Influence of invasive plant species on native plant-flower visitor interactions in a scrub forest of Anaikatty, Nilgiri Biosphere Reserve

by

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in

Wildlife Science

Under the supervision of

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AcSIR

June 2025

DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Influence of invasive plant species on native plant-flower visitor interactions in a scrub forest of Anaikatty, Nilgiri Biosphere Reserve,"** is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master of Science in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Ramesh Chinnasamy**, **Scientist-E**, Wildlife Institute of India, and co-supervision of **Mr. Ritesh Kumar Gautam**, **Scientist-C**, Wildlife Institute of India, and **Dr. P.V. Karunakaran, Senior Principal Scientist, Salim Ali Center for Ornithology and Natural History**. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by **K P Akilan** entitled "**Influence of invasive plant species on native plant-flower visitor interactions in a scrub forest of Anaikatty, Nilgiri Biosphere Reserve**" is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master of Science in Wildlife Science**.

K P Akilan has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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EXECUTIVE SUMMARY

1. Invasive alien species are one of the top five drivers of biodiversity loss globally. Invasive alien species are known to cause changes to the biotic interactions in the invaded regions. Pollination is an important limiting process in the life cycle of plants and the pollinators potentially mediate the process of invasion through novel interactions. Invasive plants can have an impact on the native plant-pollinator interactions.
2. I studied the influence of invasive plants on the native plant-flower visitor interactions in the scrub forests of Anaikatty, Nilgiri Biosphere Reserve. I determined the change in flower visitor diversity along an invasion gradient. I also compared the visitation between native and invasive plants, by looking at the difference in composition of insect interactions with native and invasive plants. I used 20 min zigzag walks in 26 plots across three months looking at insects interacting with flowers. I also estimated the density of flowers in each plot.
3. I used generalised linear mixed effects models to draw the relationship between insect richness and the proportion of invasive flowers, and between number of visits and proportion of invasive flowers. To compare the difference in composition of flower visitors between the plant species, I performed permutational multivariate analysis of variance (PERMANOVA) with bray-curtis dissimilarity index.
4. I observed 191 unique plant-flower visitor interactions of a total of 813 plant-flower visitor interactions, formed by 68 insect visitors and 28 flowering plants. Native plants, *Sida cordifolia* (25%), *Tephrosia purpurea* (20%) and *Glycosmis mauritiana* (13%) and invasive plants *Parthenium hysteriphorus* (8%) and *Ageratum conyzoides* (6%) formed majority of

the interactions. Hymenoptera and Lepidoptera are the insect orders with the most number of interactions.

5. The richness and number of flower visitors increase with increasing flower density. The richness and number of flower visitors show a negative relationship with proportion of invasive flowers. The composition of visitors is significantly different among all native flowers and between native flowers and invasive flowers.
6. This is the first study in the Nilgiris Biosphere Reserve looking at plant-flower visitor interactions in wild flowers, with a focus on the influence of invasive species. Visitation of insects to a plot has a weak negative relationship with proportion of invasive species, in this context. This study sets the baseline for future studies that could look at explaining the patterns seen, looking at relationship between the functional diversity of flowers and insects.

1 INTRODUCTION

Invasive alien species are one of the top five drivers of biodiversity loss globally (IPBES 2019). Alien species that establish beyond their geographical range and are able to spread rapidly away from their introduction site (Richardson *et al.* 2000, Pyšek *et al.* 2020). 66 percent of India's natural areas are invaded by multiple invasive alien plant species (Mungi *et al.* 2023). Invasive alien species are known to cause changes to the biotic interactions in the invaded regions. The negative effects of the invasive plants are well documented across the world. They affect various plant-animal interactions like frugivory, herbivory and pollination and alter the ecosystem services.

1.1 INVASION ECOLOGY IN THE CONTEXT OF MUTUALISTIC INTERACTIONS

There are many hypotheses in the study of invasion ecology that try to explain invasion success (Catford *et al.* 2009). There are a few that are specifically related to the mutualistic interactions between plants and animals, like pollination and frugivory. The specialist-generalist hypothesis suggests that invasive species benefit from native mutualists which are mostly generalists (Sax *et al.* 2007). Generalist mutualists would assist the invasive species. The new associations hypothesis postulates that the new associations formed in the invaded range can either benefit or impede the success of invasion (Catford *et al.* 2009). The biotic indirect effects hypothesis emphasizes the role of a third party in shaping the interactions between invasive and native species (White *et al.* 2006). For example, it looks at the role of a pollinator in the competitive interaction between an invasive and a native plant.

Pollination is an important process in the propagation of plant species and a large proportion of plant species partly or completely rely on animals to pollinate their flowers (Tong *et al.* 2023). Nearly 90 % of the plant species are animal pollinated (Ollerton *et al.* 2011, Tong *et al.* 2023). Evolutionarily, angiosperms have been pollinated by insects for nearly 86 % of their existence together (Stephens *et al.* 2023). Pollination is an important limiting process in the life cycle of plants and the pollinators potentially mediate the process of invasion through novel interactions. Given this, invasive plants can have an effect on the native plant pollination. Invasive species can share pollinators with native species and can accumulate more insect pollinators over time (Pyšek *et al.* 2011). Additionally, invasive plant species alter the community structure of native plants, attributed often to direct competitive effects (Levine *et al.* 2003).

1.2 IMPACTS OF INVASIVE PLANTS ON NATIVE PLANT-POLLINATOR INTERACTIONS

Many studies have provided evidence about the disruptive effects of invasive alien plants on native plant-pollinator interactions and corresponding emergent properties. In highly invaded areas, the invasive species reduced the connectivity among native species (Aizen *et al.* 2008). The plant-pollinator networks favour dominant super-generalist alien species (Aizen *et al.* 2008). For instance, a recent study by Brett et al (2024) looked at the spillover effect of invasive *Acacia* trees on insect visitations and seed production in native plant species. They found a significant increase in native plant visitations by generalist insect species as well as a consequent reduction in seed production of native plants, following the invasion (Brett *et al.* 2024). Additionally, they found that visitation increased on native plants adjacent to the *Acacia* trees. A similar study by Arroyo-Correa et al (2020) focused on invasive alien plant species and alien flower visitors in invaded flower-visiting networks, and found evidence that invasive alien species pushed the system towards homogenization and increased the diversity of interactions over the flowering season (Arroyo-Correa *et al.* 2020). Studies have also shown the formation of invader complexes between invasive plants and invasive flower visitor species, which could aid in the spread of the invasion (Olesen *et al.* 2002, Morales & Aizen 2006). For example, invasive ants can interact with invasive plant species to form an invader complex, having a multiplicative effect on the system (Traveset *et al.* 2013).

A study conducted in Hungary and Romania, revealed that the richness and abundance of flowering species and pollinators increased during the flowering of invasive species. Invasive species formed the dominant resources to certain species of pollinators during the invasive plants' flowering season (Kovács-Hostyánszki *et al.* 2022). A review on the effect of invasive species on plant pollination found that there is no consistent positive or negative effect (Charlebois & Sargent 2017). The effects can range from facilitation to competition to no effect and it depends on the experiment design of research projects as well as the spatial arrangement of plants. They also flag a potential publication bias on publishing studies that show negative effects of invasive species (Charlebois & Sargent 2017).

1.3 KNOWLEDGE GAPS IN THE INDIAN CONTEXT

There exist very few studies that focus on pollination with regards to invasive plant species conducted in the Indian subcontinent. A study conducted in West Bengal on the floral biology of C*hromolaena odorata* has documented 49 flower visitors to the invasive plants (Layek *et al.* 2022). In the Southern Western Ghats, a study has documented the flower visitors to invasive *Lantana camara, Sphagneticola trilobata* and *Mimosa diplotricha* across seasons and an elevation gradient (Baboo 2020). However, there are no studies looking at the impact of invasive alien plants on native plant pollination or the networks. A study conducted in the Himalayas of Kashmir assessed the plant-pollinator network structure. They found that 40% of the interactions included alien species and they were integrated into the network (Rather *et al.* 2023).

Given that the effects on pollination range from no effect to competition to facilitation, the effect seen is context and system specific (Charlebois & Sargent 2017). To understand the effect of invasive plants on native plant-pollination, the first step is to understand the patterns of diversity of flower visitors and the structure of interactions in the invaded habitat. In this light, this study focuses on the influence of invasive alien plants on the native plant-flower visitor networks to understand what happens to the plant-pollinator interactions. These interactions may have potential consequences on the success of both invasive and native plants.

1.4 OBJECTIVE

The aim of this study is to look at the influence of invasive plants on the native plant-flower visiting insect networks in open scrub forests.

Objectives

1. To determine the diversity and composition of insect flower visitors to plants across invasion levels

    a. How does richness, abundance and composition of flower visitors change across invasion levels?

Hypothesis: The diversity of flower visitors would change with invasion, as invasive species are known to reduce the native floral resources, as a consequence also affect the visitation.

Prediction: The diversity of flower visitors would decrease with increasing invasion levels favouring more generalist species. However, highest diversity of interactions will be observed at moderate invasion due to the addition of invasive plants in the existing plant-pollinator networks.

2. To compare flower visitor composition between native and invasive flowers

    a. How does flower visitor composition to invasive and native plants change?

2 METHODS

2.1 STUDY AREA

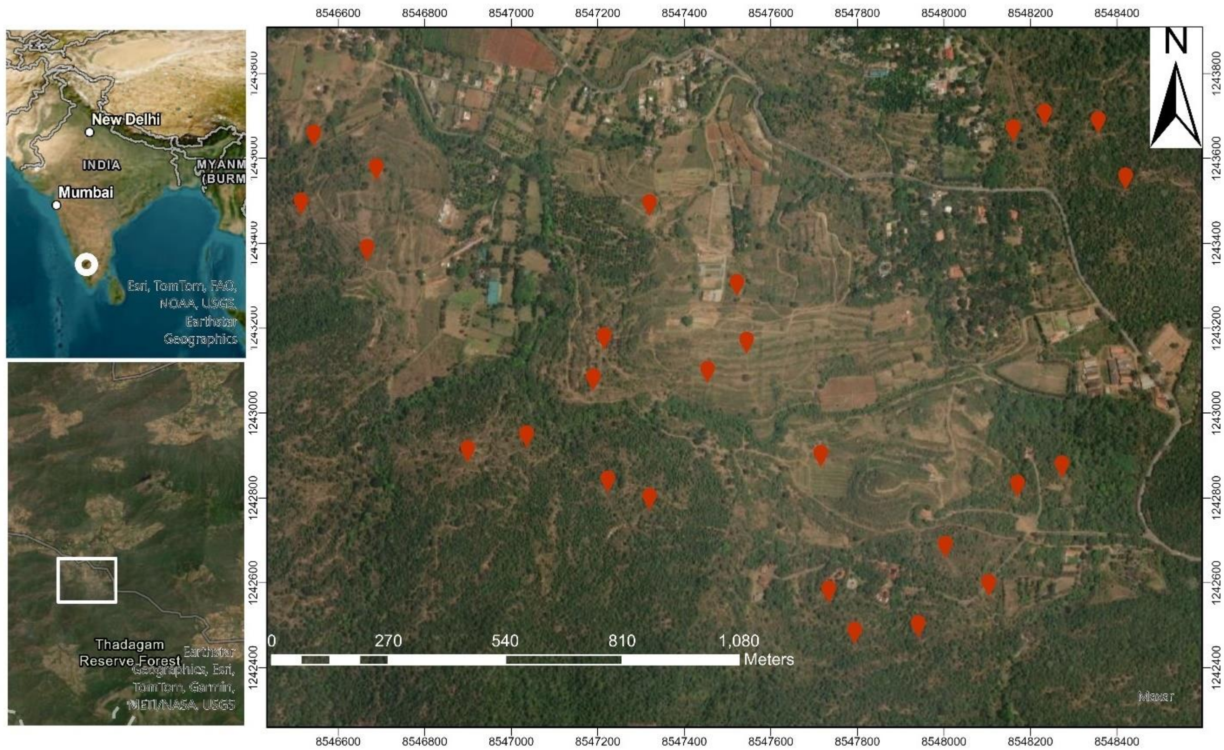

Figure 1 The locations of the 26 plots, with a minimum of 100 m spacing between them.

I conducted the study in Anaikatty, Coimbatore district in Tamil Nadu. The study area is within the Western Ghats and comes under the Nilgiri Biosphere Reserve. The forests here are broadly classified into Southern dry mixed deciduous forests (Champion & Seth 1968). Further, based on the vegetation characterisation it is divided into five groups: West Coast Tropical Semievergreen Forest between 950m - 1500m a.s.l., Southern Moist Mixed Deciduous Forest between 800m – 950m a.s.l., Southern Dry Mixed Deciduous Forest at 700m - 800m a.s.l., Dry Deciduous Scrub and Thorny Scrub occur at the lower elevations (Anitha *et al.* 2010). Thorny Scrub is the major habitat at the lower elevations characterised by high disturbance due to grazing and firewood collection (Anitha *et al.* 2010).

My study area is bound by the latitudes 11º06’21.80” and 11º05’35.80” and longitudes 76º47’04.67” and 76º48’41.00”. I focused on the open scrub habitats in and around Salim Ali Center for Ornithology and Natural History (SACON), Anaikatty, both in private lands and in forest edges, falling in the altitudinal range of 500-600 metres. Being a developing tourist spot, the area is seeing a rapid land-use change with the construction of resorts and hotels (Personal obs.).

402 species of flowering plants have been documented in this area belonging to 84 families (Balasubramanian *et al.* 2015). Invasive alien species like *Chromolaena odorata*, *Lantana camara*, *Parthenium hysteriphorus*, and *Ageratum conyzoides* co-occur at varying densities along with native species like *Senna auriculata*, *Sida cordifolia*, *Tephorsia purpurea* and *Glycosmis mauritiana*. SACON campus has a record of 178 species of butterflies among other flower visitors (Ashiq *et al.* 2024). Another study in the area has documented flower visitors in agriculture fields in the surrounding areas in the Coimbatore District (Viswanathan *et al.* 2020). The peak flowering season in the Nilgiris is between December to March (Murali & Sukumar 1994) making it appropriate for studying flower visitors. I conducted the study between January 2025 and March 2025.

2.2 FIELD METHODS

2.2.1 Insect sampling

I identified 27 plots measuring 30 m by 30 m with varying proportions of invasive flowering species after a reconnaissance survey. The selection of plots was done based on the level of invasion. The level of invasion was determined based on an ocular estimation of flower cover of the major plant species, followed by an estimation of the abundance of flowers in each plot, explained in (Section 2.2.2.). One of the sampling plots, in a private land, was cut down before I started sampling, hence only 26 plots were sampled during the study. Two plots were disturbed after my second sampling visit. These were replaced with new neighbouring plots that had similar vegetation composition. For this study, only shrubs and herbs were included. Each plot was at least 100 meters apart. At each of the plots I carried out a timed zigzag walk for 20 minutes covering the entire plot (de Souza *et al.* 2022). I observed all the insects that are visiting and interacting with a flower. Only insects touching the flowers were recorded. Each observation was recorded with the species identities of both the insect visitor and the flower. Same insect species reoccurring during the walk were considered as a new individual, unless I was directly able to identify it as an individual already observed. I photographed insects that were not identifiable on the field. These were then identified with the help of experts, keys and community identification on iNaturalist. The timer was paused when photographing, to keep the effort standardized. Each plot was visited every 12-15 days for a total of 6 times. I carried out the sampling between 9:30 am and 4:30 pm during the peak activity of insects. Across the duration of the study, I visited each plot at different times of the day to capture the varying activity of flower visitors throughout the day.

2.2.2 Flower counts

Within each plot, I laid five 1 m radius subplots – one at each corner and one at the center – and marked their centers with ribbons. To determine the diversity and abundance of flowers at each plot, my field collaborator/assistant (Mr. Murugan) and I counted the number of open flowers or floral units and recorded their species identity. This helped in accounting for the change in flowering over the flowering season. Plant species were identified with the help of ‘Flowering plants of SACON campus in the Anaikatty Hills, Western Ghats’ (Balasubramanian *et al.* 2015) . A floral unit is defined as a flower or group of flowers which require a medium sized bee to fly to rather than walk between (Dicks *et al.* 2002) (Figure 2). We counted the flowers after doing the insect sampling to minimize the flushing of insects before or during the insect sampling. We did the flower count after each insect sampling for all six replicates to account for the change in floral resources over time.

Figure 2 Images showing one floral unit (white circle) on different flower species.

2.3 ANALYSIS

I used bar plots to describe the mean density of the flowering species across space and time. Using the *bipartite* package in R (Dormann *et al.* 2008), I constructed the weighted bipartite network to visualize the interactions between the flowering plants and the insect flower visitors. A weighted bipartite network shows both interactions and the number of each interaction. Further, I used bar plots to describe the visitation by flowering species and by the orders of the flower visitors. All the bar plots were visualized using *ggplot2* package (Wickham 2016).

To draw the relationship between insect visitation and flowering species, I used Generalized Linear Mixed-effects Models (GLMM) using *lme4* package (Bates *et al.* 2015). I modelled the insect species richness (morphospecies) and number of flower visitors as a response to fixed effects of density of all flowers, proportion of invasive flowers and weather condition (sunny, partly sunny, or cloudy), with the plot ID as a random effect to account for temporal replicates. Since the data was over dispersed, I ran all the models with negative binomial distributions. The R^2 coefficients were estimated using the delta method with the function on *MuMIn* package (Nakagawa *et al.* 2017). Additionally, I ran Moran's I statistic to check whether the data was spatially autocorrelated. The models were visualized using the *ggeffects* package (Lüdecke 2018).

To understand the differences and similarity in the flower visitor assemblages between native and invasive plant species, I used non-metric dimensional scaling (NMDS) with bray-curtis dissimilarity index. The data of all six temporal replicates were pooled together for each plot before running NMDS. NMDS was performed in a two-dimension space and the solution was repeated 1000 times and the solution with the least stress was retained. I performed permutational multivariate analysis of variance (PERMANOVA) with bray-curtis dissimilarity index, using the *pairwiseAdonis* and *vegan* packages (Arbizu 2017, Oksanen *et al.* 2025). I selected six plants species with the greatest number of interactions and flower abundances, two invasives: *Parthenium hysteriphorus* and *Ageratum cordifolia,* and four natives: *Sida cordifolia, Tephrosia purpurea, Senna auriculata* and *Leucas aspera.*

I performed all the data analysis in R statistical software (version 4.5.0) (R Core Team 2025).

3 RESULTS

3.1 DESCRIBING THE FLOWERING PLANT SPECIES

There was a total of 28 species of herbs and shrubs included in the study. There were six invasive species and 22 native species. The invasive herb and shrub species with the most abundant floral resources were, *Parthenium hysteriphorus, Ageratum conyzoides* and *Chromalaena odorata*. *Sida cordifolia*, *Tephrosia purpurea*, *Glycosmis mauritiana* and *Senna auriculata* were native herbs and shrubs with the most abundant floral resources. All the species of flowers occur at varying densities across the study area with *P. hysteriphorus* and *A. conyzoides* exhibiting the maximum mean densities of flowers, 14.6 ± 0.69 (SE) and 10.7 ± 0.64 (SE), respectively (Figure 3). The change in flowering over time between January 2025 and March 2025, is shown in **Error! Reference source not found.**. Most species show a decline in flowering after January.

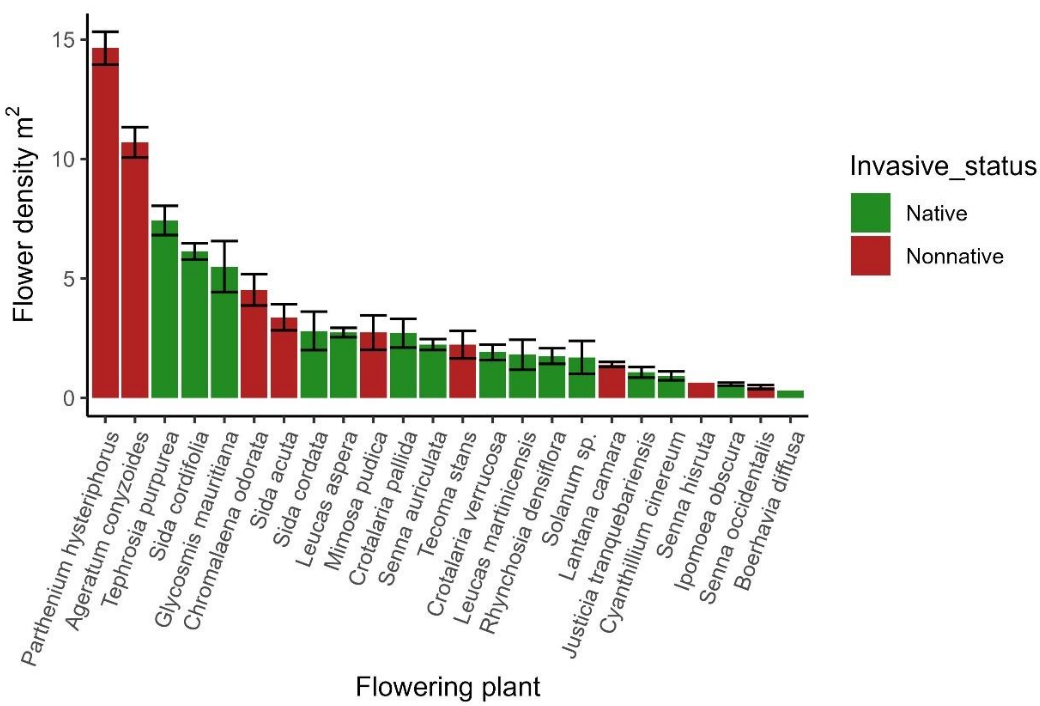

Figure 3 Density of flowering species throughout the study period.

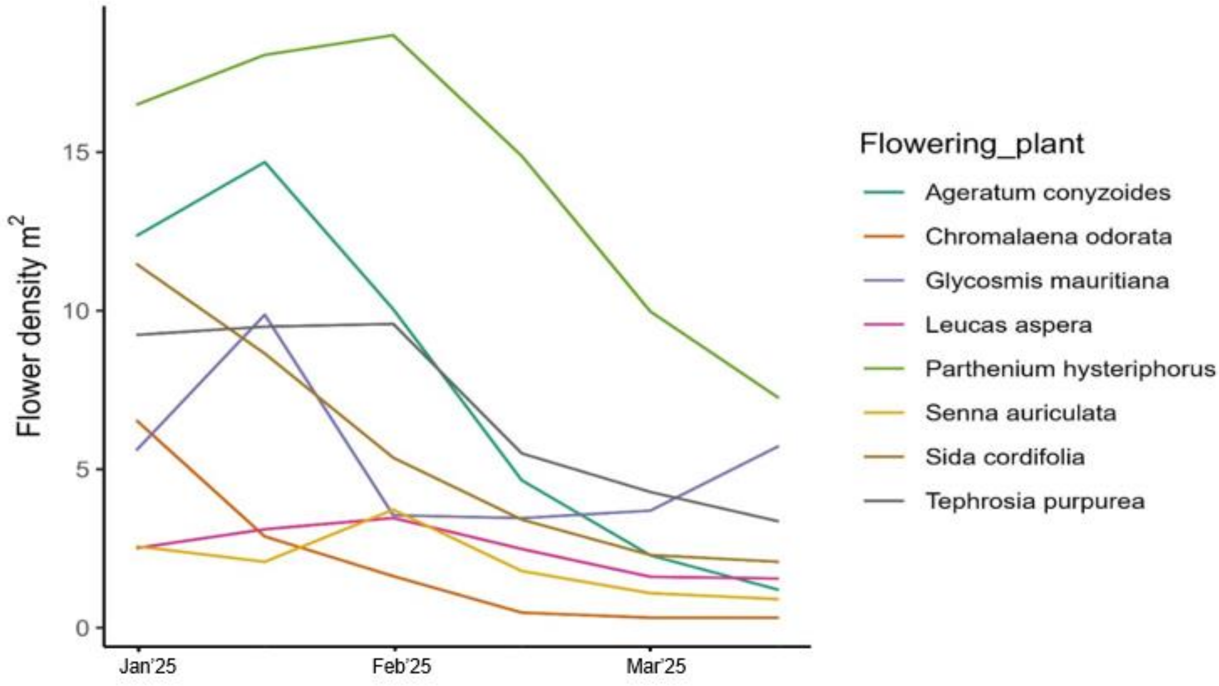

Figure 4 Change in average flower densities of major flowering species with replicate 1 starting in January 2025 and replicate 6 ending in March 2025.

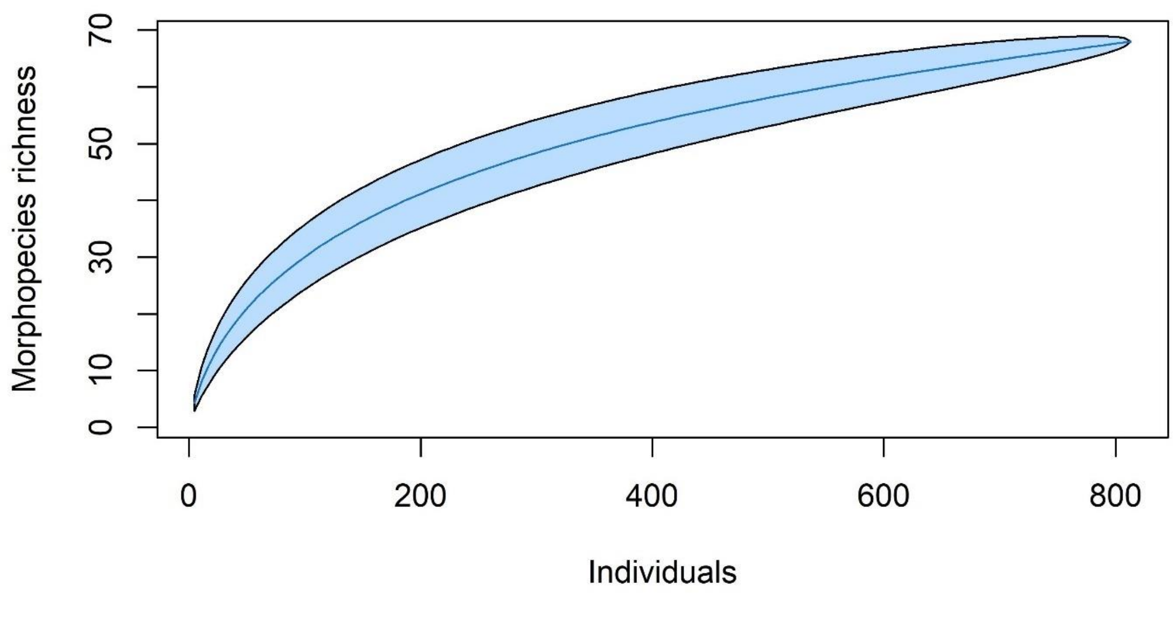

Figure 5 Species accumulation curve showing morphospecies richness against all individuals observed.

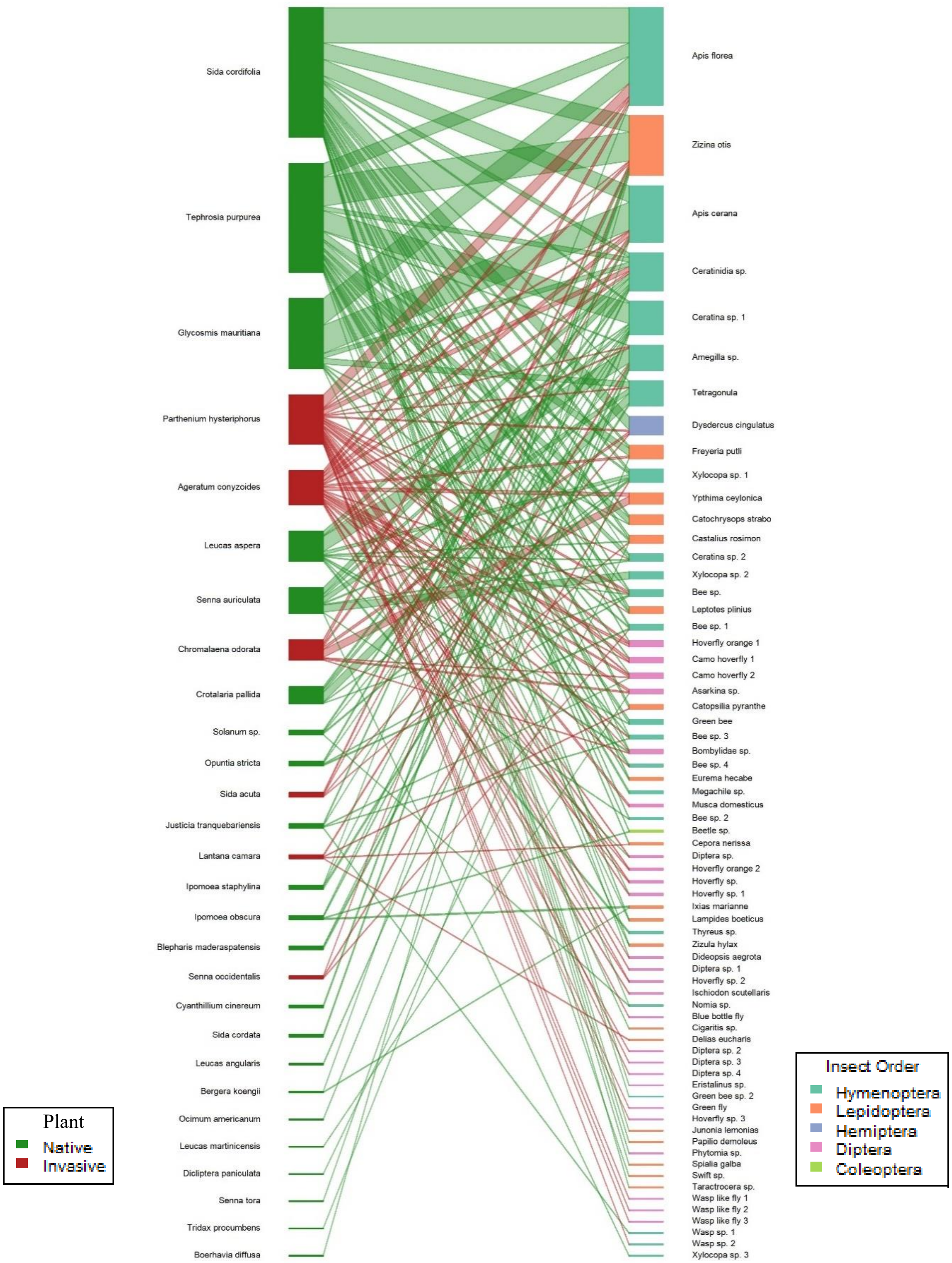

Figure 6 Bipartite network showing the interaction between flowering plants (left) and flower visitor species (right). The weighted network shows interactions between both native (green) and invasive (red) flowering plants. The width of the links indicates the relative number of interactions.

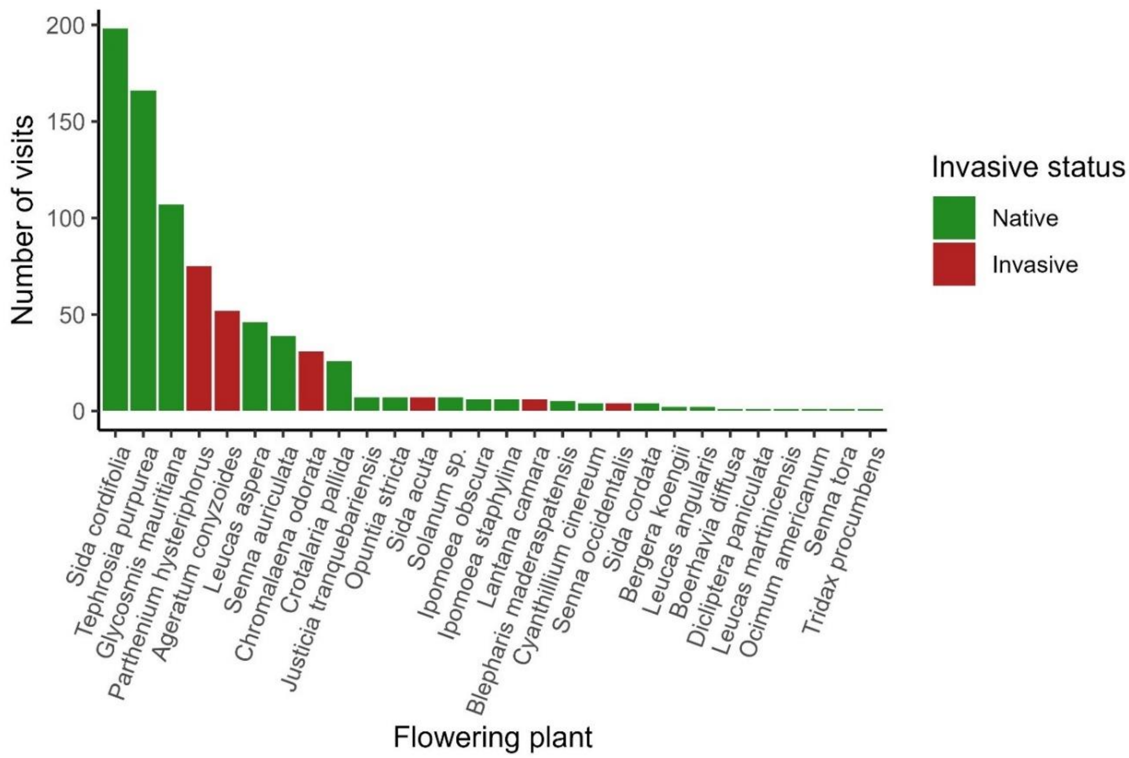

Figure 7 Bar graph shows the number of visits to each flowering plant.

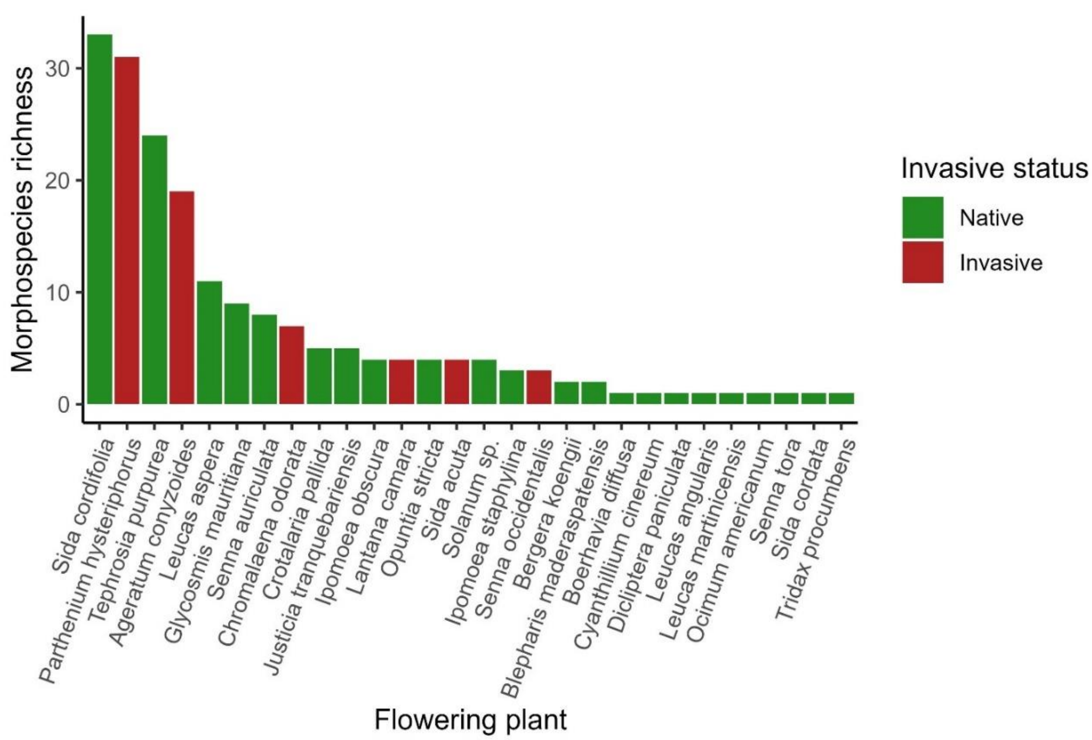

Figure 8 Bar graph showing the richness of insect morphospecies visiting each flowering plant species.

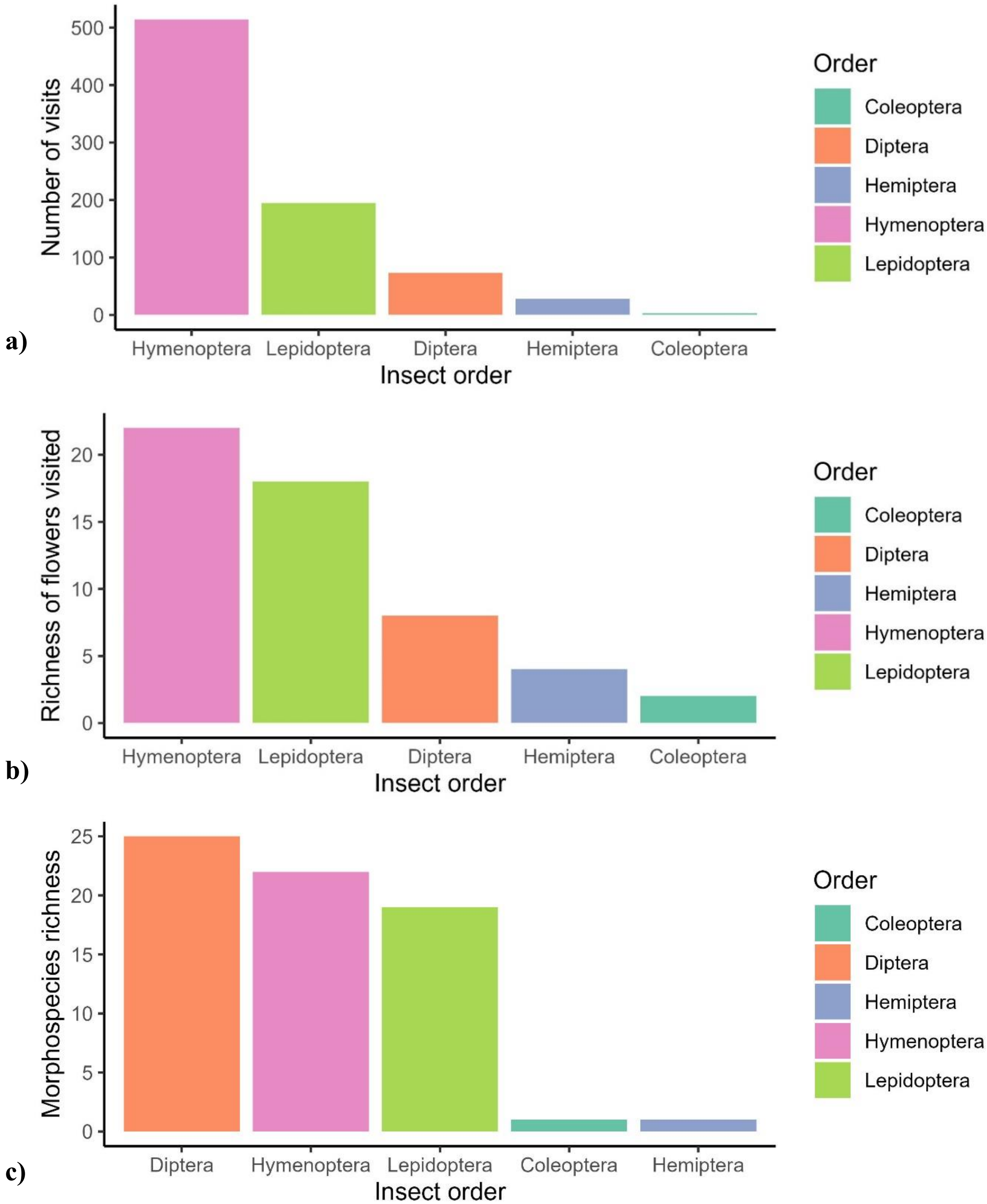

Figure 9 Bar graphs showing the insect order wise visitations. a) Total number of observed flower visits by order, b) Richness of flower species visited by each insect order and c) Number of insect morphospecies of each order.

3.2 DESCRIBING THE INTERACTIONS

I observed 191 unique plant-flower visitor interactions of a total of 813 plant-flower visitor interactions (Figure 6). These interactions were formed by 68 diurnal insect flower visitors (morphospecies) and 28 flowering plant species. Sampling effort is shown using a rarefaction curve (Figure 5). Native plants, *Sida cordifolia, Tephrosia purpurea* and *Glycosmis mauritiana* share about 460 interactions followed by *Parthenium hysteriphorus* and *Ageratum conyzoides* with 75 and 50 interactions, respectively (Figure 7). *Sida cordifolia* and *Parthenium hyteriphorus* have the greatest number of morphospecies with 33 and 31 respectively (Figure 8).

Bee species belonging to Hymenoptera order form a major proportion of the flower visitors (Figure 9). The honey bee species, *Apis florea* and *Apis cerana*, are the ones with the greatest number of interactions observed in the group. Others belonging to the *Ceratina* genus, *Amegilla* genus and *Xylocopa* genus are important bee species in the network. The other major order is Lepidoptera. *Zizina Otis* (Lesser Grass Blue) form most interactions of butterflies along with other species like, *Freyeria putli* (Grass Jewel) and *Catochrysops strabo* (Forger-me-not).

3.3 THE RELATIONSHIP BETWEEN NUMBER OF FLOWER VISITORS AND FLOWER DENSITY

I found that mean density of flowers had a positive influence on the number of flower visitors with a coefficient of 1.005 (95% CI: 1.003- 1.007, p-value < 0.001). The proportion of invasive species had a negative influence on the number of flower visitors with a coefficient of 0.555 (95% CI: 0.312 – 0.989, p-value = 0.046) (Figure 10). Weather condition did not have any significant effect on the flower visitor numbers. The model fit explained 17.8 % of the data and with the inclusion of random effects, explained 36.8 % of the data, based on the R^2 estimates (Table 1).

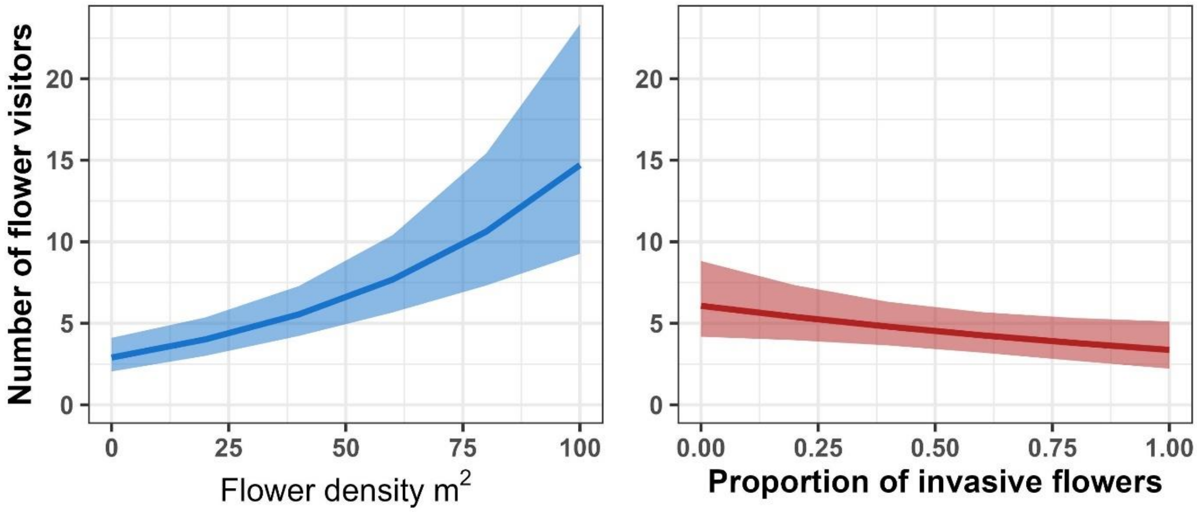

Figure 10 Predicted GLMM model showing the relationship between number of flower visitors and flower density (left) and the proportion of invasive flowers (right), with 95% confidence intervals.

Table 1 GLMM results showing the relationship between number flower visitors with floral resources.

	Number of flower visitors		
Predictors	Estimates	CI	Pr(>|z|)
(Intercept)	3.9979	2.7061 – 5.9065	**<0.001**
Flowers density	1.0164	1.0103 – 1.0225	**<0.001**
Invasive flower proportion	0.5550	0.3115 – 0.9889	**0.046**
Weather [Partly sunny]	1.3564	0.9604 – 1.9156	0.084
Weather [Sunny]	1.1337	0.8525 – 1.5075	0.388
Random Effects			
σ^2	0.28		
$\tau_{00\ Plot\_ID}$	0.10		
ICC	0.26		
N_{Plot_ID}	26		
Observations	149		
Marginal R^2 / Conditional R^2	0.178 / 0.368		

3.4 THE RELATIONSHIP BETWEEN FLOWER VISITOR RICHNESS AND FLOWER DENSITY

Looking at the relationship of flower visitor richness and floral resources indicate a similar pattern to that of number of visitors. I found that mean density of flowers had a positive influence on the flower visitor richness (morphospecies) with a coefficient of 1.004 (95% CI: 1.002- 1.006, p-value < 0.001) (Figure 11). The proportion of invasive species had a negative influence on the flower visitor richness with a coefficient of 0.620 (95% CI: 0.394 – 0.977, p-value = 0.039). Weather condition did not have any significant effect on the richness. The model fit explained 14.1 % of the data and with the inclusion of random effects, explained 25 % of the data, based on the R^2 estimates (Table 2).

3.5 DIFFERENCE IN FLOWER VISITOR COMPOSITION BETWEEN NATIVE AND INVASIVE PLANTS

The flower visitor composition is significantly different between all six flowering species (Figure 12, Table 3). The best solution of NMDS had a stress value of 0.11. There is a significant difference in flower visitor composition between native and invasive species (Figure 13). *Sida cordifolia, Parthenium hyteriphorus* and *Ageratum conyzoides* overlap slightly, however the PERMANOVA results show that they are significantly different from each other. *Glycosmis mauritiana* is significantly different from *Leucas aspera* with a high F-statistic (24.60, df = 55, p-value < 0.001). These two species are also significantly different from the other species. *Parthenium hysteriphorus* and *Ageratum conyzoides* share the lowest F-statistic (1.87, df = 75, p-value < 0.001). They are significantly different from all the other species (Table 3).

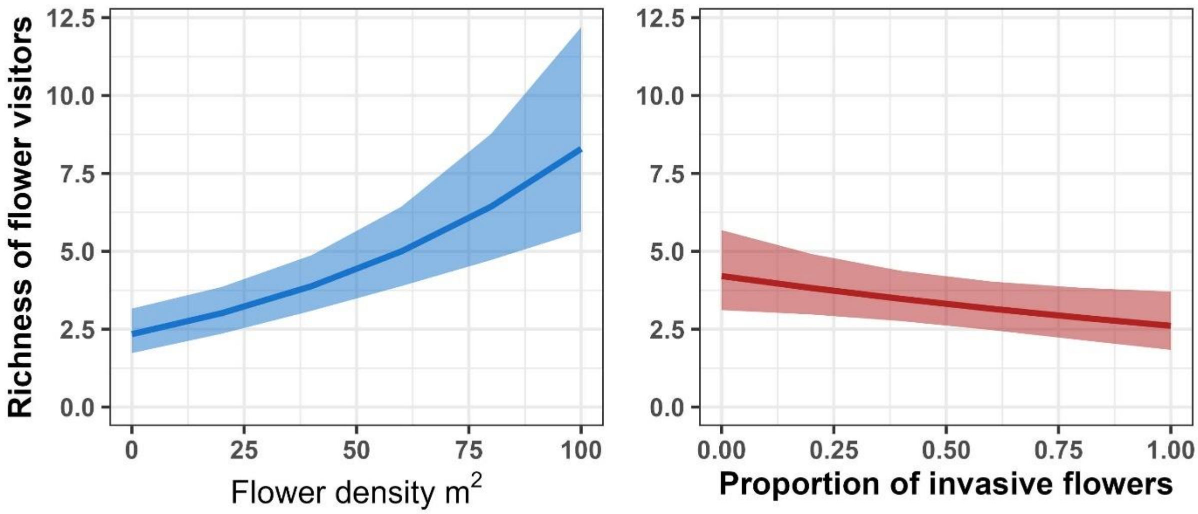

Figure 11 Predicted GLMM model showing the relationship between flower visitor richness (morphospecies) and flower density (left) and the proportion of invasive flowers (right), with 95% confidence intervals.

Table 2 GLMM results showing the relationship between flower visitor richness (morphospecies) with floral resources.

	Insect richness		
Predictors	Estimates	CI	Pr(>|z|)
(Intercept)	3.0372	2.2080 – 4.1779	**<0.001**
Flowers density	1.0127	1.0076 – 1.0179	**<0.001**
Invasive flower proportion	0.6202	0.3940 – 0.9763	**0.039**
Weather [Partly sunny]	1.1591	0.8544 – 1.5724	0.343
Weather [Sunny]	1.1287	0.8782 – 1.4507	0.344
Random Effects			
σ^2	0.24		
$\tau_{00\ Plot\_ID}$	0.04		
ICC	0.14		
N_{Plot_ID}	26		
Observations	149		
Marginal R^2 / Conditional R^2	0.141 / 0.250		

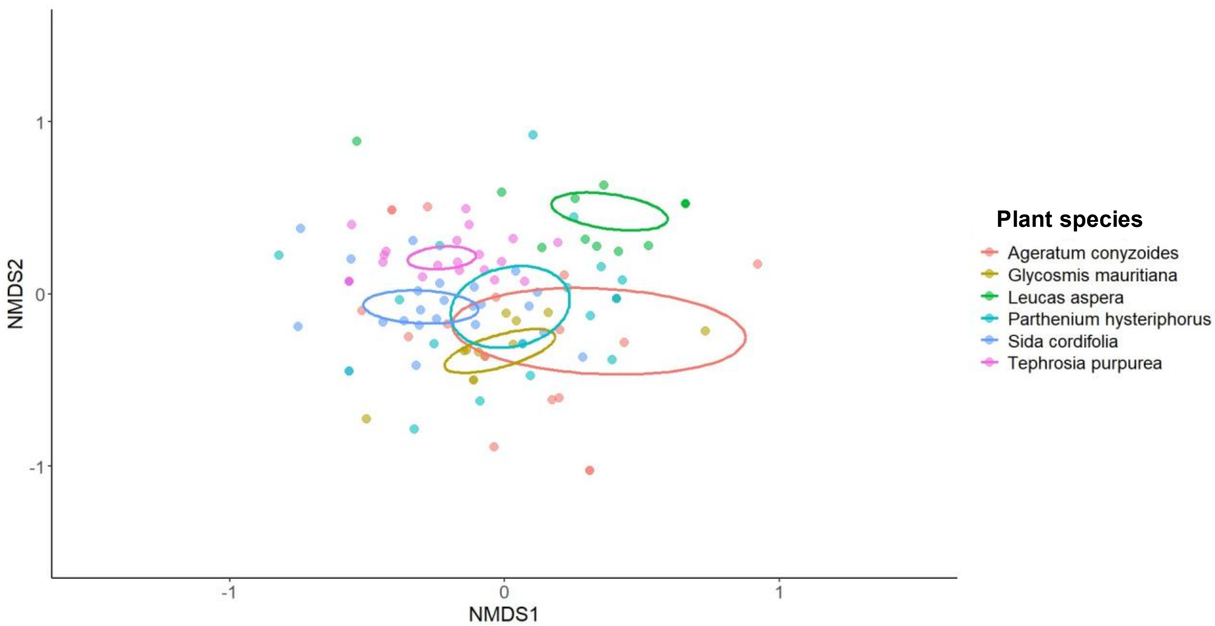

Figure 12 NMDS visualisation of the differences in composition of flower visitors between six major plant species. The ellipses represent the 95% confidence intervals of the groups.

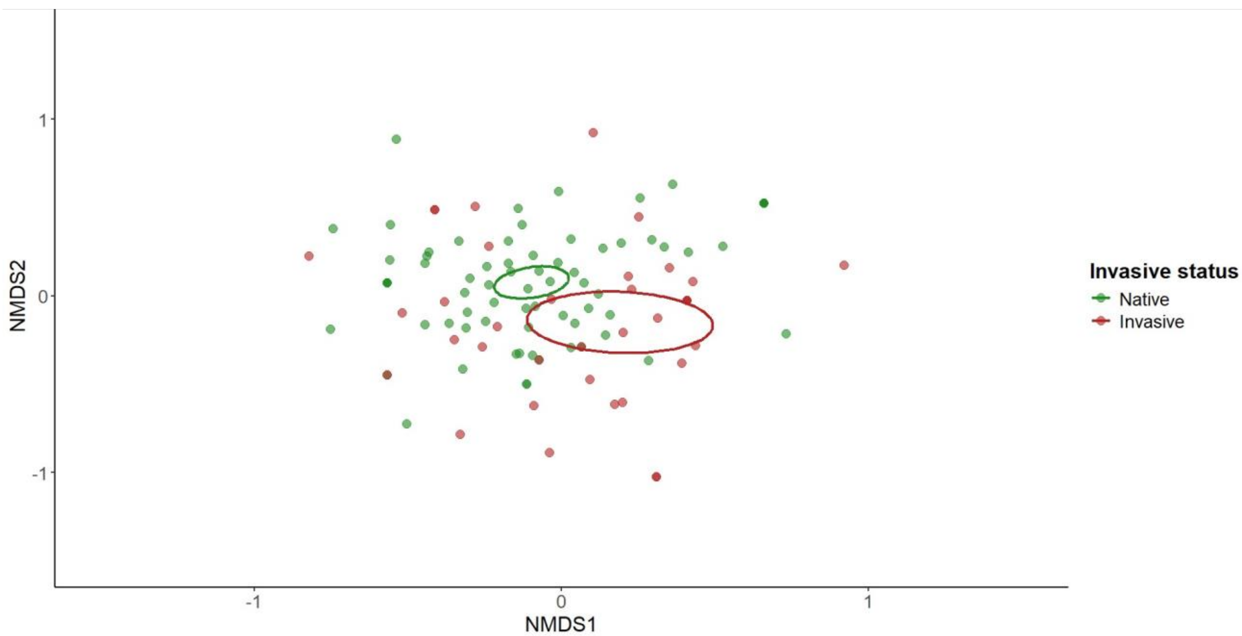

Figure 13 NMDS visualisation of the differences in composition of flower visitors between invasive (red) and native (green) plants. The ellipses represent the 95% confidence intervals of the groups.

Table 3 PERMANOVA pairwise tests showing the significance of the differences in flower visitor composition, showing F-statistic with p-values indicated by asterisk, degrees of freedom in brackets and R^2 values in smaller font below. Invasive species are in bold.

Plant species	*Glycosmis mauritiana*	***Ageratum conyzoides***	*Sida cordifolia*	***Parthenium hysteriphorus***	*Tephrosia purpurea*
Glycosmis mauritiana					
Ageratum conyzoides	8.71*** (59) *0.12*				
Sida cordifolia	8.51*** (108) *0.07*	3.16*** (111) *0.02*			
Parthenium hysteriphorus	9.75*** (72) *0.11*	1.87*** (75) *0.02*	4.11*** (124) *0.03*		
Tephrosia purpurea	23.49*** (91) *0.20*	7.83*** (94) *0.07*	9.25*** (143) *0.06*	10.76*** (107) *0.09*	
Leucas aspera	24.60*** (55) *0.31*	8.65*** (58) *0.12*	14.06*** (107) *0.11*	8.92*** (71) *0.11*	19.98*** (90) *0.18*

4 DISCUSSION

This is the first study in the Nilgiri Biosphere Reserve to study plant-flower visitor interactions in the context of invasive species. In this study, I show the diversity of plant-flower visitor interactions in an invaded scrubland. I have recorded a high diversity of diurnal flower visitors throughout the flowering season, from four different orders to 28 different plant species, both native and invasive. I found that with increasing proportion of invasive flowers, the diversity of flower visitors, both richness and number of visits decreased slightly (Figure 10; Figure 11). I also found that the composition of flower visitors differs between native and invasive plants (Figure 12, Figure 13, Table 3). These results indicate the integration of invasive species into native plant-flower visitor interactions in this area.

4.1 OVERVIEW OF PLANT-FLOWER VISITOR INTERACTIONS

I observed 813 interactions of flower visitors across 68 morphospecies of diurnal insects belonging to five order and 28 species of flowering herbs and shrubs that formed nearly 200 interactions. Another study conducted in agricultural farms in the Nilgiri Biosphere Reserve found 46 species of flower visitor morphospecies (Viswanathan *et al.* 2020). While it is not directly comparable, my study shows that these wild habitats hold a large diversity of flower visitors. Hymenoptera, mostly bees, formed more than half the visitors highlighting their role in pollination. Of these, the two honey bees belonging to the *Apis* genus are the major ones. Followed by Lepidoptera, which also formed just half of the interactions of Hymenoptera. Diptera form a very small part of the visitors, however they have the highest richness. Both bees and butterflies visit a wide variety of flowers. This highlights the high diversity present in the degrading scrublands.

4.2 INVASIVE FLOWERS HAVE FEWER INTERACTIONS BUT A WIDE VARIETY OF FLOWER VISITORS

Native flowers have a higher number of visitors in comparison to invasive flowers, with *Sida cordifolia, Tephrosia purpurea* and *Glycosmis mauritiana* accounting for nearly half of the visits (Figure 7). The invasive plants, *Parthenium hysteriphorus* and *Ageratum conyzoides* are hosts to about 125 visitors. This accounts for just 15 % of the total visits. Interestingly, they interact with a greater number of insect species than *T. purpurea* and *G. mauritiana* (Figure 8). *Parthenium hysteriphorus* has nearly as many insect species as that of *Sida cordifolia.* This shows the wide number of insect species the invasive species cater to even with lesser total interactions. A study conducted in Kashmir found 40% of the interactions included invasive species (Rather *et al.* 2023). Similarly, my study also highlights the integration of these invasive plant species into the existing native plant-flower visitor networks. However, further network analysis will be required to the statistically quantify the network metrics.

4.3 OVERALL VISITATION OF FLOWER VISITORS IS NEGATIVELY CORRELATED TO INVASIVE PLANTS

The number of flower visits increase with increasing flower density. This is an expected result as flower visitors would increase with increasing floral resources. On the other hand, with increasing proportion of invasive flowers, the number of flower visits decrease. Not only is the number of visits decreasing, but even the richness of morphospecies follow a similar trend. Richness increases with an increase in flower density, but decrease with increasing proportion of invasive flowers. This shows the negative influence invasive species have on flower visitation to a plot level. However, it is a weak relationship. It is consistent with my hypothesis that there would be a decline in the number of species. However, I predicted that at moderate levels of invasion there would be a higher diversity, but that does not hold true. This is probably because the area is heterogeneously invaded and only few plant species dominate across the landscape. This finding is also consistent with earlier studies (Loy *et al.* 2015, Livingstone *et al.* 2020). The study conducted in the open woodlands of Australia on the impacts of Asteraceae invasive plants on the pollination of native species showed that, the richness and number of visits decrease with increasing proportions of invasive Asteraceae (Loy *et al.* 2015).

I only show the relationship between the insect diversity and floral resources. Other factors such as microclimatic conditions and habitat structure need to be considered in order to explain the patterns seen better.

4.4 COMPOSITION OF VISITORS ARE DIFFERENT BETWEEN NATIVE AND INVASIVE PLANTS

The PERMANOVA pairwise results suggests that the composition of flower visitors is significantly different among all native flowers and between native flowers and invasive flowers (Table 3). This is consistent with an earlier study that looked at compositional difference (Loy *et al.* 2015). *Parthenium hysteriphorus* and *Ageratum conyzoides* share a low F-statistic indicating that the difference in their insect composition is lower. This is also indicated by the NMDS plots where there is some overlap between the two species (Figure 12). It is important to note that the R^2 values for most of the pairs are below 12%, indicating smaller effect size as it does not explain a large part of the data. This could be attributed to the low number of visits to some of the species.

4.5 LIMITATIONS OF THE STUDY

While the sampling effort indicates an accumulation of 68 morphospecies, it is important to note that all the observations are not recorded to the species level. I faced problems at two levels: first is that is on-field identification of some species is difficult, and secondly, the taxonomy of many of the species of bees and hoverflies are not well resolved.

A caveat of this finding is that, the study was conducted between January and March, however, flowering of many of the species start post-monsoon in November and December. *C. odorata* is a widespread and dominant invasive plant species that flowers in huge volumes between December and January. I expect the patterns of visitation to be slightly different, with a greater number of visits seen on invasive flowers. A previous study has shown that invasive flowers form the dominant resources for pollinators at certain seasons (Kovács-Hostyánszki *et al.* 2022). Nevertheless, the findings from my study highlights the patterns during the latter part of the flowering period (Rather *et al.* 2023). It provides insights into the patterns of plant-flower visitor networks within the open habitats in my study area. My study also does not look at the nocturnal flower visitors at play. This would be important when studying aspects of pollination.

4.6 CONCLUSION

This is the first study in the Nilgiris Biosphere Reserve looking at plant-flower visitor interactions in wild flowers, with a focus on the influence of invasive species. Visitation of insects is negatively related to the proportion of invasive flowers, in this context. This study sets the baseline for future studies that could look at explaining the patterns seen, looking at the relationship between the functional diversity of flowers and insects. Studies can also look at the effect of the invasive species on pollination of native flowers. Visitation is correlated with seed set formation (Charlebois & Sargent 2017), however, it is context specific and need to be tested in this complex system involving multiple species. Temporal changes in networks can be studied to understand the persistence of interactions over time. While many such studies are available across the world, it is lacking in the Indian context.

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