The native - exotic plant choice in green roof design: using a multicriteria decision framework to select plant tolerant species that foster beneficial arthropods

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Abstract

Green roofs are considered key elements of the urban green infrastructure since they offer several environmental benefits, including habitat provision for arthropods. To achieve these benefits and ensure green roof success, an appropriate plant selection is an important step in the design of these infrastructures. So far, as green roofs begin to spread in South American cities, most technology comes from the northern hemisphere with little local information on native experiences. Moreover, decisions of using native or exotic plant species in green roofs had never been evaluated taking into account the plant ability to tolerate roof conditions together with their potential to foster beneficial arthropods. By applying an integrative multicriteria decision framework that combined the habitat template hypothesis with the potential of plants to attract floral visitors and natural enemies, we obtained a ranked set of candidate native and exotic plant species. Among the best-ranked candidate species, we further compared the performance of six native and six exotic species in 30 experimental green roofs installed in Córdoba city, Argentina. To evaluate plant success, the occurrence and cover of each species were recorded one year after establishment under two management conditions: regular watering and weeding of spontaneous plants, and no management (15 roofs each). In addition, we registered the number of interactions between selected plants and beneficial arthropods in half of the roofs, considering the influence of available flowers. Under watering and weeding, all selected species increased their vegetative cover one year after establishment. More interestingly, native plants with no management had an advantage over exotic plant species as they exhibited a significantly higher occurrence and a slightly higher cover than exotics. Native annuals were able to reseed the following the dry season even in the absence of management, thus highlighting the relative importance of lifespan as a useful plant trait for future studies in extensive green roof design. In addition, we showed that increasing flower availability in native plants promoted a higher number of interactions with pollinators and natural enemies; a response that was not observed for the exotic plant pool. Finally, by combining data on plants' cover and beneficial arthropods interactions we were able to validate the proposed ranking and selection procedure. Given that green roofs are one of the possible solutions to ameliorate the negative effects of urban habitat loss on arthropod diversity, the development of an integrative multicriteria decision framework that takes into account the potential of native and exotic plant species to tolerate roof conditions and promote beneficial arthropods would give a new twist in plant selection processes for green roofs.

Keywords

AHP, beneficial arthropods, green infrastructure, habitat template, plant selection, PROMETHEE

1. Introduction

Green roofs are considered key elements of the urban green infrastructure as they contribute to runoff control, carbon sequestration, temperature regulation, and habitat or food provision for different organisms, mostly arthropods (MacIvor and Ksiazek, 2015; Thuring and Grant, 2016; Guarino et al., 2021; Heim et al., 2021). To achieve all these environmental benefits and ensure green roof success, an appropriate plant selection is an important step in the design of these infrastructures. Until now, decisions regarding plant species' origin in green roofs have been evaluated in relation to their roof adaptability but not including the plants' potential to foster beneficial arthropods in an integrative multicriteria decision framework. Moreover in South American cities, where green roof technology and especially the selection and use of native plant vegetation are still in its infancy (but see Jaramillo Pazmino, 2016; Cáceres et al., 2018), the use of decision tools would be helpful to integrate previous knowledge on this matter with novel conservation goals.

Green roofs originally emerged as fire protection covers that were later colonized by spontaneous plant species (Dabija, 2019). Nowadays, decisions regarding which species are most suitable for green roofs encompass a diverse universe of criteria. Given that rooftops are particularly harsh environments, the selection of plant species was initially based on the use of plant traits as hardiness surrogates. Accordingly, drought-tolerant succulent plant species, well adapted to the stressful conditions of the roof, were primarily chosen. Among these, and mostly out of its native range, *Sedum* (Crassulaceae) species usually dominate green roof vegetation over the world (Cook-Patton, 2015). Several advantages have been found in *Sedum* species, ranging from their high survival rate to their temperature regulation and water retention capabilities (Butler and Orians, 2011). Well beyond the widely used *Sedum* species, nevertheless, the trait-based selection framework significantly contributed to improving the quality of the decisions around plant selection, broadening the ecosystem benefits provided by green roofs (Van Mechelen, 2015; Lundholm and Walker, 2018; Heim et al., 2021). Most certainly, a qualitative leap in the history of modern green roof design came with the introduction of the habitat template hypothesis into the plant selection process (Lundholm, 2006). By taking into account a habitat analog, the habitat template hypothesis states that natural habitats with similar abiotic characteristics to roofs provide reliable information about the potential plant species to be used. In fact, there are several successful experiments that, by assuming habitat templates, have arrived at a plant species pool able to succeed in green roofs (e.g., Kiehl et al., 2021; Ksiazek-Mikenas et al., 2021). Thus, this approach provides an optimum ecological framework for selecting plant species which, in addition, may be easily integrated with trait-based approaches (e.g., Van Mechelen, 2015; Lundholm and Walker, 2018).

Regarding the relative success of exotic versus native plant roof cover, most examples are from the northern hemisphere with no clear performance advantages of any group (Butler et al., 2012). For its part, other temperate, semi-arid and arid regions of the world may provide good candidates for native species other than the traditional *Sedum* vegetation roofs' cover (e.g., Van Mechelen, 2015; Cáceres et al., 2018; Yee et al., 2021), but the promising horizon of better native alternatives remains to be tested within a common comparative framework. This is crucial to address the relative value of a given plant on the basis of its origin. In cases where the exotic vs. native species pools are selected by different criteria (i.e., exotics chosen by their use in roofs but natives by a habitat analog), the origin effect may lose strength as well as the conclusions obtained could gain inconsistency.

According to the "adaptation argument", native plant species would perform better on green roofs than exotics, as they use water more efficiently than their non-native counterparts (Butler et al., 2012; Paço et al., 2019). However, we cannot discard that some exotics plant species could perform even better than natives in the rather extreme environmental conditions which characterize green roof systems. Nevertheless, from the studies performed up to date, native plant species have been shown suitable for extensive green roofs characterized by low maintenance vegetation able to self-sow (Sutton, 2015; Cascone, 2019; Paço et al. 2019). Regarding biodiversity, green roofs have been shown to support a considerable diversity of arthropods from several functional groups (e.g., Knapp et al., 2019; Fabián et al., 2021). But more interestingly, a greater potential of native over exotic plant species to promote and support native biodiversity is sustained by recent studies (reviewed by Berthon et al., 2021 and de Carvalho et al., 2022). Accordingly, it is expected that the use of local native plant species will favor the urban native arthropod fauna such as herbivores, pollinators and parasitoids (e.g., Mata et al., 2021), minimizing the risk associated with exotics species like their invasive behavior or potential negative interactions (reviewed in de Carvalho et al., 2022). In spite of this, the potential of plants to attract beneficial arthropods, whether being native or not, has never been taken into account when selecting plants for roofs.

All these aspects highlight the need to integrate traditional decision frameworks designed to select plant species able to survive in extensive green roofs, like habitat template analogs, to ecological plant attributes relevant for the co-occurring urban fauna. However, neither the habitat template approach has been considered to foster biodiversity at higher trophic levels (Ksiazek-Mikenas et al., 2021), nor the comparison regarding plants' performance has been yet addressed after applying the same selection framework to both native and exotic plant species.

Multicriteria decision-making analysis (MCDA) is a useful approach to dealing with complex human decisions and a strong tool to "validate our thinking" by weighting our previous knowledge about a given problem (Saaty, 2004). In addition, MCDA has provided good examples of how to resolve complex decisions regarding green infrastructure planning and design (e.g., Asgarzadeh et al., 2014; Vlachokostas et al., 2014; Rosasco and Perini, 2019) and conservation issues (Adem Esmail and Geneletti, 2018). Here, we employed MCDA to rank and then select six native and six exotic plant species which were established in 30 experimental green roofs in Córdoba city, Argentina, as a part of a larger project designed to test the effect of plant origin on arthropod diversity. By combining the habitat template hypothesis with surrogates of plant affinity for beneficial arthropods in a multicriteria decision framework for the first time, we obtained a ranked set of candidate native and exotic plant species expected to tolerate roof conditions and able to attract floral visitors and natural enemies. In turn, and in order to have a measure of plant success, the occurrence and cover of each species were recorded one year after establishment under two management conditions: green roofs i) with regular watering and weeding of spontaneous vegetation, and ii) without management (i.e., extensive green roof). Based on the adaptation argument (Butler et al., 2012) we expect that native plant species will perform better than exotics given that the former requires less maintenance and water. At the same time, to test in the field the potential of plant species of attracting beneficial arthropods, the number of interactions with floral visitors and natural enemies were registered in the experimental green roofs. We predict that native plants will have the higher abundance of interactions with beneficial arthropods given their greater potential to promote and support native biodiversity over exotic plants (reviewed in Berthon et al., 2021 and de Carvalho et al., 2022). Lastly, and in order to validate the decision model, we developed a method to test the agreement between the rank species order obtained by means of MCDA, and the overall species' performance obtained with field data on plants' cover and beneficial arthropod-plant interactions.

2. Methods

2.1 Species lists

The whole procedure is summarized in Figure 1. First, an initial list of potential plant species for green roofs was built on the basis of published lists of plant species already registered in green roofs all over the world. To do so, we performed an initial literature search, with the keywords “green”, “roof” and “plant” in the Google Scholar platform. From this initial search we obtained a pool of 450 articles (45 web pages with ten articles each), from which we selected 29 published articles based on the following criteria:

1) they should provide information on plant species registered as growing in green roofs either as spontaneously or cultivated; 2) papers with only lists of recommended plant species but not tested in green roofs were discarded, 3) priority was given to studies that provide any measure of the plants' performance in the roofs (i.e., relative frequency, cover, density, etc.). After applying those criteria, we obtained an initial plant list with a total of 1393 plant species, representing green roofs from Europe, Asia, North, and South America. Second, the list was refined on the basis of plant life form (only herbaceous plants were included), and then regarding their occurrence in the Argentinian flora website **(**www.floraargentina.edu.ar**)** either as native or not, or their citation in any of the ornamental and cultivated plants’ guides from Dimitri and Parodi (1977) and Hurrell et al. (2006, 2007, 2009, 2017). In addition, and for ornamental exotic species only, we checked their availability in wholesale local nurseries to ensure that those species will be able to be reproduced in the short term. The final plant list contained 117 species that were classified as native with a political criterion of nativeness (*sensu* Berthon et al., 2021). Accordingly, a species was considered as native whether it was classified as such in the Argentinian flora and registered in Córdoba province. As a result, the final plant list contained 57 native and 60 exotic species (Figure 1, Supplementary Material Table S1).

2.2 Multicriteria decision making analyses

2.2.1 The decision model

Under the generic designation of Multicriteria Decision Making Analysis or aiding process (MCDA) there is a diverse group of systematic approaches originally designed to deal with multiple and often conflicting alternatives within a common decision framework (Marttunen et al., 2017). Here, to rank the 117 plant species (57 natives and 60 exotics), we combined two decision-making tools that use pairwise comparisons between alternatives (i.e., plant species). One procedure, the Analytical Hierarchical Process (AHP;

Saaty, 1980) was only used here to define and weight the criteria that plant species should ideally meet to succeed in green roofs and have the potential for attracting beneficial arthropods. A second procedure, the Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE; Brans et al., 1986) was used to rank the species according to the weight of the criteria established previously by the AHP. The combination of these two procedures is sustained by the fact that AHP gives an accurate estimate to weight the selection criteria, whereas PROMETHEE is preferred over other MCDA tools for decision problems involving few criteria and many decision alternatives (Si et al., 2016). An AHP usually starts with a graphical representation of the goal and the principal and subordinate criteria used in the decision (Figure 2). We used two types of decision criteria: one group of criteria to define the potential of a given plant species to tolerate green roof conditions, and the other group of criteria to infer the potential of a given plant species to attract flower visitors and natural enemies (Figure 2).

2.2.2 Outranking procedure and criteria definition

The complete outranking process was performed in two decision rounds, every round consisting of an AHP and a PROMETHEE procedure for native and exotic candidate species, separately. The output of the first round gave us the species' ranking only according to their tolerance to green roof conditions and based on four criteria: habitat affinity, regeneration potential, performance, and occurrence (Figure 2). As a difference with previous studies that use plants' traits within their selection framework (e.g., Cook-Patton, 2015; Van Mechelen et al., 2014), we based our selection criteria on the published information available about the species use and their performance on green roofs. We avoided the functional traits approach given the scarce information available for our native flora, making it infeasible to complete a comprehensive species x traits' matrix for both native and exotic plants with a similar accuracy. The use of functional trait-based selection frameworks, in addition, do not always give consistent results (e.g., Du et al., 2019). Furthermore, there are a huge number of green roof initiatives all over the world reporting valuable information on the habitat of the plants used and their success on roofs. Therefore, to define each criterion's value, we performed additional literature searches to fulfill the necessary information for each plant species according to Figure 2. References used to support the criteria value for each plant species are provided in the Supplementary Material Reference Lists S1 and S2. Habitat affinity was defined as the theoretical similarity of rooftops with natural habitats: rock outcrop habitats (including stonecrops, cliffs), ruderal (i.e., roadside, escaped plants), and other habitats (e.g., sand dunes, grasslands). A given plant species may spontaneously occur in more than one habitat, and so we gave maximal value to species recognized as living in both rocky and ruderal habitats. By doing so, we aimed to prioritize the habitat plasticity of a given species and its potential ability to cope with a wider range of environmental features. For instance, rocky habitats may share some features with green roofs but differ in others such as typically shallow soil depths of green roofs (Lundholm, 2006). In addition, ruderal habitats are considered good surrogates for extensive green roofs (Cascone, 2019) so that species occurring both in rocky and ruderal habitats may combine highly preferred traits according to our goal (Figure 2). Rocky, geo-diverse outcrops are an important component of the central Argentinian mountains, representing ~90% of their whole surface, and providing habitat for a rich native and endemic flora (Cantero et al., 2014, 2016, 2021).

Accordingly, there was a greater potential to find both native and exotic species from rocky outcrops than for other habitats like sand dunes, which did not occur in central Argentina (i.e., Cordoba province). On the other hand, plants from prairie grasses usually require many years to develop supportive root systems (Sutton et al., 2012) which will surpass the time of the planned experiment. Regeneration potential was a binary parameter used to identify those plant species already registered as spontaneous on green roofs or not in literature. Performance was also a categorical criterion that gathers information regarding the species' cover, germination, or survival registered in the green roofs. Finally, occurrence represents the number of studies that cite the presence of a species, always considering different green roof studies. The occurrence in the literature for a given species reflects the number of times (i.e., number of independent studies) that a given plant species was used in green roof design irrespective of their performance or selection criterion. Accordingly, it is possible to interpret occurrence as an indicative of the frequency of a given species on green roofs (e.g., Van Mechelen, 2015). For instance, most common (i.e, high occurrence) used species like *Sedum* spp. are widespread in green roof design (e.g., Dvorak and Volder, 2010; MacIvor et al., 2015 and references therein). The underlying assumption of the occurrence criterion is then related to the preference-performance relationship, but given the indirect assumption this criterion had the lowest priority degree (please see Appendix A for further details).

The second decision round gave us the final species' ranking on the basis of three criteria: the plant potential to tolerate green roof conditions (obtained by the first decision round and equivalent to the previous species' rank order number), and two criteria defined as relevant for promoting beneficial arthropods: the potential of plants to attract both floral visitors and natural enemies (Figure 2). For this purpose we decided to use direct parameters like the number of arthropod orders already registered for each species, which is a more direct measure that the attractiveness defined by the floral traits. Accordingly, attractiveness to each target group was then defined as the number of arthropod taxa (i.e., orders) registered for each plant species. For floral visitors (Hymenoptera, Diptera, Coleoptera, and Lepidoptera) we considered the total number of orders registered in the literature for each plant species. For natural enemies, we counted the number of recorded phytophagous orders cited in the literature for each plant species, considering then the number of orders as a proxy of host/prey diversity for natural enemies (parasitoids and predators). To counterbalance the fact that the same plant species may be over-represented in the literature, we defined three categories: i) plant species related to two or more arthropod orders, ii) plant species related to one arthropod order only, iii) plant species with no data available. These three categories were defined for both floral visitors and phytophagous according to the literature (Supplementary Material Reference List S2). We gave higher relative importance to the capability of plant species of attracting floral visitors than natural enemies due to biological and technical reasons. Pollinators are key organisms since most plant populations depend on them to not be at risk (Ollerton et al., 2011; Rodger et al., 2021). Furthermore, since the world is immersed in a global context of pollinator decline (Potts et al., 2010), green roofs appear as a promising strategy to promote food sources in cities (e.g., Wang et al., 2017; Kratschmer et al., 2018). In addition, although natural enemies play an important role in helping plants to control pests, we assumed that the food resources for phytophagous will be not as scarce as for pollinators given that the former depend on leaves, a resource that is less transient than flowers, and that several groups of herbivores are not detrimentally affected by urbanization (Raupp et al., 2010). Flowers, in addition, may be food resources for both pollinators and natural enemies (Wäckers, 2004; Michener, 2007). Lastly, for pollinators, we were able to gather direct information on the resources consumed, whereas for natural enemies a proxy was used by registering the availability of phytophagous hosts. This last decision reinforces the higher priority we gave to pollinators over natural enemies in the selection criteria.

The Analytic Hierarchy Process (AHP) was then used to define the criteria weights, by means of a pairwise comparison matrix of the relative importance (e.g., the importance of habitat affinity relative to colonization potential, occurrence and performance). From this process, we obtained the criteria weights. Details on the categorization and calculus of the criteria weights are given in Appendix A. From the most to the least important criteria we then have: Habitat affinity > Regeneration potential > Performance > Occurrence in the first round, and Tolerance to green roof conditions> Floral visitors attraction potential > Natural enemies attraction potential in the second round (Figure 2). These priority values were, in addition, used to validate the ranking procedure we performed separately on native and exotic species of the final list by PROMETHEE (please, see Appendix B for Model validation). Further details on the PROMETHEE procedure are given in the Statistical analyses section.

2.3 Final selection of ranked plant species to be tested on roofs

The final ranked species list gave us a comparable set of both natives and exotics on the basis of the same criteria procedure. Accordingly, the best-ranked species will be able to achieve our goal. It is worth mentioning that native seed provisioning is a critical bottleneck for nurseries in central Argentina (Eynard et al., 2020), and at the beginning of the experiment only some of the species were available for seed harvest, at the same time we obtained the exotic plantings. Moreover, to compare the plant performance and the plant-arthropod interactions for the exotic and natives, we selected six native and six exotic plant species from each list giving priority to co-generic, co-familiar plant species, or species with similar traits (e.g., succulence). To be sure we were choosing among similar ranked species, we introduced an average mark that indicates the position that a plant species with average trait values has for all the ranking criteria. Only species above the mark (i.e., those with more than the “average” trait values) were suitable to be selected. With this procedure, we had several ranked candidate species to deal with both nursery limitations and required species’ affinity to compare plant-arthropod interactions. Consequently, from the pool of ranked candidate species above the mark we chose those to be established in the experimental green roofs.

2.4 Experimental green roofs

The experiment was carried out in Córdoba city, Argentina, from August 2018 to March 2020. A call for volunteers to participate in the experiment was performed from September to November 2018 through social networks. After interviews with 106 volunteers and visits to the roofs, 30 houses were selected for the experimental setting, based on the characteristics of their roofs. Selected roofs were all flat, had a minimum size of 15m^2, and a height between 3 to 3.5m. For logistic reasons, the degree of accessibility of roofs and location in the city was also considered, as well as the time availability of the owners. The final selected roofs were distributed all over the city (Supplementary Material Figure S1).

The selected native and exotic species were grown from August to November 2018 at the nursery of the Universidad Nacional de Córdoba (Figure 1). To do so, we first collected propagules (seeds or rhizomes) of each native species from urbanized populations whenever possible, given that urban provenance may contribute to species survival in the city (e.g., Yakub and Tiffin, 2017). Most of the obtained propagules were from urban and periurban populations distributed next to Cordoba city and only one native species was obtained from a national ornamental variety available in the market (see Results). Exotics, in addition, were introduced either as rhizomes or directly obtained as plantings from wholesale nurseries. Most importantly, and despite the introduction method may influence the future plants’ performance (e.g., Ksiazek-Mikenas et al., 2021), we did not find any differences in plants' success related to this aspect (Calviño et al., unpublished results).

A modular green roof system (medium-density polyethylene 50 x 50 x 15cm modules) was selected to be installed in each of the 30 selected roofs, in February 2019. Regarding the substrate features, we decided to use a combination able to enhance moisture retention by lightweight materials. The final mix was composed of vermiculite, peat moss, and compost (2:1:1). With this combination we achieved a good organic matter content (5.4%) and adequate pH (7.2) for nutrient uptake (e.g., Best et al., 2015). The available water holding capacity was 34% (+/-6%). In addition, the 12cm-substrate depth allowed us to reduce roots' temperatures by their damping effect compared with thinner substrates, thus higher depths are preferred for semiarid climates (Best et al., 2015). It is worth mentioning that the industry of green roof substrate has scarce development in Argentina, which largely explains the decisions we made regarding substrate composition.

Each species was planted in two modules with an initial cover of 0.16m^2 per species (N=720 modules in total). Before green roof installation, plants were able to grow in their definitive modules for two months for final rustication. Two blocks of 12 modules each (two modules per species) containing the native or exotic plant treatment and separated by 2.5m, were installed on each roof (Figure S2). All experimental green roofs were initially watered after establishment, and further, we split the 30 experimental roofs into two groups with 15 roofs each (Figures 1 and S1). In one group, the plants were regularly watered manually every 15 days until field capacity, and spontaneous species were weeded for one year (hereafter, WW treatment). Regular watering was mostly performed during the dry season, and further scattered with the arrival of the first summer rains (i.e., we did not water the modules in case it rained the day before the watering schedule). In the second group, plants were left without watering or weeding (noWW treatment) for the same period. One year after installation, we recorded the species' occurrence in their original modules (N=720) and the total cover in square meters reached at the end of the assay by each species, considering the two modules together (N=320). Plant cover was estimated from digital pictures of the modules taken at 1m height using the ImageJ software (Schneider et al., 2012).

To test the attraction potential of beneficial arthropods by the selected plant species pool, we sampled the plant-floral visitors and the plant-natural enemies' interactions from December 2019. To achieve that we recorded the beneficial arthropods in the 15 green roofs under watering and weeding only, given that the plant configuration changed in the roofs without management (i.e., noWW treatment). For doing so, on each roof all the arthropods that arrived at the flowers of plants on the experimental roofs were registered for 15 minutes per treatment, identifying the species of plant visited and the number of arthropods feeding on floral rewards as floral visitors (e.g., bees, butterflies, hoverflies, flies). Sampling was performed in sunny days with temperatures above 25°C. After this, for the testing of interactions involving natural enemies, every plant species was visually examined for an additional 15 min per treatment, recording, in turn, the number of natural enemies (e.g., lady beetles, mummies of parasitoids) in each plant species. We have also recorded the total number of floral units available per treatment (i.e., native and exotic) since this variable could be of importance for arthropods. The response variable that we analyzed was the total number of beneficial interactions (i.e. the number of plant-floral visitor interactions plus the number of plant-natural enemy interactions).

2.5 Statistical analyses

All statistical analyses were performed in the R environment (version 3.6.1; R Core Team, 2019). We used PROMETHEE (*MCDA* package; Meyer et al., 2021) as the outranking method. PROMETHEE I and II functions (Bigaret et al., 2017; Meyer et al., 2021) were used to obtain the partial preorder and the complete order, respectively (Brans et al., 1986), on the basis of the criteria weights defined by AHP (Appendix A).

To test the effect of plant origin and management (WW vs. noWW) on species occurrence and cover we first performed generalized linear mixed-effects models (glmer function from the *lme4* package; Bates et al., 2018) with roof as a random term and plant origin, management and their interaction as fixed effects, assuming a binomial and Gaussian distribution of errors for plant occurrence and cover, respectively. However, we further decided not to include the random term in the models, given that it accounted for a variance near zero ($9.3 \times 10^{-5} \pm 0.06$). In addition, we compared the effect of management on the cover of each of the 12 species one year after establishment, to assess the species' performance irrespective of their origin. To do so we performed a generalized linear model (GLM) with management, plant species, and their interaction as predictors assuming Gaussian error distribution for the response variable. To evaluate the influence of native and exotic plants on the number of interactions with beneficial arthropods, we run a GLM where plant origin, the number of flowers, and their interaction were the predictors assuming a Negative binomial distribution for the response variable to account for data overdispersion with the *MASS* package (Venables and Ripley, 2002). Overdispersion tests were performed with the *DHARMa* package (Hartig, 2022). In all cases, the significance of predictor variables was determined by deviance tests with $\alpha=0.05$ for significant effects and $0.05<\alpha<0.09$ for marginally significant effects. Predicted values of each of the models were plotted with the *sjPlot* package (Lüdecke, 2021).

3. Results

By combining the habitat template hypothesis with surrogates of plant affinities for arthropods in a multicriteria decision framework, we obtained a ranked set of native and exotic plant species expected to tolerate roof conditions and able to attract floral visitors and natural enemies (Supplementary Material Ranked species lists). After the second outranking process, 29 native and 28 exotic plant species were ranked above the mark (Appendix C). Within natives, all of these candidate 29 species were registered both as growing in rocky and ruderal habitats. Regarding exotics, only *Sedum mexicanum* was identified as growing in both types of habitats. Most of the candidate exotics (23 of 28) were registered as ruderal, including ornamental species registered as escaped from cultivation (e.g., *Verbena hybrida, Zinnia elegans*). In addition, most of the candidate species (Appendix C) have the potential for attracting floral visitors from the order Hymenoptera (72% of the natives and 84% of the exotics) and phytophagous from the order Hemiptera as prey for natural enemies (72% of the natives and 78% of the exotics).

From the species situated above the mark, we chose a pool of six native and six exotic plant species to experimentally test their performance under two contrasting management conditions (i.e., WW and noWW; Table 1). Irrigation and weeding of spontaneous plants clearly benefited the occurrence and cover of both natives and exotics one year after establishment. Particularly, the effect of management on plant occurrence depended on plant origin (interaction term: *D*=3.87, *P*=0.049). Natives were more likely to occur under the noWW treatment (Figure 3). Plant origin also had a marginally significant effect on plant cover (*D*=0.10, *P*=0.09; Figure 4A), with natives having a slightly higher cover than exotics one year after establishment. However, the effect of management, in this case, was independent (*D*=0.02, *P*=0.38) and more pronounced than plant origin since all plants exhibited on average a 2.5-fold increase in cover under WW compared with noWW treatment (*D*=5.14, *P*<0.0001; Figure 4B). Looking at the individual performance of each plant species, the model indicates that there was a significant interaction between species and management (*D*=1.48, *P*<0.001). All plant species surpassed their initial cover after one year of establishment, with seven of them surpassing their original cover only under the WW treatment and three natives and two exotics surpassing their initial cover even under the noWW treatment (Figure S3).

Regarding the effects on beneficial arthropods, we found a significant interaction between plant origin and the abundance of floral units (*D*=1.11, *P*=0.05) in the total number of interactions registered. Only for the native treatment, the number of beneficial arthropod-plant interactions increased at an increasing number of floral units (Figure 5).Two native species exhibited the highest number of beneficial arthropod-plant interactions (Figure S4).

Overall, the obtained rank order reflected the relative position of a given plant species in relation to a combined measure of plant performance and beneficial plant-arthropod interactions, thus validating the procedure as a whole (please, see Appendix B for details on model validation).

4. DISCUSSION

Urban green design faces many challenges given the complex decisions involved in planning (Saaty and De Paola, 2017), especially when the goal is to conserve urban wildlife. So far, the decisions to use native or exotic plant species in green roofs had never considered the plant tolerance level and, at the same time, their potential to promote interactions with beneficial arthropods using the same selection framework. Here, by applying an integrative multicriteria decision model that combined the habitat template hypothesis with the potential of plants to attract floral visitors and natural enemies, we obtained a ranked set of candidate native and exotic plant species. We further compared the plant performance and interactions with beneficial arthropods of six native and six exotic species in 30 experimental green roofs. Our results show an advantage of native over exotic plants regarding their expected occurrence and vegetation cover registered in the experimental green roofs after the dry season. Given that the advantage of natives emerged with no management, our results support the use of natives for extensive green roof design. Most remarkably, natives were also able to interact with a greater number of beneficial arthropods as they displayed greater floral availability. Considering that our experimental design controlled for plants richness and abundance, substrate depth and quality, as well as the area covered by the experimental units, our results are strong enough to encourage the selection of native plant species to foster biodiverse green roofs.

4.1 Green roof design to foster urban biodiversity

Under the semiarid climate of Córdoba city (Cwa in the Köppen-Geiger Climatic Classification; Beck et al., 2018) and despite the limited number of species tested in just one year, our results shed light on the importance of choosing natives for future extensive green roofs. According to our expectations based on the adaptation argument (Butler et al., 2012), native plants showed an advantage over exotics under noWW since they were more likely to occur under this treatment. In fact, two of the annual native species here evaluated (*P. grandiflora* and *G. pulchella*) were able to reseed after winter even in the absence of irrigation, reaching similar cover levels to those registered by the same species under irrigation and weeding. This result illustrates how some native annuals are capable of reseeding after the dry winter season in the experimental green roofs, just as they do in their natural habitats. Furthermore, and considering that our treatment of management represents two contrasting conditions (regular watering and weeding vs no intervention), we expect that intermediate or even minor irrigation levels may broaden the spectrum of plant species suitable for green roofs. This is likely the case of the native *Z. peruviana* or the exotic *G. globosa*, two annual species that exhibited the greatest differences in cover between the two treatments (i.e., higher reseeding capacity only under irrigation and weeding). *Zinnia peruviana* and *G. globosa* had a great potential to reseed after winter under WW, with a three and a 2.6-fold increase from their initial cover, respectively. These results are in agreement with Zhang et al. (2021), who found self-sowing is a good surrogate of plant resilience in green roofs and highlights the fact that some exotic species may perform as well as natives.

On the other hand, it is interesting that some of the native and exotic plant species that did not perform well, especially in the absence of irrigation, were perennials (Appendix C). This was the case of the exotics *G. globosa, V. hybrida* and *L. maritima* and of the native *O. conorrhiza* and should not be recommended for extensive green roofs under a semiarid climate. Although we did not include plant life span in our decision framework, it seems that it is a key trait to designing low maintenance extensive green roofs in Córdoba city. Similarly, our results also agree with previous findings highlighting the importance of succulence in urban environments given their well-known high survival and recovery from drought (reviewed in Lundholm and Walker, 2018; but see Guo et al., 2021). One native (*P. grandiflora*) and one exotic (*S. mexicanum*) succulent plant species were among the plants with the highest cover values. This may also be true for the exotic *T. pallida* with a rather low succulence degree, but it should be taken with caution given its recent spread in the city (Calviño, pers. observ.). Future studies that consider life span and succulence in an integrative framework may be necessary to test these ideas.

In addition, increasing flower availability in native plants promoted a higher number of interactions with pollinators and natural enemies; a response that was not observed for the exotic plant pool. Both insect groups feed on flower resources such as pollen and/or nectar (Wäckers, 2004; Michener, 2007), but based on the fact that both natives and exotics offered floral rewards (Calviño, pers. observ.), these results open a new question regarding the quality of the resources provided by ornamental -not necessarily exotic- species. For instance, new hybrid varieties were recently obtained for the native *Glandularia* spp. (Suárez, 2020) just after this experiment was established, and it is expected that these varieties would exhibit better performance than the wild relative *G. tenera* here tested (e.g., Henson et al., 2006; for *G. tenuisecta* x *G. tenera* hybrid). Nevertheless, it has been shown that selection with only an ornamental purpose could be detrimental for some plant-insect interactions (e.g., Mach and Potter, 2018) and tests on the new hybrids should be really helpful in this regard.

Our results suggest that the use of native plants would be the best alternative considering both the beneficial interactions and the observed plant performance, despite certain species differences. Although we were able to test plant performance under two management regimes, the effect of origin on plant-arthropod interactions was tested here for the original plant design under watering and weeding only. Thus, further studies on insects considering management effects altogether with plant origin would be really helpful. Given that urban environments are usually characterized by their restricted value for animals (Apfelbeck et al., 2019), especially for insects (Egerer and Buchholz, 2021; Fenoglio et al., 2021), the idea that only minimal interventions are needed to favor biodiversity is especially attractive for conservation purposes in cities (Sikorski et al., 2021) and clearly needs further support.

4.2 Going further winners and losers: the need to reframe weeds in biodiverse green roof design

As we showed, native plants can establish crucial trophic relationships with different insect groups. However, most of the best ranked native plant species we obtained are considered weeds in our country, particularly in agricultural habitats. For instance, *G. pulchella,* with the highest number of interactions registered, is an herb highly preferred by butterflies (Beccacece, pers. obs.), but also well recognized as an herbicide-tolerant weed (Calderón, 2013). *Commelina erecta*, another successful species in our study, is able to sustain a high diversity of floral visitors and natural enemies according to the literature (Fenoglio et al., 2010; Faden, 1992) and our own data, but is also a glyphosate-tolerant undesirable weed (e.g., Gullino et al., 2016). As Egerer and Buchholz (2021) have pointed out for urban wildlife, the potential of these species to sustain arthropods' diversity justifies the need to reframe weeds. Ruderal, formerly “weeds”, can be reframed as “pollinator attractive plants'' and “beneficial insectary plants” (i.e. plants supporting alternate hosts for predators and parasitoids according to Atsatt and O'Dowd, 1976) to be included in green roofs design. This reframing may provide beneficial signatures not only to urban arthropod wildlife but also to broaden the spectrum of native species typically chosen to be established on green roofs. In this regard, considering the relative success of plant species in a broader sense, would help to integrate their potential to foster urban biodiversity as a parameter of success.

5. Concluding remarks

Our work gives tools for green roof design that help to select native and exotic plant species by using, for the first time, a consistent multicriteria decision-making approach combining the traditional criteria of plant tolerance with a novel one which mirrors the potential of plants for promoting beneficial arthropods. The method allows a scan of potential plant species for green roofs, and it has the advantage to be applied in any region of the world if necessary information to feed the model is available. In addition, the candidate ranked species list obtained here is a useful tool for local practitioners interested in promoting urban biodiversity by green roof design. By experimentally evaluating 12 species obtained after applying the MCDA, we showed that native species performed better than exotics and that increasing abundance of flowers in native plants sustained more interactions with beneficial arthropods. These results constitute new evidence for a South American city where green roof technology and, especially, the selection and use of native vegetation are taking their first steps (but see Jaramillo Pazmino, 2016; Cáceres et al., 2018). Although we used a limited number of plant species during one year, our study goes one step forward on the current methods used for plant selection in green roof design and sheds light into the importance of choosing natives for future extensive green roofs. Considering green roofs are one of the possible solutions to ameliorate the negative effects of urban habitat loss on arthropod diversity (Fenoglio et al., 2021), the development of an integrative multicriteria decision framework that takes into account the potential of both native and exotic plant species to tolerate roof conditions and promote beneficial arthropods would give a new twist in plant selection processes for green roofs.

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Table 1. Native and exotic plant species established on the experimental green roofs. First and second rank orders indicate the absolute position after the first and second PROMETHEE analyses, respectively. The total number of ranking categories obtained after each procedure is between brackets (i.e., distinct plant species may arrive at the same rank position). Please, see Methods for further details. * corresponding to *P. grandiflora* 'INTA' in our experiment.

Family	**Species**	**Origin**	**1st rank order**	**2nd rank order**
Asteraceae	*Zinnia peruviana*	native	4(16)	5(39)
Amaranthaceae	*Gomphrena pulchella*	native	6(16)	10(39)
Commelinaceae	*Commelina erecta*	native	2(16)	2(39)
Verbenaceae	*Glandularia tenera*	native	8(16)	17(39)
Oxalidaceae	*Oxalis conorrhiza*	native	6(16)	20(39)
Portulacaceae	*Portulaca grandiflora* *	native	5(16)	11(39)
Asteraceae	*Zinnia elegans*	exotic	13(23)	11(52)
Amaranthaceae	*Gomphrena globosa*	exotic	9(23)	6(52)
Commelinaceae	*Tradescantia pallida*	exotic	12(23)	19(52)
Verbenaceae	*Verbena hybrida*	exotic	13(23)	24(52)
Brassicaceae	*Lobularia maritima*	exotic	13(23)	17(52)
Crassulaceae	*Sedum mexicanum*	exotic	7(23)	7(52)

Figure Legends

Figure 1. Flow diagram showing the different steps followed throughout the experiment. AHP: Analytical Hierarchical Process, PROMETHEE: Preference Ranking Organization Method of Enrichment Evaluation. Please, see Methods for further details.

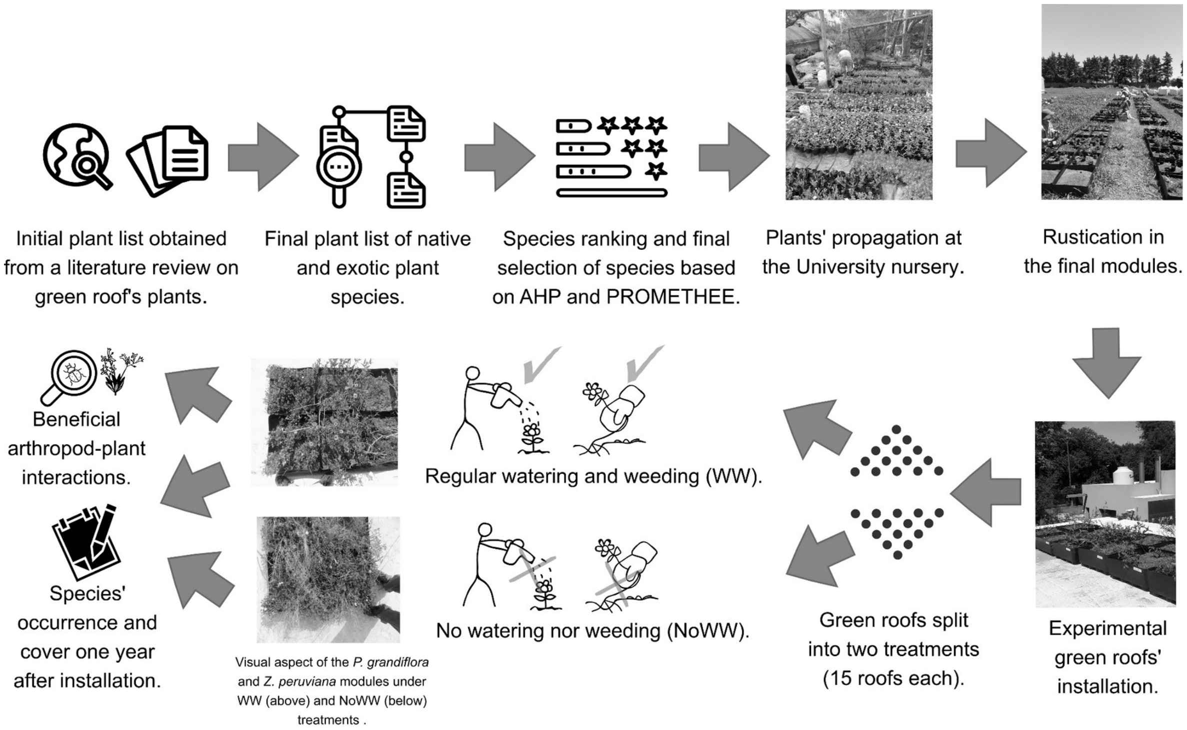
Figure 2. Structure of the criteria employed in the Analytical Hierarchical Process (AHP). Subordinate and principal criteria were used in the first (gray) and second (white) decision rounds, respectively to rank the plants in the final list Supplementary Material (Table S1). Rankings of species were obtained with the Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE) on the basis of the criteria weights obtained by AHP. Please, see methods for further details.

Figure 3. Predicted species occurrences per module in relation to origin (natives in black, exotics in gray), and management (WW= watering and weeding, filled circles, noWW=no watering nor weeding of spontaneous plants, empty circles), one year after establishment in the experimental green roofs. *P=0.05.

Figure 4. Predicted species cover (m^2) one year after establishment in the experimental green roofs in relation to A) Plant origin: native (black) and exotic (gray). B) Plant management: under watering and weeding (WW, filled symbol) and with no watering nor weeding of spontaneous plants (noWW, empty symbol). ◦P=0.09; ***$P \leq 0.0001$.

Figure 5. Predicted number of beneficial arthropod-plant interactions for the native (black) and exotic (gray) plant species in the experimental green roofs, plotted for an average of 50 (continuous lines), 150 (dashed lines) and 300 floral units (dotted lines) per species. *P=0.05.

Figure 1



Icons were developed by Alice Design, Warunk icon, Eucalyptus, Nasir Ali, faisalovers, Zach Bogart, DinosoftL, priyanka, Hermine Blanquart & Hea Poh Lin from the Noun Project (https://thenounproject.com/)

Figure 2

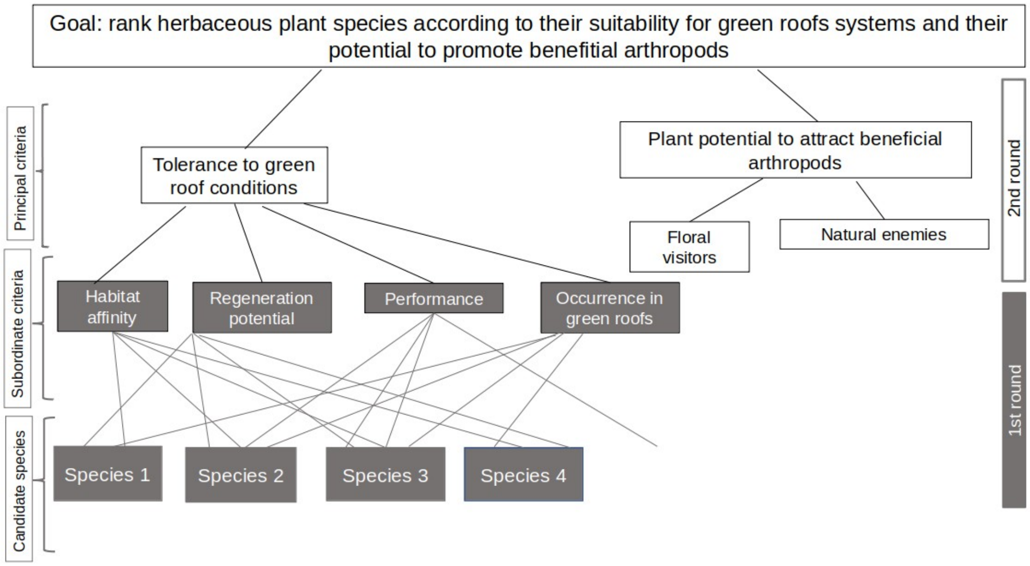

Goal: rank herbaceous plant species according to their suitability for green roofs systems and their potential to promote benefitial arthropods
Principal criteria
Tolerance to green roof conditions
Plant potential to attract beneficial arthropods
Floral visitors
Natural enemies
2nd round
Subordinate criteria
Habitat affinity
Regeneration potential
Performance
Occurrence in green roofs
1st round
Candidate species
Species 1
Species 2
Species 3
Species 4

Figure 3

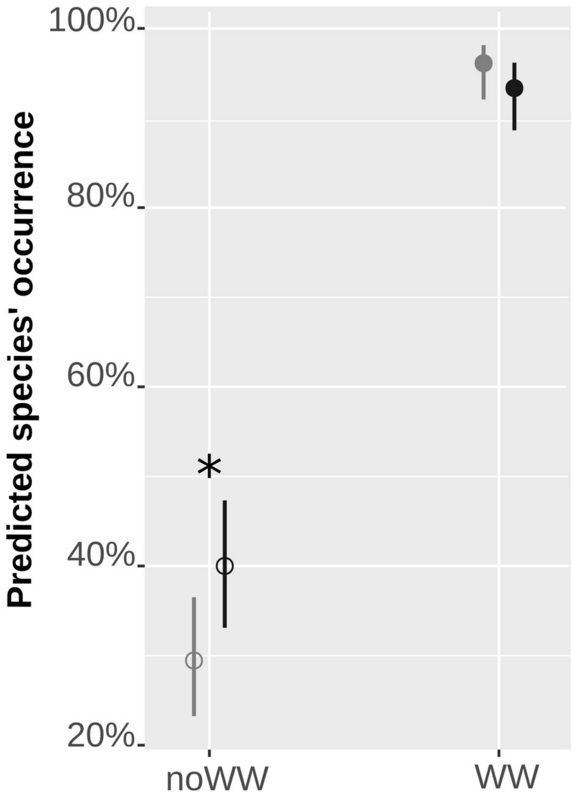


Figure 4

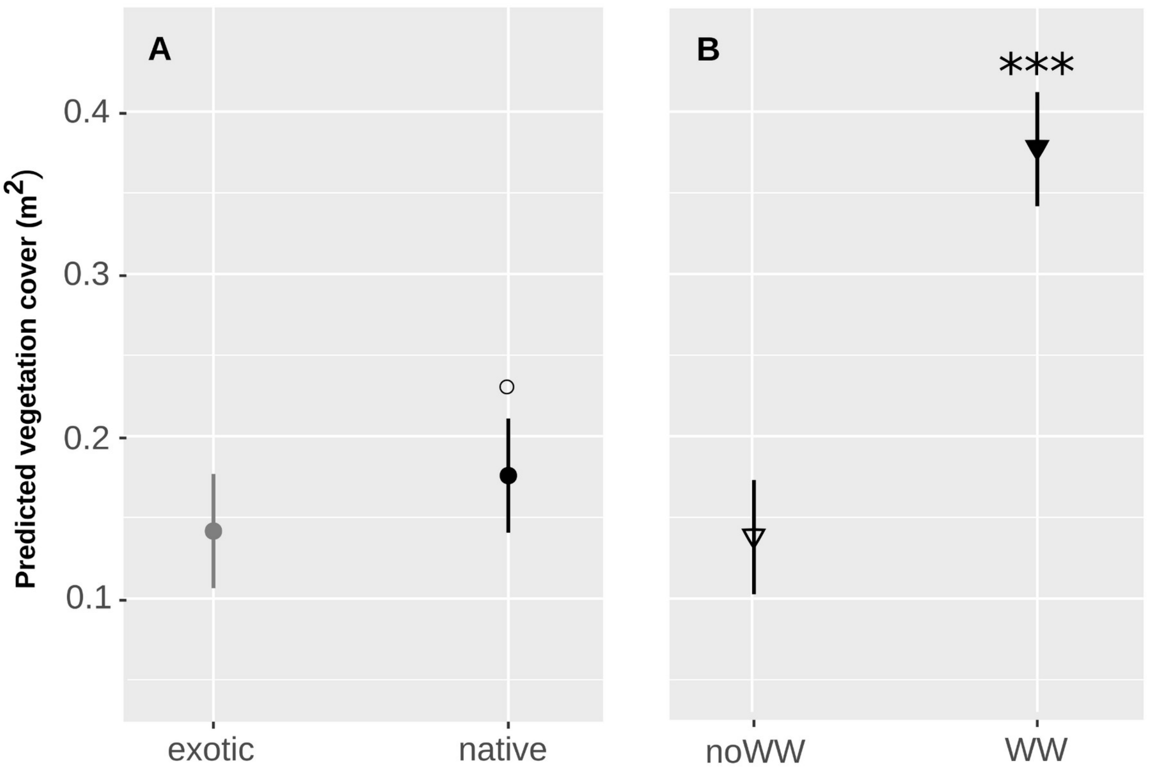
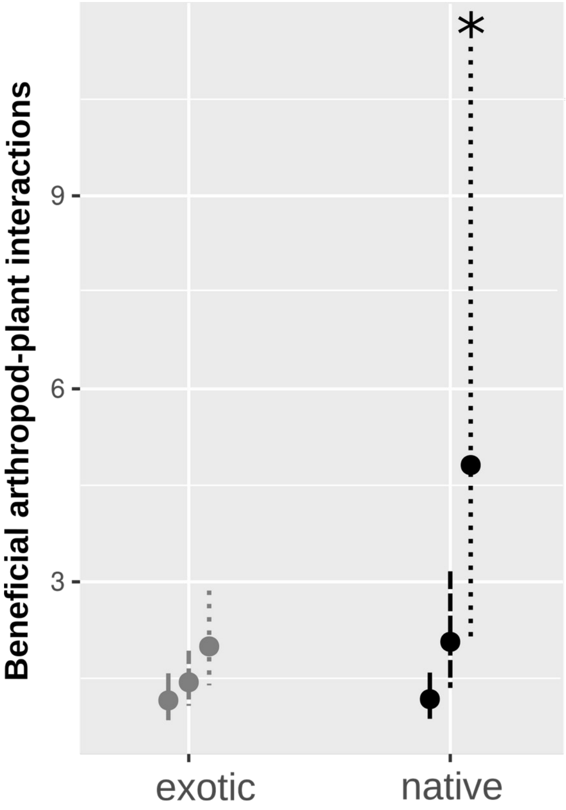

A
B
***
0.4
0.3
0.2
0.1
Predicted vegetation cover (m^2)
exotic
native
noWW
WW

Figure 5


Beneficial arthropod-plant interactions
9
6
3
*
exotic
native

Appendix A

Table A1. Numerical categorization of the criteria used in the Analytic Hierarchical Process model of Figure 1.

Selection and ranking criteria	**Description**
Habitat affinity	Represents the theoretical similarity of rooftops with natural habitats, and it was obtained by summing up values assigned to three different habitat templates: ruderal (value=1 if classified as ruderal, either equal to 0); rocky (value=1 if classified as stonecrop or rocky habitats, either equal to 0); another habitat (value=0.5 if any other habitat was registered like grassy, mountainous, coastlands, etc.).
Occurrence	The number of studies in which the species was registered in a green roof over the maximum number observed over all plant species
Regeneration potential	Whether the species was registered as spontaneous or as a colonizer (value=1) or not (value=0).
Expected performance	Whether the data available support either 50% of: cover, germination rate,survival/mortality, plants' or roofs' frequency in a given species: value= 1, whether the data support less than 50% or there are no data available: value=0.5 (*).
Floral visitors' attraction potential	Plant species related to one insect order= 1 Plant species related to two or more insect orders=2 Plant species with no data available=0
Natural enemies' attraction potential	Plant species related to one insect order= 1 Plant species related to two or more insect orders=2 Plant species with no data available=0

(*) *No data was not considered a "zero" value given that we started the selection procedure with candidate species already registered as growing in green roofs.*

Paired comparison by Analytic Hierarchy Process and criteria weight definition

The Analytic Hierarchical Process (AHP) was used to define the relative criteria weights used further in the PROMETHEE ranking method. Here we describe the method of Saaty (2008) we used to obtain the weights of the criteria illustrated in Figure 1.

The weights of the criteria used in PROMETHEE were equal to the priority vector resulting from the pairwise comparison of the criteria, the main procedure of the AHP. Originally, the AHP was used to express different judgements in the form of comparisons, a method especially useful to define decision priorities in situations involving many people (e.g., Saaty, 2004). Thus, the first step of the method consists of assigning to each pair, the importance of one criterium relative to the importance of the other criterium, according to a scale. The original Saaty's scale was divided into nine "intensities of importance" with equal importance =1, and higher numbers representing stronger importance, however, other possibilities may be useful depending on the parameter's variability (Saaty, 1990, 2004). Here, 4 x 4 and 3 x 3 pairwise comparison matrices were used for the first and second rounds, respectively (Figure 1). A shorter version of the 9-scale of Saaty was used with only four categories. For instance, habitat affinity was four times more important than occurrence, and the reciprocal means that occurrence was ¼ times more important relative to habitat affinity (Table A2). The priority vector represents the relative importance of each criterion in the whole matrix (i.e., criteria weights), and it is equal to the row averages of the normalized matrix (Saaty, 1990). Accordingly, and from the most to the least important criteria we have: Habitat affinity> Regeneration potential> Performance> Occurrence, for the first round, and Tolerance to green roof conditions for the second round> Floral visitors' attraction potential >Natural enemies' attraction potential, for the second round (Figure 2).

Table A2. Matrix for the pairwise comparison used to estimate the criteria weight in the first decision round.

	Occurrence	Colonization potential	Performance	Habitat affinity	Priority vector(*)
Occurrence	1	0.33	0.5	0.25	0.097
Regeneration potential	3	1	1.5	0.33	0.245
Performance	2	0.66	1	0.66	0.213
Habitat affinity	4	3	1.5	1	0.444

Table A3. Matrix for the pairwise comparison used to estimate the criteria weight in the second decision round.

	Tolerance to green roof conditions	Floral visitors' attraction potential	Natural enemies' attraction potential	Priority vector(*)
Tolerance to green roof conditions	1	3	4	0.623
Floral visitors' attraction potential	0.33	1	2	0.239
Natural enemies' attraction potential	0.25	0.5	1	0.137

(*) The sum of each priority vector equals 1.

Appendix B. Model evaluation

Following Qureshi et al., (1999), we addressed the evaluation of the model by dividing the process into three components: verification, validation and sensitivity. In addition to the correctness of the model, verification deals with the proper formulation of the parameters. For instance, judgement' inconsistencies may arrive from the pairwise comparison matrix (Saaty 2004).To overcome a potential inconsistency problem, we obtained the consistency ratio (CR) for each matrix developed by Saaty (1980). Judgments with CR values < 0.1 (i.e., inconsistency < 10%) are considered confident (Saaty 1980; 2004), Small CR may, on the other hand, give rise to insignificant differences between alternatives (Saaty 2004).CR were 0.045 and 0.016 for the first and second pairwise comparisons, respectively. Given that CR was less than 0.1 for both matrices, inconsistencies are less than 10% and our judgments are therefore confident (Saaty, 1980). For further details on the use of the CR, please see Model validation.

Validation deals with the predictive power of the model, and "it's a matter of degree rather than a process with a clearly identified finishing point" (Qureshi et al., 1999). Given that a model is a coarse simplification of the real world, the predicted models' performance will differ from that of the real world and absolute statistical validations are not possible (Qureshi et al., 1999). In addition, our second selection round was based on three plant attributes which account for the potential of a given species to tolerate green roof conditions and to attract both floral visitors and natural enemies, with decreasing priority levels compared with the tolerance criteria (please, see Table A3). In this regard, testing the ability for attracting insects only, would not be a reliable validation of the whole model. Therefore, and based on the priorities given to each criteria in the second decision round, we developed a procedure to validate the selected plant species according to their overall performance and to their respective priorities, that is, as both green roof tolerant species and floral visitors plus natural enemies' attractors. For doing so, and because the ability to attract any insect would depend also on the theoretical ability of the plant to survive and grow in the roof, we first developed a multiplicative index of plant suitability (MPS) to characterize each plant species based on the three criteria modeled in second decision round of Figure 2:

MPS= *plants' cover*(*p1) * *floral visitors' attraction*(*p2) * *natural enemies' attraction*(*p3)

Where floral visitors' and natural enemies' attraction are the numbers of each type of plant-arthropod interactions registered in the green roofs and p1, p2 and p3 are the relative importance of the criteria used in the second decision round (i.e,, priority vector of Table A3) for the Tolerance to green roof conditions, Floral visitors' attraction potential and Natural enemies' attraction potential, respectively. Plant cover values were those obtained for the experimental green roof assay (please, see *2.4 Experimental green roofs).* We used the MPS index as a ranking measure of the species according to their overall performance in the roof and based on the priority given to the criteria. We further tested the ability of the PROMETHEE ranking value to predict MPS (please see *Model validation* below). Because higher ranking numbers obtained with PROMETHEE give rise to less apt species according to our selection model, we expect a negative effect of the PROMETHEE rankings on the MPS index. In other words, the higher the predicted ranking by PROMETHEE, the lower the overall performance we should obtain for a given plant species.

Model validation

As a validation for the second decision round model, we tested the effect of PROMETHEE rank orders and plant origin on MPS, by means of a generalized linear model. Given that the total number of rank orders was different for native and exotic plant species (i.e., 39 and 52 total rank orders for natives and exotics, respectively), we obtained relative PROMETHEE rank orders as the absolute rank order obtained for a given species over its corresponding total rank order. Relative PROMETHEE rank order had a negative and significant effect on the multiplicative index of plant suitability (Figure A1; *z*= -5.21, *P*<0.001) and therefore, the lower the obtained PROMETHEE rank the better the plant performance, as expected.

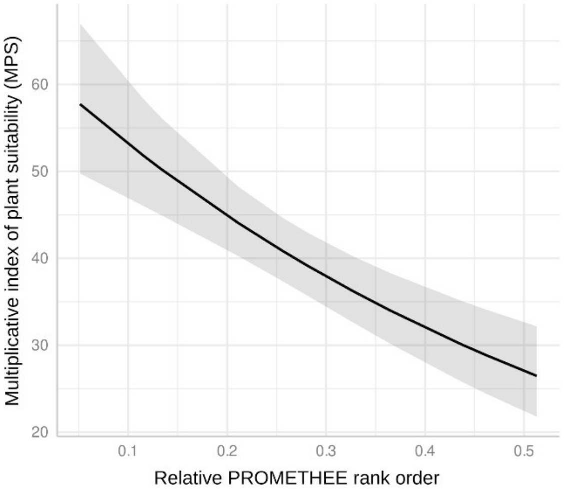


Figure A1. The effect of the relative PROMETHEE rank order obtained for the second decision round on the Multiplicative index of plant suitability (MPS) registered in 15 experimental green roofs.

The obtained results validate the overall selection process for the given priority values used in the second selection round. To this end, it may be worth asking whether increasing or decreasing the relative importance of arthropod attraction potential, would change the observed validation. This issue is a sensibility problem, and despite it is beyond the scope of the present study, we performed a series PROMETHEE rounds by decreasing and increasing the values of the priority vector and using the new rankings to validate the model according to the MPS. These analyses evince that increasing the priority of Floral visitors’ and natural enemies’ attraction potential to more than 0.40 (i.e., 0.25 plus 0.15 for floral visitors and natural enemies respectively) may give inconsistency judgment (CR ≥ a 0.10), whereas decreasing arthropods’ priority values gave us no substantial differences between alternative species (Results not shown). But most importantly, the significant negative effect of the relative PROMETHEE ranking on the MPS sustained in all consistent models (i.e., total arthropods priorities between 0.4 and 0.34) suggesting that the proposed decision method is quite robust and responds to our original goal delineated in Figure 2.

Appendix C. Candidate ranked plant species for green roofs obtained after applying the integrative multicriteria decision framework. Rank order indicates the absolute position of the species after the second PROMETHEE decision round above the mark (i.e., average imaginary species). The taxonomic order of floral visitors and phytophagous were assigned according to the references in Table S1. The final species selected to be established in the experimental green roofs are in bold. RO= Rocky outcrop habitats, RU= Ruderal, O= Other (sandy, grasslands, mountainous, etc.). Na= No data.

Rank order	**Family**	**Name**	**Origin**	**Lifespan**	**Habitat analogs**	**Floral visitors**	**Phytophagous**
1	Asteraceae	*Bidens pilosa*	native	annual	RU, RO	Coleoptera, Diptera, Hymenoptera, Lepidoptera	Coleoptera, Diptera, Hemiptera, Thysanoptera
2	**Commelinaceae**	***Commelina erecta***	**native**	**perennial**	**RU, RO**	**Coleoptera, Diptera, Hymenoptera, Lepidoptera**	**Coleoptera, Diptera, Hemiptera**
3	Convolvulaceae	*Ipomoea purpurea*	native	annual	RU, RO	Diptera, Hymenoptera	Coleoptera, Diptera, Hemiptera
4	Acanthacea	*Dicliptera squarrosa*	native	perennial	RU, RO	Diptera, Hymenoptera, Lepidoptera	Diptera, Hemiptera, Lepidoptera
4	Asteraceae	*Bidens subalternans*	native	annual	RU, RO	Diptera, Hymenoptera, Lepidoptera	Coleoptera, Hemiptera, Lepidoptera
4	Asteraceae	*Conyza bonariensis*	native	annual	RU, RO	Coleoptera, Diptera, Hymenoptera, Lepidoptera	Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera
4	Malvaceae	*Malvastrum coromandelianum*	native	perennial	RU, RO	Hymenoptera, Lepidoptera	Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera
4	Malvaceae	*Sida rhombifolia*	native	perennial	RU, RO	Coleoptera, Hymenoptera, Lepidoptera	Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera
4	Malvaceae	*Sida spinosa*	native	perennial	RU, RO	Hymenoptera, Lepidoptera	Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera
5	Asteraceae	*Conyza sumatrensis*	native	annual	RU, RO	Diptera, Hymenoptera, Lepidoptera	Diptera, Hemiptera
5	**Asteraceae**	***Zinnia peruviana***	**native**	**annual**	**RU, RO**	**Hymenoptera, Lepidoptera**	**Diptera, Hemiptera**

6	Lythraceae	*Heimia salicifolia*	native	perennial	RU, RO	Hymenoptera	Hemiptera, Hymenoptera, Lepidoptera
7	Convolvulaceae	*Ipomoea nil*	native	annual	RU, RO	Coleoptera, Diptera, Hymenoptera	Coleoptera, Hemiptera
8	Convolvulaceae	*Ipomoea cairica*	native	perennial	RU, RO	Coleoptera, Diptera, Hymenoptera	Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera
9	Asteraceae	*Parthenium hysterophorus*	native	annual	RU, RO	Na	Coleoptera, Diptera, Hemiptera
9	Poaceae	*Paspalum dilatatum*	native	perennial	RU, RO	Na	Coleoptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera
10	**Amaranthaceae**	***Gomphrena pulchella***	**native**	**annual**	**RU, RO**	**Hymenoptera, Lepidoptera**	**Hemiptera**
11	**Portulacaceae**	***Portulaca grandiflora***	**native**	**annual**	**RU, RO**	**Hymenoptera**	**Hemiptera**
12	Convolvulaceae	*Dichondra sericea*	native	perennial	RU, RO	Na	Hymenoptera, Lepidoptera
12	Poaceae	*Eragrostis pastoensis*	native	perennial	RU, RO	Na	Hemiptera, Thysanoptera
13	Asteraceae	*Schkuhria pinnata*	native	annual	RU, RO	Hymenoptera	Thysanoptera
13	Solanaceae	*Nierembergia linariaefolia*	native	perennial	RU, RO	Hymenoptera	Thysanoptera
14	Asteraceae	*Tagetes minuta*	native	annual	RU, RO	Na	Hemiptera
15	Cyperaceae	*Cyperus rotundus*	native	perennial	RU	Hymenoptera	Coleoptera, Hemiptera, Lepidoptera, Orthoptera
16	Asteraceae	*Galinsoga parviflora*	native	annual	RU	Coleoptera, Diptera, Hymenoptera, Lepidoptera	Hemiptera, Thysanoptera
17	**Verbenaceae**	***Glandularia tenera***	**native**	**perennial**	**RU, RO**	**Hymenoptera, Lepidoptera**	**Lepidoptera**
18	Cyperaceae	*Cyperus aggregatus*	native	perennial	RU, RO	Na	Orthoptera
19	Poaceae	*Setaria parviflora*	native	perennial	RU, RO	Na	Hemiptera
20	**Oxalidaceae**	***Oxalis conorrhiza***	**native**	**perennial**	**RU, RO**	**Hymenoptera**	**Na**
1	Asteraceae	*Taraxacum officinale*	exotic	perennial	RU	Coleoptera, Diptera, Hy-	Coleoptera, Diptera,

						menoptera, Lepidoptera	Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera
2	Chenopodiaceae	*Chenopodium album*	exotic	annual	RU	Coleoptera, Diptera, Hymenoptera	Coleoptera, Diptera, Hemiptera, Lepidoptera, Orthoptera, Thysanoptera
3	Aizoiaceae	*Aptenia cordifolia*	exotic	perennial	RU, O	Hymenoptera, Lepidoptera	Hemiptera
4	Poacea	*Digitaria sanguinalis*	exotic	annual	RU	Hymenoptera	Coleoptera, Hemiptera, Lepidoptera, Orthoptera
5	Amaryllidaceae	*Allium schoenoprasum*	exotic	perennial	RO, O	Hymenoptera	Hemiptera
6	**Amaranthaceae**	***Gomphrena globosa***	**exotic**	**annual**	**RU, O**	**Hymenoptera, Lepidoptera**	**Hemiptera**
7	**Crassulaceae**	***Sedum mexicanum***	**exotic**	**perennial**	**RU, RO**	**Hymenoptera**	**Hemiptera**
8	Asteraceae	*Hypochaeris radicata*	exotic	perennial	RU	Diptera, Hymenoptera	Hemiptera, Thysanoptera
8	Asteraceae	*Matricaria chamomilla*	exotic	annual	RU	Hymenoptera, Lepidoptera	Hemiptera, Thysanoptera
9	Xanthorrhoeaceae	*Bulbine frutescens*	exotic	perennial	RO, O	Hymenoptera	Na
10	Crassulaceae	*Bryophyllum daigremontianum*	exotic	perennial	RU, O	Na	Hemiptera
11	**Asteraceae**	***Zinnia elegans***	**exotic**	**annual**	**RU, O**	**Hymenoptera, Lepidoptera**	**Diptera, Hemiptera**
12	Portulacaceae	*Portulaca oleracea*	exotic	annual	RU	Hymenoptera	Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Thysanoptera
13	Crassulaceae	*Sedum acre*	exotic	perennial	RO	Hymenoptera	Na
14	Plantaginaceae	*Plantago major*	exotic	perennial	RU	Na	Hemiptera
14	Oxalidaceae	*Oxalis corniculata*	exotic	perennial	RU	Na	Coleoptera
15	Fabaceae	*Trifolium repens*	exotic	perennial	RU	Hymenoptera, Lepidoptera	Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Thysanoptera

16	Lamiaceae	*Leonurus japonicus*	exotic	biennal	RU	Hymenoptera, Lepidoptera	Hemiptera, Thysanoptera
17	**Brassicaceae**	***Lobularia maritima***	**exotic**	**perennial**	**RO**	**Diptera, Hymenoptera**	**Hemiptera**
18	Papaveraceae	*Papaver rhoeas*	exotic	annual	RU	Hymenoptera	Diptera
19	**Commelinaceae**	***Tradescantia pallida***	**exotic**	**perennial**	**RU**	**Hymenoptera**	**Hemiptera**
20	Asteraceae	*Leucanthemum vulgare*	exotic	perennial	RU	Diptera, Hymenoptera	Coleoptera, Hemiptera, Lepidoptera
21	Crassulaceae	*Sedum album*	exotic	perennial	RO	Hymenoptera	Na
22	Poaceae	*Chloris gayana*	exotic	perennial	RU	Hymenoptera	Hemiptera, Thysanoptera
23	Poaceae	*Echinochloa colona*	exotic	annual	RU	Na	Coleoptera, Hemiptera
24	**Verbenaceae**	***Verbena hybrida***	**exotic**	**perennial**	**RU**	**Diptera, Hymenoptera, Lepidoptera**	**Diptera, Hemiptera**
24	Amaryllidaceae	*Allium ampeloprasum*	exotic	perennial	RU	Diptera, Hymenoptera	Hemiptera, Thysanoptera
24	Plantaginaceae	*Veronica persica*	exotic	perennial	RU	Diptera, Hymenoptera	Hemiptera, Thysanoptera