

Considering Urban Social Functions at Fine Spatial Resolution to Understand the Distribution of Invasive Plant Species in Cities

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Abstract

Context

Cities are high sources of plant invasions. To understand mechanisms of introduction and dispersion of invasive alien species (IAS) in city, we need a thorough description of the social and structural components of urban landscapes.

Objectives

We assessed the effects of neighborhood types and their associated human activities and structural linear elements on the distributions of IAS in a French medium city (Blois). We examined how the relative contributions of these variables varied between scales of analysis.

Methods

We recorded the presence of seven IAS species in the entire city (22 km²), at three spatial resolutions: 100×100m, 200×200m and 400×400m. We characterized neighborhoods through their main covers, human uses, and ages and structural elements through impervious soil, area of and distance to roads and railways.

Results

Neighborhood type was the most important variable in explaining IAS distributions. This variable was especially important at the finest scale which allowed a fine urban classification. *B. davidii* and *B. aquifolium* were found in individual residential neighborhoods, whereas *R. pseudoacacia* and *A. altissima* were most encountered in industrial areas. The effects of the structural elements differed between species and were lower.

Conclusions

Characterizing the high spatial and functional heterogeneity of urban landscapes at fine scale is critical to understand IAS distribution patterns. We show that considering human uses and planting practices is determinant to understand IAS introduction patterns. Then, linear transport corridors and ruderal conditions explain the dispersion and establishment of IAS across the city and potentially to the surrounding natural spaces.

Introduction

Urban plant communities are composed of both a subset of the regional flora and alien horticultural plants selected for their aesthetics qualities or specific uses (Pearse et al. 2018). Some of those alien species, planted in private gardens and public spaces, can escape from those spaces and colonize adjacent areas (Marco et al. 2010). Then, they can become invasive (IAS – Invasive Alien Species, *sensu* Richardson et al. 2000) due to certain ecological traits (e.g. high rates of reproduction, dispersal or growth, high tolerance to disturbances and pollution), biotic interactions and abiotic properties of the environment (Catford et al. 2009).

In cities, patterns of alien plants result from both introduction and dispersion processes which are associated to human activities and structural elements in urban landscapes. The introduction of alien plants and propagule pressure result of the matching between the horticultural supply and the demand from private gardeners and public managers. Through the urban landscape, these plantation practices vary between neighborhoods according to their uses (i.e. industrial areas, collective or individual housing, public spaces) and plant characteristics. Plantation practices also vary between neighborhoods ages and the evolution of horticultural fashions (Mathis and Pépy 2017). For instance in Western European cities, *Ailanthus altissima* (Mill, Swingle, 1916) and *Acer negundo* (L., 1753) have been planted since end of the 18th in alignments in streets because of their fast growth and *Robinia pseudoacacia* (L., 1753) because of its showy fragrant flowers. *Buddleja davidii* (Franch, 1887) and *Berberis aquifolium* (Pursch, 1814) were planted in gardens for their abundant and colorful flowers and *Cortaderia selloana* (Schult. & Schult.f., Asch. & Graebn., 1900) has been planted in traffic roundabouts and urban parks for its large plumes (Sheppard et al. 2006; Kowarik and Säumel 2007; Sladonja et al. 2015; Straigytė et al. 2015; Tarabon et al. 2018). After their introductions, expansion of IAS through cities relies on different vectors of the urban landscape. Linear urban elements such as roads and rails have been demonstrated to facilitate seed dispersal (Ansong and Pickering 2013). For example, air flow created by trains and vehicles are vectors of dispersion for *B. davidii* (see in Tallent-Halsell and Watt 2009), and seeds of *A. negundo* and *A. altissima* could be dispersed at more than 150m away from parents on motorway (Säumel and Kowarik 2013). Besides this influence on dispersion, the ruderal conditions of roadsides, rails and more generally of urban soils can favor the establishment and persistence of IAS. Indeed, urban soils which are frequently disturbed and composed of a mixture of vegetable soil and construction fill promote the presence of pioneer invasive species (Catford et al. 2012; Dyderski and Jagodziński 2016). Considering all these functional (related to human activities) and structural (related to morphological features) elements of the urban socio-ecosystem seems crucial to understand IAS patterns.

However, the characterization of landscape urban complexity remains often very brief in ecological studies and mainly based on coarse land use classification such as « urban », « peri-urban » and « rural » (see for example Aronson et al. 2015; Ariori et al. 2017). Such over-simplistic urban classifications ignored some critical structural and social components such as road and rail networks, and human uses and histories of the different neighborhoods. In agreement with Cadotte et al. (2017, and see also Godefroid and Koedam 2007; Ramalho and Hobbs 2012; Bourne and Conway 2014; Fratarcangeli et al. 2019), we believe that a finer description of urban landscapes is needed to better understand ecological processes in cities. For example, the study of diversity and evenness of tree communities of different land uses in the city of Peel, Canada, shows that tree communities of

industrial or vacant blocks are less diverse and more rich in IAS than those of residential blocks, due to the high variety of plantation choice in residential blocks and the lack of management in vacant lots (Bourne and Conway 2014). Štajerová et al. (2017) showed that the diversity of IAS increases with diversity of urban land use in 200m grid cells used to describe a Czech Republic city.

Refining the urban landscape description involves analyzing ecological patterns at a relevant spatial scale. The analysis of flora patterns at the city scale has often been carried out at large spatial resolutions ($\geq 1 \text{ km}^2$), making it possible to assess the effects of the main land uses but obscuring the fine spatial variation of urban functions and building periods (Godefroid and Koedam 2007; Schmidt et al. 2014; Fratarcangeli et al. 2019). Other studies have detected differences in alpha diversity or community traits between different land uses, considered at fine scales (1ha or finer) that allow their history to be taken into account (Lososová et al. 2011; Johnson et al. 2018). In order to understand the diverse processes at work in the distribution of IAS in cities, a multi scale approach can allow assessing the respective contributions of urban components through scales.

In this study, we evaluated the explaining factors of seven IAS distributions at three spatial resolutions in a medium French city. We considered urban factors related to dispersion, like roads and rails, and typologies of neighborhoods based on main cover and use (hereafter called NMCU) and building ages. More precisely, we wanted to determine (i) which urban elements explain the distribution of IAS? (ii) How the relative contribution of these elements varies between scales of analysis (iii) and between IAS depending on their characteristics?

We hypothesized that (i) the distribution of IAS is linked to linear urban elements promoting their dispersion and to urban functions, which reflects plantation and management practices; (ii) the relative effects of large linear urban structures should decrease with finer spatial scales whereas the importance of urban functions should increase.

Material And Method:

Site description and sampling strategy

The city of Blois is located in central-western France (47°34'59"N, 1°19'59"E). The mean temperature is 11.6°C and annual rainfall 640 mm. The surrounded landscape is dominated by agriculture, with two important forest massifs, to the west and to the south. The Loire river crosses the city from east to west (see Appendix 1a).

Almost 50,000 peoples live in Blois and the area of the city is about 22 km². Blois has experienced a strong urban expansion between the end of the 50s (28 190 inhabitants in 1954) to the end of the 80s followed by a densification period from 90s to nowadays (46 086 inhabitants in 2017- see Appendix 2). The built of industrial area, in the north of the city, followed the construction of the A10 motorway in the 60s and slowdown in the 2010s. Around the 70s, most of the residential collective zones were erected, with notably the goal to build 1,000 housing in the zone to urbanize by priority (ZUP), created administratively in 1959, and housed 10,000 inhabitants in 2013. Whereas, the construction of the residential individual houses spread over 40 years, from 50s to 90s.

Alien species patterns were censused on the entire Blois area through three grids with contrasted spatial resolutions: a 2,198-cell grid of 100×100m, a 561-cell grid of 200×200m and a 134-cell grid of 400×400m (Fig. 1 and Appendix 3). Those spatial resolutions allowed us to refine the description of the city, especially the description of the neighborhood main cover and use (NMCU), while conserving a sufficient number of cells for statistical analyzes. All variables of interest were measured in these three grids.

Species of interest:

We recorded the location of seven IAS: *Ailanthus altissima* (Mill, Swingle 1916), *Acer negundo* (Linné, 1753), *Buddleja davidii* (Franch 1887), *Cortaderia selloana* (Schult. & Schult.f., Asch. & Graebn., 1900), *Berberis aquifolium* (Pursh, 1814), *Reynoutria japonica* (Houtt., 1777) and *Robinia pseudoacacia* (Linné, 1753). These species are recognized as invasive at a regional but also at national and international scales (IUCN, Cordier et al. 2016, Méheust et al. 2020). We chose these species because they are common in cities, easily identifiable and viewable on the field, and their dispersal ability and habitat features are contrasted and influenced by some important characteristics of urban landscape considered here (Appendix 4).

Plant data collection:

Species observations were carried out from 3 April 2018 to 17 July 2018 by walking on the streets while looking at the gardens, sometimes through hedges. Parks and vacant lots were also criss-crossed, sometimes offering views of private areas not visible from the streets. Each observer had a pair of binoculars to look at inaccessible areas and facilitate species identification. On the field, we recorded and located the presence of all individuals and groves of our seven species of interest in all the 200m cells. We aggregated these data to obtain the 400m grid and we divided the 200m cells in four to obtain the 100m grid (Appendix 3). The cells were assigned to each observer as they went along, in order to minimize travel time, allow for the exploration of contiguous cells and uncouple the observer from the type of NMCU. The date of observation in Julian day (from 93 to 198, Appendix 1h) was recorded as it influenced the phenology of species and their visual detectability. Durations of investigation in each 200m cell ranged from 1 to 75 minutes depending on the visibility and accessibility (total time of observation 178h). The portion of the area not visible depended on the type of NMCU, the least visible areas being individual residential areas (some gardens at the back of houses were sometimes completely invisible from the

street) or industrial areas, where access to the site could be totally impossible (one cell on the 200m grid). On the 200m grid, 211 cells (37%) were partially invisible but as the median value of invisible area of cell was 12%, majority of the cell was visible and the probability of false absence was limited.

Structural urban variables:

For each grid, the following information were collected: impervious surface relative to the quantity of soil available and the degree of ruderality of habitat; areas of primary, secondary roads and railway; distance to primary road or railway which are used as proxy of corridors in the city; and neighborhood main cover and use (NMCU), considered as a proxy of urban uses and history (Appendix 1b to 1g and Appendix 3). Each class of variables is supposed to affect the species spatial distribution, through their influences on species' dispersal opportunities, habitat or management (Appendix 4). They were collected using Qgis (version 3.4) on each cell.

The impervious surface index was calculated using a cloud-free Landsat 8 image (spatial resolution 30 x 30m) from 19 June 2017. From red and near infra-red channels of satellite imageries, we calculated the VrNIR-BI index which has shown accurate to identify built up area (Estoque and Murayama 2015). This index was calculated for each pixel and the average value per cell was then calculated for each grid size. With this method, water appears as a highly impervious area and so for cells containing water bodies we calculated the impervious surface index from the pixels without water.

The area of different roads and railways in each cell and the distance from the cells to the roads and railways were calculated with land use data taken from the National Institute for Geographical and Forest Information (IGN, French public institute dedicated to the geographic description of the French territory, <http://www.ign.fr/institut/>). Distances to roads and railways inform about proximity of a linear element that can favor dispersion of our species. Areas of roads and railways in cell could be a proxy for quantity of dispersal events or could be linked to the availability of ruderal habitat for species. We considered two types of roads (based on IGN classification), either primary roads that constitute the large road network between cities with high traffic and speed, or secondary roads located within city with moderate traffic. We computed road surface with the width of the pavement provided by the IGN. Distances between the centroid of each cell to the railway and the primary road were calculated under R software (R Core Team, 2018).

Neighborhood main cover and use (NMCU):

Neighborhood main cover and use (NMCU) was related to the different uses of the city: live, work, recreation, shopping, etc. They were also related to land cover such as forest, cultivation or park. We identified NMCU through field observations and 2018 aerial photos. To take into account the history of neighborhoods, some NMCU were subdivided based on the construction date of the buildings. This temporal sub-division allowed for obtaining age variability while keeping a large number of cells in each class. Building dates were collected from IGN data for 80% of the buildings. For the rest, comparisons with old aerial photographs from 1949, 1958, 1964, 1972, 1986, 1996, 2008 and 2011 were manually made. As a result, three NMCU classifications with contrasted thematic resolutions were created (Table 1, Fig. 1). Due to the necessity to keep a certain number of cells per class of NMCU for analyzes, the finest NMCU classifications were only tested for the finest grids. Table 1 summarizes the classification associated to each grain grid and the number of cells in each class (see also Appendix 3 for NMCU maps and Appendix 5 for description of NMCU classification).

Statistical analyses:

We investigated the effects of structural urban variables and NMCU on the distribution of IAS based on their presence-absence with generalized linear models (GLM) and binomial distribution. We analyzed presence-absence of IAS to limit potential bias in the estimation of surface cover. We computed for each species a GLM for each combination of grid and NMCU classification, resulting in 6 models per species (1 model at 400m grid with coarse NMCU; 2 models at 200m grid with coarse and middle NMCU; 3 models at 100m with coarse, middle and fine NMCU) for a total of 36 models. All correlations of each pair of explanatory variables were low ($r < |0,7|$, Dormann et al. 2013, Appendix 6) so all the variables were kept in the models. We added the Julian day of observation as a quantitative explanatory variable to take into account the potential effect of date on species detectability.

We used a model averaging approach to take into account the uncertainty in the model selection process (Burnham and Anderson 2002). With the package *MuMIn* (Barton 2019), we fitted all possible models nested within the full model, ranked them based on AICc and assigned them Aikake weights (w_i). The Julian day was fixed in all candidate models. We then averaged the parameters of the 95% confidence set of models (sum of $w_i > 0.95$) weighted by their w_i . We computed post-hoc comparison using the *emmeans* package (Lenth 2020) to compare relative effects of NMCU classes. We calculated the percentage of explained deviance for the model containing the variables which were significant in the average model. We then compared the relative contribution of explanatory variables using a hierarchical partitioning approach with the package *hier.part* (Walsh and Mac Nally 2004). We tested the spatial autocorrelation of residuals for GLM with all variables by computing non-parametric spline correlograms with the *ncf* package (Bjornstad 2020). We observed no or very small autocorrelations (for majority of models, $r < 0.3$ under 300m) and considered the potential effect as negligible. All statistical analyses were computed by R version 3.6.1 (R Core Team 2019).

Results

On the 200m grid, the most encountered IAS were *B. davidii* (45% of the cells), *B. aquifolium* (38%), and *R. pseudoacacia* (35%), whereas *R. japonica* was the rarest species (8%). *C. selloana* was present in 9% of the cells, but only in private gardens with no evidence of spontaneous dispersion, so we decided to exclude this species of analyzes. Maps of species distribution are in Appendix 7.

Overall, the deviance explained by models declined from 400m to 100m grid for the coarse NMCU classification (Fig. 2). Explained deviance varied from 1% (for *R. japonica* at 100m grid/middle NMCU) to 25% (for *A. negundo* at 100m grid/fine NMCU, Fig. 2).

The relative contribution represents the part of the explanation of each variable in the part explained by the model. For Julian day, the relative contribution was moderate and comprised between 2% for *B. davidii* at 100m grid/middle NMCU and 29% for *A. negundo* at 100m grid/coarse NMCU (Appendix 8). Thus, Julian day explained 2% of the 11% of deviance explain by the average model for *B. davidii*.

Structural urban variables:

Overall, relative contributions of urban linear structures and impervious soil variables decreased through spatial resolutions at coarse NMCU for all species (except of impervious for *R. pseudoacacia* and distance to rails for *A. altissima*, Fig. 2).

Some variables had significant and constant effects whatever the species whereas others had contrasted effects (Fig. 2). Area of secondary roads had a significant positive impact in 17 models (out of 36, 42% of models) for 4 species, *A. negundo*, *B. aquifolium*, *B. davidii*, *R. pseudoacacia*. This variable was mainly important for *B. davidii* (from 20% to 54% of relative contribution depending on the grid and the NMCU classification) and *B. aquifolium* (from 20% to 46%). Distance to rails had a significant negative impact on the presence of species (i.e. the presence increased at proximity of rails) for 14 models (38% of models) for all species except *R. japonica*. This variable was the second most important after NMCU for *A. altissima* (from 12% to 24% of relative contribution). Area of primary road had a significant positive effect for 12 models (33% of models) for 4 species, *A. altissima*, *B. aquifolium*, *R. japonica* and *R. pseudoacacia*. For *R. japonica*, this variable explained 21% or 23% of deviance, depending on the NMCU classification for the 200m grid. Distance to primary road was significant for 12 models (33% of models) and rail area for 20 models (55% of models) but they had different effects depending on the species considered. Distance to primary road had negative effect on the presence of *A. negundo* and *R. japonica* and positive effect on *B. aquifolium* and *R. pseudoacacia* (except at 400m grid/coarse NMCU). For *R. japonica*, distance to primary road was the only significant variable at the 100m grid. Except for this species and *R. pseudoacacia* at 400m grid/coarse NMCU, its relative contribution was low. Rail area had significant positive effects on *A. altissima*, *B. davidii* and *R. pseudoacacia* and negative effects on *A. negundo* and *B. aquifolium*. This variable was the second most important after NMCU for *A. negundo* (from 4% to 21% of relative contribution). Value of impervious soil was significant for 11 models out of 36 (30% of models) for 4 species. Its effect was negative for *A. altissima*, *A. negundo* and *R. pseudoacacia* and positive for *B. davidii*. This variable was important for *R. pseudoacacia* (from 12% to 39% of relative contribution) which made it the first variable of importance at coarse NMCU and the second after NMCU for middle and fine NMCU classification. All values of GLM test for averaged model are in appendix 9.

Neighborhood main cover and use (NMCU):

The NMCU was the most significant variable (25 models out of 36, 69% of test) among the IAS except for *R. japonica*. NMCU had the highest relative contribution (between 16% from 71%), whatever the grid, the NMCU classification and the species, except for *R. pseudoacacia* for the coarse NMCU.

The relative contribution of coarse and middle NMCU increased moderately between 400m and 100m for all species, with two exceptions: coarse NMCU for *R. pseudoacacia*, middle NMCU for *A. altissima* (Fig. 2). The relative contribution of NMCU increased with the refinement of classification for the 100m grid for all species, except *R. japonica* for which NMCU was not significant.

The forest NMCU caused problems of model convergence, so we decided to exclude it from analyses. Very few IAS were observed in this NMCU, its suppression had no effect on the results.

Invasive alien species were associated to different NMCU (Table 2). Looking at the finest classification (100m grid/fine NMCU), we mainly encountered *A. altissima* in individual residential cells before 1950, industrial before 60s and in riverbanks (Fig 3). *A. negundo* was especially linked to individual residential 1970s and riverbanks. We found *B. aquifolium* and *B. davidii* in individual residential cells of all decades before 1990s. *B. davidii* was also found in collective residential and public space. For *R. japonica*, NMCU was not a significant variable. *R. pseudoacacia* was significantly associated to the oldest and newest industrial cells, and to park. For each species, see table 2, corresponding map in Appendix 7 and corresponding figure in Appendix 10.

Discussion

This study underlines the need to improve our characterization of urban landscapes to understand ecological processes and IAS patterns in cities. Particularly, we showed that the urban distribution of some IAS depends mainly of urban functions that reflect various human activities and practices. Structural urban elements have stronger influence on large scale (400m) whilst these are functional urban elements on fine scale (100m).

Urban functions related to IAS introductions

Our results show the importance of considering urban functions at fine scales to identify contexts and locations of IAS' urban introductions. Indeed, we found that the diversity of neighborhood human activities are associated to differentiated plantation practices and IAS' introduction locations. In individual residential neighborhoods, plantation choices are mainly driven by aesthetic preferences (Cook et al. 2012). Thus, we found two shrubby species appreciated for their colorful elements and traditionally planted in domestic gardens: *B. aquifolium* with its yellow flower in the begging of spring followed by bright green foliage, and *B. davidii*, appreciated for its colorful flower blooming in summer (Tallent-Halsell and Watt 2009). We noted the absence of those species in individual residential neighborhoods of the last decades, probably indicating changes of plantation practices and of horticultural offer. This relation between individual residential and those species is probably underestimated due to proportion of invisible area in this neighborhood. In individual residential of 1970s, we also found *A. negundo*, planted by the municipality in small interstitial public places and dispersing with numerous young and spontaneous individuals to near private edges or gardens.

In collective residential areas, we only found *B. davidii*. We can assume that planting practices and motivations of collective residential managers (Blois' municipality take in charge 60% of collective residential areas) are different from those of individual house owners (simplicity vs aesthetic features, for example) and lead to different plant and IAS introductions. In industrial areas, human uses are very different from in the previous NMCU. There are working areas without domestic or public garden but only flowerbeds, showcase green spaces or green unbuilt parts of some industrial parcels. Those differences lead to the use of different species such as *R. pseudoacacia* and *A. altissima*. *R. pseudoacacia* is planted as alignment tree within some industrial sites and in streets of industrial neighborhoods (in order to offer shadow in those highly mineral and warm areas for example), and already known to invade abandoned industrial areas (Cierjacks et al. 2013). Although the presence of *A. altissima* has already been observed in industrial area (Sladonja and Poljuha 2018), we have not identified a specific use explaining its presence in that neighborhood. However, the ability of this species to tolerate drought and elevated temperature, to support a various types of soil and to growth on abandoned lots (Kowarik and Säumel 2007) could explained its high presence in industrial areas in Blois city. Interestingly, there is no relation between NMCU and *R. japonica*. Indeed, this species was not related to any particular use in city, and so it was restricted to derelict land, like road embankments, which also could be linked to its dispersion. The NMCU is the principal explanatory variable of IAS distribution, and its importance is reduced and obscured at the coarsest description, with fewer relative contribution and some non-significant relation (for *A. altissima*, *A. negundo* and *B. davidii*). Thus, fine description of the urban mosaic at fine scale of analysis allows considering the strong spatial variability of the city and identifying the relevant ecological determinants.

Linear transport elements of cities and Loire river favor IAS dispersal

Different patterns of invasion could stem from the combination between ecological features of IAS, particularly dispersal mode, opportunities of dispersion offered by the different linear elements in city and the network between cities and natural environment created by those linear elements. For example, the positive impact of railroad on *R. pseudoacacia* can be explained by the fact that its anemochorous seeds can be dispersed by airflows created by the passage of trains. Area and distance to primary road explained the spatial distribution of *R. japonica*. Indeed, road embankments are mowed 1 or 2 times per year, created leaf and stems fragments which could be dispersed by vehicles along road (Sheppard et al., 2006). Thus, primary road and railways could act as corridors of dispersion for different IAS in city. Because those linear elements connect cities together and cross the surrounding natural environment, they should transform cities in invasion source to natural environment and other cities (Ansong and Pickering 2013). Outcomes will be different for species with positive relation with secondary road area, like *B. davidii*. *B. davidii* is an anemochorous species sometimes dispersed by vehicles (Tallent-Halsell and Watt 2009), which could explained the link between area of secondary road and localization of that species in city. Contrary to primary roads, secondary roads form the road network inside city by linking the different parts of a city and the different neighborhoods. As *B. davidii* is planted in individual residential neighborhood, we could suppose that this species will be dispersed from individual residential to other neighborhoods inside city through secondary roads. This kind of synergy between dispersion mode of IAS and linear elements of city is also observed with the Loire river. Two species were encountered on the Loire riverbanks: *A. negundo* and *A. altissima*. Riverbanks of the Loire river are floodable and ruderal with weakly management (annual or two-yearly mowing). Those two species are already known to invade riparian vegetation and their winged seeds can be dispersed by water flow (Saccone et al. 2010; Säumel and Kowarik 2013; Constán-Nava et al. 2015; Straigytė et al. 2015), which explained their presence in riverbanks. However, only *A. negundo* is particularly associated to riparian vegetation, as moist soil is an important factor in the establishment of that species, whereas this is not the case for *A. altissima*. In addition, *A. negundo* is established all along the river in the neighboring departments (CBNBP, map of the distribution per 5x5km cell of *A. negundo*), its presence in riverbanks of Blois is probably due to a spontaneous dispersion along the river. On the contrary, *A. altissima* is not associated to the river in the regional distribution and its presence in numerous individual residential areas near to riverbanks indicate a possible dispersion from the city to the riverbanks. Thus, even if the presence of IAS on the riverbanks depends on different process, the urban rivers can act as a corridor and as suitable habitat, favoring IAS dispersion along the river to others cities and natural areas.

Conclusion

In urban landscapes, a critical challenge is to understand how human and ecological factors intertwine to explain ecological processes and patterns. We show that the introductions of IAS in city strongly differ between neighborhoods according to diversified human uses and planting practices. Taking these social elements into account to understand IAS distributions can only be done by analyzing ecological patterns at fine spatial scales to consider the high spatial and functional heterogeneity of urban landscapes (Lososová et al. 2011; Bourne and Conway 2014; Štajerová et al. 2017; Johnson et al. 2018). Then, linear transport corridors and ruderal environmental conditions explain the dispersion and establishment of IAS across the city and potentially to the surrounding natural spaces. All these mechanisms differ between species according to their ornamental interests and their ecological

characteristics of habitat and dispersal. This underlines the importance not to generalize the impact of city on IAS and involving differentiated measures to limit their introduction and expansion in cities. To prevent the introduction of IAS in cities, reducing the sale of potentially or confirmed IAS could be achieved by the development in horticultural retail of a label guaranteeing the species to be not invasive to ensure private and public plant consumers make informed choices (Hulme et al. 2018). Moreover, frequent disturbances and ruderal conditions of road embankments and riverbanks should be limited and these spaces should highly monitored to avoid IAS expansions.

Declarations

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Conflicts of interest/Competing interests - No conflicts of interest

Ethics approval - Not applicable

Consent to participate - Not applicable

Consent for publication - Not applicable

Availability of data and material (data transparency) : we will provided the localization of our species, likely on a data repository.

Code availability - Not applicable

Authors' contributions

Muriel Deparis performed the experiment, took over all Qgis work, analyzed the data and wrote the manuscript.

Sebastien Bonthoux and Nicolas Legay conceived, designed and performed the experiment.

Sebastien Bonthoux, Nicolas Legay and Francis Isselin co-wrote and reviewed the manuscript.

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Tables

Table 1 Neighborhoods main cover and use (NMCU) classifications associated to each grain grid and number of cells in each class.

Coarse classification	Middle classification	Fine classification	100X100m Coarse classification Number of cells (n _{tot} = 2,198)	100X100m Middle classification Number of cells (n _{tot} = 2,198)	100X100m Fine classification Number of cells (n _{tot} = 2,198)	200X200m Coarse classification Number of cells (n _{tot} = 561)	200X200m Middle classification Number of cells (n _{tot} = 561)	400X400m Coarse classification Number of cells (n _{tot} = 134)
Individual residential	Individual residential	Residential individual before 50	726	726	400	190	190	54
		50-60			64			
		60-70			77			
		70-80			52			
		80-90			80			
		After 90			53			
Collective residential	Collective residential	Collective residential	220	220	220	55	55	12
Industrial	Industrial	Industrial before 60	454	454	48	112	112	29
		60-70			58			
		70-80			102			
		80-90			102			
		90-2000			52			
		After 2000			92			
Public space	Public space	Public space	227	227	227	63	63	16
Green spaces	Vacant	Vacant	368	226	226	87	46	14
	Park	Park		61	61		13	
	Riverbanks	Riverbanks		81	81		28	
Non-urban	Forest	Forest	203	44	44	54	11	9
	Agricultural	Agricultural		159	159		43	

Table 2 NMCU classes significantly associated to the presence of IAS. NMCU is not a significant variable in the spatial distribution of *Reynoutria japonica*. All NMCU classes in this table correspond to neighborhoods associated to a higher presence probability than other NMCU. For that reason, blank cell for *R. pseudoacacia* at 100m grid/coarse NMCU does not correspond to non-significant relation, but the only NMCU class highlighted in the pairwise comparison is associated to a lower presence probability than other. NS indicates that NMCU is not a significant variable in GLM.

	<i>Ailanthus altissima</i>	<i>Acer negundo</i>	<i>Berberis aquifolium</i>	<i>Buddleja davidii</i>	<i>Robinia pseudoacacia</i>	
400m	Coarse NS	NS	· Green spaces	NS	· Individual residential	
200m	Coarse	NS	· Individual residential	· Individual residential	· Individual residential · Collective residential · Industrial · Public space · Green spaces	
	Middle	· Park · Riverbanks	· Public space	· Collective residential	· Public space	· Agricultural · Industrial · Park · Individual residential
100m	Coarse	· Individual residential	· Public space · Green spaces	· Public space · Industrial · Individual residential · Collective residential	· Individual residential · Collective residential · Industrial · Public space	
	Middle	· Park · Riverbanks	· Public space · Park	· Collective residential · Park	· Collective residential · Industrial · Vacant · Riverbanks	· Individual residential · Industrial
	Fine	· Individual residential before 1950 · Industrial before 1960 · Riverbanks	· Individual residential 1970 · Riverbanks	· Individual residential before 1950 · Individual residential 1950's · Individual residential 1960's · Individual residential 1970's · Individual residential 1980's	· Public space · Collective residential · Individual residential before 1950 · Individual residential 1950's · Individual residential 1970's · Individual residential 1980's	· Industrial after 2000 · Industrial before 1960 · Park

Figures

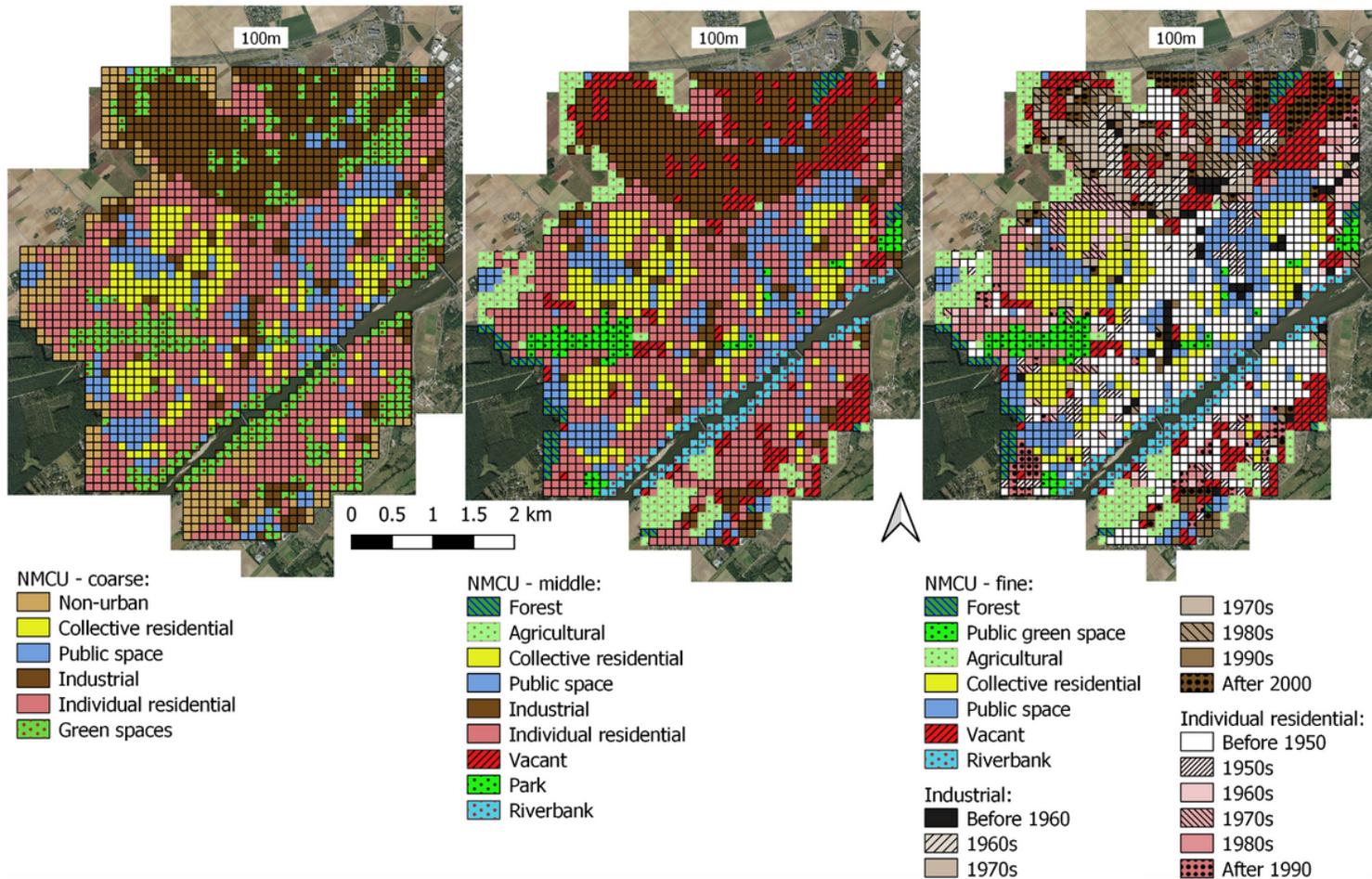


Figure 1

Coarse, middle and fine NMCU used to describe Blois city on the 100m grid. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

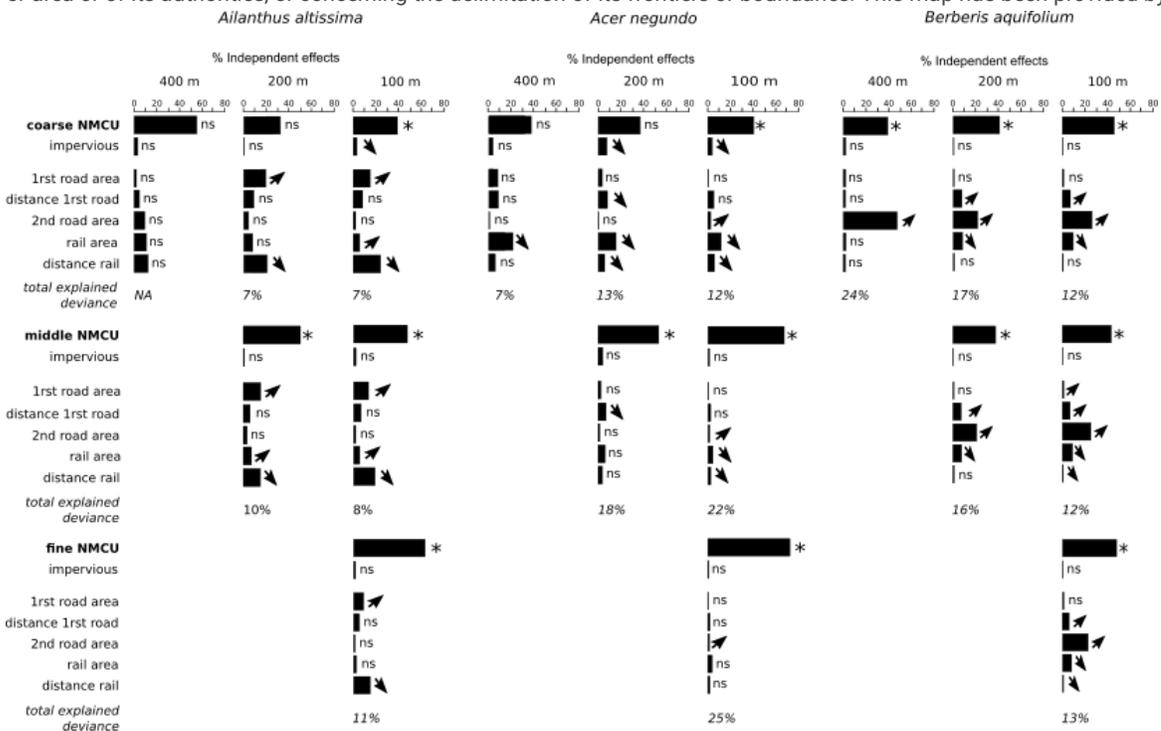


Figure 2

Results of the GLM analysis for the spatial distribution for the six species through the three spatial resolutions. All variables except Julian day are showed. The horizontal bars represent the relative importance of each variable. Total explained deviance was calculated on the total model. ↗ indicates a significant and positive effect, ↘ indicates a significant and negative effect, * indicates significant pairs comparison between NMCU and ns indicates a non-significant variable. Coarse/middle/fine NMCU: respective neighborhood main cover and use classification of the grid considered; impervious: impervious surface index; 1rst road area: area of primary road in each cell; distance 1rst road: distance from the center of the cell to the nearest section of primary road; 2nd road area: area of secondary road in each cell; rail area: area of railway in each cell; distance rail: distance from the center of the cell to the nearest section of railway.



Figure 3

Spatial distribution of *Ailanthus altissima* on the 100m grid. Colored cells are the ones where the species have been encountered, and colors correspond to the fine NMCU classification. Significant NMCU for that species are individual residential before 1950, industrial before 1960 and riverbanks. Pictures shown were taken on the field and present individuals of *A. altissima* in corresponding cells. Pictures by Muriel Deparis. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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