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EXAMINING FLORISTIC BOUNDARIES BETWEEN GARDEN TYPES AT THE GLOBAL SCALE[1]

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ABSTRACT

Gardens represent important sources of goods and services for their owners. This functionality translates directly into the types of plants cultivated in a given garden, and terminology has been developed to distinguish each category of garden according to its purpose. The factors explaining the differentiation and distribution of gardens have not previously been explored at the global scale. In this study, the plant lists for 44 sets of gardens from around the world were analyzed to explore their taxonomic similarities and the factors shaping each garden. Several biophysical and socioeconomic variables were examined at the appropriate scale for their roles in garden species distribution. Physical and climatic factors (temperature, rainfall, potential evapotranspiration and distance between settlements) were found to be significantly related with species makeup; all of these factors were less important than GDP per person, a proxy for household income, which was determined to be the primary driver of garden composition. All of the studied socioeconomic factors, such as language similarity among settlements and population density, were significant drivers of species distribution. However, the present analysis omits a number of variables due to data unavailability, such as garden size and owner gender, which have been previously recognized as influences on garden plant composition. The genera cultivated in different gardens were found to be very different from each other, and the definitions of each type are hard to establish from these data alone. Finally, the implications of likely future income variations, such those caused by severe economic crisis, and global climate change on bio-cultural diversity and food security are discussed.

Keywords: Gardens, homegardens, biodiversity, ethnobotany, food security.

RESUMEN

Examinando las fronteras florísticas entre tipologias de jardín a escala global

Los jardines son una importante fuente de bienes y servicios para los residentes de un hogar. Su función se traduce directamente en el tipo de plantas que en ellos se cultiva. Por otro lado, la terminología usada para denominar los distintos tipos de jardín en inglés (*garden*, *homegarden*, *forest garden*, etc.) varía según su función y propósito. Los factores que explican la diferenciación y distribución de los jardines a escala global no habían sido previamente explorados hasta ahora. En este estudio se han analizado los inventarios florísticos de 44 conjuntos de jardines de to do el mundo para explorar sus similitudes taxonómicas y los factores que configuran la distribución de su flora. Para ello, se escogieron distintas variables biofísicas y socioeconómicas a una escala apropiada de trabajo. Como resultado, los factores biofísicos y climáticos (temperatura, precipitación, evapotranspiración potencial y distancia entre asentamientos) se hallaron significativamente relacionados con la distribución de las especies; no obstante, todos estos factores resultaron ser menos importantes que el GDP (PIB) *per cápita*, utilizado aquí

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como indicador de los ingresos del hogar, y que se obtuvo como el principal impulsor de la composición de los jardines. También el resto de factores sociales y culturales incluidos en el análisis, como son la similitud entre las lenguas de los distintos asentamientos o la densidad de población, se encontraron como variables significativas. Cabe señalar que el presente análisis omite cierto número de variables debido a la no disponibilidad de datos. Algunas de estas variables son el tamaño del jardín o el género de su dueño, las cuales han sido reconocidas previamente como agentes influyentes en la composición vegetal de los jardines. El estudio concluye que los géneros vegetales cultivados en los conjuntos de jardines son muy diferentes entre sí y que, por lo tanto, las distinciones entre tipologías de jardín son difíciles de establecer a partir de tan solo datos florísticos. Por último, se discuten también las implicaciones que podrían tener posibles futuras fluctuaciones en el nivel de la renta (causadas por una severa crisis económica) o el cambio climático, sobre la diversidad bio-cultural y la seguridad alimentaria.

Palabras clave: Jardines, huertos familiares, biodiversidad, etnobotánica, seguridad alimentaria.

1. INTRODUCTION

Humans have cultivated their immediate living environments since the Neolithic (Brownrigg 1985), and some of these cultivated areas, particularly those adjacent with or close to the homes of their owners and smaller than the average size of an agricultural plot, are commonly classified as gardens (Vogl *et al.* 2004). The exact definition of "garden" depends heavily on context, and according to Vogl *et al.* (2004), an ethnoecological approach to garden classification might include a generic category for "garden" along with several specific subcategories (e.g., "coffee garden", "field garden", "home garden", "cocoa garden"). Therefore, classifying gardens at the regional scale is not always straightforward, and any labeling effort should be accompanied by the precise definitions of the variables and gradients used to distinguish between types. At the global scale, many types of gardens, each with different plant composition and purpose, have been described. However, most scientific literature has classified gardens into only two groups: domestic gardens (e.g., Daniels, Kirkpatrick 2006; Loram *et al.* 2008, Bigirimana *et al.* 2012), and homegardens (e.g., Kumar, Nair 2004; Blanckaert *et al.* 2004; Das, Das 2005). The key element linking all types of gardens is that local residents have autonomy over the space, although they may delegate this responsibility to others, such as professional designers or hired gardeners (Cameron *et al.* 2012).

Domestic gardens have been defined by Gaston *et al.* (2005) as the private spaces adjacent to or surrounding dwellings and they may be composed of lawns, ornamental and vegetable plots, ponds, paths, patios or temporary buildings such as sheds and greenhouses. In the same way, Bhatti and Church (2000) describe a domestic garden as an area of enclosed ground, cultivated or not, within the boundaries of an owned or rented dwelling, where plants are grown and other materials are arranged spatially. Depending on the characteristics of the cities and towns in which they are located, domestic gardens can contribute nearly one third of the total urban area (Domene, Saurí 2003; Gaston *et al.* 2005; Mathieu *et al.* 2007). Therefore, studies regarding domestic gardens have traditionally focused on urban biodiversity (Smith *et al.* 2006; Davies *et al.* 2009; Doody *et al.* 2010), ecosystem services (Tratalos *et al.* 2007; Cameron *et al.* 2012), socio-economic patterns for greening, (Luck *et al.* 2009; Hunter, Brown 2012), water consumption (Syme *et al.* 2004; Hurd 2006) and even psychology and well-being (Clayton 2007; Freeman *et al.* 2012).

The term "homegarden", also known as the "kitchen garden", "dooryard garden", or "agroforestry homegarden" (among many other variations), has received several definitions, although none has gained universally acceptance (Kumar, Nair 2004). Homegardens have been primarily described as social and economic units of rural households, in which crops, trees, shrubs, herbs and livestock are managed to provide food, medicine, shade, cash, poles and socio-cultural functions (Christanty 1990; Campbell *et al.* 1991; Shackleton *et al.* 2008). Fernandes and Nair (1986) reported that homegardens should therefore be considered as intensively cultivated agroforestry systems managed within the compounds of each household. In a predominantly subsistence-oriented economy, homegardens provide an array of outputs (Jose, Shanmugaratnam 1993), but although many are used for food and commercial production, others contain only lawn and ornamental species (Vogl *et al.* 2004). This broad definition of the term has led to the characterization of homegardens as a category with indeterminate boundaries. The existing scientific research regarding homegardens has mostly been conducted in tropical areas and is oriented towards ethnobotany (Agelet *et al.* 2000; Eichemberg *et al.* 2009), agroforestry production and food security (Wezel, Bender 2003; Kumari *et al.* 2009), ecology (Gajaseni, Gajaseni 1999; Kumar 2011) or biodiversity issues (Kabir, Webb 2008; Akinnifesi *et al.* 2010).

The precise differences between these two garden categories are still unclear, and their characteristic features are often mixed in practice. Generally, "domestic gardens" are associated with urban environments, while "homegardens" are mainly considered as rural agroforestry systems (Vogl *et al.* 2004). Furthermore, homegardens are associated with a more utilitarian perspective, while domestic gardens are mainly cultivated for recreational and aesthetic value. However, many other types of garden have been described, and others remain unexplored. The processes of global change and the specific characteristics of each region blur the boundaries of garden types, and the classification of gardens is not always easy.

The distribution of cultivated plants, unlike that of native vegetation, is influenced by many factors beyond biophysical variables such as temperature, precipitation and the movement of land masses (Kendal *et al.* 2012). Indeed, socio-economic variables (e.g., population and housing density, education, age, home ownership, income) have been described as better predictors of the vegetation cover in private gardens than biophysical variables (Hope *et al.* 2003; Luck *et al.* 2009; Marco *et al.* 2010). In the same way, colonialism has resulted in widely dispersed cities with similar cultivated landscapes, which mimic those of their shared colonial homeland (Reichard, White 2001; Ignatieva, Stewart 2009). Therefore, the cultural background and behavior of residents can partly overcome the natural tendencies of plant dispersal (Head *et al.* 2004).

There has been almost no attempt to describe the composition and distribution of the flora of gardens at the global scale (Thompson *et al.* 2003). The number of studies that document the differences in species composition between gardens is also limited (Cameron *et al.* 2012), but floristic surveys and plant inventories of these ecosystems have increased in recent years (e.g., Albuquerque *et al.* 2005; Daniels, Kirkpatrick 2006; Tynsong, Tiwari 2010), providing the opportunity to analyze them at the global scale. Kendal *et al.* (2012) explored the distribution patterns for all types of cultivated urban flora at the global scale and concluded that physical variables, especially mean annual temperature, were the most important to species composition. However, the importance of social factors on the distribution of cultivated plants was also documented. In the present study, a similar methodology with a focus on private gardens and accurate data at the appropriate scale is used.

This study aims to refine the classification gardens described in the scientific literature and to assess the factors determining their plant composition. Plant inventories for 44 sets of gardens from around the world are compared according to their previous classification (e.g., "domestic gardens", "homegardens", and "mixed gardens"). A comparison of global garden vegetation may provide clues about the structure, cultivation and use of these spaces in different societies around the world. Moreover, a better understanding of the distribution of cultivated vegetation in urban and rural gardens will contribute towards the better management of natural resources, conservation of biodiversity in anthropogenic environments and enhancement of food security worldwide.

2. MATERIAL AND METHODS

2.1. Selection of plant inventories

Publications containing plant garden inventories were obtained by searching titles, abstracts and keywords within Web of Science, Scopus, Google Scholar, and other relevant journals not included in these databases. Several key terms were searched (e.g., garden*, yard, lawn, plant*, flor*, vegetat*), both alone and in multiple combinations, until no new relevant publications were found. The keywords were also searched in several combinations using "AND" and "OR" statements to generate more accurate results. Further studies were obtained from the references of previously located studies. The term "garden", for the purpose of this study, is defined as the private area around a home used for the planting of ornamental plants as well as for the production of food and other agricultural products. Furthermore, a garden must be cultivated for leisure, home consumption or as a means of generating income. Garden studies without plant inventories, along with those in which plant inventories were mixed with other environments or garden types, were excluded. Floristic surveys which could not be assigned to a specific location with precise coordinates were also discarded. Finally, the garden typology, main research question(s), key words, and type of plants inventoried for each study were also recorded.

2.2. Selection of variables

Several physical and socioeconomic variables were collected to analyze the distribution patterns of garden flora at the global scale. Accurate data were selected at the appropriate scale to describe particular locations within countries. The climatic data included mean annual temperature (°C), mean annual rainfall (mm), and monthly potential evapotranspiration (mm). Mean annual temperature and rainfall were obtained from each study or, when not reported by the authors, from the World Meteorological Organization (2013). Potential evapotranspiration was calculated using the methods of Willmott and Kenji (2001) with a gridded raster of a 50x50 km cell. Distances in kilometers between each location were calculated using the great-circle method.

The socioeconomic data presented in the literature differed for each study; therefore, different sources were examined to obtain proxy data for multiple variables. The selected variables were chosen according to those considered significantly influential in Kendal *et al*. (2012) and other scientific publications (e.g., Hope *et al*. 2003; Marco *et al*. 2008; Luck *et al*. 2009; Bigirimana *et al*. 2012). Population density (persons/km^2) in the year 2000 was used as a proxy for the urban to rural gradient and was obtained using the gridded raster method (25x25 km) of CIESIN and CIAT (2005). Gross Domestic Product (GPD; millions of US $), obtained from CIESIN (2002), was used as a proxy for household income. In this case, more recent data were unavailable, values for the year 1990 were taken from a gridded raster (25x25 km) based on the SRES B2 Scenario. Dominant language family, obtained from the map in Goode (2006), was chosen as a proxy for the influence of cultural background. As the specific language of each community was not reported in all of the articles, a broader scale was selected, reducing the number of categories and amplifying the influences of cultural background and colonialism. When more than one location was used in a study, average values were generated for each variable and the plant inventory; the centroid between all points was used for great circle distances.

The uses of a given garden are reflected by its plants. Therefore, different types of gardens are associated with different cultivated plants. Each paper reviewed categorizes its surveyed gardens in a distinct way. The descriptions and categorizations given by the authors are reported in the classification of each inventory. However, no distinction has been made between “homegarden”, “home garden”, house garden” and “home-garden”. All of these terms have been included in the same category as “homegarden”.

2.3. Data analysis

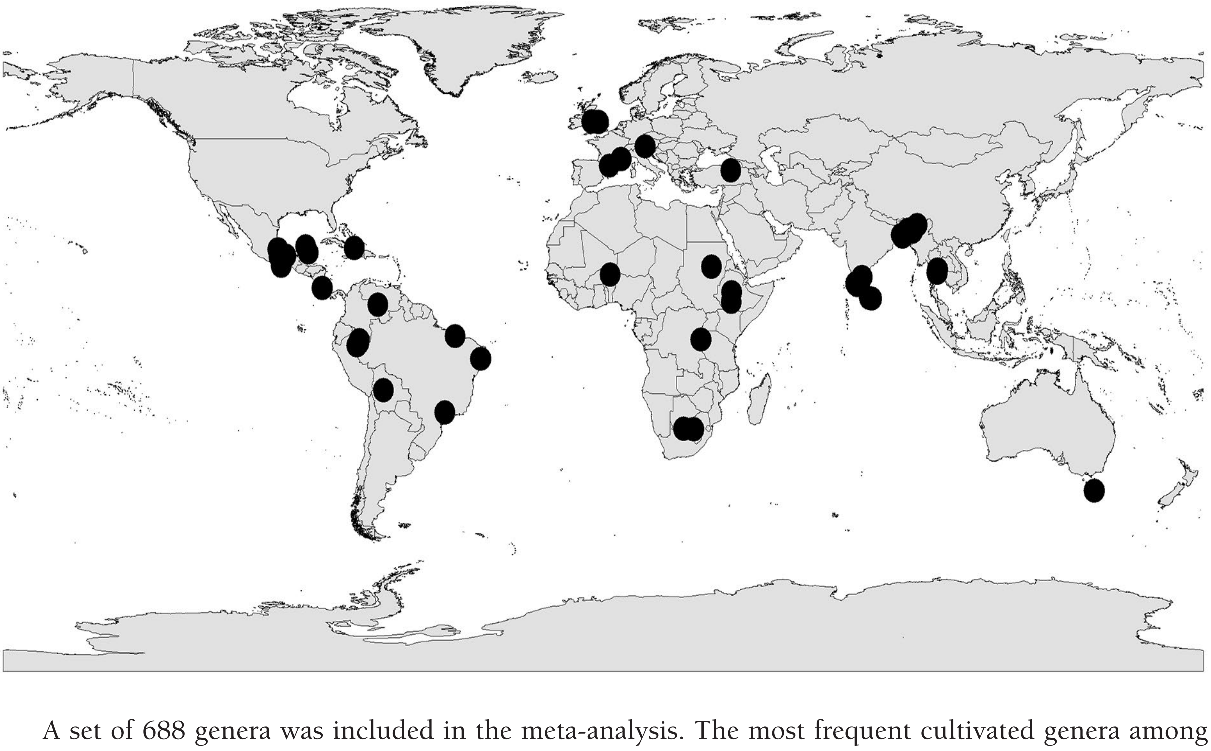
The plant inventories were examined for orthographic mistakes and standardized according to The International Plant Name Index database (IPNI 2013). Genus was selected as an appropriate taxonomic category for meaningful statistical analysis (Krebs 1999; Kendal *et al*. 2012). To reduce the stochastic noise, those genera present at relative frequencies of less than 6.82% were excluded from the study. For the same reasons, plant inventories containing less than 20 genera were also discarded. The variables obtained through Geographical Information Systems (potential evapotranspiration, GDP and population density) were processed with ArcGis v10 (ESRI 2012). Non-metric Multidimensional Scaling (NMDS) with the Bray-Curtis dissimilarity index (Faith *et al*. 1987) was run with the *vegan* package in R 2.15.2 (Team 2012) and used to investigate the relative taxonomic similarities between garden flora.

A standard linear regression model was applied to test the significance of different environmental, socioeconomic and cultural variables against the dissimilarity level of the different inventories. The Bray-Curtis dissimilarity index was set as the dependent variable and was transformed by squaring to improve the normality of residuals. The independent variables selected for the model were pairwise differences in mean annual temperature, mean annual rainfall, mean annual potential evapotranspiration, GDP per person, population density and distance between settlements. All of these variables were transformed by taking the square root to improve the normality of the residuals. Coded dummy variables for the differences between garden types and dominant language families were also included in the model (0=same, 1=different). A stepwise procedure using the Akaike Information Criterion (AIC) was conducted to obtain the most adjusted linear regression model, and multicollinearity was measured using the Variance Inflation Factor (VIF). The spatial correlation between the environmental data and the distances between each settlement was tested using the Mantel test with the package *ade4*. Because no significant result was observed (P=0.078) for this test, spatially weighted regression was not conducted (Lichstein *et al*. 2002; Kendal *et al*. 2012).

3. RESULTS AND DISCUSSION

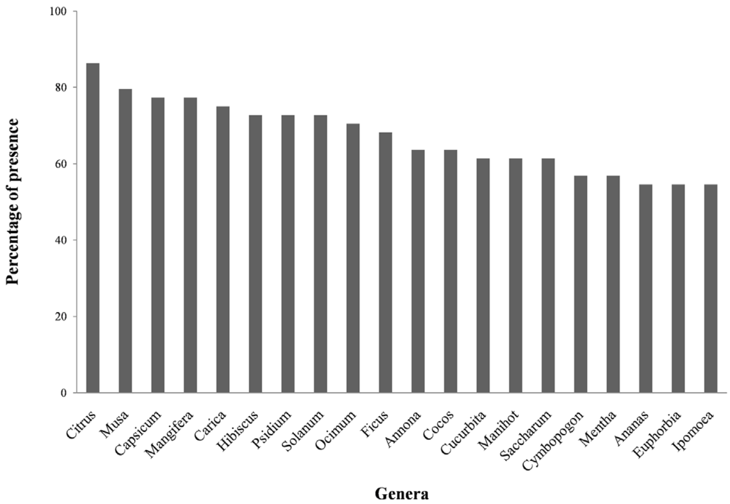
A total of 44 plant lists from different studies covering a global distribution were selected to analyze the floristic dissimilarities between gardens (Figure 1). The main research questions, key words and interests for all of the studies were examined to analyze their research purposes and to classify them into synthetic research categories. Five main categories were established: biodiversity, ethnobotany, agroforestry production, ecology and landscaping. Each study could be classified into one or more of these categories. Biodiversity issues (65.9%) were the most prevalent among the research, but ethnobotany (31.82%) and agroforestry production (27.27%) were also of significant importance to garden research. Plant uses were recorded in more than 75% of the studies, most of them studies of homegardens. Because many categories were applied to describe plant uses (e.g., timber, medicinal, food, fruit, fencing, construction), only those coincident for all plant inventories were selected for the present study. Using this approach, plants used for food supply were the most important category (57.97%), followed by medicinal (30.19%) and ornamental species (26.7%). A single plant may have multiple uses and can be classified into several categories simultaneously.

Figure 1. Locations of the 44 plant inventories compiled for this study. Those inventories representing more than one settlement are located using their geographical centroids.



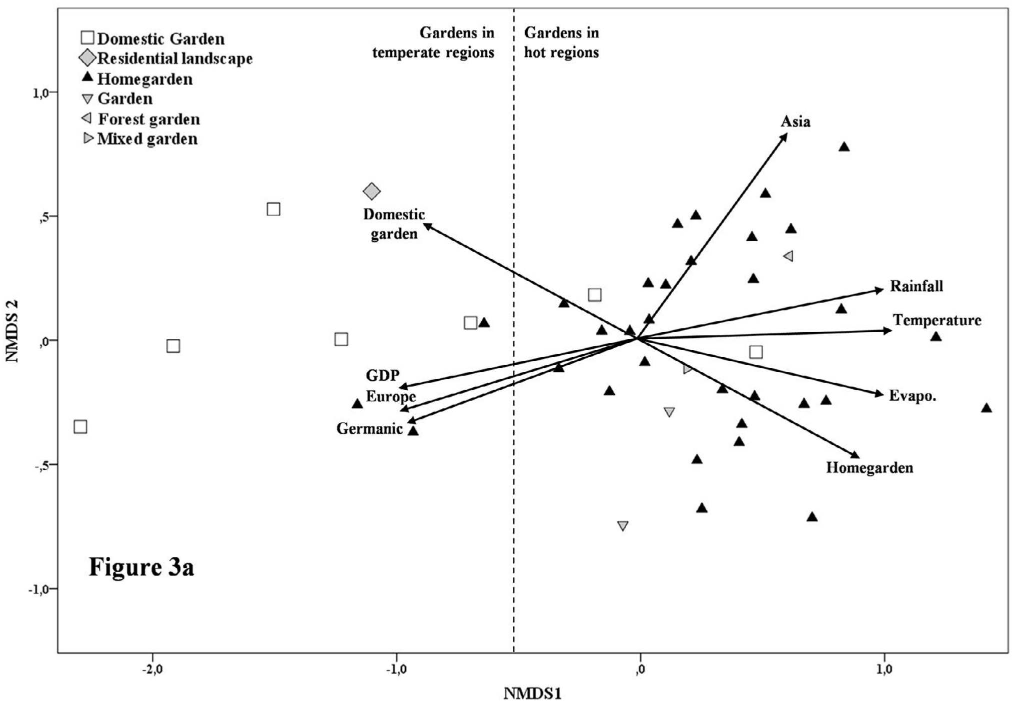
A set of 688 genera was included in the meta-analysis. The most frequent cultivated genera among the inventories were *Citrus* (86.36%), *Musa* (79.55%), *Capsicum* (77.27%), *Mangifera* (77.27%) and *Carica* (75%) (Figure 2). Only 3.17% of the studies had no genera in common. However, 96.41% of the inventories had a Bray-Curtis dissimilarity index of over 0.5, suggesting that the plants grown in gardens around the world are substantially different.

Figure 2. The 20 most representative genera across all inventories and their relative frequencies.



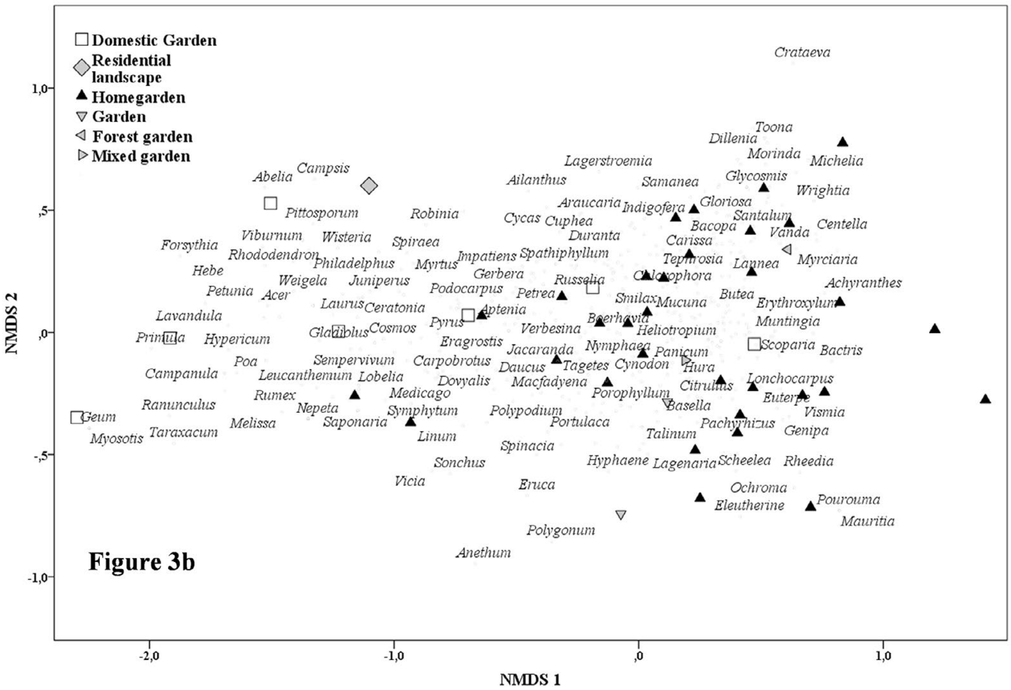
The NMDS ordination (Figure 3a) represents the taxonomic dissimilarities between all of the samples according to their categories. Temperature was calculated to be the strongest environmental gradient (R^2=0.61), but many other physical and social environmental gradients, including potential evapotranspiration (R^2=0.50), GDP per person (R^2=0.47) and Germanic spoken languages (R^2=0.47), were also significantly related to plant type (p<0.005). Two main clusters were identified, separating those gardens grown in temperate regions from those grown in hot regions. No clear differentiation was found between arid, tropical and subtropical gardens.

Figure 3a. Non-metric Multidimensional Scaling Analysis (NMDS) ordination plot of the Bray-Curtis distance between each garden's cultivated flora (Stress=0.152). Each symbol represents a different garden type according to the classifications of the authors. Grey symbols indicate categories that were also classified as homegardens or domestic gardens in the scientific literature. Physical and social environmental gradients calculated as significant (P<0.01) are represented as vectors indicating the direction of the environmental gradient (Germanic=Languages with the same Germanic origin; Evapo.=Potential Evapotranspiration; GDP=Gross Domestic Product per person).



Genera were mapped on the ordination to clarify which scored highly for each NMDS axis (Figure 3b). For the first NMDS axis, *Digitalis*, *Geum* and *Myosotis* scored positively, while *Centella*, *Areca*, *Achyranthes* scored negatively. Genera that scored highly on the second NMDS axis included *Crataeva*, *Adenanthera* and *Alstonia* in the positive direction and *Anethum*, *Polygonum* and *Scheelea* in the negative direction.

Figure 3b. Genera with a frequency of greater than 9.09% are shown in the ordination. To avoid label overlapping, only the most common genera are represented.



Multiple linear regression (Table 1) shows that all of the significant variables included in the model explain more than 50% of the total dissimilarity variation with the adjusted R^2. Difference in GDP is the strongest significant variable explaining taxonomic dissimilarity. Other physical and social variables, such as difference in mean annual temperature and distance between settlements, were also determined to be important significant co-variables. To a lesser extent, differences in potential evapotranspiration, family language, garden typology, and mean annual rainfall were found to be moderately but significantly related with taxonomic dissimilarity. Population density, intended as a proxy for the urban-to-rural gradient, was also found to be a significant variable in the model. The VIF values indicate a slight but acceptable multicollinearity between differences in mean annual temperature and potential evapotranspiration.

Table 1. Results from the multiple linear regression of selected variables on the Bray-Curtis dissimilarity matrix (Adjusted R-squared: 0.5361). All selected variables were included in the final model (AIC=-1037.605). VIF values are included to interpret multicollinearity. P-value defined as *P<0.01. **P<0.001.

	Coefficient	VIF
Constant	0.2336**	
Square root of difference in GDP per person (millions of US $)	0.0133**	1.7
Square root of difference in mean annual temperature (ºC)	0.0527**	2.3
Square root of distance between study sites (km)	0.0000**	1.2
Square root of difference in potential evapotranspiration (mm)	0.0090**	2.1
Settlements with different dominant language family	0.0504*	1.3
Studies of different garden type	0.0323*	1.4
Square root of difference in mean annual rainfall (mm)	0.0010*	1.1
Square root of population density (persons/km²)	-0.0014*	1.2

3.1. Boundaries between "domestic gardens" and "homegardens"

The results of the present study indicate that many gardens have been inventoried from different regions and territorial contexts around the world. Each author applies the most appropriate descriptive label for his or her study garden according the research interests of the work. Globally, but especially in tropical areas, homegardens have attracted more scientific attention due to their roles in food production and agrobiodiversity conservation. In contrast, garden studies of developed countries in temperate areas have mainly focused on domestic gardens to analyze issues related to urban biodiversity, such as biological invasions, or other matters like garden water consumption. The dissimilarities between garden floristic compositions suggest that there is a slight distinction between domestic gardens and homegardens, although the boundaries between the categories are not distinct, especially in warmer regions. Many taxa are present in all types of gardens regardless of classification, confirming that the differences of garden types are subtle and dependent on their purposes and particular characteristics. In agreement with this view, homegardens located in temperate areas have more genera in common with nearby domestic gardens than with other homegardens in warmer regions. Regarding taxonomic dissimilarities within the categories, domestic gardens are significantly more different from each other than are homegardens. However, the latter gardens also differ depending on multiple biophysical, socioeconomic and cultural factors. In this respect, homegardens have been impacted by "acculturation", the process through which a culture is transformed by the widespread adoption of cultural traits from another society. This process has direct consequences on the plant species grown in gardens and the extent to which they are used (Caballero 1992). Thus, traditionally managed homegardens are under the threat of transformation into more homogeneous gardens.

3.2. Factors correlated to plant diversity in gardens

The present study suggests that plant diversity in selected gardens from around the world is significantly related to many physical, socioeconomic and cultural variables. The results suggest that temperature, which has been long been considered as the primary driver of plant distribution, is less important than differences in GDP per person. However, temperature, distance between settlements and potential evapotranspiration remain very important significant variables in the explanation of the taxonomic dissimilarity between gardens. To a lesser extent, cultural background (settlements sharing the same language family), garden type, mean annual rainfall and population density also contribute positively to differences in cultivated genera.

Physical and climatic variables, specifically temperature, act as important filters of plant distribution. Kendal *et al*. (2012), using similar methodology, concluded that the main driver of global distribution for plants cultivated in green urban areas was temperature. In the current study, difference in mean annual temperature was an important factor in plant distribution but was not the main predictor. Distance between settlements was also a significant influential variable. The distribution of plants cultivated in gardens, unlike that of native flora, does not necessarily follow spatial correlation patterns, because their dispersion is caused by both natural and anthropogenic processes. According to the inventories analyzed in the present study, homegardens have similar percentages of native and alien plants. In domestic gardens, an average of three quarters of the species are alien. Therefore, distance between settlements has a powerful effect on the former type. Differences in mean annual potential evapotranspiration and in mean annual rainfall were both included in the model, although the latter variable had limited explanatory power. This result can be explained by the manipulation of climate through human activities such as irrigation whereby the contribution of extra water compensates for the lack of rain. In contrast, temperature is difficult to alter in outdoor gardens without the construction of greenhouses or similar structures.

Among the socioeconomic and cultural variables considered in the analysis, the explanatory power of GDP per person is most significant. A relationship between human resource abundance and plant diversity in urban ecosystems has been observed in many cities and is named the "luxury effect" (Hope *et al*. 2003). Social scientists also call this phenomenon the "prestige effect", and it involves the symbolic display of identity and social status beyond economic ability (Martin *et al*. 2004; Kinzig *et al*. 2005; Grove *et al*. 2006; Troy *et al*. 2007). For example, Lubbe *et al*. (2010) reported that garden plants in highclass neighborhoods have mainly ornamental functions, while those of lower-class neighborhoods have more utilitarian functions. According to the present study, gardens in regions with low GDP per person are typically classified as homegardens and contain more utilitarian plants, such as fruit, vegetables, or timber plants, which are nearly absent from gardens in wealthier areas. Ornamental woody plants are characteristic of urban domestic gardens in temperate regions. Because private management is the most common management style among the analyzed gardens, a great range of goods and services could be obtained from them by their owners. Conversely, public gardens handled by governments fulfill other functions and are not as closely linked to the income and personal preferences of local people.

Regions sharing the same dominant language family have a lower taxonomic dissimilarity index, confirming the significant role of cultural background on the distribution of garden species at the global scale. This influence has been reported to be especially prevalent in colonized areas (Crosby 1996; Ignatieva, Stewart 2009; Kendal *et al*. 2012). In terms of garden type, a taxonomically justifiable distinction does exist between the two main categories. The predominant species in domestic gardens include *Hedera helix*, *Lonicera sp*., *Hydrangea macrophylla*, *Lavandula sp*., *Rosa sp*., and *Rosmarinus officinalis*, while the most prevalent plants in homegardens include *Citrus sp*., *Mangifera indica*, *Musa paradisiaca*, *Capsicum anuum* and *Carica papaya*. However, taxonomic matches between these two groups are still abundant, and the classification of gardens must depend on variables beyond floristic composition. Population density was shown to be negatively related with taxonomic dissimilarity. Therefore, gardens in densely populated areas are much more similar than are gardens in sparsely populated regions. Previous research has documented that people tend to prefer plants for their own gardens that are growing in nearby gardens (Zmyslony, Gagnon 1998; Nassauer *et al*. 2009), and this effect may be amplified in urban areas.

Many other factors not included in the present analysis have been shown to influence the floristic composition of gardens at different scales and with different effects. Several studies have indicated that housing or farming age and size can positively contribute to the greater biodiversity of homegardens (Kumar *et al*. 1994; Larsen, Harlan 2006; Eichemberg *et al*. 2009). Education, gender, median house value and even home ownership are also influential factors in determining the types of plants grown by people in their gardens (Yabiku *et al*. 2008; Larson *et al*. 2009; Zhou *et al*. 2009). Especially in domestic gardens, preferences linked to aesthetic value have also been described as important drivers of plant choices (Martin *et al*. 2003; Spinti *et al*. 2004; Nielson, Smith 2005). On a broader scale, political legacy, as measured through a steep socio-economic gradient, was found to be a relevant explanatory variable for plant diversity in the city of Tlokwe in South Africa (Lubbe *et al*. 2010).

3.3. Gardens flora and biodiversity conservation

Gardens from around the world host a wide range of species incorporated from many sources, both natural and artificial. This elevated species richness, combined with the large area that gardens occupy at the global scale, provides many opportunities for conservation. Several studies have recognized the potential value of horticultural flora to biological diversity and their role in providing resources to wildlife (Owen 1991; Kendle, Forbes 1997; Smith *et al*. 2006; Davies *et al*. 2009). Tropical homegardens preserve a number of landraces and cultivars, as well as rare and endangered species (Watson, Eyzaguirre 2002). However, the future transformation of these ecosystems may be determined by social trends (Wiersum 2006). The taxonomic comparison of selected plant inventories indicates that a substantial percentage of gardens have high levels of taxonomic dissimilarity despite their relative closeness. Therefore, gardens may be considered heterogeneous habitats, with distinct territorial idiosyncrasies that result in a great variety of species. In rural environments, protecting the identity of a territory entails preserving the natural values of its gardens. Small variations in several socioeconomic variables, such as income level or population density, may affect biodiversity patterns. Furthermore, ornamental horticulture has been recognized as the main route by which invasive plant species are introduced into developed countries (Dehnen-Schmutz *et al*. 2007; Sanz-Elorza *et al*. 2008), and the uncontrolled management of garden wastes can act as a source for the establishment of these non-native plants (Batianoff, Franks 1998; Sullivan *et al*. 2005; Rusterholz *et al*. 2012). In urban areas, the focus of conservation should also consider the quality of life of the inhabitants (Miller 2005). Environmental education, the use of a common language for communication with decision makers and planners, the involvement of different stakeholders, and even the inclusion of experts from different scientific disciplines can offer a wider perspective on terms such as "diversity" or "conservation" (Miller, Hobbs 2002; Cilliers *et al.* 2004). Gardens can serve as an interface between the natural and the urban and can contribute to the incorporation of ecological values into society. Therefore, the importance of gardens should encourage global awareness of environmental protection.

3.4. Food security, economic crisis and their likely impact on garden floras

The main reason for gardening is the satisfaction of the needs and requirements of the garden's owners. However, these needs are not always the same in all places and at all times. For example, the food security guaranteed through urban and peri-urban agriculture (UPA) has long been considered a significant component of the livelihood strategies for many households (Frankenberger, McCaston 1998; Marsh 1998; Bernholt *et al.* 2009; Thompson *et al.* 2009). Approximately one-seventh of the total world food production is obtained through UPA, which includes the contributions of gardens (Olivier 1999). In tropical developing countries, homegardens may contribute over one third of the total calories and protein consumed (Torquebiau 1992). This production may be obtained directly through the harvest of edible fruit, vegetables, nuts and other products, or it may be obtained indirectly by selling the enhanced and sustained production. For this reason, homegarden production is worthy of recognition as a source of "health" food, which offers many important intangible benefits (Kumar, Nair 2004). Because gardens are dynamic environments, they are relatively sensitive to changes in environmental and socioeconomic conditions. Therefore, a severe economic situation may cause changes in the way garden plants are grown in developed countries. Social groups and families that are closer to poverty thresholds may change the structure and functionality of their gardens to readapt them for food production. In other areas, gardeners may alter their production focus from subsistence to semi-commercial or commercial production according to market forces (Peyre *et al.* 2006). These changes may alter the vegetation structures of gardens, resulting in the dominance of exotic crops and plants instead of traditional production systems and their associated ecosystem services. However, more research is needed to clarify how gardens evolve and which factors cause change. This knowledge, combined with research conducted in other disciplines, would help in establishing viable strategies for the improvement of household nutritional security.

3.5. Limitations of available data

An exhaustive literature review was conducted to find inventories of garden plants from around the world. However, data were not available from all geographical and climatic areas, with a particular lack of research in North America and Northern Asia. Therefore, more research on garden plants is necessary, especially in temperate areas. Additionally, the criteria of the selected inventories varied widely between studies. Several of the selected plant lists were incomplete, including only the most representative species or those considered useful or cultivated, which may have biased the results, although the main conclusions remain robust. Regarding the variables used in the meta-analysis, data were selected to match the appropriate working scale. However, these data may not be sufficiently precise or detailed for some regions.

The socioeconomic dataset was obtained completely from external sources and was less detailed than the physical and climatic data. Moreover, these data were used as proxies for income or cultural background. Any analysis that combines these data is inherently complex and should be assessed carefully. Many other data were not included in the analysis due to unavailability, including education level, gender, age soil type, and these factors have been previously described as important influences on garden floristic composition (see, for example, Cook *et al.* 2012). Much about the global distribution of garden plants remains to be explored, and the present results should be interpreted in light of the existing scientific literature on these issues (Hope *et al.* 2003; Ignatieva, Stewart 2009; Kendal *et al.* 2012).

4. CONCLUSIONS

The analysis of taxonomic dissimilarities between the 44 plant lists from gardens around the world revealed conclusive information about the key factors determining their floristic differences. Unexpectedly, climatic and physical factors, particularly temperature, were not the main drivers of garden species distribution, although they were significantly related. Difference in GDP per person, used here as a proxy for household income, was instead the most important factor. The urban and rural green spaces of private property are usually exploited by their owners to obtain goods and services. This situation creates interests, benefits and opportunities that do not exist in public cultivated areas. Therefore, income level was able to exceed the significance of the physical and climatic variables that explain the botanical distribution for most of Earth's ecosystems. Other socio-economic variables, such as urban density (used as a proxy for the urban-to-rural gradient) and regions sharing the same language family, also shape the composition of garden flora at the global scale.

Many garden types have been described in the scientific literature in a variety of territorial and ethnoecological contexts, although "domestic gardens" and "homegardens" are the most used labels. Urban domestic gardens are associated with high rent residential urban areas in developed countries with temperate environments. In contrast, homegardens are typically associated with rural sites in hot and tropical environments with lower income levels and a predominantly subsistence economy. The present analysis provides significant insight into the differentiation of these two categories. However, boundaries between the types based on taxonomic similarities are still difficult to establish, and no precise criteria have been obtained. Furthermore, not all types of gardens have been studied and inventoried for all regions, and further research is necessary to analyze the biological structure of gardens and their species distribution at the global scale. Gathering information about the owners of these gardens is also essential for establishing strong comparisons. Further research should focus on determining the differences between gardens according to the variables used in a particular analysis.

Gardens are dynamic ecosystems that evolve over time and face the challenge of constantly adapting to current societal pressures. Alterations in socioeconomic dynamics can cause changes in the structure of gardens and their biodiversity. Moreover, severe economic crisis or situations resulting from global climate change may lead to significant changes in the uses of gardens. In near future, gardens currently for leisure in some areas may be converted into gardens for food production, and those already cultivated for subsistence may become more market-oriented. Future research should be concerned with exploring the factors that cause these changes in each territorial context. Knowledge of the trends that determine plant garden composition, and of the ways economic and climate change may affect them, will provide information about how to manage the bio-cultural diversity of gardens.

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