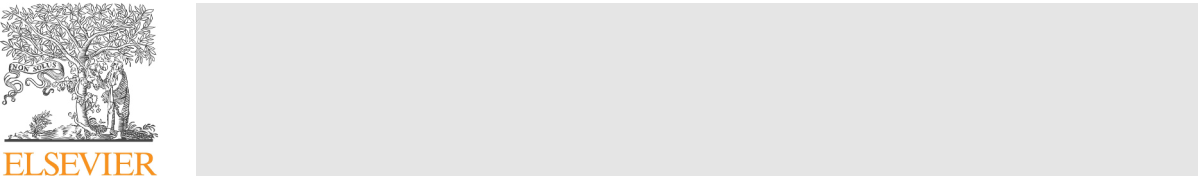
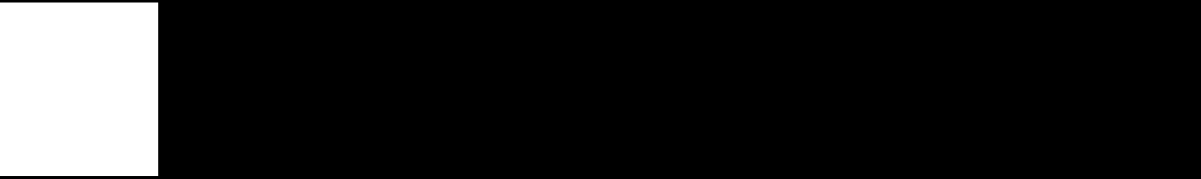
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Aliens in the city: Towards identifying non-indigenous floristic hotspots within an urban matrix

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ABSTRACT

Urban natural green spaces are becoming increasingly impacted by anthropogenic disturbances, promoting alien plant invasions. Using a rapidly developing city in South Africa as a case study, we related distribution, com-position, and ordering of alien plant species to environmental and anthropogenic factors to identify drivers of invasiveness. Vegetation surveys were used to identify and quantify (in terms of composition and density) alien species within 30 natural green spaces. Floristic characteristics were then related to levels of non-natural dis-turbance and selected abiotic parameters. Based on the relationships observed, selected floristic parameters were used to develop an Alien Invasive Index to identify ‘invasive alien hotspots’. Collectively, 80 alien plant species (from 30 families) were found, 35 of which are invasive. The most speciose families were Asteraceae > Fabaceae > Verbenaceae. Their representatives, specifically the invasive shrubs*Lantana camara* (Verbenaceae) and *Chromolaena odorata* (Asteraceae) and alien herbs *Conyza sumatrensis*, *Bidens pilosa* and *Tagetes minuata* (Asteraceae) were also the most dominant in terms of frequency across sites and density. APrincipal Component Analysis showed invasive alien plant species composition to be most strongly related to level of disturbance, followed by distance to informal settlement and soil moisture content. The Alien Invasive Index could discriminate between sites with low and high levels of invasiveness, and its suitability was validated by the fact that sites with very high index values were in close proximity to informal settlements. The study demonstrates the value of combining classical *in situ* vegetation surveys and overlay analysis using Geographic Information System for prioritising green spaces and alien species for management in cities that are limited in terms of financial resources.

**1. Introduction**

Urban plant invasion is a global phenomenon that has been reported to have implications on human health, fire regimes, indigenous biodi-versity, water resources, and safety and security risks (Pyšek and Richardson, 2010; Potgieter et al., 2020 and references therein). For-mally defined as non-indigenous species that have antagonistic effects on the habitats into which they are introduced, either directly or in-directly, alien plants (Lamsal et al., 2018) have become a major focus in invasion science (Novoa et al., 2020). When alien plants are successful in establishing reproductive populations, they are classified as natur-alised, and once they spread their range into new regions, they can become invasive (Blackburn et al., 2011; Razanajatovo et al., 2016). Identifying the biotic and abiotic factors that drive this invasiveness remains a major challenge in invasion science and has hindered our



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ability to prevent, manage, and predict invasions.

Urbanisation brings about changes in land use and is a major driver of change in natural vegetation patterns (Seto et al., 2011; [Concepción](#page9) et al., 2015). This scenario applies to many developing cities ([Cobbinah](#page9) et al., 2015) and other parts of the developing world (Cobbinah and Amoako, 2012) where non-natural disturbances are a common feature of urban ecosystems and influence alien plant invasions through changes in intensity and frequency (Keeley and Brennan, 2012). Non-natural disturbances such as mowing, soil extraction and dumping, as opposed to natural disturbances such as fire and tree fall, and distance from human habitation, have been shown to have a major influence on the presence of alien species in urban green spaces (Sullivan et al., [2005](#page10); Muratet et al., 2008). Anthropogenic disturbances can promote alien invasion by destroying indigenous plants through regeneration failure (Hobbs and Yates, 2003), and successful alien plant invasions

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appear to be more common in anthropogenically-altered than natural habitats (Niemela, 1999). Anthropogenic disturbances can create edges open to invasion (Hobbs and Yates, 2003) and also give rise to dispersal corridors that promote alien plant invasion (Lake and Leishman, 2004; Alston and Richardson, 2006). However, there are some idiosyncrasies concerning disturbance-induce plant invasion. In urban grasslands, alien plant invasions have been linked to disturbances related to cul-tivation, grazing, and trampling (Tyser and Worley, 1992) which though present in some cities (e.g., Durban in South Africa [Drury et al., [2016](#page9)]) are less frequent in urban forests.

In developing countries, urban areas are increasing tremendously (Rouget, 2015), and by 2030 the urban threshold of 50 % will very likely be exceeded (Boon et al., 2016). As cities (built-up areas) and urban populations grow within these countries grow, many natural urban green spaces are becoming increasingly fragmented (Alston and Richardson, 2006), transformed, degraded, and eroded of biodiversity (Zhao et al., 2010; Concepción et al., 2015). The conservation of the remaining habitats (and biodiversity within them), which are often surrounded by human settlements (Hobbs and Yates, 2003), will be of vital importance (Godefroid and Koedam, 2007; Zhao et al., 2010) in the face of climate change given that anthropogenic factors, land-cover alteration, and urban design geometry contribute to an increase in urban surface and atmospheric temperatures (Abutaleb et al., 2015). In this regard, understanding the interplay between social and ecological systems in modulating plant invasions in urban landscapes is important ([Gill and Williams, 1996](#page9); [Alston and Richardson, 2006](#page9)).

While numerous studies have developed indicators for quantifying levels of biodiversity (e.g., Ferreira et al., 2005; Matzdorf et al., 2008), and biodiversity hotspots in particular (Schmidt et al., 2014), there have been fewer efforts to develop indices or indicators for ranking areas based on levels of alien plant invasion (Crossman et al., 2011) within urban landscapes. Nevertheless, there is growing agreement that cities may be ‘alien hotspots’ (Kühn et al., 2004; Celesti‐Grapow et al., [2006](#page9). There are reports from the developing world (e.g., Kateregga and Sterner, 2007) that prevalence of known drivers of invasiveness (e.g., levels of disturbance [Godefroid, 2001]) and indicators of alien plant impacts should be considered in such an exercise (Gaertner et al., 2009; Hejda et al., 2009). A few studies have also attempted to develop in-dices of invasiveness to prioritise riparian zones for alien plant eradi-cation and control in rapidly urbanising countries such as South Africa (e.g., van Wilgen et al., 2007), but this has not been applied across biomes/habitat types. This is due to the complexity of dealing with issues around invasion biology, such as the lack of alien distribution data in developing cities, levels of transformation, and urban hetero-geneity, amongst others. This is the case for many rapidly developing African cities, such as Durban in South Africa, where there are often no formal systems for prioritising areas or species for control and eradi-cation operations despite national guidelines (e.g., National Environ-mental Management: Biodiversity Act [NEMBA], 20 [Act no. 10 of 2004]) ([Department of Environmental Affairs (South African),](#page9) 2016).

A demand for more land for settlement, agriculture, transport and infrastructure (Rouget, 2015) in cities like Durban has been accom-panied by the introduction and increased presence of numerous alien plant taxa over the last four decades (Alston and Richardson, 2006; Bhagwat et al., 2012). Approximately 900 alien plant species have es-tablished in natural areas of South Africa, c. 600 of which have become invasive, dispersing into natural ecosystems (van Wilgen, 2018). South Africa has invested large resources into trying to control invasive alien plants (IAPs) (van Wilgen et al., 2008), but despite these efforts cities such as Durban continue to exhibit high levels of alien plant invasion thought to be linked to increasing urbanisation, pollution and habitat loss (Roberts and O’Donoghue, 2013). This together with the fact that Durban is situated in the middle of a biodiversity hotspot (Maputaland-Pondoland-Albany) made the city an ideal case study which addressed the following research questions in the context of alien plants in an urban matrix: (1) are alien plant distribution, species composition

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(number of species), and density related to environmental (soil moisture, wind speed, and air temperature) and anthropogenic (in-cluding levels of non-natural disturbance) factors?; (2) what are the drivers of invasiveness?; (3) can selected floristic parameters be used to develop an Alien Invasive Index (AII) for identifying invasive alien hotspots? Knowledge of how land use changes and the associated non-natural disturbances may directly or indirectly impact on IAPs within these green spaces would allow for more focused and effective control/ eradication programmes (Adam et al., 2017) within cities.

**2. Methods**

*2.1. Study site selection*

As mentioned above, the city of Durban in KwaZulu-Natal, South Africa, was selected here as the case study area, in which 30 green spaces within the eThekwini Metropolitan Area (EMA) were surveyed (see Supplementary Table 1). The EMA covers 2556 km2, and green spaces (c. 33 % of this area) are interspersed between industrial areas and housing (formal and informal). There are > 14 000 green spaces across the EMA which form part of the Durban Metropolitan Open Space System (D’MOSS) (eThekwini Municipality, 2017) and site se-lection involved a combination of spatial techniques and ground-truthing, with the intention of identifying 30 sites, with a minimum of six sites in each of the five sectors of the EMA (viz. North, South, East, West, and Central) (see Supplementary Table 1). Additionally, we en-sured that our site selection accommodated all four major vegetation types within the EMA, viz. forest, grassland, savanna, and thicket. A combination of overlay analysis (using roads, informal settlements, industry, and housing layers) in ArcMap (version 10.3, ArcGIS) and ground-truthing was used to establish whether the sites were > 10000 ha in size, accessible by road, and not located in steep in-accessible riparian zones.

*2.2. Vegetation surveys and quantification of sampling effort*

At each of the 30 sites, eight 5 × 5 m quadrats were laid out more than 10 m apart and at least 2 m from any mowed/concrete/tarred curb edges. Sampling was conducted over a two-year period (2016 and 2017) with 15 sites (n = 120 quadrats) being sampled in each year. At each site, four quadrats were sampled in Autumn-Winter (May-June) and four in Spring-Summer (November-December) to capture seasonal changes in the vegetation (Sershen et al., 2019). Within each quadrat, the abundance (number of individuals or clumps in the case of some shrubs, due to their growth form) and cover area (%) were recorded for all non-graminoid life forms (viz. trees, shrubs, herbs), while only cover area (%) was recorded for graminoid taxa due to their clonal habit (Kambaj et al., 2018). Flowering or fruiting plant specimens were col-lected from quadrats at each site over the course of the two years for identification purposes, and herbarium vouchers were deposited at the Ward Herbarium (Westville Campus, University of KwaZulu-Natal).

Data from eight quadrats at each of the 30 sites (n = 240) were used for all analyses, including species accumulation curves, which were constructed using abundance data in EstimateS 9.0 (Colwell, 2013) to determine whether the sampling effort was adequate. Graminoids were not included in the species accumulation curves since only % cover data were available. The percentage sampling effort was calculated by di-viding the number of species found *in situ* by the projected number of species based on the Chao2 estimator. Sampling completeness was achieved when the sampling effort reached a minimum of 80 % (e.g., Moro et al., 2014).

*2.3. Identification and categorisation of flora and species/family ordering*

Plant species were identified using field guides (Boon, 2010;[Pooley,](#page10) [1998](#page10)) and other published literature. Nomenclature and taxonomic

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authorships follow the New Plants of Southern Africa (NewPOSA) website of the South African National Biodiversity Institute ([South](#page10) African National Biodiversity Institute (SANBI, 2019a). Alien taxa ca-tegorisation was based on the National Environmental Management: Biodiversity Act (NEMBA), 2016 (Act no. 10 of 2004), and Alien and Invasive Species List 2016 (Department of Environmental Affairs (South African), 2016) of South Africa. The Act recognises Category 1–3 IAP species: 1) may not be grown and must be controlled; 2) are of com-mercial or utility value, which may only be grown with a permit under controlled circumstances; and 3) may have amenity value and which may be grown, but not planted, propagated, imported or traded, or grown within 30 m of watercourses. Descriptions of all non-declared alien plant species were based on the Weeds and Invasive Plants (WIP) [(2016)](#page10). In some cases (especially for naturalised exotics), the alien status was determined using SANBI (2019b). Alien species not de-scribed in any of the above-mentioned sources were regarded as 'non-categorised’ alien taxa.

In the present study, alien species (in terms of density) and family representation (in terms of composition) were ranked to identify the top three (dominant) species and families across all sites (after Jones et al., [2017](#page9)). For this ranking, density for individual families and species was summed at site level and averaged for the study area.

*2.4. Abiotic parameters, levels of disturbance and proximity to land use types*

At all 30 sites air temperature (°C), and wind speed (m/s) were recorded using a handheld pocket weather meter (Kestrel 3000, Nielsen-Kellerman, Pennsylvania, USA). Soil moisture content (%) was also measured with a HH2 Moisture Meter (Delta-T Devices Ltd, Cambridge, UK). The selection of these parameters was based on the following: air temperature and soil moisture have been shown to be major drivers of vegetation patterns (Frei et al., 2018) and processes such as seed germination and seedling recruitment. Many alien species are wind-dispersed, and the geometric configuration of urban land-scapes has been shown to influence wind conditions (Müller et al., [2013](#page10)). Additionally, the study area is predicted to experience climate change associated alterations in temperature and rainfall. We did not consider soil nutrients as our unpublished data from previous studies showed levels of essential nutrients such as nitrogen and phosphorous in green spaces within the city to be highly variable at temporal and spatial scales owing to anthropogenically-induced runoff and erosion events. Abiotic measurements were carried out at all sites for each quadrat between 8–11 AM on the day on which the quadrat was sam-pled. Three measurements were made for each parameter at five points (each corner and the mid-point) in each quadrat, yielding n = 5 mea-surements per quadrat, and n = 40 per site (n = 20 Autumn-Winter and n = 20 Spring-Summer).

Levels of unnatural disturbance were assessed at all sites during the last year of sampling using a scoring matrix (see Supplementary Table 2) based on the following typology: footpaths and trampling, li-vestock browsing (browse line or damage to foliage), wood harvesting (stumps left behind), agriculture (presence of planted/harvested fields), resource abstraction (soil, water, stones), solid waste (dumping), ef-fluent (storm water, urban, industrial), and recent burning (planned/ unplanned). Each site was scored in terms of level for each type of disturbance (1 = very low, 2 = low, 3 = moderate, 4 = high and 5 = very high) via three parallel walked transects (approximately 50 m). The scores for each disturbance type were then averaged with the po-tential maximum level of disturbance being 5. The scores for the eight disturbance types were then summed (at site level; maximum score = 40) and expressed as a percentage of the potential maximum score (40). These percentiles were then used as the disturbance level value for each site and plotted as a boxplot (SPSS Inc., Version 25, Chicago, IL), to delimit five disturbance classes: very low (≤ 24), low (25–28), medium (29–30), high (31–39), and very high (≥ 40).

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A spatial proximity tool (‘generate near table’ [ArcMap, version

10.3, ArcGIS]) was used to measure the distance (m) of each quadrat to the closest land use feature (roads, informal settlements, housing, in-dustry) (after Doriwala and Shah, 2010). The sites were also mapped (in ArcMap) to show their relative proximity to housing, industry and in-formal settlements, and location within the study area in relation to the five sectors described earlier.

*2.5. Alien invasive index and identification of invasive alien hotspots*

The total number of IAPs, non-IAPs as well their densities at each of the 30 sites surveyed were used to formulate an Alien Invasive Index (AII):

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| AII*=* | IC | ID | Expression (1) |  |
| CC | CD |  |



Where IC = IAP species composition at site, CC = cumulative alien plant species compostion (sum of all sites), ID = IAP species density at site, and CD = cumulative alien species density (sum of all sites)

Factors included in the calculation of the index were shown to be significantly related to each other (see below Results). Our decision to exclude disturbance level was based on the skewed distribution of va-lues for this parameter. The site-specific AII values were then used to identify ‘invasive alien hotspots’ across the study area by plotting the values in a boxplot and delimiting four classes of increasing invasion: 1

* low (≤ 0.018), 2 = medium (0.019–0.024), 3 = high (0.025–0.067) and 4 = very high (≥ 0.068). The 30 sites were then overlaid (using ArcMap) on the human settlement layer for the city and tagged with the level of disturbance for the site to generate a map that can be used to spatially represent existing invasive alien hotspots (high to very high AII), emerging hotspots (medium AII) and sites of early invasive de-tection (low AII).

*2.6. Statistical analysis*

Data for all sites (eight quadrats in each of 30 sites yielding n = 240 quadrats) were pooled prior to all statistical analyses (carried out in SPSS, Version 25). All data were tested for normality using the Shapiro Wilks/Kolmogorov-Smirnov test. Non-parametric data were log/arcsine (for percentages) transformed where necessary. In order to determine the most important variables a PCA was conducted with the following variables: alien (invasive and non-invasive) plant floristics (composi-tion and density), distance to land use feature class layers (viz. distance to roads, industry, and informal settlements), abiotic factors (viz. air temperature, soil moisture content and wind speed), and disturbance level. The Scree plot of the eigenvalues for all components was used to determine the number of principal components (PCs) to retain, i.e., those before the last inflection point of the graph. Based on this ana-lysis, five PCs (accounting for > 74 % variance) were retained. A non-parametric correlation test (Spearman rank) was used to test for the following relationships amongst the following parameters: AII, alien plant floristics, abiotic factors, and disturbance level.

**3. Results**

*3.1. Land use patterns across the study area and site environmental characteristics*

The five sectors in which the study sites were varied in terms of environmental characteristics. Altitude differed significantly (*P*< 0.05) (Table 1), with the western and northern sectors having the highest (588.83 m) and lowest (77 m) average altitude, respectively. In terms of proximity to the coastline, sites from the west were furthest away (most inland), followed in decreasing order by central, east, south, and north sectors.

There were clear differences across sectors in terms of % land

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**Table 1**

Altitude and disturbance level for each of the five sectors of the EMA (n = 6 sites per sector).

|  |  |  |  |
| --- | --- | --- | --- |
| Sector | Average altitude (m) | | Disturbance level |
|  |  | |  |
| North | 77.00 ± 40.43 c | | 27.67 ± 4.27 a |
| East | 109.00 | ± 58.15 c | 32.67 ± 3.72 a |
| South | 92.5 ± 57.01 c | | 29.5 ± 3.51 a |
| Central | 335.33 | ± 113.34 b | 29 ± 9.14 a |
| West | 588.83 | ± 227.31 a | 27.83 ± 4.75 a |

Values represent mean ± SD (n = 30) and are significantly different when followed by different letters (*P* < 0.05, ANOVA).

covered by the built environment: for industrial areas, south (49 %) > east (23 %) > central (21 %) > west (4%) > north (2%); for in-formal settlements, south (49 %) > north (19 %) > west (18 %) > central (8 %) > east (6 %), and for formal settlements, south (40 %) > north (23 %) > central (13 %) > west (13 %) > east (8 %). These results show that the south sector is most affected in terms of coverage by all built environment types, the east is least affected in terms of formal and informal settlements, and the north is least affected in terms of industry. In terms of cumulative area of green space sampled in this study, the sectors ranked as follows: west > south > east > central and north (data not shown).

Day temperatures across sites ranged from 16.49 ± 1.1 °C (Site 16, savanna) to 33.85 ± 1.9 °C (Site 23, savanna) and mean day tem-perature (all sites pooled) was 24.57 ± 3.8 °C (see Supplementary Table 3). Wind speed across sites ranged from 0.27 ± 0.3 m/s (Site 1, forest) to 4.01 ± 1.7 m/s (Site 23, savanna), and mean wind speed (all sites pooled) was 1.14 ± 0.8 m/s. Soil moisture content differed widely across sites from 3.49 % (Site 24, thicket) to 19.78 % (Site 2, forest), and mean soil moisture (all sites pooled) was 12.30 ± 4.1 %. However, there were no significant differences across sectors in terms of mean day temperature, mean wind speed, and mean soil moisture content (*P* > 0.05, ANOVA).

The gradient of non-natural disturbance that was generated via *in* *situ* assessments indicated that all sites exhibited some level of dis-turbance. There were variable combinations of disturbance types across sites, but footpaths or trampling and effluent (storm water, urban, in-dustrial) were the most (observed at 93 % of sites) and least (observed at 3% of sites) commonly observed disturbances, respectively (data not shown). The distribution of sites (n = 30) across the five disturbance categories defined using a boxplot was as follows: 16.67 % of sites with very low, 36.67 % with low, 16.67 % with medium, 26.67 % with high and 3.33 % with very high levels of disturbance (see Supplementary Table 1). The five sectors ranked as follows in terms of average dis-turbance level: east > south > central > west > north (Table 1). Sites in the east were mainly disturbed by solid waste dumping and had a higher presence of built up areas. Sites in the south were disturbed mainly by human footpaths and solid waste dumping, and were not in close proximity to built up areas as the north (data not shown). Central regions were more prone to fires and had the highest disturbance due to high levels of solid waste dumping. Sites in the north and west regions were more isolated from the main city centre, and sites in the west were not in close proximity to housing. The main source of disturbance in the outer west sector was cattle grazing. In terms of the 30 sites in-vestigated here, the most frequent vegetation type was forest for the north and south sectors, and savanna for the east, west, and central sectors.

*3.2. Floristics and levels of invasiveness*

Cumulatively, 80 alien species (invasive and non-invasive) were found when 30 sites were sampled in two seasons (see Supplementary Table 4). These species belong to 30 families, with the top three families

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being Asteraceae (n = 18), Fabaceae (n = 12), and Verbenaceae (n = 5). These three families contributed 35 species (46 %) to the total number of alien plant species found, and the mean family composition (all sites combined) was relatively low (4 ± 0.39) but ranged widely (4–16) across sites. The top five sites in terms of family composition were sites 16 (n = 16), 2 and 9 (n = 15), 3 (n = 14) and 1 (n = 13), and the bottom-ranked sites were 27 (n = 7), 20 and 29 (n = 6), 28 (n = 5), and 4 (n = 4). North and south sectors had the highest pre-sence of IAPs, and both had predominately forest vegetation (see Supplementary Table 1).

Thirty-five of the alien species found could be categorised (Category 1–3) according to the NEMBA typology (see Methods section): n = 29 for Category 1; n = 4 for Category 2 and n = 2 for Category 3. Furthermore, seven naturalised exotics, and 28 non-declared aliens were found. This implies that 35 (44 %) of the aliens found within the study area are considered invasive. The mean number of IAPs per site was equivalent to nine but ranged widely (3–16) across sites. The top five sites based on IAPs presence were sites 2 (n = 16; forest), 9 (n = 14; thicket), 25 (n = 14; savanna), 6 (n = 13; savanna), and 13

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (n = 13; | forest), while | the five bottom ranked sites | were sites | 11 |
| (n = 5; | savanna), 21 | (n = 5; grassland), 28 (n = 4; | savanna), | 29 |
| (n = 4; grassland), and 4 (n = 3; forest). | | |  |  |

Alien plant species composition (invasive and non-invasive) across sites ranged from 9 to 25 species (Fig. 1), with a mean composition of 18 ± 4.2. The top five most speciose sites were 2 (n = 25; forest), 3 (n = 24; thicket), 6 (n = 24; savanna), 13 (n = 22; forest) and 18 (n = 22; thicket), and the five bottom ranked sites were 27 (n = 9; grassland), 28 (n = 9; savanna), 4 (n = 10; forest), 29 (n = 11; grass-land), and 21 (n = 12; grassland).

Alien plant species density (invasive and non-invasive) across the study area ranged from 0.07 to 3.76 individuals/m2 (Fig. 1), with a mean density of 0.97 ± 0.75 individuals/m2. Site 7 (grassland) had the highest non-IAP (n = 3.76 individuals/m2) and IAP (n = 1.82 in-dividuals/m2) species density. The top five ranked sites in terms of total alien plant density were sites 7 (3.76 individuals/m2; grassland), 20 (2.53 individuals/m2; savanna), 10 (1.80 individuals/m2; savanna), 23

(1.68 individuals/m2; savanna), and 5 (1.55 individuals/m2; grassland), and the bottom ranked sites were 14 (0.35 individuals/m2; forest), 4 (0.33 individuals/m2; forest), 16 (0.31 individuals/m2; savanna), 29

(0.14 individuals/m2; grassland), and 17 (0.07 individuals/m2; sa-vanna). The top five alien plant species in terms of density were*Tagetes* *minuata* L. (5.71 ± 5.88 indivduals/m2), *Rumex crispus* L.(5.32 ± 1.17 individuals/m2), *Bidens pilosa* L. (2.8 ± 2.31 in-dividuals/m2), *Conyza sumatrensis* (Retz.) E. Walker (2.8 ± 0.81 in-dividuals/m2) and *Lantana camara* L. (2.6 ± 1.2 indviduals/m2). One of these species is recognised as invasive (*L. camara*) while the re-maining four species are not. The five bottom ranked species were *Passiflora subpeltata* Ortega*, Sonchus oleraceus* L.*, Trichocereus macro-gonus* (Salm-Dyck) Riccob.*, Verbena brasiliensis* Vell. and *Xanthium strumarium* L. (all 1 ± 0 individual/m2).

The frequency of occurrence across sites for individual alien species ranged from 3 to 25%, with the average frequency being 20 %. Alien species with the highest frequency across the sites were *L. camara* (87 % of sites; invasive), *Chromolaena odorata* (L.) R.M.King & H. Rob. (77 % sites; invasive), *C. sumatrensis* (77 % of sites, not declared), *B. pilosa* (73

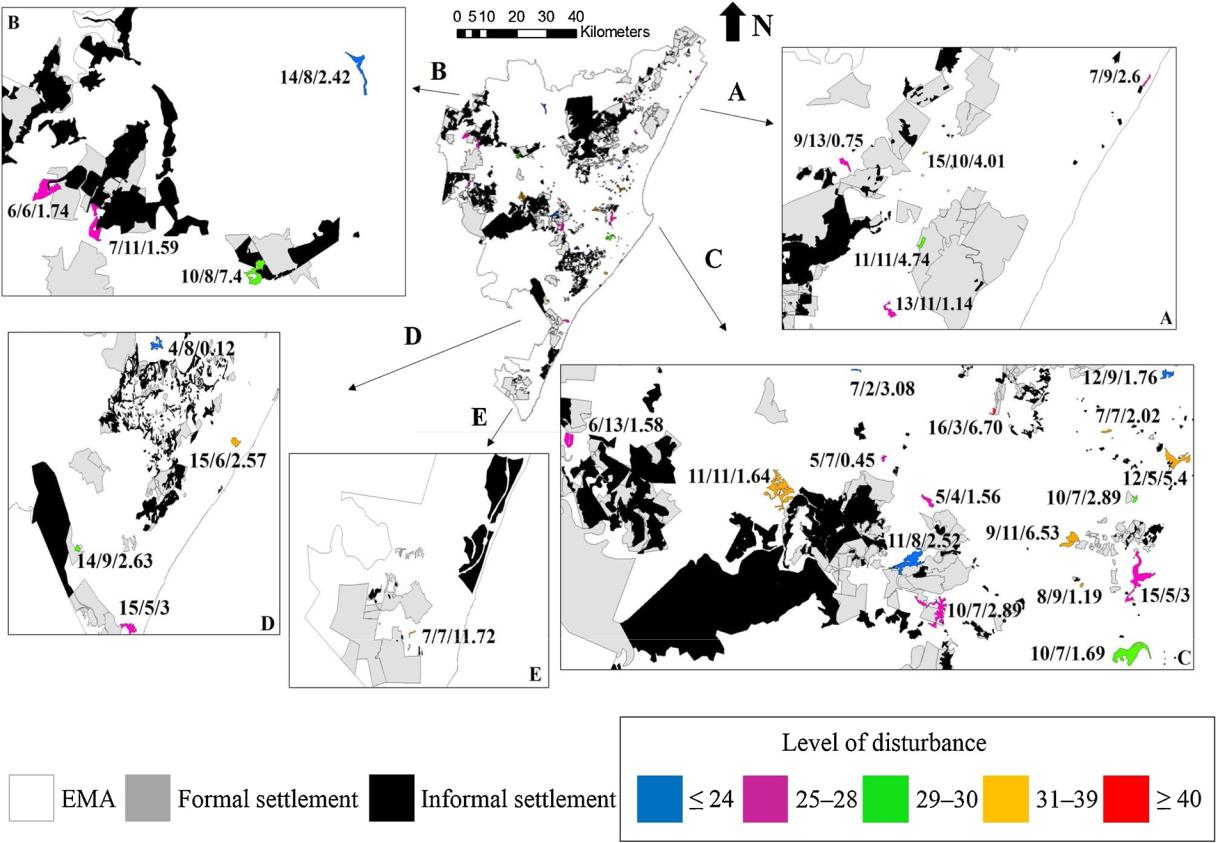
* of sites, not declared), and *T. minuata* (70 % of sites, not declared) (see Supplementary Table 5).

*3.3. Identifying hotspots of invasiveness in relation to environmental parameters*

Across sectors, alien plant species composition was significantly different between the central and north sectors but comparable among other sectors (*P* = 0.033, ANOVA). Alien plant species density and family composition were comparable across sectors (*P* = 0.248 and

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**Fig. 1.** Distribution of alien species (including invasive alien plants [IAPs]) across the Durban Metropolitan Open Space System sampling sites (coloured polygons)within the eThekwini Municipality. Each coloured polygon represents a level of disturbance: blue = very low; purple = low; green = medium; yellow = high; red = very high. A–E represent parts of the study area in greater detail. Values associated with each site represent IAP species composition, non-IAP species composition, and IAP species density (individuals/m2), respectively.

*P* = 0.101 (ANOVA), respectively) (Table 2). When all sites within asector are considered (Fig. 1), the highest aggregate (sum) of non-IAP species was as follows: north (n = 130) > west (n = 111) > south (n = 107) > east (n = 105) > central (n = 85). When the five sectors are ranked in terms of IAPs aggregate, the west sector drops two places in rank: north (n = 61 species) > south (n = 57 species) > east (n = 51 species) > west (n = 47 species) > central (n = 45 species). Despite these differences, the data suggest that both IAP and non-IAP species were present in high numbers across sites, in all five sectors.

The top five ranking sites in terms of alien species composition ranged between medium (29–30) and high (31–39) levels of dis-turbance, whilst the bottom sites ranged between very low (≤ 24) and low (25–28) levels of disturbance. The top five ranked sites in terms of IAP species composition ranged between very low (≤ 24) and very high (≥ 40) levels of disturbance, and the bottom five sites ranged between very low and high levels of disturbance.

**Table 2**

Alien species composition and density, family composition across, and AII for all five sectors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sector** | Alien species | | Alien species | Family | AII |
|  | composition | | density | composition |  |
|  |  |  |  |  |  |
| **North** | 21.67 | ± 3.14 a | 0.94 ± 0.52 a | 20 ± 5.28 a | 0.036 ± 0.03 a |
| **East** | 17.5 ± 2.26 ab | | 1.42 ± 1.24 a | 16 ± 3.14 a | 0.047 ± 0.03 a |
| **South** | 17.83 | ± 4.26 ab | 0.57 ± 0.49 a | 17 ± 4.08 a | 0.02 ± 0.02 a |
| **West** | 18.5 ± 3.67 ab | | 1.24 ± 0.73 a | 17 ± 3.72 a | 0.037 ± 0.03 a |
| **Central** | 14.17 | ± 4.75 b | 0.69 ± 0.27 a | 13 ± 1.17 a | 0.030 ± 0.03 a |

Values represent mean ± SD (n = 30) and are significantly (*P* < 0.05) dif-ferent when labelled with different letters (ANOVA).

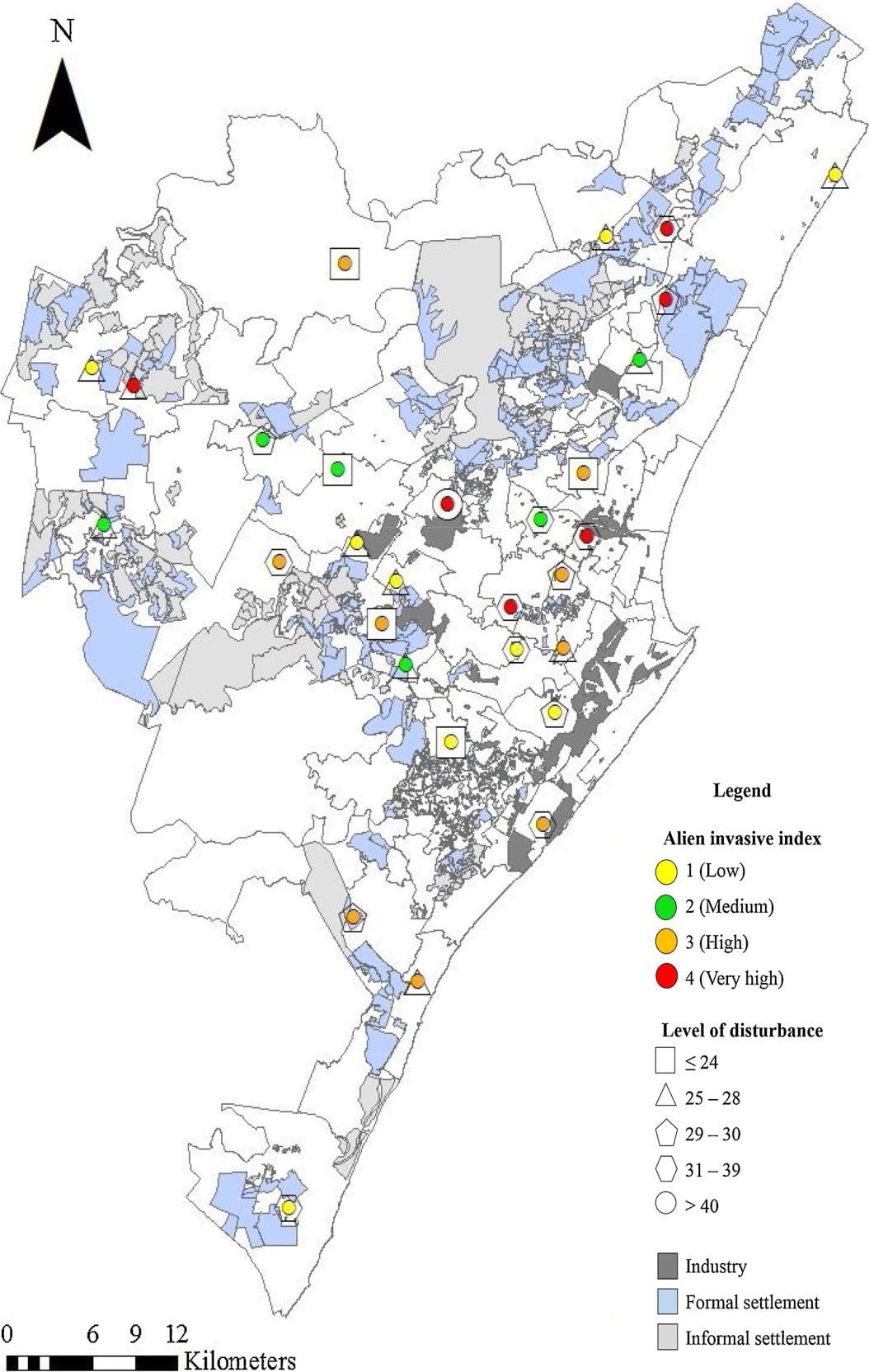
The five sectors ranked as follows in terms of AII values (calculated based on Expression 1, Methods): east (0.047 ± 0.03) > west (0.037 ± 0.03) > north (0.036 ± 0.03) > central (0.030 ± 0.03) > south (0.02 ± 0.02) (Table 2). However, there were no significant differences in mean AII value across sectors (*P*= 0.721, ANOVA), and no significant correlations between AII and floristics parameters or level of disturbance (data not shown at sector scale). When individual sites in the study area were compared there were significant differences (*P <* 0.001, t-test) in the AII, and values were distributed across the four defined AII classes as follows: 20 % (sites 2, 3, 7, 9, 19 and 25) were very high (labelled ‘class 4′), 30 % (sites 1, 8, 10, 13, 14, 18, 22, 24 and

1. high (labelled ‘class 3′), 20 % (sites 6, 11, 20, 23, 26 and 27) medium (labelled ‘class 2′), 30 % (sites 4, 5, 12, 15, 16, 17, 21, 28 and
2. low (labelled ‘class 1′) ([Fig. 2](#page6)). This means that 50 % of the sites (spread across all vegetation types) can be classified as alien hotspots, i.e., class 3 or 4 sites in terms of AII, while the remaining 50 % (spread across all vegetation types) represent emerging invasive alien hotspots (class 2) and early invasive detection sites (class 1). When site data was pooled, the AII was significantly positively correlated with levels of disturbance, IAP species composition, total alien plant species compo-sition and soil moisture content, whilst significantly negatively corre-lated with wind speed (see Supplementary Table 6).

A PCA was used to test for relationships among floristic, abiotic, and land use parameters ([Fig. 3](#page7)), and five parameters (labelled components henceforth) accounted for 74 % variance in the data. In [Fig. 3](#page7), only the first three PCs are shown. Distance to roads (PC1) accounted for 22 % variance in the data and was highly related with non-IAP species composition, IAP species density, non-IAP species density, and total alien plant species density (see Supplementary Table 7 for *R*2 values). Total alien plant species density loaded most high for PC1. Level of

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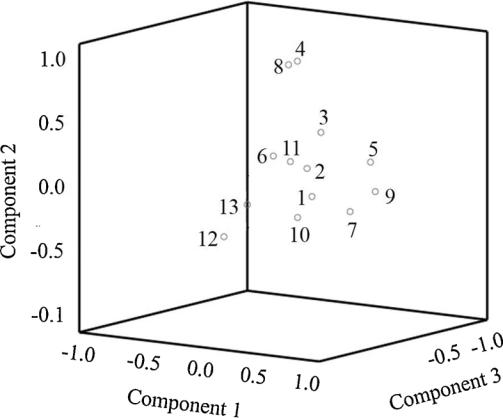


**Fig. 2.** Alien invasive index (AII) highlighting sites that are invaded. Classes of AII range from 1 (low: 0.001–0.018), 2 (medium: 0.019–0.024), 3 (high: 0.025–0.067)

and 4 (very high: 0.068–0.094). All red dots are indicative of invasive alien hotspots across all sites in the EMA, and shapes represent the level of disturbance (%).

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**Fig. 3.** Principal component analysis (PCA) plot for the first three components.Each number (1–13) represents a principle component used in the PCA: 1 = distance to roads; 2 = levels of disturbance; 3 = distance to informal settle-ment; 4 = IAP species composition; 5 = IAP species density; 6 = non-IAP species composition; 7 = non-IAP species density; 8 = total alien plant species composition; 9 = total alien plant species density; 10 = temperature; 11 = soil moisture content; 12 = wind speed; 13 = distance to industry. The cumulative % of variance were as follows: PC1 = 22 %; PC2 = 42 %; PC3 = 55 %.

disturbance (PC2) accounted for 42 % of the variance and was highly related with IAP species composition and negatively with wind speed. Invasive alien plant composition loaded most high for PC2. Distance to informal settlements (PC3) accounted for 55 % of the variance and was highly related with total alien plant species composition and negatively with levels of disturbance. Total alien plant species composition loaded most high for PC3. Invasive alien plant composition (PC4) accounted for 66 % of the variance and was highly related with soil moisture content and negatively with distance to roads. Soil moisture content loaded most high for PC4. Invasive alien plant species density (PC5) accounted for 74 % of the variance and was highly related with tem-perature, which loaded most high for PC5 (see Supplementary Table 7 for *R*2 values).

**4. Discussion**

*4.1. Alien floristics in the study area*

Using a rapidly developing city in South Africa as a case study, we sought to develop an approach to identifying alien plant hotspots within an urban matrix. Despite the fact that just 30 of 2915 recognised green spaces in the city were sampled, 80 alien species (invasive and non-invasive) were recorded, and the composition and density of these species were compared with a number of anthropogenic and environ-mental factors. According to a very recent report ([eThekwini](#page9) Municipality, 2018), there are a total of 106 IAPs found in the city of Durban. This is a relatively high number for an area of 2556 km2; since on average, 259.7 alien species were found across 54 European cities (Pyšek, 1998). However, it must be noted that most of the species featured in the above-mentioned report for Durban ([eThekwini](#page9) Municipality, 2018) were based on surveys of parks and nurseries, and not systematic assessments of alien species composition and density/ abundance. This is largely because South Africa like many countries in the developing world faces increasing environmental challenges, which include urbanisation, rising numbers of informal settlements, limited infrastructural and service provision and, unemployment while trying to maintain the quality and quantity of green spaces (Pillay and Pahlad, [2014](#page10)).

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*4.2. Taxonomic and life form coverage, and family/species ordering of alien flora in the study area*

Even though alien species were present in all 30 of the sites sam-pled, species composition varied greatly across sites (Fig. 1). However, despite these inter-site differences at the species level, 46 % of the species found belonged to just three (viz. Asteraceae, Fabaceae, and Verbenaceae) of the thirty families recorded. Asteraceae and Fabaceae are considered large Angiosperm families, consisting of > 20 000 spe-cies globally (Angiosperm Phylogeny Website (APW), 2019). Aster-aceae and Fabaceae were also part of the top three dominant families for alien plant composition in urban areas of other studies (e.g., Pauchard and Alaback, 2004). Recent floristic studies for grasslands and forests within the city have shown Asteraceae and Fabaceae to be dominant alien families ([Drury et al., 2016](#page9); [Kambaj et al., 2018](#page9)).

Of the five most dominant species in terms of frequency across sites, both *L. camara* (Verbenaceae) and *C. odorata* (Asteraceae) are invasive shrubs, whilst the remaining three species are alien herbaceous Asteraceae species (*C. sumatrensis*, *B. pilosa,* and *T. minuata*). South Africa has 170 of the global list of 622 invasive alien trees (357) and shrubs (265) (Richardson and Rejmánek, 2011). *Lantana camara* is considered invasive due to its ability to reduce indigenous species di-versity and composition, decrease soil fertility and alter ecosystem services (Taylor et al., 2012). This is based on its ability to produce allelochemicals (Sharma et al., 2005; Taylor et al., 2012), rapid growth rate, short life cycle, high reproductive potential and competitive ability (Kohli et al., 2006). Globally, *L. camara* is a common and very challenging invasive species to manage (Goodall and Erasmus, 1996). Like *L. camara, C. odorata* produces allelopathic chemicals (Goodall and Erasmus, 1996) and is an aggressive pioneer species, particularly in disturbed habitats, and a prolific seed producer (Erasmus, 1985; Goodall and Erasmus, 1996). Similarly, the high frequency of some of the other species mentioned above is based largely on their re-productive strategy (Pérez-Fernández et al., 2019) and ability to colo-nize disturbed areas (Taylor et al., 2012) which are major contributors to invasiveness. *Conyza sumatrensis,* for example, thrives in abandoned arable land, road edges and close to roads and railways, and produces vast amounts of achenes (> 200 000 per individual) with high dispersal potential in the air (Anastasiu and Memedemin, 2012). *Bidens pilosa* also has allelopathic properties, and each plant produces approximately 80 floral heads with up to 3000 seeds per individual and has the ability to invade various habitats, including disturbed areas, roadsides, and open spaces (Mahmoud et al., 2015). *Tagetes minuata* has small seeds that attach easily to the fur of animals, thereby aiding in dispersal, and produces secondary anti-herbivory metabolites (Martinez‐Ghersa et al., [2000](#page10)).

Interestingly, the three most dominant families in terms of species composition (Asteraceae, Fabaceae, and Verbenaceae) were also the most dominant in terms of density. All three of the dominant alien taxa in terms of density (*T. minuata* [Asteraceae]*, R. crispus* [Polygonaceae] and *B. pilosa* [Asteraceae]) are non-declared alien herbs within the city. In fact, 56 % of the aliens recorded were herbs and as alluded to above there were very few (15 %) of the alien species recorded in this study were trees. The reasons for the dominance of these species are similar to those made for species that were most frequent across sites; for ex-ample, *T. minuata* has allelopathic properties (Arora et al., 2015), *R.* *crispus* has very high seed production, multiple flowering times in oneyear, quick establishment from seed, high germination rates, and can regenerate vegetatively ([viz. cuttings] Pino et al., 1995) and sexually (Pérez-Fernández et al., 2019).

*4.3. Drivers and hotspots of invasiveness*

Urbanisation is associated with a number of disturbances that pro-mote the introduction, spread, and impacts of aliens (Pyšek, 1998; Alston and Richardson, 2006; Botham et al., 2009). In this study, all 30

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sites sampled exhibited some level of disturbance, with the most com-monly observed types of disturbance being solid waste dumping, trampling, footpaths, and fires (planned vs. unplanned), which have been associated with alien invasions ([Berry et al., 1994](#page9)).

In the present study, the PCA reduced the 13 variables considered to five principal components. Level of disturbance (PC2) was strongly related to IAPs composition and significantly negatively related with distance to informal settlements and wind speed. It is well established that alien species composition can increase in response to anthro-pogenic activity and disturbances (e.g., Hobbs and Huenneke, 1992; Celesti‐Grapow et al., 2006) and this relationship is modulated by the structure, activities, and land use practices associated with the built-up areas within an urban matrix (Niemala, 1999; Godefroid and Koedam, [2007](#page9)). As in many developing countries (Berry et al., 1994), Durban hosts both formal and informal housing settlements and as the distance to an informal settlement (PC3) decreased, the degree of disturbance increased significantly, suggesting that informal settlement-related disturbances may be driving the increase in alien plant species com-position and density. Wind conditions in natural habitats can be altered by the built environment surrounding them (Abutaleb et al., 2015). In the present case, a reduction in wind speed within the urban matrix studied appears to have increased species composition by possibly re-ducing the dispersal potential of a number of alien species that rely heavily on wind for dispersal. However, this relationship is not well understood and needs further investigation.

There was a significant positive relationship between distance to roads (PC1) and IAP species density, non-IAP species composition, non-IAP species density, and total alien plant species density. However, there was a negative relationship between distance to roads and IAP species composition. We believe these patterns are partly an artefact of the sampling regime (quadrats were laid at least 2 m from any mowed/ concrete/tarred curb or road edge/verge). The curb maintenance methods presently employed within the city involve clearing/grass cutting at edge features, and these edges represent potential dispersal corridors that were not sampled. Other studies (e.g., Tyser and Worley, [1992](#page10); Lake and Leishman, 2004; Alston and Richardson, 2006) have shown that disturbances from transport routes produce dispersal cor-ridors that promote alien plant invasion. Increased wind speed along urban corridors such as roads have also been shown to increase the prevalence of alien species (Kowarik and Von der Lippe, 2011). Transport routes also lead to increased temperature (Umar and Kumar, [2014](#page10)), which in turn influences evapotranspiration rates. This may explain why in the present study, IAP species composition (PC4) was related to soil moisture content, and IAP species density (PC5) was strongly related to temperature. Several studies have suggested that many alien plant species are likely to be favoured by higher tempera-tures (Frenot et al., 2005; Thuiller et al., 2008) and moist conditions ([Lim et al., 2014](#page10)).

Controlling/eradicating alien invasion, particularly in the cities of developing countries with limited resources, requires the rapid identi-fication and continuous monitoring of alien plants, as well as prior-itization of areas and species for clearing. Cities are believed to host alien invasive hotspots, but this is very rarely described quantitatively (but see Kühn et al., 2004; Celesti‐Grapow et al., 2006). While it is common to define hotspots by the mere number of aliens species pre-sent ([viz. alien species richness]; Celesti‐Grapow et al., 2006), we at-tempted to develop and use AII to identify hotspot of invasiveness. Muratet et al. (2008) attribute these hotspots to the central positioning of cities to major transport routes while Hobbs and Huenneke (1992) assert that human activities and the associated disturbance lead to in-creased alien establishment in cities. The current study supports this assertion by showing that IAP species composition was strongly related to the presence of informal settlements and by implication high dis-turbance levels. Furthermore, the study showed that apart from the drivers of invasiveness identified by the PCA (level of disturbance, distance to informal settlements, distance to roads), the AII developed

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could be used to identify six hotspots of invasiveness (sites 2, 3, 7, 9, 19 and 25 [AII class 4 in Fig. 2]). The very high index of invasiveness at four (2, 7, 9, 25) of these six sites could be attributed to high (31–39) to very high levels (≥ 40) of disturbance, while the fifth site (3) has a medium level of disturbance (Fig. 1). It should also be noted that sites 2, 7, 9, and 25 were also subject to high levels of solid waste dumping (which included garden refuse), while site 25 is situated in a densely populated urban area (with many home gardens). Highly disturbed natural green spaces are prone to the establishment of garden-escapees from adjacent or nearby parks, and gardens (Pyšek, 1998; Botham et al., [2009](#page9)), and the dumping of garden refuse can also lead to the spread of alien species ([Foxcroft et al., 2008](#page9)).

The utility of the AII developed in this study in identifying alien hotspots within an urban matrix is validated by the fact that it was significantly positively correlated with disturbance. However, it must be mentioned that the highest-ranked site (site 19) in terms of this index was subject to low (26) levels of disturbance. A potential reason for this anomaly may be the high density (0.81 individuals/m2) of *Populus* x *canescens* (Aiton) Sm. (Salicaceae), which was also unique tothis site. This species is known to form dense stands (through profuse suckering) in moist areas and propagates vegetatively, limiting its ability to spread (Henderson, 1991). Site 19 was fairly moist (see Supplementary Table 3) compared with surrounding sites. The dense stands and high numbers of mature individuals suggest that this is an established population and likely to have occupied the site for several years, or possibly decades. The index was also useful in identifying emerging alien hotspots, viz. sites belonging to class 2: 6, 11, 20, 23, 26, and 27. These sites exhibited fairly low means for disturbance level, invasive alien species composition, and density compared with class 4, but a higher non-invasive alien species composition and density.

**5. Concluding remarks and recommendations**

The present study set out to determine alien plant species compo-sition, density, and distribution across an urban matrix within a rapidly expanding city, with the intention of developing an index to identify hotspots of invasiveness. A wide range of alien taxa were recorded, many of which are recognised as invasives globally. There was some taxonomic bias at the family level in terms of respresentation (46 % of all species belonged to Asteraceae, Fabaceae, and Verbenaceae), fre-quency across sites and densities. Of the five most dominant species identified, two were invasive (*L. camara* [Verbenaceae] *and C. odorata* [Asteraceae]) and three were non-invasive (*C. sumatrensis*, *B. pilosa* and *T. minuata* [Asteraceae]), suggesting the invasive potential of the latterthree.

The major drivers of invasiveness appear to be disturbance (parti-cularly that associated with informal settlements), soil moisture con-tent, and temperature. The AII developed included IAP species com-position and density, cumulative alien plant species composition, and cumulative alien plant species density as variables, and was useful in identifying alien hotspots. The AII was strongly related to level of dis-turbance and should be applied to other cities in South Africa and globally to assess its utility in prioritising sites for alien species control/ eradication. In terms of Durban, the established alien hotspots identi-fied using the AII and the dominant species (*L. camara*and *C. odorata*) represent an immediate management priority. The traits that promote the invasiveness of these dominant species (invasive and non-invasive) should also be investigated, despite the enormity of the task to generate a comprehensive understanding of the factors that drive alien inva-siveness within cities. Finally, the findings show the value of combining classical *in situ* vegetation surveys and overlay analysis using GIS for prioritising green spaces and alien species for management in cities that are limited in terms of financial resources.

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**CRediT authorship contribution statement**

**Minoli Appalasamy:** Methodology, Formal analysis, Investigation,Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Syd Ramdhani:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing - review & editing, Visualization, Supervision, Project admin-istration, Funding acquisition.Conceptualization, Methodology, Validation, Resources, Data curation, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influ-ence the work reported in this paper.

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**References**

Abutaleb, K., Ngie, A., Darwish, A., Ahmed, M., Arafat, S., Ahmed, F., 2015. Assessment of urban heat island using remotely sensed imagery over Greater Cairo. Egypt. Adv. Rem. Sens. 4, 35. <https://doi.org/10.4236/ars.2015.41004>.

Adam, Y., Ngetar, N.S., Ramdhani, S., 2017. The assessment of invasive alien plant spe-cies removal programs using remote sensing and GIS in two selected reserves in the eThekwini Municipality. KwaZulu-Natal. S. Afr. J. Geomatics 6, 90–105. [https://doi.](https://doi.org/10.4314/sajg.v6i1.6) [org/10.4314/sajg.v6i1.6](https://doi.org/10.4314/sajg.v6i1.6).

Alston, K.P., Richardson, D.M., 2006. The roles of habitat features, disturbance, and distance from putative source populations in structuring alien plant invasions at the urban/wildland interface on the Cape Peninsula, South Africa. Biol. Conserv. 132, 183–198. <https://doi.org/10.1016/j.biocon.2006.03.023>.

[Anastasiu, P., Memedemin, D., 2012. *Conyza sumatrensis*: a new alien plant in Romania.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0020)

[Bot. Serb. 36, 37–40](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0020).

Angiosperm Phylogeny Website (APW), 2019. Angiosperm Phylogeny Website. (Accessed June 2019). <http://www.mobot.org/MOBOT/research/APweb/>.

Arora, K., Batish, D.R., Singh, H.P., Kohli, R.K., 2015. Allelopathic potential of the es-sential oil of wild marigold (*Tagetes minuta* L.) against some invasive weeds. J. [Environ. Agric. Sci. 3, 56–60](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0030).

Berry, M.G., Robertson, B.L., Campbell, E.E., 1994. Impacts of informal settlements on south-eastern Cape coastal vegetation (South Africa). Glob. Ecol. Biogeogr. Letters 4, [129–139](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0035).

Bhagwat, S.A., Breman, E., Thekaekara, T., Thornton, T.F., Willis, K.J., 2012. A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. in Australia, India and South Africa. PLoS One 7, 1–10. [https://doi.org/10.1371/](https://doi.org/10.1371/journal.pone.0032407) [journal.pone.0032407](https://doi.org/10.1371/journal.pone.0032407).

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson, J.R.U., Richardson, D.M., 2011. A proposed unified framework for biological inva-[sions. Trends Ecol. Evol. 26, 333–339](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0045).

Boon, R., 2010. Pooley’s Trees of Eastern South Africa. Flora and Fauna Publications [Trust, Durban](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0050).

Boon, R., Cockburn, J., Douwes, E., Govender, N., Ground, L., Mclean, C., Roberts, D., Rouget, M., Slotow, R., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. Bothalia-African Biodivers. and Conserv. 46, 1–12. [https://doi.org/10.4102/abc.](https://doi.org/10.4102/abc.v46i2.2112) [v46i2.2112](https://doi.org/10.4102/abc.v46i2.2112).

Botham, M.S., Rothery, P., Hulme, P.E., Hill, M.O., Preston, C.D., Roy, D.B., 2009. Do urban areas act as foci for the spread of alien plant species? An assessment of tem-poral trends in the UK. Divers. Distrib. 15, 338–345 10.1111/j.1472-[4642.2008.00539.x](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0060).

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

Cobbinah, P.B., Amoako, C., 2012. Urban sprawl and the loss of peri-urban land in [Kumasi, Ghana. Int. J. Soc. Humanit. Sci. Res. 6, 388–397](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0070).

Cobbinah, P.B., Erdiaw-Kwasie, M.O., Amoateng, P., 2015. Africa’s urbanisation:

*Flora 269 (2020) 151631*

implications for sustainable development. Cities 47, 62–72. [https://doi.org/10.1016/](https://doi.org/10.1016/j.cities.2015.03.013) [j.cities.2015.03.013](https://doi.org/10.1016/j.cities.2015.03.013).

Colwell, R.K., 2013. Estimates: Statistical Estimation of Species Richness and Shared Species From Samples (Version 9.1. 0. User’s Guide and Application). (Accessed June 2018). <http://purl.oclc.org/estimates/>.

Concepción, E.D., Moretti, M., Altermatt, F., Nobis, M.P., Obrist, M.K., 2015. Impacts of urbanisation on biodiversity: the role of species mobility, degree of specialisation and spatial scale. Oikos 124, 1571–1582. <https://doi.org/10.1111/oik.02166>.

Crossman, N.D., Bryan, B.A., Cooke, D.A., 2011. An invasive plant and climate change threat index for weed risk management: integrating habitat distribution pattern and dispersal process. Ecol. Indic. 11, 183–198. [https://doi.org/10.1016/j.ecolind.2008.](https://doi.org/10.1016/j.ecolind.2008.10.011) [10.011](https://doi.org/10.1016/j.ecolind.2008.10.011).

Department of Environmental Affairs (South African), 2016. National Environmental Management: Biodiversity Act (10/2004): Alien and Invasive Species List, 2016, [Government Notice #864, Government Gazette 40166 (Accessed September 2018).](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0095) .

Doriwala, H., Shah, N.C., 2010. GIS-Based analysis of facility provision accessible to [different socio-economic groups in Surat City. World Appl. Sci. J. 9,](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0100) 740–745.

Drury, C.C., Ramdhani, S., Naidoo, S., Carbutt, C., Boodhraj, R., Mbatha, P., 2016. A lot gone but still hanging on: floristics of remnant patches of endangered KwaZulu-Natal Sandstone Sourveld. Bothalia-Afr. Biodivers. Conserv. 46, 1–13. [https://doi.org/10.](https://doi.org/10.4102/abc.v46i2.2110) [4102/abc.v46i2.2110](https://doi.org/10.4102/abc.v46i2.2110).

[Erasmus, D.J., 1985. Achene Biology and the Chemical Control of *Chromolaena odorata*.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0110)

[University of Natal, South Africa](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0110).

eThekwini Municipality, 2017. State of Biodiversity Report 2016/2017. (Accessed 12 June 2018). http://www.durban.gov.za/City\_Services/development\_planning\_ management/environmental\_planning\_climate\_protection/Publications/Documents/ [StateofBiodiversityReport.pdf/](http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/StateofBiodiversityReport.pdf/).

eThekwini Municipality, 2018. State of Biodiversity Report 2017/2018. (Accessed 12 June 2018). http://www.durban.gov.za/City\_Services/development\_planning\_ management/environmental\_planning\_climate\_protection/Publications/Documents/ [StateofBiodiversityReport.pdf/](http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/StateofBiodiversityReport.pdf/).

Ferreira, M.T., Rodríguez-González, P.M., Aguiar, F.C., Albuquerque, A., 2005. Assessing biotic integrity in Iberian rivers: development of a multimetric plant index. Ecol. Indic. 5, 137–149. <https://doi.org/10.1016/j.ecolind.2005.01.001>.

Foxcroft, L.C., Richardson, D.M., Wilson, J.R., 2008. Ornamental plants as invasive aliens: problems and solutions in Kruger National Park, South Africa. Environ. Manag. 41, 32–51. <https://doi.org/10.1007/s00267-007-9027-9>.

Frei, E.R., Bianchi, E., Bernareggi, G., Bebi, P., Dawes, M.A., Brown, C.D., Trant, A.J., Mamet, S.D., Rixen, C., 2018. Biotic and abiotic drivers of tree seedling recruitment across an alpine treeline ecotone. Sci. Rep. 8, 11–12. [https://doi.org/10.1038/](https://doi.org/10.1038/s41598-018-28808-w) [s41598-018-28808-w](https://doi.org/10.1038/s41598-018-28808-w).

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P.M., Convey, P., Skotnicki, M., Bergstrom, D.M., 2005. Biological invasions in the Antarctic: extent, impacts and implications. Biol. Rev. 80, 45–72. <https://doi.org/10.1017/S1464793104006542>.

Gaertner, M., Den Breeyen, A., Hui, C., Richardson, D.M., 2009. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a meta-analysis. Prog. Phys. Geogr. 33, 319–338. <https://doi.org/10.1177/0309133309341607>.

Gill, A.M., Williams, J.E., 1996. Fire regimes and biodiversity: the effects of fragmenta-tion of south eastern Australian eucalypt forests by urbanisation, agriculture and pine [plantations. For Ecol. Manag. 85, 261–278](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0150).

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

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

Goodall, J.M., Erasmus, D.J., 1996. Review of the status and integrated control of the invasive alien weed, *Chromolaena odorata*, in South Africa. Agric. Ecosyst. Environ. 56, 151–164. <https://doi.org/10.1016/0167-8809(95)00647-8>.

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

[Henderson, L., 1991. Invasive alien woody plants of the Orange Free State. Bothalia-Afr.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0175)

[Biodivers. Conserv. 21, 73–89](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0175).

Hobbs, R.J., Huenneke, L.F., 1992. Disturbance, diversity, and invasion: implications for conservation. Conserv. Biol. 6, 324–337. https://doi.org/10.1046/j.1523-1739.1992. [06030324.x](https://doi.org/10.1046/j.1523-1739.1992.06030324.x).

Hobbs, R.J., Yates, C.J., 2003. Impacts of ecosystem fragmentation on plant populations: generalising the idiosyncratic. Aust. J. Bot. 51, 471–488. [https://doi.org/10.1071/](https://doi.org/10.1071/BT03037) [BT03037](https://doi.org/10.1071/BT03037).

Jones, S.K., Ripplinger, J., Collins, S.L., 2017. Species reordering, not changes in richness, drives long‐term dynamics in grassland communities. Ecol. Lett. 20, 1556–1565. <https://doi.org/10.1111/ele.12864>.

Kambaj, O.K., Naidoo, S., Govender, Y., Ramdhani, S., 2018. A floristic comparison of three Northern Coastal Forests differing in disturbance history. Bothalia-Afr. Biodivers. Conserv. 48, 1–13. <https://doi.org/10.4102/abc.v48i1.2262>.

Kateregga, E., Sterner, T., 2007. Indicators for an invasive species: water hyacinths in Lake Victoria. Ecol. Indic. 7, 362–370. [https://doi.org/10.1016/j.ecolind.2006.02.](https://doi.org/10.1016/j.ecolind.2006.02.008) [008](https://doi.org/10.1016/j.ecolind.2006.02.008).

Keeley, J.E., Brennan, T.J., 2012. Fire-driven alien invasion in a fire-adapted ecosystem.

Oecologia 169, 1043–1052. <https://doi.org/10.1007/s00442-012-2253-8>.

Kohli, R.K., Batish, D.R., Singh, H.P., Dogra, K.S., 2006. Status, invasiveness and en-vironmental threats of three tropical American invasive weeds (*Parthenium hyster-ophorus* L., *Ageratum conyzoides* L., *Lantana camara* L.) in India. Biol. Invasions 8,1501–1510. <https://doi.org/10.1007/s10530-005-5842-1>.

Kowarik, I., Von der Lippe, M., 2011. Secondary wind dispersal enhances long-distance

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dispersal of an invasive species in urban road corridors. NeoBiota 9, 49. [https://doi.](https://doi.org/10.3897/neobiota.9.1469)

[org/10.3897/neobiota.9.1469](https://doi.org/10.3897/neobiota.9.1469).

[Kühn, I., Brandl, R., Klotz, S., 2004. The flora of German cities is naturally species rich.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0220)

[Evol. Ecol. Res. 6, 749–764](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0220).

Lake, J.C., Leishman, M.R., 2004. Invasion success of exotic plants in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. Biol. Conserv. 117, 215–226. <https://doi.org/10.1016/S0006-3207(03)00294-5>.

Lamsal, P., Kumar, L., Aryal, A., Atreya, K., 2018. Invasive alien plant species dynamics in the Himalayan region under climate change. Ambio 47, 697–710. [https://doi.org/10.](https://doi.org/10.1007/s13280-018-1017-z) [1007/s13280-018-1017-z](https://doi.org/10.1007/s13280-018-1017-z).

Lim, J., Crawley, M.J., De Vere, N., Rich, T., Savolainen, V., 2014. A phylogenetic analysis of the British flora sheds light on the evolutionary and ecological factors driving plant invasions. Ecol. Evol. 4, 4258–4269. <https://doi.org/10.1002/ece3.1274>.

Mahmoud, T., Gairola, S., El-Keblawy, A., 2015. *Parthenium hysterophorus* and *Bidens pi-losa*, two new records to the invasive weed flora of the United Arab Emirates. J. New[Biol. Rep. 4, 26–32](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0240).

Martinez‐Ghersa, M.A., Ghersa, C.M., Benech‐Arnold, R.L., Donough, R.M., Sanchez, R.A., 2000. Adaptive traits regulating dormancy and germination of invasive species. Plant Spec. Biol. 15, 127–137. <https://doi.org/10.1046/j.1442-1984.2000.00033.x>.

Matzdorf, B., Kaiser, T., Rohner, M.S., 2008. Developing biodiversity indicator to design efficient agri-environmental schemes for extensively used grassland. Ecol. Indic. 8, 256–269. <https://doi.org/10.1016/j.ecolind.2007.02.002>.

Moro, M.F., de Sousa, D.J.L., Matias, L.Q., 2014. Rarefaction, richness estimation and extrapolation methods in the evaluation of unseen plant diversity in aquatic eco-systems. Aquat. Bot. 117, 48–55. <https://doi.org/10.1016/j.aquabot.2014.04.006>.

Müller, N., Ignatieva, M., Nilon, C.H., Werner, P., Zipperer, W.C., 2013. Patterns and trends in urban biodiversity and landscape design. Urbanization, Biodiversity and [Ecosystem Services: Challenges and Opportunities. Springer, Dordrecht, pp. 123–174](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0260).

[Muratet, A., Porcher, E., Devictor, V., Arnal, G., Moret, J., Wright, S., Machon, N., 2008.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0265)

[Evaluation of floristic diversity in urban areas as a basis for habitat management.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0265)

[Appl. Veg. Sci. 11, 451–460 10,3170/2008-7-18530](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0265).

Niemela, J., 1999. Ecology and urban planning. Biodivers. Conserv. 8, 119–131. Novoa, A., Richardson, D.M., Pyšek, P., Meyerson, L.A., Bacher, S., Canavan, S., Catford,

J.A., Čuda, J., Essl, F., Foxcroft, L.C., Genovesi, P., 2020. Invasion syndromes: a systematic approach for predicting biological invasions and facilitating effective management. Biol. Invasions 1–20. https://doi.org/10.1007/s10530-020-02220-w. [Pauchard, A., Alaback, P.B., 2004. Influence of elevation, land use, and landscape](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0280) context

on patterns of alien plant invasions along roadsides in protected areas of [South‐Central Chile. Conserv. Biol. 18, 238–248](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0280).

Pérez-Fernández, M.A., Elliott, C.P., Valentine, A., Oyola, J.A., 2019. Seed provenance determines germination responses of *Rumex crispus* (L.) under water stress and nu-trient availability. J Plant Ecol. 12, 949–961. <https://doi.org/10.1093/jpe/rtz034>.

Pillay, S., Pahlad, R., 2014. A gendered analysis of community perceptions and attitudes towards green spaces in a Durban Metropolitan residential area: implications for climate change mititgation. Agenda 28, 168–178. <https://doi.org/10.1080/10130>.

Pino, J., Haggar, R.J., Sans, F.X., Masalles, R.M., Hamilton, R.S., 1995. Clonal growth and [fragment regeneration of *Rumex obtusifolius* L. Weed Res. 35, 141–148](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0295).

[Pooley, E., 1998. A Field Guide to Wild Flowers of KwaZulu-Natal and the Eastern Region.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0300)

[Natal Flora Publications Trust, Durban](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0300).

Potgieter, L.J., Douwes, E., Gaertner, M., Measey, J., Paap, T., Richardson, D.M., 2020. Biological invasions in South Africa’s urban ecosystems: patterns, processes, impacts, and management. In: van Wilgen, B., Measey, J., Richardson, D., Wilson, J., Zengeya, [T. (Eds.), Biological Invasions in South Africa. Springer Cham, pp. 275–309](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0305).

Pyšek, P., 1998. Alien and native species in Central European urban floras: a quantitative

*Flora 269 (2020) 151631*

[comparison. J. Biogeogr. 25, 155–163](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0310).

Pyšek, P., Richardson, D.M., 2010. Invasive species, environmental change and man-[agement, and health. Annu. Rev. Environ. Resour. 35, 25–55](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0315).

Razanajatovo, M., Maurel, N., Dawson, W., Essl, F., Kreft, H., Pergl, J., Pyšek, P., Weigelt, P., Winter, M., Van Kleunen, M., 2016. Plants capable of selfing are more likely to become naturalized. Nature Commun. 7, 1–9. [https://doi.org/10.1038/](https://doi.org/10.1038/ncomms13313) [ncomms13313](https://doi.org/10.1038/ncomms13313).

Richardson, D.M., Rejmánek, M., 2011. Trees and shrubs as invasive alien species–a [global review. Divers. Distrib. 17, 788–809](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0325).

Roberts, D., O’Donoghue, S., 2013. Urban environmental challenges and climate change action in Durban, South Africa. Environ. Urban. 25, 299–319. [https://doi.org/10.](https://doi.org/10.1177/0956247813500904) [1177/0956247813500904](https://doi.org/10.1177/0956247813500904).

[Rouget, M., 2015. Land-use planning and biological invasions. Quest 11, 18–20](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0335).

[Schmidt, M., Mölder, A., Schönfelder, E., Engel, F., Schmiedel, I., Culmsee, H., 2014.](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0340)

Determining ancient woodland indicator plants for practical use: a new approach [developed in northwest Germany. For. Ecol. Manag. 330, 228–239](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0340).

Sershen, Drury, C.C., Carbutt, C., Ramdhani, S., 2019. Seed banks of subtropical grassland patches within an urban matrix in South Africa: reflecting the past and foretelling the future. Botany 97, 231–244. <https://doi.org/10.1139/cjb-2018-0155>.

Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global urban land expansion. PLoS One 6, 1–9. <https://doi.org/10.1371/journal.pone.0023777>.

Sharma, G.P., Raghubanshi, A.S., Singh, J.S., 2005. Lantana invasion: an overview. Weed Biol. Manag. 5, 157–165. <https://doi.org/10.1111/j.1445-6664.2005.00178.x>.

South African National Biodiversity Institute (SANBI), 2019a. New Plants of Southern Africa (NewPOSA). (Accessed February 2019). <http://posa.sanbi.org/>.

South African National Biodiversity Institute (SANBI), 2019b. Red List of South African Plants. (Accessed February 2019). <http://redlist.sanbi.org/>.

Sullivan, J.J., Timmins, S.M., Williams, P.A., 2005. Movement of exotic plants into coastal [native forests from gardens in northern New Zealand. New Zeal. J. Ecol. 29, 1–10](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0370).

Taylor, S., Kumar, L., Reid, N., Kriticos, D.J., 2012. Climate change and the potential distribution of an invasive shrub, *Lantana camara* L. PLoS One 7, 1–14. [https://doi.](https://doi.org/10.1371/journal.pone.0035565) [org/10.1371/journal.pone.0035565](https://doi.org/10.1371/journal.pone.0035565).

Thuiller, W., Richardson, D.M., Midgley, G.F., 2008. Will climate change promote alien plant invasions? Biological Invasions. Springer, Berlin. [https://doi.org/10.1007/978](https://doi.org/10.1007/978-3-540-36920-2_12)-[3-540-36920-2\_12](https://doi.org/10.1007/978-3-540-36920-2_12).

Tyser, R.W., Worley, C.A., 1992. Alien flora in grasslands adjacent to road and trail [corridors in Glacier National Park, Montana (USA). Conserv. Biol. 6, 253–262](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0385).

Umar, U.M., Kumar, J.S., 2014. Spatial and temporal changes of urban heat island in Kano [Metropolis, Nigeria. Int. J. Res. Eng. Sci. Technol. 1, 1–9](http://refhub.elsevier.com/S0367-2530(20)30131-6/sbref0390).

van Wilgen, B.W., 2018. The management of invasive alien plants in South Africa: strategy, progress and challenges. Outlooks Pest Manag. 29, 13–17. [https://doi.org/](https://doi.org/10.1564/v29_feb_04) [10.1564/v29\_feb\_04](https://doi.org/10.1564/v29_feb_04).

van Wilgen, B.W., Nel, J.L., Rouget, M., 2007. Invasive alien plants and South African rivers: a proposed approach to the prioritization of control operations. Freshw. Biol. 52, 711–723. <https://doi.org/10.1111/j.1365-2427.2006.01711.x>.

van Wilgen, B.W., Reyers, B., Le Maitre, D.C., Richardson, D.M., Schonegevel, L., 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. J. Environ. Manag. 89, 336–349. [https://doi.org/10.1016/j.jenvman.](https://doi.org/10.1016/j.jenvman.2007.06.015) [2007.06.015](https://doi.org/10.1016/j.jenvman.2007.06.015).

Weeds and Invasive Plants (WIP), 2016. Weeds and Invasive Plants: An Online Checklist.

(Accessed February 2019). <http://agis.agric.za/wip/>.

Zhao, J., Ouyang, Z., Zheng, H., Zhou, W., Wang, X., Xu, W., Ni, Y., 2010. Plant species composition in green spaces within the built-up areas of Beijing, China. Plant Ecol. 209, 189–204. https://doi.org/10.1007/s11258-009-9675-3.

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