Environmental Science and Policy 112 (2020) 293–304

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Property price effects of green interventions in cities: A meta-analysis and implications for gentrification[★]

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ARTICLE INFO

Keywords:
Cities
Ecosystem services
Hedonic pricing
Nature-based solutions
Benefit transfer
Property value

ABSTRACT

Although green interventions, like nature-based solutions, contribute to more sustainable urban environments and provide ecosystem services to urban populations, some impacts are not well understood. This particularly applies to social impacts in the domain of environmental justice, including (green) gentrification. Gentrification refers to a process in which green urban renewal raises property prices, which results in an influx of affluent people, displacing poorer residents. Our study conducts a meta-analysis based on 37 primary hedonic pricing studies, to estimate value transfer functions that can assess the effects of nature types on property prices in various urban settings. Urban nature has positive impacts on house value in the areas surrounding it, which depend on population density, distance to, and the type of, urban nature. We illustrate how the estimated benefit transfer function can be applied to natural interventions in a Dutch city, and visualize the obtained effects using mapping. These maps show the distance decay of the cumulative effects of urban nature interventions on the house value at the city and the neighbourhood levels. Our application estimated increases in local property values up to a maximum of 20 % compared with properties not affected by the interventions, with value equivalent of 62,650 USD, at average prevailing price level in a particular area in Utrecht. When new nature is being planned in urban areas our mapping approach can be used for guiding assessments of potential undesirable effects on property values that may lead to green gentrification, and for identifying where additional policies may be needed to contribute to environmental justice.

1. Introduction

Population projections indicate that trends of increased urbanization will continue (UN, 2018), which will increase pressure on the urban environment. This highlights the importance of creating sustainable urban living environments which are healthy, attractive and resilient to climate change (Estrada et al., 2017; Gill et al., 2007), but also to take an environmental justice and sustainable development perspective to urban development. This calls for moving towards generating, improving and maintaining social, economic and environmental justice by both scientists and practitioners.

A whole array of approaches is used to address urban sustainability, which for example focus on ecosystem services, ecosystem-based adaptation and mitigation, green and blue infrastructure, as well as nature-based solutions[1] . An advantage of urban green interventions such as nature-based solutions is that they often provide multiple co-benefits (Raymond et al., 2017). For example, a park cools the city, captures precipitation, limits air pollution, and contributes to biodiversity and recreation. Moreover, introducing nature to a city can make the city aesthetically more attractive and increase social cohesion. However, there is insufficient knowledge on the way that different types of nature may affect other social domains such as gentrification. The latter refers to a process in which green urban renewal through the provision of ecosystem services creates added value on the property

[★] Paper prepared for the special issue "Advancing urban ecosystem service implementation and assessment considering different dimensions of environmental justice" in the journal Environmental Science and Policy edited by: Francesc Baró, Nadja Kabisch, Johannes Langemeyer, Edyta Łaszkiewicz.

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[1] Nature-based solutions are interventions aimed as positive responses to societal challenges that involve the innovative application of knowledge about nature, inspired and supported by nature. These interventions can have the potential to simultaneously meet environmental, social and economic objectives (European Commission, 2015). Examples are urban parks, forests, rivers, and lakes and combinations of so-called grey and green infrastructure, like sustainable drainage systems, green roofs and green walls.

https://doi.org/10.1016/j.envsci.2020.06.024
Received 6 September 2019; Received in revised form 26 June 2020; Accepted 29 June 2020
1462-9011/

market as the effects of being located close to nature are capitalized in house value, which raises property and rental prices, and results in an influx of affluent people, displacing original poorer residents (Anguelovski et al., 2018). Hence, social injustices may be produced through ecosystem services-based urban policies and planning (Langemeyer, this issue). This possibility of green gentrification needs to be considered in urban planning since the most needy can be deprived of ecosystem services and their benefits that urban nature offers (Hochstenbach, 2017; Hochstenbach and Musterd, 2018). Gentrification is often associated with the United States, but green gentrification in particular is not a foreign concept in Europe or elsewhere, with many prominent cities seeing the departure of low-income residents in areas with improved green conditions (Harris, 2008; Gould and Lewis, 2016; Cole et al., 2019; Hochstenbach, 2017; Anguelovski et al., 2018).

A disturbing development for urban planners and dwellers is that gentrification is enhanced the past decades, with an increased percentage of lower income neighborhoods being displaced in 2000s compared to the 1990s (Maciag, 2015). Being caused by a variety of underlying processes, gentrification has recently been associated with the increased suburbanization of low-to-middle-income earners in Europe, and increased concentration of high-income earners in urban areas (Hochstenbach and Musterd, 2018). As an unintended consequence of green urban interventions, green gentrification signals latent social processes that urban planners need to acknowledge, monitor and manage to ensure that benefits of urban nature and ecosystem services provided by it can be universally promoted. Therefore, potential gentrification consequences of green renewal or other kinds of green interventions in residential areas need to be carefully considered before, during and after their introduction. Consideration should be given as to how environmental managers might focus activity and investment to balance environmental opportunities with the ongoing priorities of delivering socially inclusive, ecologically rich and climate change-resilient green spaces (Bell et al., 2017).

The hedonic pricing method is often used to measure the effect of environmental amenities on house prices. This method estimates the direct use value of nature to property owners as is embedded in house prices (for method beckground see Champ et al., 2003; for some recent applications see Sohn et al., 2020; Czembrowski and Kronenberg, 2016; Schläpfer et al., 2015). This analysis provides insights into the value local property owners attach to ecosystem services provided by nature in cities as is reflected in a willingness-to-pay as a mark-up for properties that are located close to urban nature sites. Insights into the benefits of nature-based solutions as well as the potential gentrification consequences of introducing nature to an area need to be considered by policy makers and city planners (Lafortezza et al., 2018), for which a better understanding of how house prices relate with different types of urban nature is useful.

In this study we perform a meta-analysis with the following objectives: to estimate relationships between property prices and different types of urban nature; and to illustrate the applicability of the derived value transfer function. Our study can provide first steps towards a better understanding and future modelling of potential implications of gentrification through house market dynamics, to limit adverse social impacts from the environmental justice and sustainable development perspectives on urban development. Our meta-analysis is based on 37 previously published hedonic pricing studies which estimated relationships between urban nature and house prices for specific areas. Even though conducting a primary hedonic pricing study in a particular area can give more reliable estimates for this particular area, such a study is data intensive and time consuming. In case a detailed site-specific valuation study is not feasible, applying benefit transfer method and value transfer functions in particular can serve as a useful alternative. Value transfer may also be useful for scaling up previous value estimates from local/regional to national or even continental levels, for example to estimate the impact of certain interventions at a European scale. We claim that such an application of value transfer may have the distinct advantage that transfer errors that occur at the local scales may average out at larger scales, potentially improving the accuracy and credibility of value transfer results. Further research on the validity of this claim is warranted. Moreover, a meta-analysis can give insights into overall patterns of results found in the literature of primary hedonic pricing studies (Bateman and Jones, 2003), and enhance our understanding of how different nature types, or green interventions, influence property price developments.

Our study extends a previous meta-analysis of hedonic house price relations with urban open space by Brander and Koetse (2011) in three ways. First, our study extends the types of urban nature (forest, park, green space, undeveloped land, and agricultural land) to also include blue nature, such as lakes, rivers and canals for a more detailed examination of how house prices relate with different urban nature types. Second, including more (recent) studies increases the statistical power of the analyses. Moreover, this update increases the number of included countries and regions, which allows estimating regional value transfer functions. Third, we illustrate the application of the derived value transfer function to actual nature-based solution projects from a recently developed database called the Urban Nature Atlas (www.naturvation.eu/atlas), and derive implications for gentrification. Quantitative assessment tools are thus complemented in our approach by visualised analytical tools, such as mapping, to plot price effects of proximity to new green projects on the housing markets in cities. By gaining a better understanding of the drivers of increased house prices, the issues associated with gentrification can be acknowledged, better monitored and addressed. In this way, this paper presents the quantification and assessment of ecosystem services and their impacts on urban populations by urban nature through interdisciplinary methods applied to understand distributive justice (Baró et al., 2020), with a particular focus on property markets as signal of potential green gentrification.

The remainder of this paper is structured as follows. Section 2 describes the database and statistical methods. Section 3 presents the results of the value functions and discusses how they compare with previous studies. Section 4 illustrates the applications of the derived value transfer functions to nature-based solution projects from the Urban Nature Atlas. Section 5 concludes.

2. Data and methods

The data used for the meta-model estimation contains observations that are value points obtained from primary hedonic pricing studies, evaluated at various distances from urban nature, which results in multiple value point observations per study. The meta-analysis presented in this paper builds on the earlier meta-analysis of primary hedonic price studies conducted by Brander and Koetse (2011) that analyzed the effects of urban green space on property prices. For reasons of consistency and comparability we have followed the same procedure for literature search as Brander and Koetse (2007) and Brander and Koetse (2011). In searching for studies specific key words were used which included three main components: valuation method, location, and the type of nature or ecosystem service. The resulting literature search yielded a collection of papers that included 37 new hedonic pricing studies that analyze the effect of proximity to both green and blue open spaces on house prices in urban areas. These articles were published between 2000 and 2017 and were not included in the original meta-analysis. Detailed description of the database is found in the Supplementary Material S1.

The meta-analysis presented in this study uses a multi-level model, in which value observations are at the first level and the primary study is the second level (see Bateman and Jones, 2003; Schmidt and Hunter, 2004; Brander and Koetse, 2011). The idea behind this approach is that there are characteristics in the context or in the methodological approach that determine whether observations are clustered at some levels. This means that clustered observations reveal systematic patterns between each other according to a specific characteristic, and not with other observations in the sample. Observations included in the model are weighted with the inverse square of sample size used in the primary study to account for the quality of primary estimates.

The estimated model is:

$$y_{ij} = \alpha + \beta^S \boldsymbol{X}_{ij}^S + \beta^M \boldsymbol{X}_{ij}^M + \beta^T \boldsymbol{X}_{ij}^T + \beta^D \boldsymbol{X}_{ij}^D + \mu_j + \varepsilon_{ij} \quad (1)$$

where i stands for the first level (observation) and takes values from 1 to 803, and j stands for the second level (primary study) and takes values from 1 to 37. The dependent variable y_{ij} is based on the estimated coefficients extracted from the primary valuation studies and transformed to our marginal effect size, i.e. the percentage change in house price due to a decrease in distance to nature of 100 m. The error term is split into two components, μ_j and ε_{ij}: the error term at the study level and the error term at the observation level, respectively. Both error terms are assumed to have zero mean and to be uncorrelated, meaning that they have constant variances σ_μ and σ_ε. Model specification with regions at the second level has been estimated, but performed worse in terms of model fit, and is therefore not presented here. Regional dummies for Asia, Europe and North America were also tested in order to control for the level of regional effect differences, but proved to be statistically insignificant, and were thus not included in the final model. In the case of the primary study at the second level, it can be expected that value observations that come from the same study might be closer to each other than values from other studies due to some intrinsic unobserved determinants which cannot be captured by the independent variables included in the model, such as for example similar data sets or preference for a particular research method, specific to each primary study.

The independent variables are separated into four groups. The vectors β^S, β^M, β^T and β^D, contain the estimated model coefficients for the variables included in $\boldsymbol{X}_{ij}^S$, $\boldsymbol{X}_{ij}^M$, $\boldsymbol{X}_{ij}^T$ and $\boldsymbol{X}_{ij}^D$, respectively.[2] The vector $\boldsymbol{X}_{ij}^S$ includes study and location variables, such as estimation point, as well as GDP per capita and urban population density. We have used GDP per capita instead of for example purchasing power per capita as it is consistent with the common practice and the previously conducted meta-analysis on the effect of urban green space on house prices (Brander and Koetse, 2011). It is also a common metric to correct for price level in the estimated meta-model, where average effect values from individual primary studies are analyzed. The vector $\boldsymbol{X}_{ij}^M$ includes methodological variables, such a distance over which the effect was obtained in a primary study, and model specification. The vector $\boldsymbol{X}_{ij}^T$ contains variables that identify the type of urban nature or biome. The vector $\boldsymbol{X}_{ij}^D$ contains the dummy representing landscape diversity of urban nature. This is a new variable that is added to this meta-model, which measures whether an urban nature site contains two or more natural landscapes, such as green parkscape and waterscape. This variable will capture the additional green premium, or price mark-up, that is attributed to the landscape diversity of urban nature (Łaszkiewicz et al., 2019).

Note, that in the way multiscape is defined in this study, it does not reflect the quality level (including maintenance, aesthetic quality, etc.) of urban green and blue areas, their quantity or abundance of other green and blue areas in the vicinity of valued nature.

For continuous independent variables such as evaluation point, distance, income and population density, the centered logarithm is introduced. The reason is that it allows us to interpret the constant as the capitalized value of urban nature in property prices for the reference urban nature type category and at the average values of independent variables, i.e. the effect at the average evaluation point and over the average distance, for a location with average income and density levels. Table 1 gives the coding of the variables and their means for the overall sample, as well as for subsamples for Europe and North America. We note here that the difference between the variables "evaluation point" and "distance" lies in the difference between spatial and methodological variables. In particular, "evaluation point" reflects the average distance *at which* the valuation was performed in a primary study, and is thus a spatial variable. At the same time, "distance" reflects the average distance *over which* the valuation was performed in a primary study, is connected to the scale of effect measurement, and is thus a methodological variable.

We estimate Eq. (1) for subsamples for Europe and North America in order to identify different patterns that are specific to each of the value functions of how urban nature affects property prices in these two regions. Such effect differences may arise due to various factors governing local preference for urban nature, for example its socio-cultural aspects such as favoring specific types of urban nature, general abundance of nature in and surrounding the cities, and income level. These aspects may influence both the level of willingness to pay for urban nature via property prices, and the relative significance of various factors contributing to the value of urban property.

3. Results of the hedonic pricing meta-analysis

In this section we describe the results of the hedonic pricing meta-analyses (Table 2). Model 1 is estimated for the whole sample and includes primary hedonic pricing studies from all over the globe, Model 2 is based on European studies, and Model 3 is based on North American (essentially, U.S.) studies. Our dependent variable is a relative indicator, meaning that in absolute monetary terms the value of nature or its characteristics may differ dependent on prevailing house prices.

Model 1 is estimated based on 803 value observations from 37 primary studies, Model 2 based on 159 value observations from 8 primary studies, and Model 3 on 562 value observations from 25 primary studies. Variances at both levels are statistically significantly greater than zero for all three models, which means that clustering of errors at the primary study level contributes significantly to the explanation of total variance. Due to its hierarchical structure, a multi-level model does not have a straightforward absolute fit indicator except for the log-likelihood statistic. In this case the models cannot be compared in terms of model fit because they are estimated on different sets of data.

The constant in the three models measures the percentage change in house price due to moving 100 m closer to the peri-urban nature (reference group of urban nature type), when the effect is measured at average or reference values of independent variables. That is, in Model 1 the constant measures the effect of a house price change of 0.220 % due to moving 100 m closer to peri-urban nature without a multiscape feature, at a distance of 162 m (average evaluation point), measuring the change over a distance of 154 m (average distance), at an average GDP per capita (USD 43,011), for an average population density (810 inhabitants per km2), using a non-linear functional form. Respective average values of independent variables for the interpretation of models 2 and 3 can be found in Table 1.

Among the location independent variables, evaluation point is negative and statistically significant in all models 1–3, meaning that houses at locations further from urban nature collect lower green premium compared to houses located closer to nature, and indicating decreasing returns to distance as the distance from urban nature increases. Coefficients of income per capita are both negative (model 1) and positive (models 2 and 3) but in all cases statistically insignificant against expectations and earlier findings on the positive and statistically significant relation between GDP per capita and WTP for urban nature

[2] Property prices are likely to be influenced by other variables, like the availability of public transport, which could not be included in our analysis because they were lacking in the primary valuation studies. Omitted variables would only bias our main coefficients of interest, which are the nature type variables, in case they significantly influence the relation between nature and property prices. For instance, this would occur if the availability of public transport would change the relationship between property prices and the presence of nature. There is no reason to expect that this is the case systematically, so we argue that our estimates are robust to these omitted variables.

Table 1
Variable description and sample statistics (st.dev. in parentheses).

Variable	Description	Overal sample mean	Europe-only mean	North America-only mean
N observations		**803**	**159**	**562**
Dependent variable				
% change	% change in property price due to 100 m decrease in distance to urban nature	0.924 (1.857)	1.497 (2.317)	0.823 (1.74)
	minimum ; maximum	*−7.251; 13.550*	*−7.251; 13.118*	*−5.960; 13.55*
Study and location variables:				
Asia	1 = primary study conducted in Asia, 0 = otherwise	0.022	0	0
Europe	1 = primary study conducted in Europe, 0 = otherwise	0.198	1	0
North America	1 = primary study conducted in North America, 0 = otherwise	0.700	0	1
Evaluation point*	Distance at which primary measurement took place	162	178	157
	minimum ; maximum	*1; 7116*	*1; 7116*	*1; 2912*
GDP *	GDP per capita in 2016 US dollars	43,012	42,321	45,958
	minimum ; maximum	4,235; *55,747*	*13,145; 55,747*	*25,837; 52,983*
Population density *	Population density in number of people per km^2	810	480	1006
	minimum ; maximum	*23; 6014*	*23; 4371*	*138; 6014*
Methodological variables				
Distance*	Distance over which the effect was valued in primary study	154	143	168
	minimum ; maximum	*0.30; 2400*	*1; 1000*	*0.30; 2400*
Linear	1 = linear functional form used in primary study, 0 = otherwise	0.087	0.321	0.034
Double-log	1 = double-log functional form used in primary study, 0 = otherwise	0.621	0.302	0.696
Semi-log	1 = semi-log functional form used in primary study, 0 = otherwise	0.267	0.377	0.235
Box-Cox	1 = box-cox functional form used in primary study, 0 = otherwise	0.025	0	0.036
Type of urban nature / biome:				
Forest	1 = effect of an urban forest is captured in primary study, 0 = otherwise	0.136	0.252	0.101
Park	1 = effect of an urban park is captured in primary study, 0 = otherwise	0.328	0.289	0.329
Other urban green space	1 = effect of other open green space is captured in primary study (such as neighbourhood green spaces, pocket parks, green corridors), 0 = otherwise	0.146	0.195	0.125
Blue	1 = effect of urban blue nature is captured in primary study (such as lake, ponds, rivers, streams, canals, urban sea coasts, wetland), 0 = otherwise	0.255	0.075	0.326
Peri-urban	1 = effect of peri-urban nature bordering on urban areas is captured in primary study (such as undeveloped land, agricultural land, golf course), 0 = otherwise	0.136	0.189	0.119
Lansdcape diversity				
Multiscape	1 = studied nature in the primary study resembles multiple landscape types (such as green and blue), 0 = otherwise	0.412	0.572	0.331

Note: * We do not report the standard deviation as these are average values at estimation, i.e. average ln(x).

(Brander and Koetse, 2011). The coefficient of the population density is positive, which is in line with expectations from previous studies, but is not statistically different from zero in either of the three estimated models. Current findings thus indicate independence of the relative weight of the green premium relative to distance in the composition of property price throughout various levels of income and urban density.

A linear model specification in a primary hedonic pricing study (methodological variable) significantly adds to the average level of the effect of urban nature on property prices in models 1 and 3, and acts as a methodological control variable. Distance over which the effect is estimated is not statistically different from zero at conventional significance levels in either of the models. This variable acts as a methodological control variable of decreasing returns to distance as the measurement range increases in primary studies.

All models in Table 2 feature a specification that includes 4 dummies for urban biomes, or types of urban nature, such as urban forest, park, other green urban spaces, blue urban nature, in addition to peri-urban nature (reference category). These variables signify the different ways that types of urban green space are capitalized in house prices. Globally (model 1), urban parks (0.78 %) and blue nature (0.57 %) add statistically significantly to the value of urban property compared to peri-urban nature, resulting in total in 1.00 % higher property values for a park and 0.79 % for blue nature, ceteris paribus. The multiscape dummy in model 1 is a proxy for the diversity of urban nature, which increases house prices by an additional 0.5 %.

The European model reveals statistically significant positive coefficients for urban forest, urban park and blue nature, resulting in the expected increase in the house price due to moving 100 m closer to an urban forest or park in a European city of 1.82 %, 2.06 % and 0.47 %, respectively. The multiscape variable was excluded from the model for the European sub-sample to avoid multicollinearity. The North American model reveals statistically significant and positive coefficients only for urban blue nature, which compared to peri-urban nature results in the effect size of 0.59 %. The multiscape dummy in model 3 has a positive coefficient (p-value < 0.063), again suggesting positive returns to diversity of urban nature.

We observe differences in the effects of different types of urban nature on house prices in North America and Europe; urban blue nature is appreciated on both continents, while urban forest and parks are particularly appreciated in Europe. We note that the American and the European sub-samples differ; the population density and urban income per capita have higher average levels in American cities compared to European ones (Table 1), which would be expected to result in stronger effects of the presence of nature on house prices through scarcity and income mechanisms. However, our models show no statistically significant association between urban density respectively income, and the effect of proximity to urban nature on house prices. This suggests that observed differences in estimated effects could be attributed to differences in preferences for nature between American and European urban residents.

4. Value function application for the case of Utrecht: European Urban Nature Atlas and implications for gentrification

In this section we illustrate the application of our value transfer functions. These functions can be used to estimate the influence of planned nature in cities on property prices. This way city planners can obtain insights into impacts of nature development projects on the prices and affordability of properties. Although our analysis does not capture rental prices directly, it can be expected that increased property

Table 2
Hedonic pricing meta-regression estimation results. The dependent variable is the % change in house price due to 100 m decrease in distance to nature (coefficients are reported with their t-statstics in parentheses).

	MODEL 1 Whole sample (global)	MODEL 2 Europe only	MODEL 3 North America only
Constant	0.220	0.127	0.241
	(0.75)	(0.16)	(0.88)
Location variables			
Evaluation point (ln)	−0.549***	−0.263**	−0.581***
	(-4.28)	(-2.03)	(-3.04)
GDP per capita (ln)	−0.204	0.898	0.230
	(-0.42)	(0.58)	(0.25)
Population density (ln)	0.170	0.096	0.232
	(1.03)	(0.20)	(1.24)
Methodological variables			
Linear functional form	0.683***	1.585	0.761***
	(2.72)	(1.57)	(2.64)
Distance (ln)	−0.031	−0.698*	−0.024
	(-0.47)	(-1.82)	(-0.39)
Type of urban nature *(reference group: peri-urban nature)*			
Forest	0.526	1.821**	0.373
	(0.93)	(2.50)	(1.18)
Park	0.781***	2.056***	0.548
	(3.11)	(5.67)	(1.49)
Other urban green space	0.504	−0.035	0.739*
	(1.35)	(-0.05)	(1.66)
Blue nature	0.572**	0.471**	0.591**
	(2.25)	(2.48)	(2.35)
Lansdcape diversity			
Multiscape	0.500**		0.680*
	(1.97)		(1.86)
Random variables			
Estimate variance (study)	1.096**	3.719**	0.882**
	(0.35)	(2.84)	(0.57)
Residual variance	2.046**	2.757**	1.776**
	(0.46)	(0.61)	(0.59)
Estimation statistics			
−2LL	−1467	−318	−986
AIC	2960	660	1992
VPC	0.349	0.574	0.332
N observations	803	159	562
N studies	37	8	25

*. **. *** indicate statistical significance at the 10 %. 5 %. and 1 % level. respectively.

values are in the end passed on to renters in the form of higher renter prices, although this depends on local conditions, such as price regulations or quotas in rental markets. Price increases as a result of the development of nature in cities may under certain circumstances result in gentrification, if lower-income households cannot afford the high prices and are replaced over time by new residents with higher incomes. Our value transfer functions can be used to raise awareness of this issue and serve as a first quick scan by showing whether high property price increases can be expected in an area as a result of planned nature development, which may trigger a gentrification process. However, it should be realized that the occurrence of gentrification is a complex process that, among others, depend on the socio-economic conditions in an area, how the development process is conducted, and what other policies are in place in a city that may limit gentrification processes, like social housing. If the quick scan application of the value transfer function shows the potential of substantial property price increases, then additional examination should be conducted to explore whether indeed gentrification will be problematic and how such adverse effects can be limited. Moreover, apart from gentrification, our value functions show the value of urban green and blue through house prices, irrespective of the owner and use of the house.

4.1. Value transfer function

To illustrate the application of our estimated value transfer function, we have made use of the Urban Nature Atlas (the NATURVATION project: www.naturvation.eu/atlas). It includes an extensive, albeit not exhaustive, selection of green urban initiatives and interventions across Europe that have been completed, are being planned or are in implementation in varying urban conditions, with wide differences in socioeconomic, ecological and geographic circumstances. The Urban Nature Atlas includes intervention-specific information, such as the type of urban nature and landscape, ecosystem services provided by it, the type of intervention and institutional context, urban sustainability challenges, budget amount, etc. (Almassy et al., 2017). We illustrate the application of our estimated value transfer functions for a Dutch city, Utrecht. with 10 green urban initiatives (described in the Online Supplementary Material S2), although the value functions are more broadly applicable to other cities since they are based on global primary valuation studies. Utrecht was chosen as an illustrative example since it experiences environmental pressures as well as ongoing population growth due to its central position in the country and rich cultural heritage which attracts new inhabitants. Moreover, affordability of housing for low-income households and gentrification is a concern of city planners in Utrecht (Utrecht Municipality, 2019).

For the application, the global value transfer function based on estimated meta-regression model 1 is reported below (Eq. (2), results from Table 2). LN stands for a natural logarithm, D stands for a dummy variable that takes a value of 1 if true, and 0 otherwise. We also recall that all continuous explanatory variables are centered logarithms of respective average values of independent variables as found in Table 1.

$$
\begin{aligned}
&\%\text{ change in house price due to 100m decrease in distance to nature}\\
&(\text{GLOBAL}) = 0.220 - 0.549{*}(\text{LN}(\text{Evaluation point}) - \text{LN}(162)) -\\
&\quad 0.204{*}(\text{LN}(\text{GDPpc}_{\text{Inc}}) - \text{LN}(43.011))\\
&\quad + 0.170{*}(\text{LN}(\text{Population density}) - \text{LN}(810))\\
&\quad + 0.683{*}\text{D}(\text{Linear model}) - 0.031{*}(\text{LN}(\text{Distance})\\
&\quad - \text{LN}(154)) + 0.526{*}\text{D}(\text{Forest})\\
&\quad + 0.781{*}\text{D}(\text{Urban park})\\
&\quad + 0.504{*}\text{D}(\text{Other urban green}) + 0.572{*}\text{D}(\text{Blue})\\
&\quad + 0.500{*}\text{D}(\text{Multiscape}) \qquad (2)
\end{aligned}
$$

Table 3 presents relevant variables for applying the value transfer function to nature interventions in Utrecht. Inner-city variability in income can be quite substantial. In this application we have used city average values for population density and per capita income, conform

Table 3
Key explanatory variables for the city of Utrecht.

	Utrecht. Netherlands
Average GDP per capita (USD)[a]	53.558
Average house price (2017, USD) [a,b]	341.588
Average value of housing property (2017, USD) [a,c]	260.850
Average population density (pers/km^2)	3658
Range of the evaluation point (m)	100 − 4000

[a] Assumed prevailing exchange rate of 1 EUR = 1.11 USD.
[b] Average house price is determined on the basis of all sold housing properties in a given year, within a municipality. Source: Statistics Netherlands (CBS, https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83625NED/table?ts=1567154700379).
[c] Average value of house price (WOZ. in Dutch) is the value that is determined by each municipality for all housing property within its administrative borders for the purposes of taxation. It is based primarily on the market value of housing property (Waarderingskamer, 2010, 2017). Source: Statistics Netherlands (CBS. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37610/table?fromstatweb).

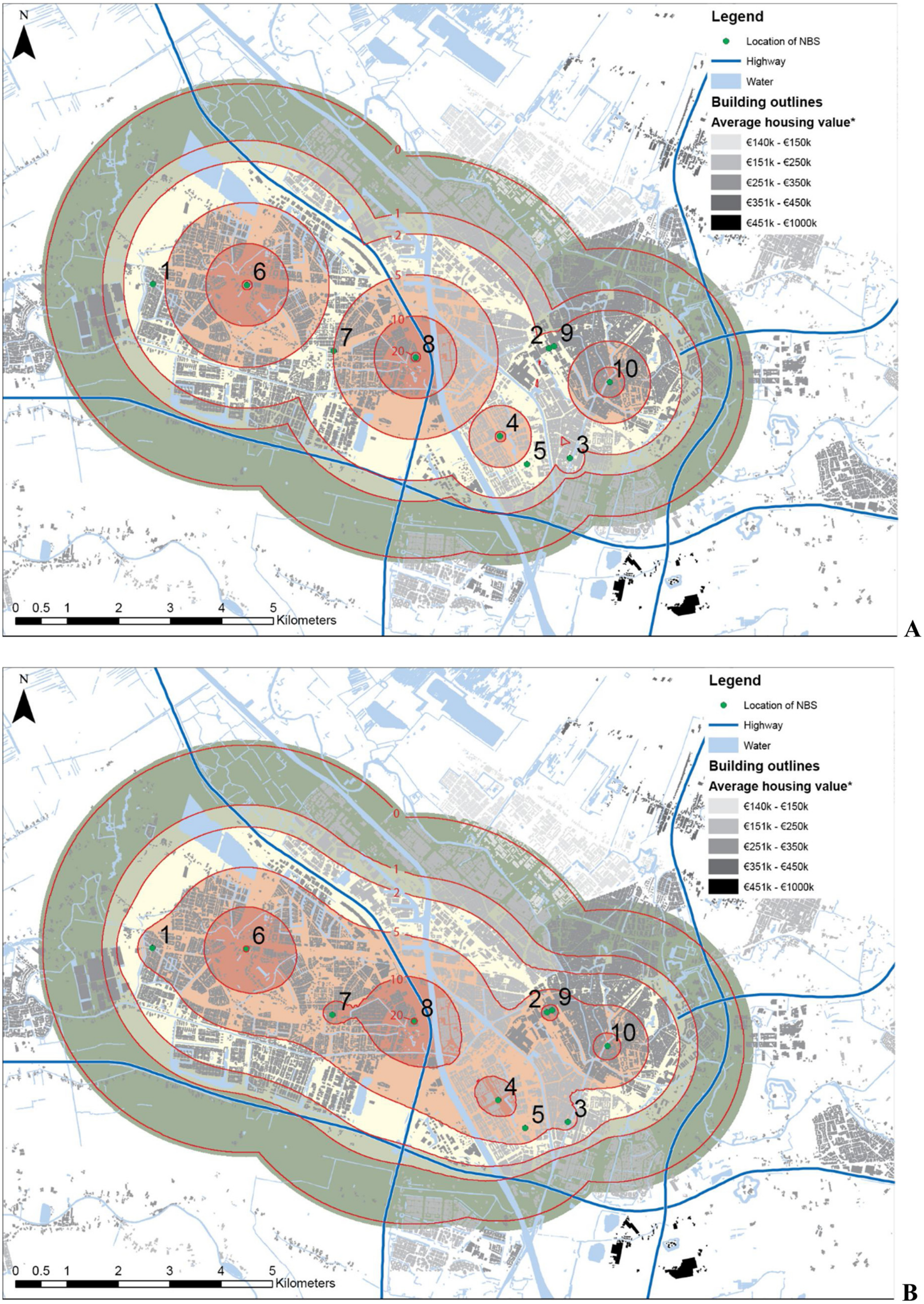

Fig. 1. City-level application: estimated extent of spatial impacts of multiple nature-based interventions on house value in Utrecht using model 1 (global value transfer). Panel A: maximum effect for the overlapping values; panel B: the sum of effects for the overlapping values.
*Average housing values at the neighbourhood level in Utrecht for the base level of 2017, (CBS, 2017).

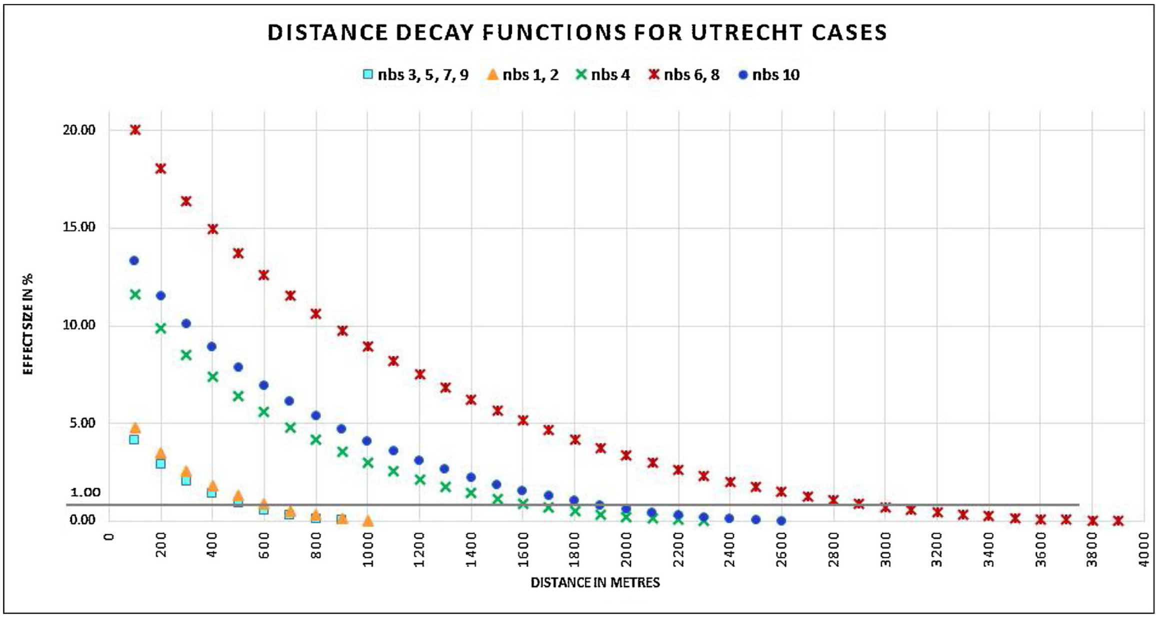

Fig. 2. Distance decay functions for the 10 urban nature interventions in the city of Utrecht. plotting the estimated cumulative effect of urban nature-based solutions (nbs) on house value using model 1 (global value transfer), with the marked 1 percent threshold value.

the derivation of the value function in the meta-function. Information on the value of housing property on the neighborhood level was obtained from the Statistics Netherlands (Table 3).

4.2. Effect visualisation

For visualization purposes, we have mapped the data on the estimated effects of the selected interventions on the housing market. To our knowledge, this is a first use of mapping to such application where socio-economic impacts are related to the location of urban nature. Earlier uses of mapping in relation to urban green included a variety of health effects of urban green and green interventions (Reid et al., 2009; Dadvand et al., 2012; Norton et al., 2015; Flacke et al., 2016), mental health (Gascon et al., 2015), physical activity (Lwin and Murayama, 2011; Brown et al., 2014), social need (McPhearson et al., 2013), crime and violence (Gorham et al., 2009; Wolfe and Mennis, 2012). By combining our classical representation of results, as shown in previous tables, with a visual application on a map, we can make a more integrated representation of the application results, at a city level. Such visualisation to our knowledge has not been done in previous meta-analysis applications. The background layer of the map on Figs. 1 and 3 contains different shades of grey on building footprints to provide a better visualization of urban fabric, and the average values of housing property at the neighbourhood level in Utrecht for the base level of 2017, which are readily available from the Statistical Office (CBS, 2017). Cumulative effects (as explained below in this section) are displayed as aggregates on a a per-pixel basis, leading to a spatially continuous representation. Highways act as additional orientation landmarks in the city.

It is possible that nature interventions in urban areas appear close to each other, and that their effects can therefore overlap. If this occurs, assessments of an individual impact of each intervention may not be the best way of understanding, presenting and analysing its impacts as they are not able to show those overlapping impacts of nature on a neighbourhood or a city level. First, we shall describe and interpret individual effects (marginal and cumulative) of a specific intervention on the house value, which will be followed by a reflection on the value of overlapping effects of multiple interventions on the house value on the neighbourhood level.

Marginal effects resulting from the application of the global value transfer (model 3) should be interpreted in the same way as the results of the estimated meta-models in Section 3. For example, for intervention 6 (Maxima Park), houses that are found 300 m away from the park would expectedly increase in value by 1.41 % if they would be found 200 m away from the park (see Table S3, column 3 in the Supplementary Material). However, marginal effect representation on a map is not straightforward as it does not reflect the total effect of an intervention on property value at a specific location, which is often used for estimations of welfare changes. Alternatively, in such cases cumulative effect is able to reflect such a total effect as it sums marginal effects throughout the range at which a positive marginal effect of urban nature is estimated.

The maps on Fig. 1 thus portray cumulative effects of urban nature interventions on property values for 10 interventions in the city of Utrecht, which included urban parks, small green patch parks and blue nature (canal renovation and sustainable drainage system). We notice that different interventions have expectedly different effects on the house value, in particular in terms of the range at which this effect is positive, as well as the size of the effect. For example, for urban parks like interventions 6 and 8, the positive effect stretches up to 3900 m from the intervention and reaches a maximum cumulative effect of 20 % for properties found directly at the park compared to those found at 3900 m distance. This is essentially the effect of the park on the property value compared to the property where this effect is not positive, or is not present anymore. For urban blue nature like interventions 1 and 2, the positive effect stretches up to 1000 m with the maximum cumulative effect of 4.77 %, and for other urban green nature with a multiscape like intervention 4, the positive effect stretches up to 2300 m with the maximum cumulative effect of 11.64 %. Fig. 2 resembles the distance decay functions estimated for Utrecht interventions, by type of intervention. Besides, Supplementary material contains Table S3 where application results for the interventions 3 through 6 are presented and include both marginal and cumulative estimated effects.

The resulting differences in house value depend on the prevailing house value in the area, which differ throughout the city. For the case of the Maxima Park (intervention 6), the maximum cumulative effect of 20.05 % would translate into the expected difference in value of 62,656 USD for the average house value of 312,400 USD in the area. At the same time, for the City Island Ring Park (intervention 4), the maximum cumulative effect of 11.64 % would translate into the expected

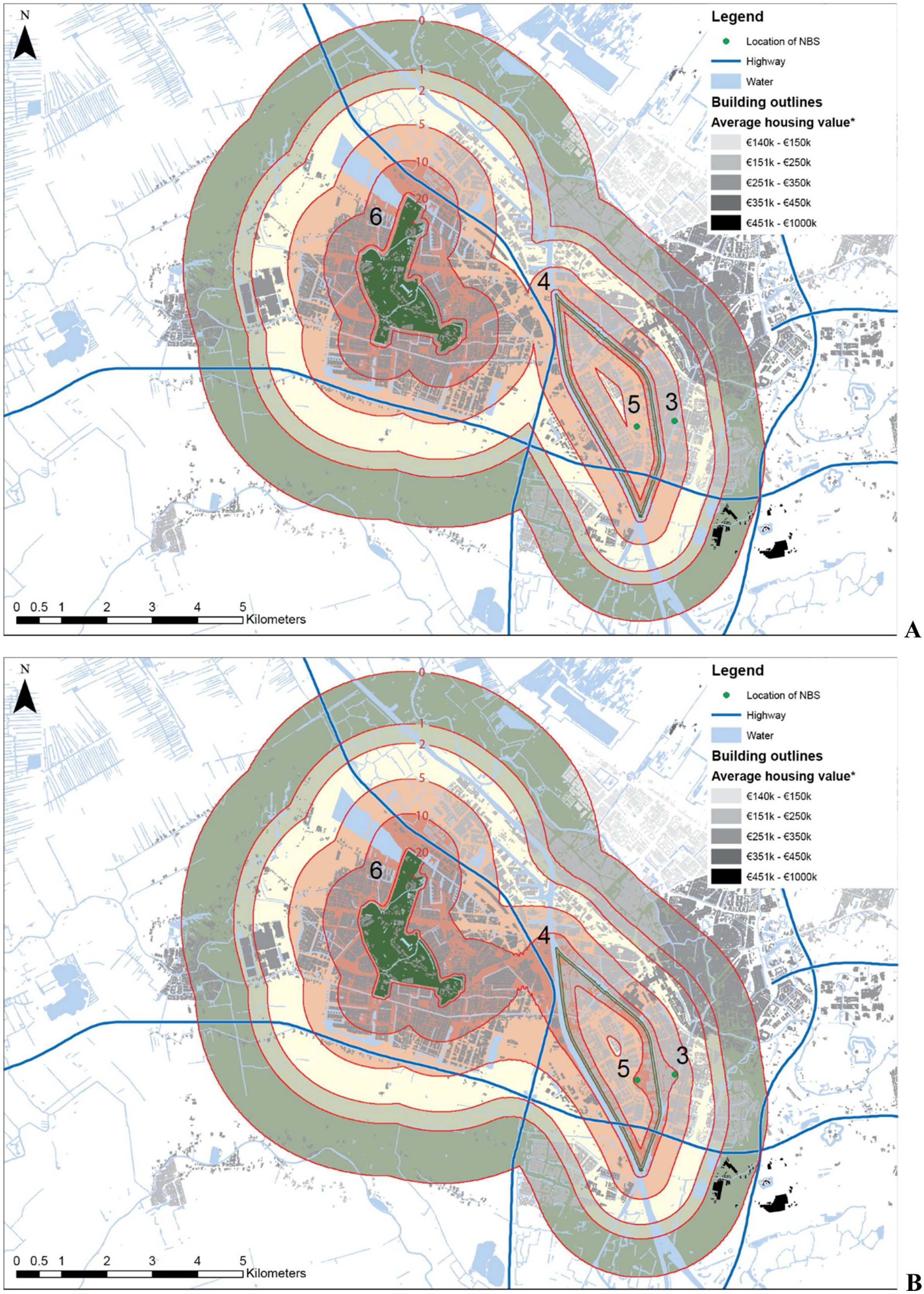

Fig. 3. Case-specific application: estimated effects of the City Island park ring (4) and the Maxima Park (6) with their respective shapes, plotting the cumulative effect of urban green on house value using model 1 (global value transfer). Panel A: maximum effect for the overlapping values; panel B: the sum of effects for the overlapping values.
*Average housing values at the neighbourhood level in Utrecht for the base level of 2017, (CBS, 2017).

difference in value of 22,535 USD for the average house value of 193,600 USD in the area. For a green neighborhood square (intervention 3), the maximum cumulative effect of 4.11 % would translate into the expected difference in value of 8736 USD for the average house value of 212,300 USD in the area.

As we pointed above, the effect ranges and effect sizes differ for various green and blue interventions as we have applied them to the 10 cases in the city of Utrecht. Fig. 2 shows the distance decay functions for all these cases, marking the maximum cumulative effects and the spread of their respective ranges. We note that due to the functional form of the global value transfer function, some depicted distance decay functions have a long tail when approaching zero. For example, the estimated positive cumulative effect of interventions 6 and 8 (urban parks) stretches as far as 3900 m, which may seem unrealistic. Marking the 1 % threshold for the cumulative effect, below which the effect on the house value may essentially be seen as negligible, may provide a so-called effective range of cumulative effects. In such a case, the effective range of the cumulative effect for urban green and blue interventions drops to 2900 m for the urban parks (nr. 6 and 8), and to 500 m for urban blue nature (nr. 1 and 2). Such an approach to interpretation of value transfer function application results may offer more realistic indications of actual value changes at the city level.

However, as Fig. 1 shows, the cumulative effects of each particular intervention overlap in many instances, even for the selection of 10 interventions which are taken as illustrations in this particular case, with other interventions in a city. This means that the overall resulting effect on the house value may be even higher than the effect of a single intervention. Besides, some of the interventions cover a bigger area, which means their point representation on a map is not realistic. To explore this, we have zoomed into the intervention 4, the City Island Ring park, where a continuous park ring is being created along the canals surrounding the City Island of Utrecht. Fig. 3 shows the shape of the City Island and its park (in green), and its effect sizes throughout the surrounding area. In this particular case, the effects stretch both within the City Island, and outside the City Island. We have also depicted interventions 3 and 5 to illustrate the overlap of a major intervention 4 with minor interventions at a neighborhood scale. For example, houses at the third ring of intervention 4 (the City Island Ring park), within the City Island would expectedly increase in value by 8.54 %. However, the presence of intervention 5 (Food for Good garden) may add extra value to those houses as they overlap with the first ring of intervention 5. Adding both overlapping effects together at this location would result in the expected increase in property value of 12.66 %, or 25,153 USD for the average house value in the area (Fig. 3, panel B). Another example of overlapping effects at this local scale is the cumulative effect of the major urban park in Utrecht, Maxima Park (intervention 6), which we have also depicted with its actual shape. In this way, the non-trivial effects of the Maxima Park overlap with the non-trivial effects of the City Island Ring Park, which was not evident at the city level (Fig. 1A, the two interventions do not seem to overlap). As Fig. 3B shows, there is an extensive area where the cumulative effects of interventions 4 and 6 overlap in the non-trivial range. For example, in the area where the yellow effect rings of both interventions overlap, the properties located in this area may experience a double effect on their value, adding up to 10–11 % in total. It is important to notice here that theory does not provide a rule of thumb concerning value transfer function applications and overlapping effects of multiple urban green and blue areas as in the cases discussed above. Essentially, it is natural to assume that vicinity of multiple urban nature areas would add more to the property value in a particular location than vicinity of a single piece of nature. However simple addition of individual cumulative effects of multiple interventions should be overestimating the true effect, due to the decreasing returns to scale and, thus, not only due to the distance decay, but also due to the amenity satiation effect. We further discuss this point in Section 5. We thus suggest that the highest of the overlapping effects would serve as a lower bound for the total effect estimation (Figs. 1 and 3, panel A), while addition of all overlapping effects would serve as its upper bound (Figs. 1 and 3, panel B). For the same example, the effect of the City Island Ring park (effect ring 6 of intervention 4 in Supplementary material S3) in the Hoge Weide area would alone correspond to the expected increase of house value of 5.58 %, or 14,500 USD; the additional effect of the Maxima Park (effect ring 15 of intervention 6, idem) would add extra 5.67 % to the expected increase of house value and total 33,380 USD, at average prevailing value in the area of 289,300 USD per property.

5. Discussion

5.1. Value transfer function and its limitations

In this section we address main limitations associated with the results of our estimated value transfer function and its application. In general, a meta-analysis can only take into account variables that are common to all primary valuation studies that are included in the analysis. As such, a first possible limitation of our study is that is that the set of explanatory variables included in our model is restricted. For example, relevant excluded variables could include additional contextual or spatial variables, such as area sizes of studied nature areas or availability of other nature areas that may be used as substitutes for the nature areas under study. These variables were not available for all primary studies in our sample and can therefore not be included in the presented meta-models. Systematic inclusion of such additional information in future primary valuation studies should not only enrich the primary hedonic pricing studies, but will strengthen the evidence base for meta-analyses and thus improve the benefit transfer applications by better informing practitioners and policy-makers on the expected effect of green policies in urban areas.

Another limitation of hedonic pricing studies is the lack of information from transactions data on specific ecosystem services that homeowners are willing to pay for when they pay a higher price for a property that is closely located to nature. This means that without additional data from each primary study it is not possible to explicitly pinpoint and hence control for ecosystem services in our analysis. We added Supplementary Tables S4.1 and S4.2 which show the distribution of ecosystem services that were mentioned in primary valuation studies, as assumedly being related to the type of nature examined in that study. These tables show that a broad range of ecosystem services were associated with the specified nature types including: (1) provisioning services, like raw materials from forests, (2) regulating services, like flood and climate regulation from blue nature, and (3) habitat services, like biodiversity from parks. The five most frequently reported services are: recreation, aesthetic appreciation, noise reduction, flood regulation and water purification.

Although our case study in Utrecht is merely meant as an illustration to demonstrate general applicability of the method, it also reveals a trade-off that this method poses in terms of scale. While a city level application offers a quick scan of effects of multiple nature interventions, an application at a local level may offer more precise estimates especially if the actual shape of interventions can be depicted. Here, the practitioner has to realise that obtained effect estimates are originating from averaged affects and studies collected all over the world, without specific reference to urban morphology or the housing market. Therefore, it is important to stress that our approach can be used for applications in other EU cities, and more widely for assessing the values of urban green and blue at national or even continental scales. We argue that such scaling up may have the added advantage that transfer errors that occur at local scales may average out at larger scales, which would improve the accuracy and credibility of value transfer results. As far as we could find, empirical work on this particular issue is lacking, and future studies are needed to look into the validity of this claim.

Our estimates of the (dollar) value changes may be considered quite conservative. This is due to the fact that while the indicator of average property value is related to house sales prices, it lags behind the ongoing developments in the housing market which may bring about greater changes in the spot sales prices. When new nature is being planned in urban areas our mapping approach can be used for assessing potential undesirable property price effects that may lead to green gentrification, and for identifying where additional policies may be needed to limit such effects, like social housing.

Simple addition of multiple overlapping effects may lead to over- or underestimation of values. As table S1 reveals, 18 out of 37 primary studies used in our meta-analysis included multiple nature types in the vicinity of housing properties, all of which were assumed to simultaneously influence the purchasing price. This means that if primary studies have modelled the availability of other natural areas in the study site, they should have identified unique effects of each of those multiple types of nature on the house price. This implies that effect sizes of home properties obtained in the meta-analysis can be attributed to a particular type of urban nature, independent of the presence of other types of urban nature in the vicinity of property of interest. Because we have not explicitly modelled substitution in our meta-analysis due to data restrictions, value transfer should lead to value underestimation (overestimation) when the policy site has a lower (higher) availability of substitutes compared to the average availability of substitutes of study sites in our meta-analysis sample. More empirical work on the effects of substitute availability is needed, especially in the context of meta-analysis and value transfer.

Finally, our example serves purely illustrative purposes, and applications for other locations can be made depending on valuation needs and data availability. While value transfer based on the European and the North American functions (models 2 and 3, respectively) can be derived in a similar way, we note that the European function based on model 2 should be treated with particular caution for benefit transfer purposes as it appears to overestimate the effects of most types of nature on house prices, judging by the fact that the value function suggests that value effects of urban nature spread over unrealistically long distances. In that respect the predictive validity of the global value transfer function is substantially higher. Therefore, for all applications, the global value transfer (model 1) is suggested as the preferred function at the moment.

5.2. *Using the value transfer functions to identify potential gentrification issues*

Our application of the value transfer functions illustrates how different green interventions have a variety of effects on the housing market, and under which circumstances large effects on house value can occur. Neighbourhoods in the vicinity of multiple green interventions may experience higher percentage increases in house value due to the cumulative effects. Clearly, the absolute amount of house value changes depends on local conditions, such as prevailing house value in the area, which may vary substantially within a city. Our mapping analysis can be used to visualise in which areas high percentage increases in house value can be expected due to the creation of additional nature in cities, and show whether this occurs in areas where house value are already high. This information can be used to visualise the quantified information on the expected effects on the housing market, and serve as a quick scan for identifying areas where green gentrification may occur (Hochstenbach. 2018), although gentrification is a complex process for which additional examination would be needed to determine its severity and possible solutions. For instance, in some neighbourhoods the development of nature can increase value of housing where the average house value is already high. In such a neighbourhood, a gentrification process can already be ongoing and improved green infrastructure may further accelerate it. As in the example above of Hoge Weide area above, a yearly gross income of approximately 71,700 USD, which is about twice modal income in the Netherlands, would be necessary to be able to obtain a mortgage for financing a purchase of a 322,680 USD house. Moreover, rental prices and house prices are connected to the value of house property. This implies that increasing house prices are reflected in higher rental prices that may become unaffordable for lower-income households, in particular for younger adults who often have to rely on the financial support from their parents even after moving out of their parents' home (Hochstenbach, 2018; Amsterdam Municipality, 2019).

It should be noted that the development of urban nature is often not the main cause of problems with affordability of housing for low-income households (Amsterdam Municipality, 2019), but the effects of nature on property value and property prices can exacerbate such problems. This does not mean that additional nature should not be developed, since it brings various benefits that are clearly valued by people as is reflected in their willingness to pay higher prices for property close to nature. It does mean that possibly undesirable effects, like green gentrification, should be assessed when new nature is being developed in urban areas, and additional policies may be needed to limit such effects. Mapping approach such as multi-layering of data can be even more helpful for policy and practice offering an integrated approach to the solution of urban challenges. For example, combining city maps of nature intervention impact on the house value with additional information, such as physical and mental health status of city residents or prevailing environmental conditions (Flacke et al., 2016; Gascon et al., 2015) as well as crime and violence levels (Gorham et al., 2009; Wolfe and Mennis, 2012) may better guide city planners on the decisions concerning the best areas for green interventions as well as signal problematic areas for potential green gentrification. Possible solutions could be the development of social housing in existing green neighbourhoods in order to promote social and environmental inclusion and keep neighbourhoods accessible for low-income families. Moreover, a more even provision of green spaces throughout the city would ensure equal benefits for all inhabitants.

6. Conclusion

Ecosystem services provided by nature interventions, such as nature-based solutions, present an opportunity for cities to offset problems from increased urbanization and climatic changes. By combining natural characteristics with grey infrastructure. urban nature creates benefits for citizens and visitors, and results in a more aesthetically pleasing city. However, the economic and social impacts of natural interventions remain insufficiently considered in urban ecosystem services assessments (Marshall and Gonzalez-Meler, 2016). Nature-based solutions often impact the housing market with rising house and rental prices. As a result, and most often unintentionally, lower income populations become displaced by better-off inhabitants, and thus become deprived of the advantages of urban nature that are of particular benefit to them (Lovell et al., 2018). Such processes of green gentrification need close monitoring that can be facilitated by an assessment of the impact of (newly) developed green and blue areas on housing markets.

This study conducted a meta-analysis to estimate value transfer functions that can be used for assessing the impacts of urban nature on house prices at different distances from the nature site. Compared to a previous study (Brander and Koetse, 2011) our updated meta-analysis includes more types of urban nature and more observations from different countries, which among others allows for estimating regional benefit transfer functions. The results show that urban nature has an impact on house prices in the areas surrounding it, and that the magnitude of this effect decreases as house distance from nature increases, revealing conventional distance decay relationship. Furthermore, the results show that the impact on property prices differ by type of nature intervention. In particular, homebuyers value the presence of a park or blue nature in the vicinity of their property more the presence of other types of urban nature. This effect can be explained by the high direct use value (Hein et al., 2006) created by many ecosystem services of urban parks and blue nature such as aesthetics, recreational opportunities and local climate regulation.

In our application of the European value transfer function to green interventions in a Dutch city of Utrecht, we have used maps to overlay the effects of these interventions on the housing market with the average value of housing property in the city. This information can be used for identifying areas where green gentrification may occur. These maps show the distance decay of the cumulative effects of urban nature interventions on the house value at the city and the neighbourhood levels. We estimated increases in local property values up to a maximum of 20 % compared with properties not affected by the interventions, with value equivalent of 62,650 USD, at average prevailing price level in a particular area in Utrecht. Besides, overlapping effects of nature may in specific neighbourhoods double the increases in property values from 5 to 6% to 10–11 %. We recognize that simple addition of individual cumulative effects of multiple interventions should be overestimating the true effect, and thus suggest that the highest of the overlapping effects could serve as a lower bound for the total effect estimation, while addition of all overlapping effects would serve as its upper bound. Further research should shed light into the dynamics of multiple overlapping effects of urban nature.

Our analysis showed that the presence of urban nature has a distinct positive impact on housing prices in the areas surrounding it. This insight is useful for monitoring the societal dimension of green interventions, tailoring policy and helping stakeholders build understanding of the environmental, economic, and social impacts of green urban interventions. Future research on nature-based solutions in cities and their impacts on house prices can focus on nature interventions and the process of gentrification using integrated urban justice assessments, because planning and implementation of nature interventions require integration of multiple data and balancing stakeholder priorities and interests. Doing this could provide more direct insights into the potential societal impacts that nature-based solutions can create, in addition to assessing benefits that they bring to cities on an ecological or aesthetic level.

CRediT authorship contribution statement

M. Bockarjova: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing. **W.J.W. Botzen:** Conceptualization, Methodology, Validation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition. **M.H. van Schie:** Software, Writing - review & editing, Visualization. **M.J. Koetse:** Conceptualization, Methodology, Validation, Writing - review & editing.

Declaration of Competing Interest

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

Acknowledgments

This research received funding from the Horizon 2020 Framework Programme of the European Union, NATURVATION project (grant number 730243). We are also indebted to Nikola Lipovac and Alberto Oeo for their assistance in database compilation.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2020.06.024.

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