Not assessed