

Greening Approaches of Green Roof for Flower-Visiting Insects

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Abstract: The use of green roofs is being promoted and likely to increase, since they have the potential of providing suitable environment for flower-visiting insects in urban area. Human population density is high and limited in green spaces at ground level in Taipei city; green roofs are popular with the residents in a variety of benefits. We confirmed the carefully designed green roof had the potential value for flower-visiting insect populations. The suitability index curve is a valuable tool to describe the relationship between flower-visiting insects and greening variable and used to estimate the optimal value of greening variables for attract more flower-visiting insects on a limited area of green roof. A geometric mean approach of habitat suitability index model of green roof was found, which was used to assess green roof quality for flower-visiting insects by four greening variables. These research findings involve greening approaches and planning strategies, and could help effectively utilize the limited area of green roof to attract more flower-visiting insects in urban area.

Keywords: Flower-Visiting Insect, Green Roof, Greening Approach, Suitability Curve, Suitability Index Model

1. Introduction

The population of the world is growing rapidly and the majority of the population lives in cities (UN-Habitat, 2010). This phenomenon has caused various urban environmental problems, and green roofs are widely used as a strategy for improving urban environmental quality. Green roofs are one of the most promising ecological engineering techniques available for increasing green surfaces (Mitsch, 2012) and are regarded as important wildlife habitats in urban areas (Brenneisen, 2006; Carter and Butler, 2008; Coffman and Davis, 2005; Colla et al., 2009; Davies et al., 2010; Gedge and Kadas, 2005; Kadas, 2006; Köhler, 2006; Ksiazek et al., 2012; Macivor and Lundholm, 2011; Oberndorfer et al., 2007; Snep et al., 2011; Tonietto et al., 2011).

Flower-visiting insects, like bees and butterflies, may be more attracted to suitable green roof vegetation because of the provision of appropriate food sources or pollen resources (Coffman and Waite, 2010; Everaars et al., 2011; Gedge and Kadas, 2005; Lundholm, 2006). Thus, carefully designed green roofs have the potential to be used as a counter-measure for habitat loss for flower-visiting insects at the ground level

in urban areas, and will collectively support more species (Bates et al., 2013; Colla et al., 2009; Davies et al., 2010; Ksiazek et al., 2012; MacIvor and Lundholm, 2011; Molles, 2005; Smallidge and Leopold, 1997; Tonietto et al., 2011). Green roofs could function as novel habitat islands in urban settings (Tonietto et al., 2011).

Flower-visiting insects in quantities and vitality have been found to be influenced by the plant area of the green roof (Coffman and Waite, 2010; Madre et al., 2013; Matteson and Langellotto, 2010; Oberndorfer et al., 2007; Schindler et al., 2011). Floral abundance is the major factor limiting local flower-visiting insects (like bee and butterfly) diversity in heavily urbanized settings (Matteson and Langellotto, 2010; Tonietto et al., 2011), because floral resources provide a good environment for cavity-nesting bees (Everaars et al., 2011; Ksiazek et al., 2012), and bee diversity increases with the diversity of blooming plants on green roof (Tonietto et al., 2011). Nectar plants also attract butterflies in metropolitan areas (Sharp et al., 1974). The continuous availability of substrate in the environment had

shown to be dependent partly on the age of the green roof. Older green roofs indicated that the substrates in the environment were stable, and the numbers of insects would increase (Matteson and Langellotto, 2010; Schrader and Böning, 2006).

Green roof sit on the top of building. Arthropod species numbers did not significantly correlate with the distance of the green roof from the ground (Schindler et al., 2011). Green roofs on tall buildings and skyscrapers are ideal wildlife habitats (Everaars et al., 2011), and a good effect on insects living (Iwasak et al., 2005) in cities. Sunlight is one of the major factors limiting bee and butterfly richness on the rooftops (Matteson and Langellotto, 2010), because sunlight is less limited on most rooftops, florally rich green roof could provide important living environment for flower-visiting insects, especially in inner-city areas where ground-level green space are often shaded by buildings. The locations of green roof had an influence on insect diversity (Coffman and Waite, 2010). The studies of Madre et al. (2013) and Tonietto et al. (2011) showed that the green space proportions within a 500 m radius of a green roof had a positive effect on bee and arthropod vitality and abundance.

Taipei City, the capital of Taiwan, has a population of nearly three million people within a total area of 272 km². The population density is over 10,000 people/km², making Taipei City the seventh most populous city in the world. In the city center, the population density may reach 25,000/km². Parks and green space areas are less than 5% of total area (Taipei City Government, 2014); the potential of increase in green space on the ground is thus limited. Urbanization was a major cause of decreasing flower-visiting insects (Jiang, 2012; Zhou, 2009). Like as, there were more than 110 types of butterflies identified in 1936, 69 from 1960 to 1970, and 50 in 2008 (Zhou, 2009). The most frequently seen species was *Zizeeria maha okinawana*, followed by *Pieris canidia*, 10 of 50 species were less common, and the remainder of the species were rare (Jiang, 2012; Zhou, 2009). The Taiwan Biodiversity Information Facility (TAIBIF, 2014) recorded 18 kinds of bees from 1985 to 2010; the most prevalent species was *Apis mellif* with 40% abundance, followed by *Apis cerana* with 10% abundance. The database also showed bees did not record after 2002 in the Taipei city center (TAIBIF, 2014).

The state of decreasing flower-visiting insects is in progress in this highly developed city, Taipei. Therefore, we conducted the manufactured habitat in green roof study focusing the relationship between flower-visiting insects and greening variables of green roof. We would answer the follow questions: determined the greening variables influences on flower-visiting insects, and which were used

to establish habitat suitability index (HSI) curves. Got the appropriate greening approaches for attract more flower-visiting insects on the limited area of green roof by HSI curves. Established HSI model of green roof is to serve as a basis for predicated living environment quality and applied to establish green roof for flower-visiting insects.

2. Materials and Methods

2.1. Site Characteristics and Greening Variables Survey

The average building area is less than 800 m² and more than four of five buildings are below twelve stories in Taipei city (Taipei City Government, 2013). We selected 26 public buildings; 19 had set up resting place for people of extensive green roofs that were under maintenance, with planting mediums at depths below 20 cm, and the remaining four buildings had not set up green roofs (Fig. 1). These 26 building rooftops were in an exposed position because no taller buildings around it, therefore the duration of sunlight was not measure.

Flower-visiting insects and seven greening variables were been collected at 26 studied sites; survey period of ten green roofs and four general roofs were from May to November 2012, nine green roofs and three general roofs were from May to November 2013, and once a month. Greening variables included the green roof area, total plant area, nectar plant area, nectar species, the age of the green roof, the distance from green roof to the ground level, and green space ratio of green roofs surroundings. All 15 buildings were been constructed more than 20 years ago, and the ages of the green roofs ranged from 2.5 to over 5 years old. The entire green roof and general roof areas ranged from 142 to 643 m². The surrounding green space ratio was the total green space area divided by the land area within a 500 m radius from the green roof, which were been measured by aerial photography in 2012 and 2013.

Nectar plants refer to plants with flowers that produce nectar to attract Flower-visiting insects. The plants and nectar plants were identified by TAIBIF (TAIBEI, 2014) and Lin (2008a, 2008b).

During the investigation period, a total of 159 plants species belonging to 59 families were been recorded, with the five largest plant areas belonging to *Eremochloa ophiuroides* and *Zoysia matrella* in the Poaceae family, *Heterocentron elegans* in the Melastomataceae family, *Ficus vaccinioides* Hemsl. ex King belonging to Moraceae, and *Sedum* belonging to Crassulaceae. Fifty of 159 were nectar plants species, 10 for butterflies and bees, 16 for bees and 24 for butterflies.

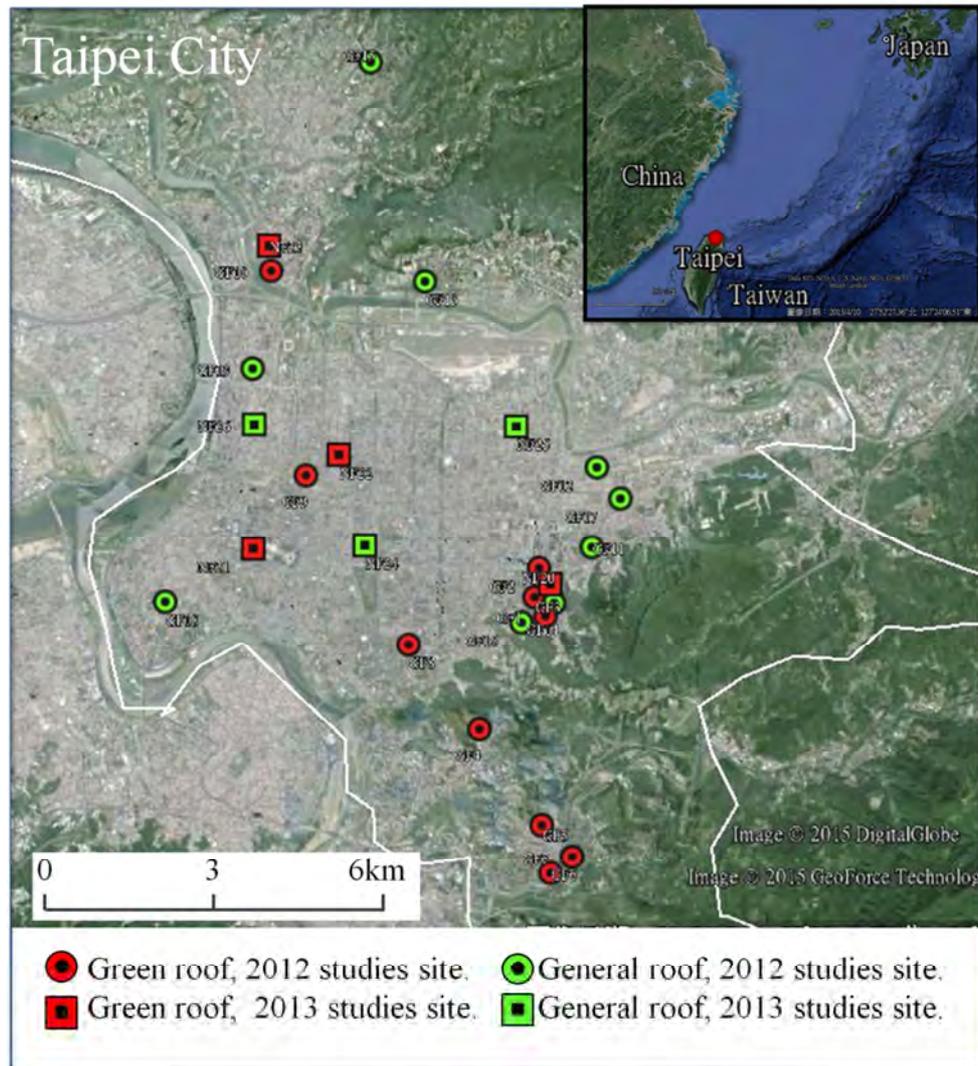


Figure 1. Map of the location of 19 green roofs and 7 general roofs in Taipei city.

2.2. Flower-Visiting Insects Sampling

We investigated flower-visiting insects at 11 green roofs and 4 general roofs. Two collection methods employed at each site. First, flower-visiting insects landed on plants were been captured with insect nets during the 1-hour periods starting at 9:00 to 10:00 am, and 1:30 to 2:30 pm. Second, hanging traps with a pineapple chunk on a plate was been placed at intervals of 25 m². At sites with vegetation below 1 m, traps were been mounted on 0.6 m dowels. After finishing the sampling work with the nets, traps were been placed at each site for approximately 24 hours. The investigation of each site was once a month, total twelve times from May 2012 to April 2013. Flower-visiting insects were identified by genus and species through TAIBEI (TAIBEI, 2014) and Insects (Zhang, 1998, 2001).

The flower-visiting insects were recorded 2,199, bees were 475, butterflies were 1574 and wasps were 150 during the investigation period. There were two species of bees belonging to the Apidae family, with *Apis mellifera* (n=258) and *Apis cerana* (n=117). Butterflies were 12 species belonged to five families, with the most frequent species was

Zizeeria maha okinawana (n=1098) and *Pieris canidia* (n=343). Wasps were four species belonging to the Vespidae family and numbers of each species were similar, like as *Delta pyriforme* (n=46), *Vespa affinis* (n=30). We calculated flower-visiting insect species diversity using the Shannon index and species richness. But the values of Shannon's diversity index and specie richness of each site were very low, which would not be discussed in the next.

2.3. Data Analysis Methods

ANOVA analysis was used to the differences among greening variables of green roof and flower-visiting insects. Then, we used correlation analysis to test the relationship between flower-visiting insects and greening variables of green roofs, and greening variables that were found to be significantly related were selected for further analysis.

The research's objectives would get the greening approaches for attractive more flower-visiting insects on a limited area of green roof. We adopted the habitat suitability index (HSI) method to derive research findings that concept based on hypothesized species-habitat relationships rather

than statements of proven cause and effect relationships (USGS, 2014), and noted that maximum numbers of target species were associated with optimal habitat conditions (USFWS, 1981; Schamberger and O'Neil, 1986). The HSI curve was drawn by plotting the number of target species and a certain habitat variable. The number of target species would be directly converted into an index of suitability, ranging from 0.0 to 1.0 for species (0.0 indicating unsuitable conditions and 1.0 optimal condition); which can be applied to assess the suitability of the variable in meeting species' habitat requirements (USFWS 1986a). As study's concept of USFWS (1981), Schamberger and O'Neil (1986) for the HSI curve, if a specific greening variable is set to a certain value, the other values of the greening variable at the sampling station with the highest flower-visiting insect numbers should be considered to be optimal, then that HSI curve was drawn by the scatterplot of flower-visiting insects and certain greening variable.

Then, all HSI curves were integrated into a HSI model used to interpret the complexities of habitat and to assess habitat quality; and the model is mechanistic and knowledge-based, combining both research data and expert opinion (Amici, et al. 2010; Wang and Lin 2013; Zohmann et al. 2013). We deliberately selected HSI method, which could be used to made green roof for flower-visiting insects through greening approaches.

We modified the HSI model to create a flower-visiting insects' index on green roof (HSI GF). Flower-visiting insects is represented by a set of greening variable, with the essential characteristic of appropriate green roof being that it enables high flower-visiting insects numbers. Each greening variable used in the habit suitability index (HSI) curve describes the relationship between a particular greening variable and flower-visiting insects, using values between 0 (no flower-visiting insects numbers) and 1 (very high flower-visiting insects numbers). All CSI curves are then integrated to create the HSI GF model. Mathematical and logical relationships used to calculate HSI GF scores varied, depending upon the number and types of HSI GF variables included in the model. We used continued product (CP), arithmetic mean (AM), or geometric mean (GM) (i.e., $[x_1 \times x_2 \times \dots \times x_n]$, $[x_1 + x_2 + \dots + x_n] / n$, and $[x_1 \times x_2 \times \dots \times x_n]^{1/n}$, respectively) (Grebekov et al. 2006; USFWS 1981; USFWS 1986b) to combine variables representing flower-visiting insects requisites, or tangible resources.

It is known that a good design green roof could attract more flower-visiting insects. The HSI GF model can be employed to calculate flower-visiting insects in relation to greening variables, and it is potentially possible to also consider effective and easier green roof management strategies for flower-visiting insects using this method.

3. Results

3.1. Comparing the Green and General Roofs

Flower-visiting insects were compared for the green and

general roofs. With the use of t-tests, a significant difference was found for flower-visiting insects numbers on green roofs versus general roofs ($t = 5.570$, $p = 0.000$). We also separately test bees, butterflies and wasps, a significant difference was found for each kinds of insect on green roofs versus general roofs. The two types of roofs were similar in all aspects except for the green components, and the t-test results supported that a good design green roofs were a better habitat for flower-visiting insects. The general roofs were not be discussed on the following processes.

Meanwhile, the site area, green roof height (from ground level), and surrounding green space ratio was not significantly different between the green and general roofs. The average area of the green roofs was 306.1 m^2 (SD=201.72), the average height from ground level was 13.6 m (SD=7.45), and the average surrounding green space ratio was 18.7% (SD=8.75). The average area of the general roofs was 489.2 m^2 (SD=149.08), the average height from ground level was 13.3 m (SD=4.72), and the average surrounding green space ratio was 20.6% (SD=10.43).

3.2. Influential Greening Variables in Flower-Visiting Insects

The number of flower-visiting insects examined relied on greening variables of green roof. The difference between the flower-visiting insects and six greening variables (site area, total plant area, nectar plant area, nectar plant species, the age of the green roof, and surrounding green space ratio) was significant. However, the height the green roof from the ground level had no significant effect in terms of the number of flower-visiting insects.

Furthermore, after correlation analysis, the results indicated that the number of flower-visiting insects achieved a significant level of correlation with nectar plant areas ($r=0.805$, $p=0.000$), nectar plant species ($r=0.772$, $p=0.000$), the age of the green roof ($r=0.564$, $p=0.000$), and surrounding green space ratios ($r=0.504$, $p=0.000$) which all had high positive correlations.

Under the correlation discussion, the key greening variables for numbers of flower-visiting insects were nectar plant area, nectar plant species, the age of the green roof, and surrounding green space ratio; which were integrated with flower-visiting insects data in order to establish HSI. We examined the scatterplot of the lowered correlation coefficients of site area and total plant area, which were eliminated.

3.3. HSI for Flower-Visiting Insects

We adopted HSI method to formulate each greening variable. According the results of the correlation analysis, HSI curve represented the relationships between the flower-visiting insects and four greening variables (nectar plant area, nectar plant species, the age of the green roof, and surrounding green space ratio). First, the normalized of number of flower-visiting insects with each greening variable was used to plot a scatterplot; Then, the maximum normalized of number of flower-visiting insects would be drawn HSI

curve, as showed as Fig. 2 to 5.

Each HSI curve reflected the state of a certain greening variable with the maximum flower-visiting insects, which was used to determine the optimal state of each greening variables attracted more flower-visiting insects on the limited area of green roof.

As indicated in Fig. 2-5, increasing nectar plant area, nectar plant species, the age of green roof and surrounding green space ratio with more flower-visiting insect numbers. Moreover, if nectar plant area reached 140 m², nectar plant species are more than 22, green roof is established more than 46 months, and the surrounding green space of green roof is more than 30%, which green roof may be the branch of habitat in compact city with the great potential for attracted many flower-visiting insects.

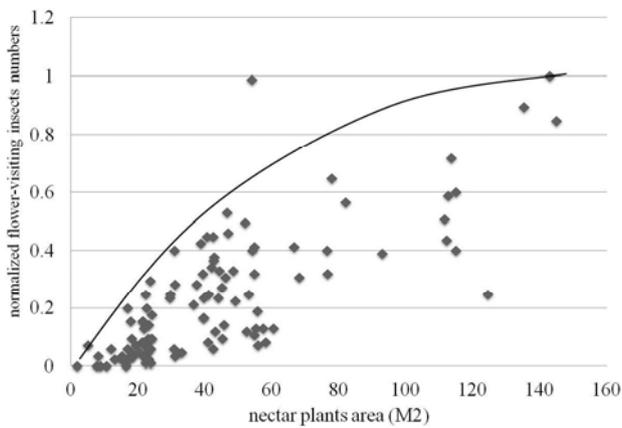


Figure 2. Habitat suitability index (HSI) curve for normalized flower-visiting insect numbers versus nectar plant area. HSI curve drawn by if the value of nectar plant area was fixed, and which state could attract maximum flower-visiting insect numbers. The curve shown if the nectar plant area reaches 140 m², the limited area of green roof could attract more flower-visiting insects.

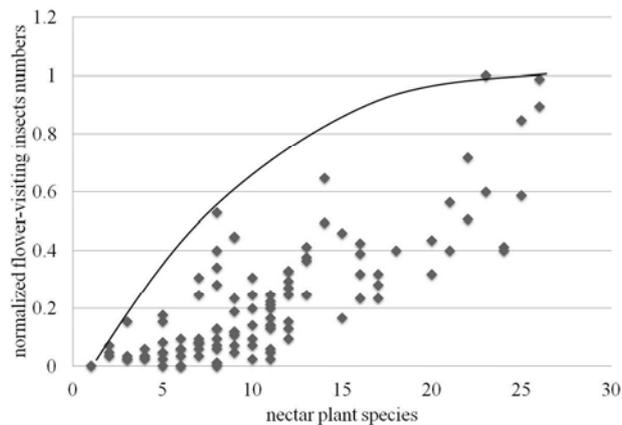


Figure 3. Habitat suitability index curve for normalized flower-visiting insect numbers versus nectar plant species numbers. That curve indicate the effects of nectar plant species on flower-visiting insect numbers, and shown if the nectar plant species was more than 22, the limited area of green roof could attract more flower-visiting insects.

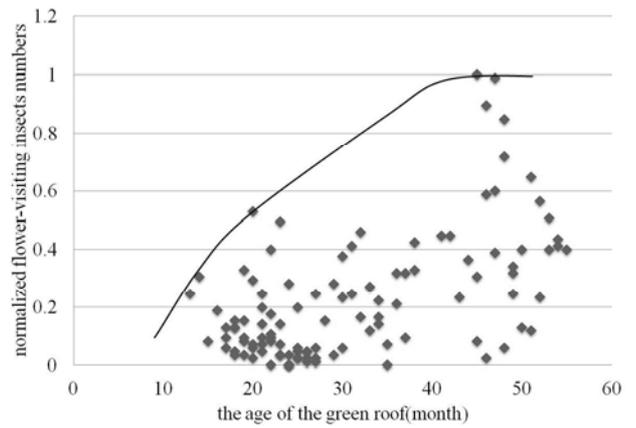


Figure 4. Habitat suitability index curve for normalized flower-visiting insect numbers versus the age of green roof. The curve indicate if we establish a green roof more than 46 months that could attract more flower-visiting insects on the limited area of green roof.

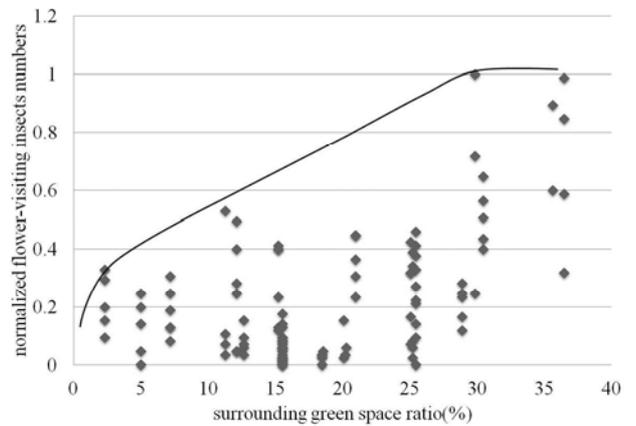


Figure 5. Habitat suitability index curve for normalized flower-visiting insect numbers versus the surrounding of green space. The curve shown if the surrounding green space of green roof is more than 30%, which may play a stepping stone for flower-visiting insect and could attract more flower-visiting insects on the limited area of green roof.

3.4. HSI Model for Flower-Visiting Insects

The HSI model was produced from the formulae of all HSI curves, applied to manage greening variables to achieve high levels of flower-visiting insects on the limited area of green roof. First, we applied a general linear model procedure to test for the dependent variables of flower-visiting insects and the interaction effect of independent greening variables (nectar plant species, nectar plant area, the age of green roof and surrounding green space ratio). The interaction effect of each greening variable was not significant, then which would not be weighted accordingly in the HSI model test.

The estimated values of the formulated model using CP, AM, and GM, were therefore verified with field data for flower-visiting insects, and goodness of fit was evaluated. The GM approach was found to provide the best fit and was most appropriate for indicating greening variables on green roof, as shown in equation (1) below:

$$HSIGF = (HSI_{\text{nectar plant species}} \times HSI_{\text{nectar plant area}} \times HSI_{\text{the age of green roof}} \times HSI_{\text{the surrounding green space ratio}})^{1/4} \quad (1)$$

4. Discussion and Conclusions

We confirmed the greening approaches of green roof for attract more flower-visiting insects in compact city, such as Taipei. TAIBIF (2014) indicated that bee and butterfly populations were rapidly declining in the center of Taipei city after 2002. Although the flower-visiting insects on the green roofs represented only a few species during the survey period, our research findings clearly demonstrated the fact that a carefully designed green roof could become an appropriate living environment for flower-visiting insects.

Nectar plant area, nectar plant species and the age of the green roofs were the key positive variables viability. Coffman and Waite (2011) and Madre et al. (2013) reported that the more complex vegetation influenced species richness and abundance on green roofs. Since provided appropriate food and pollen resources could encourage flower-visiting insects living in heavily urbanized settings (Everaars et al., 2011; Ksiazek et al., 2012; Matteson and Langellotto, 2010; Tonietto et al., 2011). The established green roof with age had a more stable environment in terms of substrate availability and habitat stability for arthropods (Schrader and Böning, 2006).

The distance from the ground to green roof had no impact on flower-visiting insects numbers, the research finding was similar the research of Schindler et al. (2011). There were no the shadow cast by the neighbouring buildings in all studies sites, and the sunlight state of most building roofs were similar in Taipei city. Everaars et al. (2011), Matteson and Langellotto (2010) asserted that there are higher sun exposure at higher building that may provide suitable environment for nectar plants and flower-visiting insects in urban. Although high-rise buildings are prevalent in cities, the carefully designed green roof could become a potential habitat for flower-visiting insects.

The surrounding green space ratio of green roofs had positive effects on the number of flower-visiting insects. The proportion of natural areas surrounding the green roofs had an impact on insects survival (Dauber et al., 2003; Matteson et al., 2010; Steffan-Dewenter et al., 2000; Tonietto et al., 2011). Green roofs are a stepping stone to environmental protection in cities (Goddard et al., 2010), and the maintenance of a minimum number of distant patches can support a sustainable local species population in highly urbanized areas (Snep et al., 2011). There have more green areas in the suburbs, which may meant more host plants for butterflies and nesting space for bees and wasps. Ksiazek et al. (2012) showed that pollinator diversity depends on the quality of the surrounding vegetation. Our suggestion of location planning for green roofs should improve the diversity of flower-visiting insects in Taipei City.

We got greening approaches of nectar plant area, nectar plant species, the age of green roof, and the location selections of green roof by HSI curves. For the reason of maintenance cost, sedums and grass composed a significant percentage of the overall plant area on the green roofs in Taipei city.

According our research findings the moderate greening approaches to establish green roof that would attract more flower-visiting insects. That may a win-win strategy for the limited area of green roof in Taipei city.

The four HSI curves of greening variables were integrated into the HSI model using the GM approach. This result mainly illustrates the ease of obtaining a reliable prediction of flower-visiting insects by estimating HSI model and using field data for only nectar plant area, nectar plant species, the age of green roof and the surrounding green space ratio. If we deeply consider the model that could be applied to improved decision making and management strategies of green roof for attract more flower-visiting insects. An effective strategy promote and bloom the green roofs for flower-visiting insects in urban is important (Carter and Fowler, 2008)

Although our findings recorded only a few flower-visiting insect species in the studied sites, and, Dauber et al. (2003), Ksiazek et al. (2012), and Tonietto et al. (2011) also showed that green roofs supported lower abundance of bees than nearby urban green spaces, their argument was that these habitable spaces would support many species, and have the potential to make greater contributions to urban ecosystems (Butler et al., 2012). In the face of stress and increased population and land use, green roofs are potentially important for offsetting habitat loss in Taipei City.

The study investigated a series of values of four greening variables. Then we suggest greening approaches to construct green roofs for attract more flower-visiting insects. Due to the limited space of the roof sites, the green roof area was generally small in Taipei City; therefore, the findings of this study are suitable for green roofs in small areas.

This researches results may not be suitable the difference situation of the cities. We made a useful operational process and method that is applied to the discussion of how good habitats can be created for flower-visiting insects everywhere.

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