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Relative attractiveness of ruderals and ornamental plants to flower-visiting insects in a tropical anthropogenic landscape

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ABSTRACT

Insects are declining in many parts of the world. Under this context, flower gardens are useful for insect conservation in human settlements. However, this tool is rarely used in the tropics due to low awareness and lack of information on suitable plants. Therefore, our objective was to identify a planting design for native insect conservation in anthropogenic landscapes in Sri Lanka. We selected seven wild, ruderal plant species and a cultivated ornamental plant, *Zinnia elegans*. We established three planting designs with four replicates each: (1) only ruderal plants, (2) ruderal plants mixed with *Z. elegans,* and (3) only *Z. elegans*. Insect monitoring was done in each replicate for five sunny days. Over the entire study, we observed > 16,000 visits from 96 insect species and seven orders. Hymenopterans and lepidopterans comprised the most species and the most visits to the plots. The three planting designs differed significantly in terms of insect visitation and richness. For most insect orders, the ruderal design was more or equally attractive to insects compared to the mixed design, and more attractive than the *Z. elegans* design. Insect community composition was also significantly different among three designs, with 38 species identified as significant indicators of one of the planting designs. The highest number of indicator species was recorded in the ruderal design. Our recommendation depends on the landscape context. The ruderal planting design was best for insects and easy to establish and maintain, but the mixed design (a close second) might be more suitable in areas with high human activity due to its pleasing aesthetics.

1. Introduction

Insects play a crucial role in ecosystem function and provide many benefits to humans (Losey and Vaughan, 2006). Unfortunately, beneficial insects such as pollinators have been declining globally over the last several decades (Hallmann et al., 2017; Potts et al., 2010). Drivers of this decline include anthropogenic factors such as loss and fragmentation of habitats, intensive agriculture, over use of pesticides and herbicides, climate change, diseases, and pests (Hendrickx et al., 2007; Potts et al., 2010) Therefore, it is essential to develop suitable strategies to restore insect biodiversity and their associated ecosystem services.

In view of conservation of insects, simple and easily applicable strategies hold the best potential (Losey and Vaughan, 2006). One such strategy is to re-integrate floral habitat into resource-poor, human-modified landscapes (Borda-Niño et al., 2017; Pontin et al., 2006). The availability of plant-derived resources such as nectar, pollen, refuge, nesting substrates, and overwintering sites positively influence the diversity and abundance of beneficial insects (Gill, 2013; Landis et al., 2005). These resources sustain survival, development, and reproduction of beneficial insects (Berndt and Wratten, 2005) and enhance pest suppression (Lu et al., 2014).

The provision of floral resources to enhance beneficial insect populations can be achieved by either incorporating a single most suitable species or a mixture of plant species (Pontin et al., 2006). Many flower-visiting insects are generalists and can use resources from a wide variety of plants (Fontaine et al., 2009). However, to conserve a diversity of flower-visiting insects, the entire plant community is important (Kearns and Inouye, 1997). Therefore, plant mixtures (rather than single species), with their diverse floral resources and micro habitats, have potential to support more diverse communities of insects (Blaauw and Isaacs, 2015). In addition to the conservation benefits, these plantings can facilitate several other functions such as erosion

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control, harvesting edible plant parts and aesthetic benefits (Isaacs et al., 2009). Though large flower plantings are often used to enhance insect communities, effectiveness of smaller scale plantings, particularly around human settlements, remain unclear.

Human settlements (e.g., cities and towns) offer a unique ecological environment due to the urban heat island effect (Taha, 1997) and high habitat heterogeneity (Band et al., 2005), which provide diverse nesting and foraging opportunities for animals (Sattler et al., 2010; Shwartz et al., 2014). Moreover, plant species richness is usually higher around human settlements than in rural areas (Kühn et al., 2004; Owen, 2010). Further, flowers around human settlements are less often contaminated with pesticides than flowers close to agricultural areas (Hostetler and McIntyre, 2001). Recent research suggests that cities may in fact act as 'refuges' for flower-visiting insects such as pollinators (Hall et al., 2016). However, very little of this work has been conducted in tropical regions (but see Frankie et al., 2009 and 2013).

Flower gardens are a landscape feature that have the potential to enhance insect abundance in human settlements (Shackleton and Ratnieks, 2016; Smith et al., 2006). However, garden plants are often non-native species or horticulturally-modified plant varieties, which may not be attractive to beneficial insects (Garbuzov and Ratnieks, 2014). On the other hand, some studies revealed no difference between native and non-native plots in terms of the insect visitors (Garbuzov and Ratnieks, 2014; Majewska et al., 2018). Even though a large number of plant lists, including native and non-native species, have been produced to promote wildlife gardening, those are mainly based on personal observations, experience, opinion and perhaps, uncritical recycling of earlier lists (Garbuzov and Ratnieks, 2014). Therefore, there is a need to select planting designs with suitable plant species based on reliable data rather than personal opinion and experiences. This is particularly true for tropical regions, where certain information is lacking.

The objective of this study was to test the attractiveness of different planting designs on the flower-visiting insect community in Makandura, Sri Lanka. We compare three planting designs: (1) a design with only ruderal, wild plants, (2) a design with only a commonly cultivated garden plant (*Zinnia elegans)*, and (3) a design with ruderal plants mixed with *Z. elegans*. We ask how different planting designs affect insect visitation, richness, and community composition. Aesthetics of the three planting designs was evaluated previously by the authors and the mixed design was appreciated more than the other two designs both by environmentalists and the general public (Wijesinghe et al., 2017); we expected that the mixed design would be most attractive to the insect community as well, due to its higher plant diversity. Our results, which deviated from our expectations, can be applied to promote conservation of native Sri Lankan insect fauna while enhancing the beauty of anthropogenic landscapes.

2. Materials and methods

2.1. Study location

This experiment was conducted at the Regional Agriculture Research and Development Center (lat: 7.3204 ° north and long: 79.9974 ° east), Makandura, Gonawila, Sri Lanka during June to December 2015. The Gonawila area covers 35 km^2, borders a river, and includes a variety of land use / land cover types such as industrial zones, government offices, a state university, densely built residential gardens, and agricultural lands. Sri Lanka is considered one of the eight "hottest hotspots" for global biodiversity (Myers et al., 2000). The climate of Sri Lanka is tropical, with distinct wet and dry seasons. The area receives 1960 mm of average annual rainfall, and average temperatures range from approximately 23 °C to 31.7 °C. The soil type is Red Yellow Podzolic with Alluvial soil as a top layer. The experiment plots were surrounded by naturally occurring vegetation including grass species and both fields were at least 200 m away from the regular cropping fields where agro chemicals are applied.

2.2. Establishment of three different planting designs

An experiment was established to compare the attractiveness of wild, ruderal plants with a popular ornamental plant. All species are annual herbs and are approximately less than 65 cm tall. Seven ruderal species were selected based on their abundance in the surrounding landscapes and based on previous studies on seed germination and phenology (Wijesinghe et al., 2014, 2015): *Spermacoce assurgens* Ruiz and Pav., *Leucas zeylanica* (L.) R. Br., *Tridax procumbens* L., *Merremia tridentata* (L.) Hallier f., *Emilia sonchifolia* (L.) DC. ex DC., *Ipomoea triloba* L., and *Cyanthillium cinereum* (L.) H.Rob. The selected ruderal species had different colour flowers, including white, yellow, and purple or violet, to maximize their attractiveness to a variety of insects. Among them *L. zeylanica*, *M. tridentata, E. sonchifolia* and *C. cinereum* are native to Sri Lanka, while the other species are naturalized exotics.

We compared the seven ruderal plant species to an ornamental cultivated species, *Zinnia elegans.* A member of the Asteraceae family, a taxonomic group thought to be attractive to a wide variety of insects (Dufour, 2000), *Z. elegans* is often suggested as an attractive plant for pollinators in the popular media (e.g., Sansone, 2017) and extension documents (e.g., Sandve, 2017). Called an "old garden favorite" by the Missouri Botanical Garden (http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a618), it is commonly grown in Sri Lanka and around the world.

Three planting designs were used in the experiment: (1) only wild, ruderal plants ("ruderal"), (2) ruderal plants mixed with *Z. elegans* ("mixed"), and (3) only *Z. elegans* ("Zinnia") (Fig. 1). Plots were 3m × 3m, and each experimental plot was separated from other plots by at least 20 m (Fig. 2). Plots were arranged in a completely

Fig. 1. Photographs showing the visual appearance of three different planting designs a) Design with only ruderal plants b) Mixed design and c) Design with only *Z. elegans*.

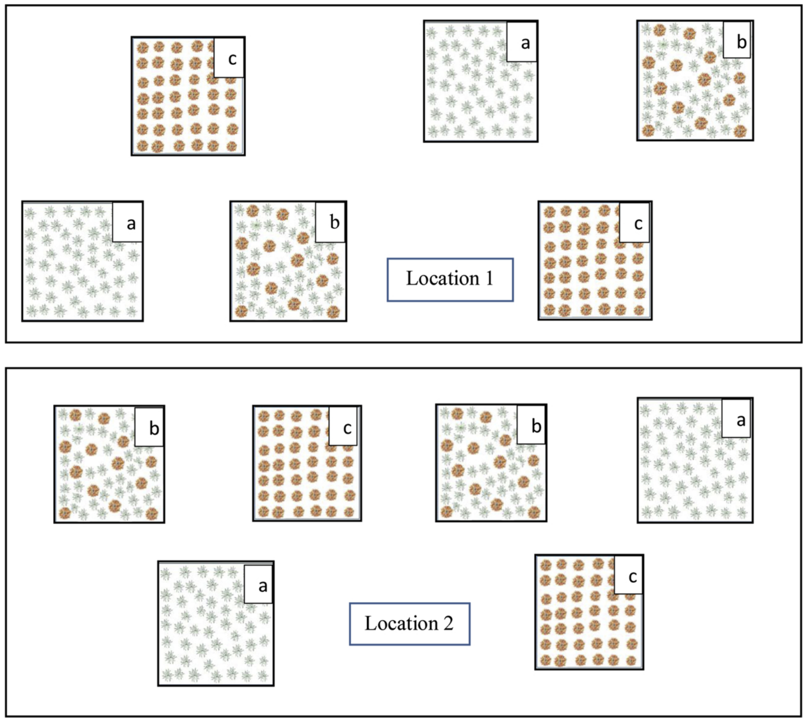

Fig. 2. Schematic layout of the three planting designs (3m × 3m each) in two different locations a) Design with only ruderal plants b) Mixed design and c) Design with only *Z. elegans*.

randomized design with four replicates in two different locations ("north" and "south") which were located 200 m apart from each other.

Prior to planting, the sites were cleared of existing vegetation with deep tilling (12 cm) followed by mechanical weed removal. Direct seeding was employed to establish all three designs. To establish the ruderal and mixed designs, the seed rate of each ruderal plant species was determined based on a previous study (Wijesinghe et al., unpublished data). Accordingly, we used the following amount of seeds for each ruderal species: *S. assurgens* (1.275 g), *L. zeylanica* (3.46 g), *T. procumbens* (0.403 g), *M. tridentata* (37.19 g), *E. sonchifolia* (0.513 g) *I. triloba* (46.66 g) and *C. cinereum* (0.244 g). Seeds were mixed with fine sand prior to sowing to distribute seeds uniformly in the planting designs. To ensure an equal number of plants (n = 144) per species in the different replicates of the ruderal design, we thinned the seedlings of ruderals leaving 28 individuals of each *S. assurgens*, *L. zeylanica*, *E. sonchifolia* and *C. cinereum*; 15 individuals of *T. procumbens*; 12 individuals of *M. tridentata;* and 5 individuals of *I. triloba*. These number were decided based on the growth habits of the plants (Wijesinghe et al., 2015). For establishing the mixed design (n = 144), 18 *Z. elegans* plants were planted randomly in each plot. In addition, the seeded ruderals were thinned, leaving 25 individuals each from *S. assurgens*, *L. zeylanica*, *E. sonchifolia* and *C. cinereum*; 12 individuals of *T. procumbens*; 10 individuals of *M. tridentata;* and 4 individuals of *I. triloba*. For the Zinnia design, 13.5 g of seeds were used to establish *Z. elegans*, based on the recommendation from Armitage (1993) and plants were thinned out leaving 100 *Z. elegans* plants per plot.

2.3. Maintenance of the planting designs

For the ruderal and mixed designs, watering was done at two day intervals up to one month after sowing, and thereafter at weekly intervals or as required. However, for the Zinnia design, watering was done at two day intervals throughout the study period. During the establishment period (4 weeks), weeding was done in all the designs fortnightly and thereafter occasionally. Pinching was done as required to induce more flowering branches in *Z. elegans* plants and liquid foliar fertilizer (Maxicrop) was applied at weekly intervals to encourage flowering (only to the Zinnia design). Plants were trimmed as necessary to ensure that they did not overgrow the patch perimeter.

2.4. Monitoring of insect activity in three different planting designs

Insect observations began after all species were flowering. Before the start of data collection, a reference specimen collection of insects was prepared following standard entomological procedures. Reference insects were identified using available keys (Karunaratne and Edirisinghe, 2008), field guides (d'Abrera, 1998; Bedjanic et al., 2007), and an expert-identified reference specimen collection lodged in the Invertebrate Systematics and Diversity Facility (ISDF) in the Department of Zoology, University of Peradeniya.

Data collection took place between December 11–22 2015. During that time period, activity and abundance of all insects was monitored on five separate days in each experimental plot. Each day, plots were monitored from 7.00 a.m. to 6.00 p.m. at hourly intervals. For the few species that could not be identified during the preliminary study, photographs were taken with a digital camera and later identified in the laboratory using the available literature. Some of the hymenopteran and dipteran insects that were newly recorded were collected using a hand net and were curated properly. Ten minutes per hour was spent counting and identifying insects by walking four cycles around each plot. All insect species in flight or at rest on plants were recorded in a field data sheet. Temperature and relative humidity were recorded in each plot, in hourly intervals at the time of collecting insects. We used a humidity meter with dew point and thermometer (Model ID: 4309917, ECM).

2.5. Statistical analysis

To examine the effect of planting design on insect visitation and richness, we used linear mixed-effects models. We created separate models for richness and visitation, with planting design, insect order, and their interaction term modeled as fixed effects, and sample location (north or south) modeled as a random effect. When significant interactions were identified, the simple main effects were also analyzed. Mixed-effects models were run with the “lme” function in R package “nlme” (Pinheiro et al., 2019). Model residuals were tested for spatial autocorrelation with Moran’s I, using GeoDa 1.14 (Anselin et al., 2006) with 999 permutations. After the richness model was found to have residual spatial autocorrelation, we incorporated latitude and longitude of each plot into the model as exponential spatial correlation structure (using the “correlation” argument in function “lme”), and then re-tested model residuals for spatial autocorrelation.

A one-way PERMANOVA was used to identify differences in community composition between the three planting designs. Mean visitation numbers for each species to each replicate plot (averaged over all five sample days) was the response variable, and planting design was the grouping variable. Bray-Curtis distance was used to measure dissimilarities between plots. Significance was calculated based on 10,000 random permutations.

To further understand differences in the insect communities between the three planting treatments, we used indicator species analysis to see whether individual species associated with one of the planting designs. Indicator values for each species in each group were calculated using Dufrêne and Legendre’s (1997) method based on the concentration of species’ abundance and the faithfulness of species occurrence in each group. The highest indicator value for a given species across groups was used as the overall indicator value of that species, and the indicator value was tested for statistical significance using a randomization technique. PERMANOVA and indicator species analysis were conducted using PC-ORD 6.0.

3. Results

3.1. Overall findings

Over all sample plots and time periods, we recorded a total of 16,159 insect visits to the experimental plots. Insect visitors included 96 species in 7 orders (Table 1). The order Hymenoptera was represented by the most species (34), followed closely by Lepidoptera (31). Other orders were represented by ten or fewer species. Out of the insect species recorded, two endangered bee species (*Systropha tropilcalis* and *Apis florea*) and five vulnerable species (*Megachile hera, M. lanata M. umbripennis, Apis cerana* and *Amegilla puttalama)* from the national red list (MOE, 2012) were recorded in both designs with ruderal plants (ruderal and mixed designs) whereas only a single vulnerable bee species was recorded in the Zinnia design (*A. cerana*).

3.2. Effect of planting designs on species richness and visitation

Because the initial model of species richness at the experimental plots had significant spatial autocorrelation in the residuals (Moran’s I = 0.269, pseudo p value = 0.002), we incorporated spatial correlation structure into the model. The final model had a significant effect of planting design, insect order, and their interaction (Table 2), and had no significant spatial autocorrelation (Moran’s I = -0.079, pseudo p value = 0.131). Analysis of simple main effects (Fig. 3) showed that insect richness differed significantly among the three designs for six of the seven orders. For all orders except Orthoptera, there was no significant difference between the ruderal and mixed planting designs, but both designs had significantly higher species richness than the Zinnia design. The richness of hymenopterans and lepidopterans were high (> 25 and 15 species, respectively) in both ruderal and mixed designs.

Insect visitation at experimental plots also varied based on planting design and insect order, with a significant interaction between the two variables (Table 3). There was no significant spatial autocorrelation in the model residuals (Moran’s I = 0.026, pseudo p value = 0.244). Analysis of simple main effects revealed that visitation differed significantly between designs for all insect orders except Diptera (Fig. 4). As with species richness, the Zinnia design had lower visitation than both the ruderal and mixed designs. However, in contrast to species richness, the ruderal and mixed planting designs differed from each other in terms of visitation of hymenopterans and lepidopterans. For those two orders, visitation was significantly higher in the ruderal planting design.

3.3. Effects of planting design on insect community composition and indicator species

According to the results of the PERMANOVA, there was a significant difference ($p < 0.001$) in community composition between planting designs (Table 4) and all three designs significantly differed ($p < 0.05$) from each other (Table 5).

Thirty-eight insect species were found to be significantly associated with one of the planting designs (Table 1). The highest number of indicator species (30) was found in the design with ruderal plants, followed by the mixed design (05), and the Zinnia design (03). Most indicator species for the ruderal plant design were hymenopterans or lepidopterans, although all orders were represented except Odonata. Indicator species for the mixed design included two hymenopterans and three lepidopterans. Indicator species for the Zinnia design included Hymenoptera, Lepidoptera, and Diptera (one species each).

3.4. Temporal visitation pattern of insects in the three planting designs

Visitation of total insects in all three planting designs increased from 7.00 a.m. to a peak visitation between 11.00 a.m. to 12.00 noon, followed by another peak with lower intensity between 1.00 p.m. to 2.00 p.m. (Fig. 5). Temporal visitation patterns to each planting design differed somewhat according to insect order. The overall pattern seen for all insects was driven largely by hymenopterans and lepidopterans, which had the highest number of visits and showed a similar temporal trend (Appendix 1). However, visitation in other insect orders peaked early in the morning (e.g., Coleoptera, Orthoptera, and Odonata), while Diptera visitation peaked later in the day. For some orders, the relative attractiveness of different planting treatments shifted throughout the day, but in general, the ruderal planting treatments received equal or more visitors than other treatments through most of the day.

4. Discussion

With insects declining around the globe, there is a pressing need to develop approaches that support insect biodiversity. This is particularly true in the tropics, where few studies have focused on this important issue. Our study compared the attractiveness of three planting designs to the flower-visiting insect community in an anthropogenic landscape in Sri Lanka. We found a significant effect of planting design on insect visitation, richness, and community composition. Unexpectedly, the design with only ruderal plant species was, by many measures, the most attractive design to insect visitors. Our results illustrate the value of planting floral resources in human-dominated landscapes in the tropics, and can be used to inform conservation in a biodiversity hotspot.

In general, the Zinnia planting design attracted fewer visits, from fewer species, than the two designs that included ruderal plants. Although Zinnias are often touted as pollinator-friendly plants, it is perhaps not surprising that the design with a single plant species attracted fewer insect species and visits than more diverse planting designs. The link between insect diversity and plant diversity has long been recognized (Murdoch et al., 1972). However, more surprising is the fact that the ruderal planting design, with seven plant species, appears to be more attractive to the insect community than the mixed planting design with eight plant species. On average, the ruderal plantings attracted more insect species (although not significantly so)

Table 1
Observations, relative abundance, and indicator value of species in each planting design.

Species	# of sample periods observed[a]	Relative abundance in each design			Indicator Value[b]
		Ruderal	Mixed	Zinnia	
Order Hymenoptera (34 species)					
Family: Apidae					
Amegilla puttalama Strand, 1913+	40	50	50	0	
Amegilla sp.1	10	13	87	0	
Apis cerana Fabricius, 1793+	55	4	9	**88**	87.6**
Apis florea Fabricius, 1787++	3	63	38	0	
Braunsapis sp.1	17	48	39	13	
Ceratina binghami Cockerell, 1910	39	49	51	0	
Ceratina hieroglyphica Smith, 1854	40	**56**	44	0	56.4**
Tetragonula iridipennis Smith, 1854	59	42	38	20	
Thyreus sp.1	39	47	53	0	
Thyreus sp.2	27	**64**	36	0	63.6*
Xylocopa sp.1	5	0	41	59	
Family: Halictidae					
Halictus lucidipennis Smith, 1853	37	53	47	0	
Hoplonomia westwoodi (Gribodo, 1894)	33	**70**	30	0	70.1*
Lasioglossums sp.1	17	62	38	0	
Leuconomia sp.1	8	83	17	0	
Lipochritus sp.1	28	58	42	0	
Nomia iridescens	38	53	47	0	
Nomia sp.1	26	**73**	27	0	73.1**
Systropha tropicalis Cockerell, 1911++	40	**65**	35	0	64.5**
Family: Megachilidae					
Coelioxys sp.1	40	50	50	0	
Euaspis carbonaria	27	52	48	0	
Megachile hera Bingham, 1897	25	**86**	14	0	85.6**
Megachile lanata Fabricius, 1793+	40	55	45	0	
Megachile umbripennis+	28	**71**	29	0	71.4**
Megachile sp.1	31	46	54	0	
Family: Vespidae					
Antepipona ovalis	39	**71**	29	0	71.2**
Delta campaniforme	39	51	49	0	
Laridae sp.1	3	**100**	0	0	75*
Ropalidia marginata	29	37	**62**	1	61.9*
Family Vispidae, sp. 1	36	**72**	28	0	71.9**
Scolia sp.1	20	24	**76**	0	75.8*
Family: Nyssonidae					
Bembix borrei	40	**54**	46	0	54.3*
Family Eumenidae, sp.1	19	**80**	20	0	79.5*
Family: Specidae					
Chalybion bengalensis	19	**71**	29	0	71*
# of indicator species		***13***	***2***	***1***	***16***
Order Lepidoptera (31 species)					
Family: Pieridae					
Appias albino Boisduval, 1836	18	18	56	27	
Belenois aurota Fabricius, 1793	1	0	0	100	
Catopsilia pomona Fabricius, 1775	15	11	**71**	18	71.4*
Delias eucharis Drury, 1773	2	0	100	0	
Eurema hecabe Linnaeus, 1764	45	42	39	20	
Leptosia nina Fabricius, 1793	10	36	64	0	
Family: Nymphalidae					
Acraea violae Fabricius, 1807	10	9	9	**82**	81.8*
Danaus chrysippus Linnaeus, 1758	20	**80**	20	0	79.8**
Euploea klugii Moore, 1888	9	0	94	6	
Junonia atlites Linnaeus, 1758	51	**56**	32	11	56.1**
Junonia almanac Linnaeus, 1758	46	**73**	22	5	73.2**
Junonia lemonias Linnaeus, 1758	14	0	**100**	0	100**
Mycalesis mineus Linnaeus, 1758	5	80	20	0	
Parantica taprobana Felder, 1865	3	7	7	86	
Ypthima ceylonica Hewitson, 1864	32	28	**71**	1	70.9**
Family: Lycaenidae					
Azanus ubaldus Stoll, 1782	5	76	18	6	
Chilades lajus Stoll, 1780	2	0	50	50	
Chilades pandava Horsfield, 1829	18	**98**	2	0	98.2**
Jamides alecto Felder, 1860	1	100	0	0	
Jamides bochus Stoll, 1782	8	89	11	0	
Jamides coruscans Moore, 1877	2	100	0	0	
Jamides celeno Cramer, 1775	13	**97**	2	1	96.8**
Zizula hylax Fabricius, 1775	21	**98**	2	0	97.7**
Zizina otis Fabricius, 1787	20	**99**	1	0	98.8**
Family: Hesperiidae					

(*continued on next page*)

Table 1 (*continued*)

Species	# of sample periods observed[a]	Relative abundance in each design			Indicator Value[b]
		Ruderal	Mixed	Zinnia	
Taractrocera maevius Fabricius, 1793	29	0	56	44	
Telicota bumbusae Moore, 1878 +	37	0	50	50	
Pelopidas mathias Fabricius, 1798 + +	20	**87**	13	0	87.2**
Family: Papilionidae					
Papilio demoleus Linnaeus, 1758	29	49	3	47	
Pachilopta hector Linnaeus, 1758	4	0	14	86	
Papilio polytes Linnaeus, 1758	2	0	8	92	
# of indicator species		***9***	***3***	***1***	***13***
Order Coleoptera (9 species)					
Family: Coccinellidae					
Family Coccinellidae, sp. 1	53	45	36	19	
Family Crysomeliadae, sp. 1	40	41	40	19	
Family: Crysomeliadae					
Cassida sp. 1	10	0	56	44	
Family Crysomeliadae, sp. 2	1	0	0	100	
Family: Curculionidae					
Cylas formicarius	35	**86**	14	0	85.5**
Family Curculionidae, sp. 1	25	45	55	0	
Family: Meloidae					
Family Meloidae, sp. 1	34	46	54	0	
Family: Carabidae					
Cicindela sp. 1	25	67	21	12	
Family: Scarabaeidae					
Oxycetonia versicolor	3	0	0	100	
# of indicator species		***1***	***0***	***0***	***1***
Order Diptera (10 species)					
Family: Muscidae					
Musca domestica	45	31	42	26	
Family: Stratiomyidae					
Hermetia illucens	31	23	30	47	
Order Diptera, sp. 1	9	0	0	**100**	100**
Order Diptera, sp. 2	7	0	0	100	
Order Diptera, sp. 3	3	0	0	100	
Order Diptera, sp. 4	11	**84**	16	0	84.2**
Order Diptera, sp. 5	19	28	72	0	
Order Diptera, sp. 6	26	55	45	0	
Order Diptera, sp. 7	23	**67**	33	0	66.7*
Order Diptera, sp. 8	18	**67**	33	0	66.7*
# of indicator species		***3***	***0***	***1***	***4***
Order Hemiptera (4 species)					
Family: Alydidae					
Leptocorisa oratorius	27	59	18	23	
Family: Lygaeidae					
Spilostethus sp. 1	21	**59**	41	0	59.2*
Family: Pentatomidae					
Family Pentatomidae, sp. 1	30	47	53	0	
Family Pentatomidae, sp. 2	24	54	42	4	
# of indicator species		***1***	***0***	***0***	***1***
Order Orthoptera (6 species)					
Family: Acrididae					
Family Acrididae, sp. 1	7	**67**	33	0	66.7*
Family Acrididae, sp. 2	36	55	27	18	
Family Acrididae, sp. 3	21	35	42	23	
Family: Tettigoniidae					
Family Tettigoniidae, sp. 1	25	**70**	14	16	69.8**
Family Tettigoniidae, sp. 2	23	51	37	12	
Family: Membracidae					
Family Membracidae, sp. 1	12	71	6	24	
# of indicator species		***3***	***0***	***0***	***3***
Order Odonata (2 species)					
Family: Libellulidae					
Diplacodes trivialis (Rambur, 1842)	22	51	44	5	
Neurothemis tullia (Drury, 1773)	23	44	56	0	
# of indicator species		***0***	***0***	***0***	***0***

Species red list status: + Least Concerned; + + Vulnerable; + + + Near Threatened (Source: MOE, 2012).

[a] Out of a possible 60 (3 designs x 4 replicates x 5 sample periods).

[b] Only statistically significant values are shown (* $p \leq 0.05$, ** $p \leq 0.01$). Indicator values range from 0 to 100, with 100 indicating that a species points to that group perfectly.

Table 2
Linear mixed-effects models of species richness in experimental plots. Design, insect order, and their interaction term were modeled as fixed effects, while sample location (north or south) was modeled as a random effect. The model included an exponential spatial correlation structure based on latitude and longitude of each plot.

	d.f.	SS	F value	p value
Design	2	634	63.59	< 0.0001
Order	6	3817	522.82	< 0.0001
Design: Order	12	1367	97.42	< 0.0001

and significantly more visits from lepidopterans and hymenopterans (the two most diverse and abundant insect groups) than did the mixed planting. Furthermore, of the 38 insect species found to be significantly associated with one of the planting designs (i.e., indicator species), 30 were associated with the ruderal planting design. We speculate that, in the mixed design, comparatively fast growing and taller Zinnia might have provided shade to the ruderals which in turn reduced the number of flowering units per plant.

Both the ruderal and mixed design were highly successful at attracting a diversity of insects, including multiple red-listed species. In contrast, the Zinnia design only attracted about half of the insect species of the other two designs. While most visitors were hymenopterans and lepidopterans, not all insects visited the plots to feed on floral resources. *Emilia sonchifolia,* one of the ruderal plants, provided mating habitat and acted as a feeding plant of the hemipteran seed bug *Spilostethus* sp.; both adult and larval stages were observed on this plant. *E. sonchifolia* also was a host plant for the larval stage of three lepidopteran species. *Leucas zeylanica,* another ruderal plant, served as a mating place for the hemipteran stink bug *Pentatomidae* sp., which was observed as adults and eggs on the plant. A wasp nest (species unknown) was found glued to the stem of *Cyanthillium cinereum* in the mixed design, and ground nests of Halictidae bees were observed in areas adjoining the ruderal and mixed designs. Many insect visitors, such as wasps, Coccinellidae beetles, and dragonflies, are predators that were likely visiting the plantings to search for prey, although some of those species also consume floral resources.

Insect visitation to the three planting designs varied with time of

Table 3
Linear mixed-effects models of insect visitation in experimental plots. Design, insect order, and their interaction term were modeled as fixed effects, while sample location (north or south) was modeled as a random effect.

	d.f	SS	F	p value
Design	2	11,497	67.63	< 0.0001
Order	6	342,644	671.83	< 0.0001
Design: Order	12	20,377	19.98	< 0.0001

day. Insects change their daily activity pattern to avoid predators, to reduce conflict with competitors, and to exploit food resources (Kronfeld-Schor and Dayan, 2003). Changing environmental factors throughout the day, such as solar radiation, temperature, wind, and humidity may also have profound effects on insect activity (Peixoto and Benson, 2009). For all insect orders except Diptera, visitation was low in the afternoon. This may be due to high air temperatures, which can be potentially lethal for insects (Rawlins, 1980; Van der Have, 2002). This trend could further be attributed to the availability and composition of nectar produced by plants, which varies with time of day (Kulloli et al., 2011). In all focal plant species except *C. cinereum,* pollen and nectar were available from the morning; pollen and nectar of *C. cinereum* were available starting from 11.00 a.m. (Wijesinghe et al., Unpublished). Our findings reveal the importance of sampling at multiple times of day or targeting the sampling period to the activity patterns of the taxa of interest. Sampling only in early mornings or evenings would have obscured differences between our three planting designs. It is likely that insect visitation would also differ over the course of the year, although our study design did not allow us to examine these differences. Further research should extend the sampling period to incorporate seasonal variation.

Over all, our research highlights the value of specific planting designs with unutilized ruderals over the designs with popular garden plants (like Zinnias) for insect conservation in a biodiversity hotspot. Incorporating these plantings around human settlements in Sri Lanka could partially mitigate negative effects of habitat loss. It is important to remember that any landscape changes, including adoption of planting designs, are largely driven by aesthetic experiences of humans

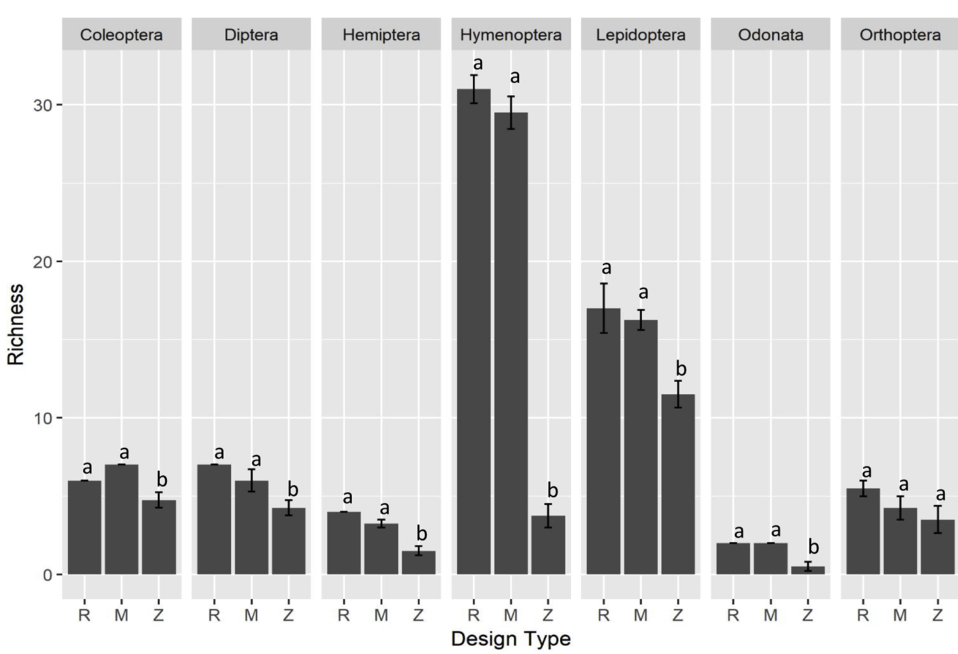

Fig. 3. Species richness of different insect orders under different planting designs. Lower case letters show significant ($p < 0.05$) Tukey HSD tests for each simple main effect; Coleoptera $p < 0.001$; Diptera $p = 0.01$; Hemiptera $p < 0.001$; Hymenoptera $p < 0.001$; Lepidoptera $p = 0.013$; Odonata $p < 0.001$; and Orthoptera $p = 0.197$. R = Design with only ruderal plants; M = Mixed design and Z = Design with only *Z. elegans.*

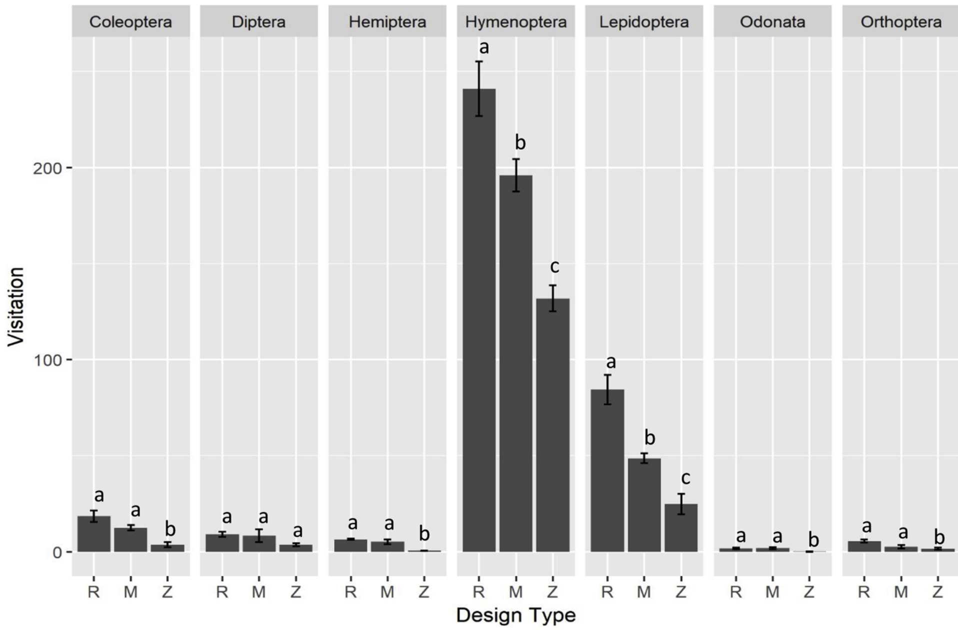

Fig. 4. Visitation for different insect orders under different planting designs. Lower case letters show significant ($p < 0.05$) Tukey HSD tests for each simple main effect. Coleoptera $p = 0.002$; Diptera $p = 0.198$; Hemiptera $p < 0.001$; Hymenoptera $p < 0.001$; Lepidoptera $p < 0.001$; Odonata $p = 0.022$; and Orthoptera $p = 0.014$. R = Design with only ruderal plants; M = Mixed design and Z = Design with only *Z. elegans*.

Table 4
One-way PERMANOVA on the effects of planting design on insect community composition.

Source	d.f.	SS	MS	F	P
Design	2	1.972	0.986	56.514	< 0.001
Residual	9	0.157	0.017		
Total	11	2.129			

Table 5
Posthoc pairwise comparisons for community composition in planting designs.

Comparison	t	p
Ruderal vs. Mixed	2.771	0.030
Ruderal vs. Zinnia	9.994	0.030
Mixed vs. Zinnia	8.805	0.031

(Gobster et al., 2007). Our previous research (Wijesinghe et al., 2017) showed that both environmentalists and the general public preferred the mixed planting design over the other two designs. However, our ecological data suggest that the ruderal plantings are generally more attractive to the insect community. Furthermore, the ruderal planting design incurred lower cost (only seeds) and lower maintenance than the other planting designs. Tradeoffs such as these are commonly encountered in conservation planning (Hirsch et al., 2011). Because the mixed design was still quite attractive to insects, and was preferred by humans, that design might be the better option for areas with high visibility or substantial human traffic. On the other hand, the selected ruderal plant species naturally occur in disturbed secondary vegetation in all the three major agro-ecological zones of the country, thus can easily be incorporated into intentional planting designs outside of high visibility areas, or can simply be allowed to grow where they establish themselves on the edges of agricultural lands. Embedding social considerations such as aesthetic factors into conservation planning is more likely to lead to successful outcomes (Ban et al., 2013). Although our observations are regionally focused, the idea of incorporating ruderals to anthropogenic landscapes could be extended to any part of the world.

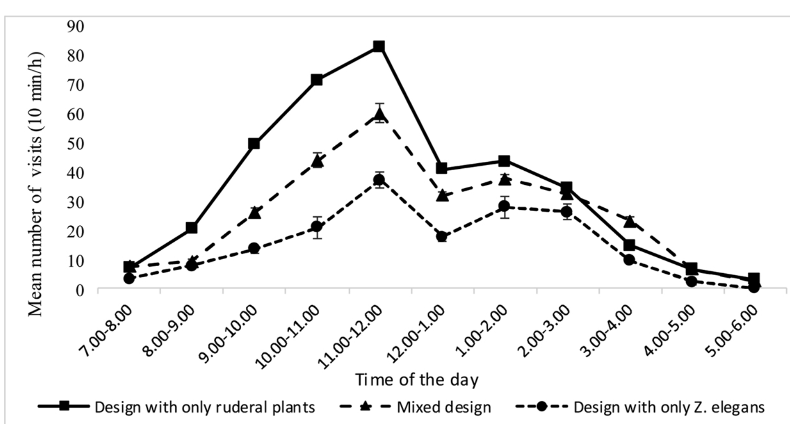

Fig. 5. Temporal visitation pattern of all insects to the three planting designs. Design with only ruderal plants, mixed design, and design with only *Z. elegans*.

5. Conclusion

Based on the results, the highest insect richness, visitation and the highest number of indicator species were recorded in the design with ruderals followed by the mixed and Zinnia designs. Although our previous study found that the mixed design was highly appreciated by humans due to its aesthetic beauty, from the conservation point of view, the ruderal design could be recommended over the other two designs. Nevertheless, the present study highlights the importance of incorporating ruderals into anthropogenic landscapes to promote sustainable planting designs which are also capable of conservation of insects.

CRediT authorship contribution statement

Erandi Wijesinghe: Investigation, Validation, Writing - original draft. **Emily S. Minor:** Formal analysis, Visualization, Writing - review & editing. **Inoka Karunarathne:** Methodology, Writing - review & editing, Supervision. **Kapila Yakandawala:** Conceptualization, Writing - review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

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

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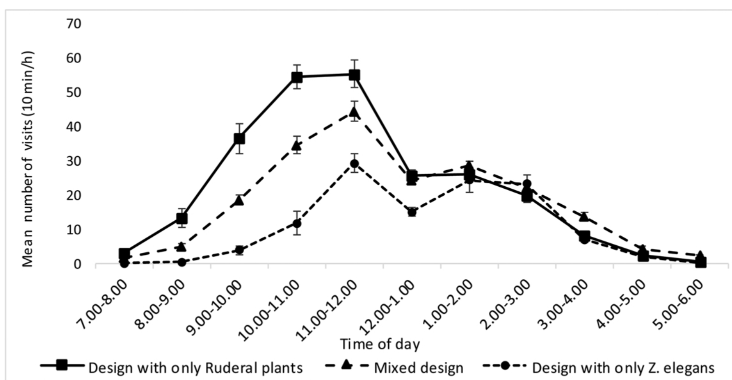
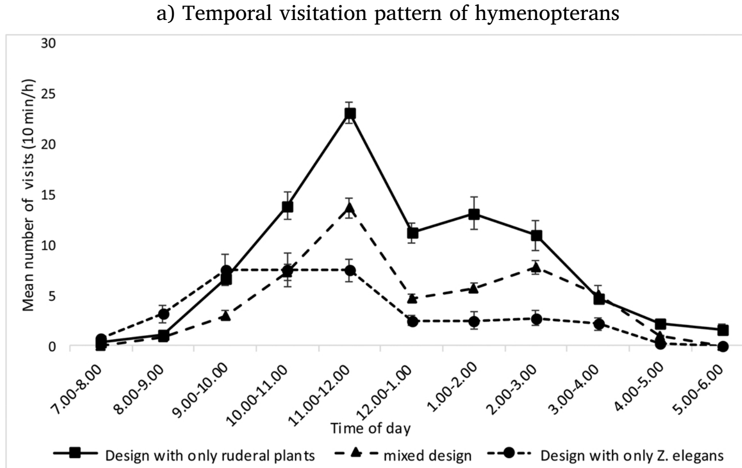
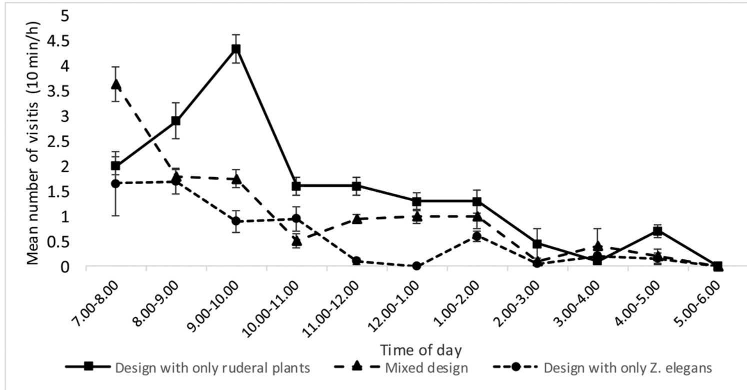
Appendix 1 Temporal visitation patterns of different insect groups in the three planting designs. Design with only ruderal plants, mixed design and design with only *Z. elegans*



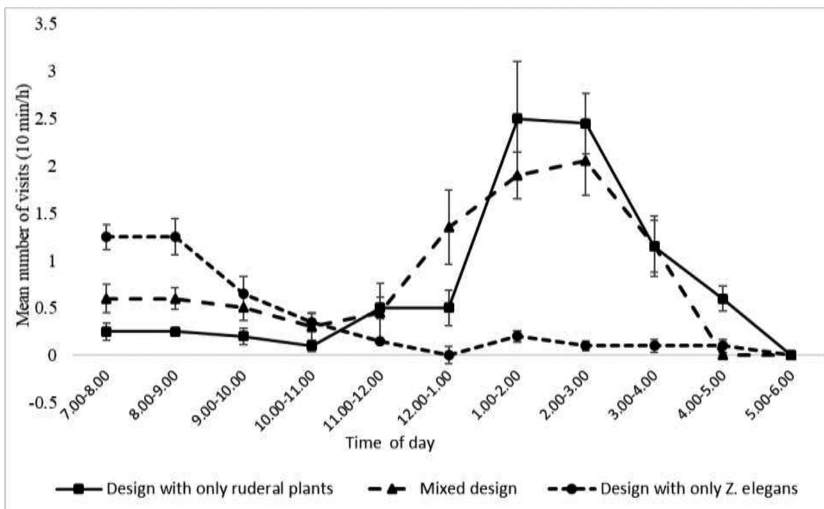
a) Temporal visitation pattern of hymenopterans



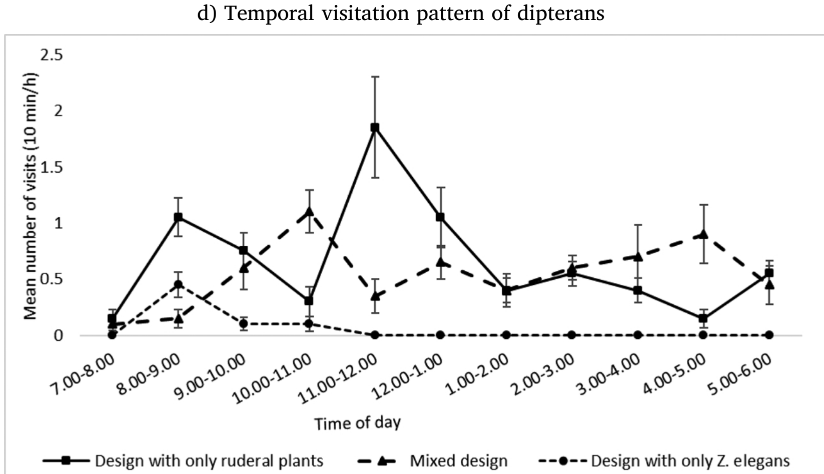
b) Temporal visitation pattern of lepidopterans



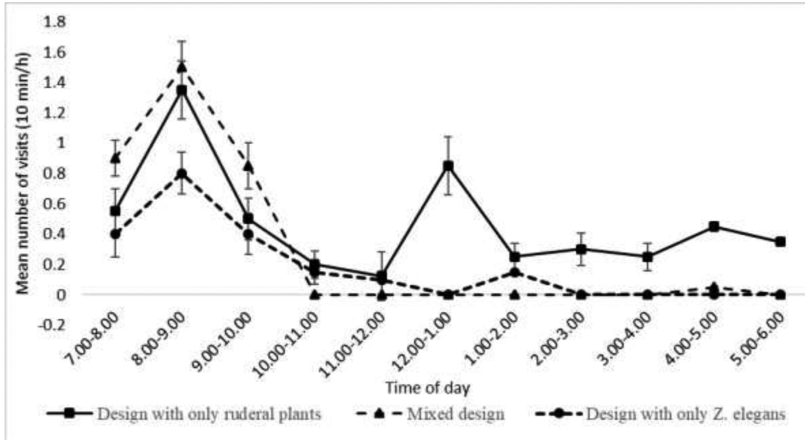
c) Temporal visitation pattern of coleopterans



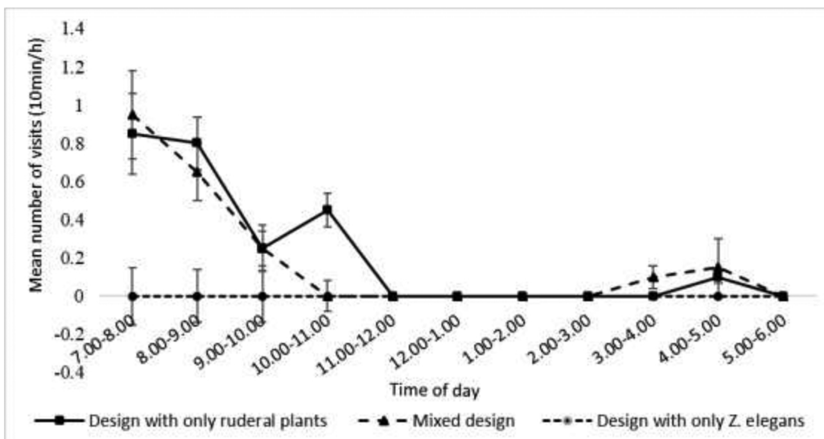
d) Temporal visitation pattern of dipterans



e) Temporal visitation pattern of hemipterans



f) Temporal visitation pattern of orthopterans



g) Temporal visitation pattern of odonatans

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