Environmental Management & Policy Research Institute

Butterflies as Climate Change Indicators: A study in different Eco-climatic Zones of Karnataka – Phase II

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9. Abstract:

Butterflies are bio indicators of environment and climate change. The diversity of butterflies in five study areas (Agumbe, Bengaluru, Dharwad, Gulburga and Mangalore) in different eco-climatic zones of Karnataka was studied during the year 2021-22, to make comparison with the Phase I study conducted in 2016-17. 183 species of butterflies (Agumbe 111, Mangalore 105, Bengaluru 84, Dharwad 80 and Gulbarga 69) belonging to six families are reported. Family Nymphalidae and Lycaenidae dominated in both phases. Winter/Rainy season supported more diversity. Species richness was highest during winter in all the places and *Catopsilia* sp. was the most dominant species in the whole of Karnataka in both phases of study. The dominant species in study areas were *Cupha erymantis*, *Ypthima huebneri*, *Catopsilia* sp. and *Euploea* sp. Study indicated that the climate variations across the past five years was not influential in changing the diversity pattern of butterflies. A Butterfly Identification Application enabled long term Butterfly Monitoring Program, which can elucidate the probable impacts of climate change on butterfly diversity, is recommended for all the districts of Karnataka.

10. Keywords: Climate Change, Bio indicators, Diversity indices, Abundance, Species richness, Eco-climatic zones, Seasons.
11. Project team:

1. Name: Dr. O. K. Remadevi,
   Designation: Consultant, Principal Investigator
2. Name: Ms. Jane Maria D Souza
   Designation: Project Associate, Co- Principal Investigator
3. Name: Dr. Deepak Naik
   Designation: Project Associate
4. Name: Mr. Chaturved Shet
   Designation: Project Associate

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Executive Summary

The species composition and diversity are reported to be closely linked to the eco-climatic factors in the ecosystem and hence any changes in these factors shall be surely reflected in the biological framework of the system. Though many organisms reflect the impact of climate change, insects, especially the butterflies, which are extremely sensitive to even minor changes, serve as the best candidates for analysing the extent of impact. Short life cycles with several generations in a year also make them good study candidates for assessing the environmental changes. They play important roles and contribute to major ecosystem services such as pollination, food source for higher organisms, environment indicators of pollution, landscape changes, climate change etc. Butterflies are useful in studies of community ecology as indicators of ecosystem health.

Karnataka, over the years, especially in the last decade, has witnessed increase in atmospheric temperature and overall change in climate. Limited information on the diversity of butterflies is available from only selected areas in the eco-climatic zones of Karnataka. Our study in 2016-17 compiled baseline data on the diversity and distribution of butterflies in five study areas in different eco-climatic zones of Karnataka. The present study was executed to get the current status after about four years from the Phase I (P1) study and to evaluate whether diversity of butterflies has changed in relation to climatic variations, if any. It was planned to collect sitewise and seasonwise information, which can draw comparisons with the earlier data. Present study was planned in this background with the following main objectives:

1. Study the diversity of butterflies in green spaces of the five selected districts in different eco-climatic zones of Karnataka.
2. Seasonal variance in the diversity and abundance of butterflies in the study areas.
3. Comparison of diversity data with the data generated in the Phase I study conducted during 2016-17.
4. Correlation of the butterfly diversity with climatic parameters in the study areas.

A review of the available data and information on the diversity and distribution of butterflies in India, in Western Ghats and specifically in Karnataka is undertaken. We also reviewed global literature on butterflies and the factors affecting their prevalence and diversity in diverse scenarios and in the wake of climate change. Methodology and sites of study were same as in Phase I study. Surveys were conducted in each month in each of the green spaces. The transects walked were approximately 500m in distance and the data on the occurrence of butterflies was recorded from 2.5m on either side of the transect and up to a height of 5m.

Data was pooled to classify according to seasons. October to January is considered as winter, February to May as summer, and June to September as rainy season. Temperature data was collected from two sources viz. India Meteorological Department (IMD) and Karnataka State Natural Disaster Monitoring Centre (KSNDMC). The prevalence of the butterflies area wise and season wise was compiled based on the total number of sightings during the study period. Butterflies which were observed 100 times or more were classified as 'Very Common', between 30 and 99 were classified as 'Common', between 6 and 29 as 'Rare' and 5 and below as 'Very Rare'. The diversity measures namely richness, abundance, and various diversity indices (Shannon, Simpson, Chao-1, Evenness) were computed for each location, month/season wise. The beta diversity was analysed through bray-curtis, Non-metric dimension scale (NMDS), Hierarchical Cluster Analysis (HCA), correlation of diversity and climatic parameters was computed.

During the study, 183 species of butterflies belonging to six families were observed from all the study areas. There were clear variations in the diversity parameters in the different study sites and seasons. The highest number of species was recorded in Agumbe i.e. 111 species followed by 105 species in Mangalore, 84 species in Bengaluru region, 80 species in Dharwad and 69 species in Gulbarga region. Though species richness is higher in Agumbe and Mangalore, abundance is higher in Bengaluru followed by Gulbarga. The study observed high Shannon and Simpson index in Gulbarga due to the high species evenness. In this Phase II study, the overall dominant species was *Catopsilia* sp., *Ypthima huebneri* was second, *Euploea* sp. was third, *Junonia lemonias* was fourth and *Eurema hecabe* was fifth in dominance. The 10 dominant species of the P2 study are among the first 10 dominant species of P1 study. The dominant species in Agumbe, Bengaluru, Dharwad, Gulburga and Mangalore were *Cupha erymantis*, *Ypthima huebneri*, *Catopsilia* sp., *Catopsilia* sp. and *Euploea* sp. respectively. The zone wise dominant species were mostly same as that in the P1.

The species richness and abundance was high during winter and rainy seasons in all the zones. The diversity indices (Shannon and Evenness) also show that winter and rainy seasons were with the highest values. Only Dharwad showed highest value in summer season. The species composition widely varied in the different study zones. Mangalore and Agumbe showed 47% similar pattern. Bengaluru and Dharwad also showed similar species composition (48%), whereas Gulbarga which has very distinct climatic factors like highest temperature and low humidity profiles shared very few species with other zones (15% with Agumbe).

The seasonal variation in the eco-climatic zones was compared with the data of P1 study. It was observed that the species richness was highest during winter in all the places except Mangalore (richness was high in rainy season) in both the periods of study (2016-17 and 2021-22). This indicates that there is no much variation in the species richness pattern even after four years. The abundance was also similar in Agumbe, Bengaluru and Mangalore in both P1 and P2. In the Gulbarga and Dharwad the abundance was higher in the winter season during P2 and in rainy season during P1. However, summer is the season with lowest diversity in all zones.

From the Phase I and II study conducted in 2016-2017 and 2021-2022, a total of 206 butterfly species are recorded from the five study areas in different eco-climatic zones of Karnataka. Family Lycaenidae and Nymphalidae were the dominant ones in P2 study. In P1 Nymphalidae dominated followed by Lycaenide. In the pooled data of P1 and P2, Family Nymphalidae and Lycaenidae represented highest number of species (i.e. 30% and 29.6%) followed by Hesperiidae (18%), Pieridae (12.6%), Papilionidae (9.2%) and only one species is represented from Riodinidae family. A total of 125 genera represented 206 species of butterflies, wherein the genus *Papilio* represented highest number of species (10) followed by *Junonia* with 6 species. Four genera represented 5 species each, 2 genera with 4 species, 10 genera with 3 species, 21 genera with 2 species and 84 genera with only single species.

This report gives the second set of data of the diversity of butterflies in each of the five study areas in different eco-climatic zones in Karnataka in three seasons of the year. The current study formed a database for comparison with Phase I data. It is found that there is no significant variation in the richness and abundance of butterflies in the eco-climatic areas after four years of study. In all the areas winter/rainy season supported more diversity. The seasonal variations are a clear indication that climatic factors do have clear influence on butterfly diversity. In both phases of study, the dominant species in whole of Karnataka (in specific study areas) and in each of the eco-climatic areas were more or less same. The family distribution and dominance also did not vary much. This indicates that the climate variations across the past five years were not detrimental or influential in changing the diversity pattern of butterflies. Such studies and documentation can be made in the coming years, yearly or at four or five year intervals to get a database on a spatial and temporal scale to see whether there is any change in diversity and abundance of butterflies in relation to climatic changes in these areas and to elucidate the probable impacts of climate change on butterfly diversity.

As a futuristic approach to strengthen the study, it is intended and recommended to continue the studies as a Butterfly Monitoring Program in all districts of Karnataka with the help of public (citizen science) to showcase the importance of butterflies as ecological and climate change indicators. Interested novice participants can be trained to identify butterflies using field guides and Butterfly Identification App (BIA) developed and tested during this study. School students, Frontline forest staff and Range forest officials of KFD and locals who can identify butterflies can participate in regular transect walks and collect data which can be transferred to an online portal designed to handle such data and timely analysis can be done by EMPRI and other scientific institutions which can be helpful in modelling and projections for better interpretation of climate change. The butterfly Database shall be a dynamic one and will be housed in the Karnataka State Knowledge portal for Climate Change. The baseline data developed through the Phase I and Phase II studies shall serve to compare with the future data and interpret the impacts of climate variability/change on butterfly biodiversity. From such a perspective, this study forms a land mark research.

ಸಾರಾಂಶ: ಯೋಜನೆಯ ಶೀರ್ಷಿಕೆ

ಪ್ರಭೇದಗಳ ಸಂಯೋಜನೆ ಮತ್ತು ವೈವಿಧ್ಯತೆಯು ಪರಿಸರ ವ್ಯವಸ್ಥೆಯಲ್ಲಿನ ಪರಿಸರೀಯ ಅಂಶಗಳೊಂದಿಗೆ ನಿಕಟ ಸಂಬಂಧ ಹೊಂದಿದೆ. ಆದ್ದರಿಂದ ಈ ಅಂಶಗಳಲ್ಲಿನ ಯಾವುದೇ ಬದಲಾವಣೆಗಳು ವ್ಯವಸ್ಥೆಯ ಜೈವಿಕ ಚೌಕಟ್ಟಿನಲ್ಲಿ ಖಂಡಿತವಾಗಿಯೂ ಪ್ರತಿಫಲಿಸುತ್ತದೆ. ಅನೇಕ ಜೀವಿಗಳು ಹವಾಮಾನ ಬದಲಾವಣೆಯ ಪರಿಣಾಮವನ್ನು ಪ್ರತಿಬಿಂಬಿಸುತ್ತವೆಯಾದರೂ, ಕೀಟಗಳು, ವಿಶೇಷವಾಗಿ ಚಿಟ್ಟೆಗಳು, ಸಣ್ಣ ಬದಲಾವಣೆಗಳಿಗೂ ಸಹ ಅತ್ಯಂತ ಸೂಕ್ಷ್ಮವಾಗಿರುತ್ತವೆ ಹಾಗೂ ಪ್ರಭಾವದ ವ್ಯಾಪ್ತಿಯನ್ನು ವಿಶ್ಲೇಷಿಸಲು ಅತ್ಯುತ್ತಮ ಅಭ್ಯರ್ಥಿಗಳಾಗಿ ಕಾರ್ಯನಿರ್ವಹಿಸುತ್ತವೆ. ಪರಿಸರ ಬದಲಾವಣೆಗಳನ್ನು ನಿರ್ಣಯಿಸಲು ಒಂದು ವರ್ಷದಲ್ಲಿ ಹಲವಾರು ತಲೆಮಾರುಗಳೊಂದಿಗಿನ ಕಡಿಮೆ ಜೀವನ ಚಕ್ರಗಳು ಹೊಂದಿರುವುದರಿಂದ ಉತ್ತಮ ಅಧ್ಯಯನ ನಡೆಸಲು ಸಹಾಯ ಮಾಡುತ್ತವೆ. ಅದಲ್ಲದೆ, ಪರಾಗಸ್ಪರ್ಶ, ಉನ್ನತ ಜೀವಿಗಳಿಗೆ ಆಹಾರ ಮೂಲ, ಮಾಲಿನ್ಯದ ಪರಿಸರ ಸೂಚಕಗಳು, ಭೂದೃಶ್ಯ ಬದಲಾವಣೆಗಳು, ಹವಾಮಾನ ಬದಲಾವಣೆಗಳಲ್ಲಿ ಪ್ರಮುಖ ಪಾತ್ರಗಳನ್ನು ನಿರ್ವಹಿಸುತ್ತವೆ ಮತ್ತು ಪ್ರಮುಖ ಪರಿಸರ ವ್ಯವಸ್ಥೆಯ ಸೇವೆಗಳಿಗೆ ಕೊಡುಗೆ ನೀಡುತ್ತವೆ. ಚಿಟ್ಟೆಗಳು ಪರಿಸರ ವ್ಯವಸ್ಥೆಯ ಆರೋಗ್ಯದ ಸೂಚಕಗಳಾಗಿ ಸಮುದಾಯ ಪರಿಸರ ವಿಜ್ಞಾನದ ಅಧ್ಯಯನಗಳಲ್ಲಿ ಉಪಯುಕ್ತವಾಗಿವೆ.

ಕರ್ನಾಟಕ, ವರ್ಷಗಳಲ್ಲಿ, ವಿಶೇಷವಾಗಿ ಕಳೆದ ದಶಕದಲ್ಲಿ, ನಿಜವಾಗಿಯೂ ವಾತಾವರಣದ ಉಷ್ಣತೆಯ ಹೆಚ್ಚಳ ಮತ್ತು ಹವಾಮಾನದ ಒಟ್ಟಾರೆ ಬದಲಾವಣೆಗೆ ಸಾಕ್ಷಿಯಾಗಿದೆ. ಕರ್ನಾಟಕದ ಪರಿಸರ ಹವಾಮಾನ ವಲಯಗಳಲ್ಲಿನ ಕೆಲವು ಪ್ರದೇಶಗಳಿಂದ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆಯ ಬಗ್ಗೆ ಬಹಳ ಕಡಿಮೆ ಮಾಹಿತಿ ಮಾತ್ರ ಲಭ್ಯವಿದೆ. 2016–17ರಲ್ಲಿ ನಮ್ಮ ಅಧ್ಯಯನವು ಕರ್ನಾಟಕದ ಪರಿಸರೀಯ ವಲಯಗಳ ಐದು ಅಧ್ಯಯನ ಪ್ರದೇಶಗಳಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ವಿತರಣೆಯ ಮೇಲೆ ಬೇಸ್‌ಲೈನ್ ದತ್ತಾಂಶವನ್ನು ಪಡೆಯಲು ಸಕ್ರಿಯಗೊಳಿಸಿದೆ. ಹಂತ 1ರ ಅಧ್ಯಯನದಿಂದ ಸುಮಾರು ನಾಲ್ಕು ವರ್ಷಗಳ ನಂತರ ಪ್ರಸ್ತುತ ಸ್ಥಿತಿಯನ್ನು ಪಡೆಯಲು ಮತ್ತು ಹವಾಮಾನ ಬದಲಾವಣೆಗಳಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆಯು ಬದಲಾಗಿದೆಯೇ ಎಂದು ಮೌಲ್ಯಮಾಪನ ಮಾಡಲು ಪ್ರಸ್ತುತ ಅಧ್ಯಯನವನ್ನು ಕಾರ್ಯಗತಗೊಳಿಸಲಾಗಿದೆ. ಹಿಂದಿನ ದತ್ತಾಂಶದೊಂದಿಗೆ ಹೋಲಿಕೆ ಮಾಡಬಹುದಾದ ಪ್ರದೇಶವಾರು ಮತ್ತು ಋತುವಾರು ಮಾಹಿತಿಯನ್ನು ಸಂಗ್ರಹಿಸಲು ಯೋಜಿಸಲಾಗಿದೆ. ಈ ಹಿನ್ನೆಲೆಯಲ್ಲಿ, ಈ ಅಧ್ಯಯನವನ್ನು ಈ ಕೆಳಗಿನ ಮುಖ್ಯ ಉದ್ದೇಶಗಳೊಂದಿಗೆ ಯೋಜಿಸಲಾಗಿದೆ:

1. ಕರ್ನಾಟಕದ ಪರಿಸರ ಹವಾಮಾನ ವಲಯಗಳಲ್ಲಿ ಆಯ್ದ ಐದು ಜಿಲ್ಲೆಗಳ ಹಸಿರು ಸ್ಥಳಗಳಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆಯನ್ನು ಅಧ್ಯಯನ ಮಾಡುವುದು.
2. ಅಧ್ಯಯನದ ಪ್ರದೇಶಗಳಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ಸಮೃದ್ಧಿಯಲ್ಲಿ ಕಾಲೋಚಿತ ವ್ಯತ್ಯಾಸ.
3. 2016–17ರಲ್ಲಿ ನಡೆಸಲಾದ ಹಂತ 1 ಅಧ್ಯಯನದಲ್ಲಿ ರಚಿಸಲಾದ ದತ್ತಾಂಶದೊಂದಿಗೆ ವೈವಿಧ್ಯತೆಯ ದತ್ತಾಂಶದ ಹೋಲಿಕೆ.
4. ಅಧ್ಯಯನದ ಪ್ರದೇಶಗಳಲ್ಲಿ ಹವಾಮಾನ ನಿಯತಾಂಕಗಳೊಂದಿಗೆ ಚಿಟ್ಟೆ ವೈವಿಧ್ಯತೆಯ ಪರಸ್ಪರ ಸಂಬಂಧ.

ಈ ಅಧ್ಯಯನದಲ್ಲಿ, ಮೊದಲಿಗೆ ನಾವು ಭಾರತದಲ್ಲಿ, ಪಶ್ಚಿಮ ಘಟ್ಟಗಳಲ್ಲಿ ಮತ್ತು ನಿರ್ದಿಷ್ಟವಾಗಿ ಕರ್ನಾಟಕದಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ವಿತರಣೆಯ ಬಗ್ಗೆ ಲಭ್ಯವಿರುವ ದತ್ತಾಂಶ ಮತ್ತು ಮಾಹಿತಿಯನ್ನು ಪರಿಶೀಲಿಸಲು ಪ್ರಯತ್ನಿಸಲಾಗಿದೆ.

ನಾವು ಪ್ರಪಂಚದಾದ್ಯಂತದ ಚಿಟ್ಟೆಗಳ ಮಾಹಿತಿ ಸಾಹಿತ್ಯವನ್ನು ಮತ್ತು ವೈವಿಧ್ಯಮಯ ಸನ್ನಿವೇಶಗಳಲ್ಲಿ ಅವುಗಳ ಹರಡುವಿಕೆ ಮತ್ತು ವೈವಿಧ್ಯತೆಯ ಮೇಲೆ ಪರಿಣಾಮ ಬೀರುವ ಅಂಶಗಳನ್ನು ಪರಿಶೀಲಿಸಿದ್ದೇವೆ. ವಿಧಾನ ಮತ್ತು ಅಧ್ಯಯನದ ತಾಣಗಳು ಹಂತ–1ರ ಅಧ್ಯಯನದಂತೆಯೇ ಇದ್ದವು. ಪ್ರತಿಯೊಂದು ಹಸಿರು ಸ್ಥಳಗಳಲ್ಲಿ ಪ್ರತಿ ತಿಂಗಳು ಸಮೀಕ್ಷೆಗಳನ್ನು ನಡೆಸಲಾಯಿತು. ನಡೆದಾಡಿದ ಟ್ರಾನ್ಸೆಕ್ಟಳು ಸರಿಸುಮಾರು 500ಮೀ ದೂರದಲ್ಲಿವೆ ಮತ್ತು ಚಿಟ್ಟೆಗಳ ಸಂಭವಿಸುವಿಕೆಯ ದತ್ತಾಂಶವನ್ನು ಟ್ರಾನ್ಸೆಕ್ಟ್‌ನ ಎರಡೂ ಬದಿಗಳಲ್ಲಿ 2.5ಮೀ ಮತ್ತು 5ಮೀ ಎತ್ತರದವರೆಗೆ ದಾಖಲಿಸಲಾಗಿದೆ. ಋತುಗಳ ಪ್ರಕಾರ ವರ್ಗೀಕರಿಸಲು ದತ್ತಾಂಶವನ್ನು ಸಂಗ್ರಹಿಸಲಾಗಿದೆ. ಅಕ್ಟೋಬರ್‌ನಿಂದ ಜನವರಿವರೆಗೆ ಚಳಿಗಾಲ, ಫೆಬ್ರವರಿಯಿಂದ ಮೇ ವರೆಗೆ ಬೇಸಿಗೆಕಾಲ ಮತ್ತು ಜೂನ್‌ನಿಂದ ಸೆಪ್ಟೆಂಬರ್‌ವರೆಗೆ ಮಳೆಗಾಲ ಎಂದು ಪರಿಗಣಿಸಲಾಗುತ್ತದೆ. ತಾಪಮಾನದ ದತ್ತಾಂಶವನ್ನು ಎರಡು ಮೂಲಗಳಿಂದ ಸಂಗ್ರಹಿಸಲಾಗಿದೆ. ಭಾರತೀಯ ಹವಾಮಾನ ಇಲಾಖೆ (ಐ.ಎಂ.ಡಿ.) ಮತ್ತು ಕರ್ನಾಟಕ ರಾಜ್ಯ ನೈಸರ್ಗಿಕ ವಿಪತ್ತು ಮೇಲ್ವಿಚಾರಣಾ ಕೇಂದ್ರ (ಕೆ.ಎಸ್.ಎನ್.ಡಿ.ಎಮ್.ಸಿ). ಅಧ್ಯಯನದ ಅವಧಿಯಲ್ಲಿ ಕಂಡುಬಂದ ಒಟ್ಟು ಸಂಖ್ಯೆಯ ಆಧಾರದ ಮೇಲೆ ಪ್ರದೇಶವಾರು ಮತ್ತು ಋತುವಾರು ಚಿಟ್ಟೆಗಳ ಹರಡುವಿಕೆಯನ್ನು ಸಂಕಲಿಸಲಾಗಿದೆ. 100 ಅಥವಾ ಅದಕ್ಕಿಂತ ಹೆಚ್ಚು ಬಾರಿ ಗಮನಿಸಿದ ಚಿಟ್ಟೆಗಳನ್ನು ಅತ್ಯಂತ ಸಾಮಾನ್ಯ, 30 ಮತ್ತು 99ರ ನಡುವೆ ಸಾಮಾನ್ಯ, 6 ಮತ್ತು 29ರ ನಡುವೆ ಅಪರೂಪ ಮತ್ತು 5 ಮತ್ತು ಕೆಳಗಿನವುಗಳನ್ನು ಬಹಳ ಅಪರೂಪ ಎಂದು ವರ್ಗೀಕರಿಸಲಾಗಿದೆ. ವೈವಿಧ್ಯತೆಯ ಅಳತೆಗಳೆಂದರೆ ಸಂಪದ್ಭರಿತತೆ, ಸಮೃದ್ಧತೆ ಮತ್ತು ವಿವಿಧ ವೈವಿಧ್ಯತೆಯ ಸೂಚ್ಯಂಕಗಳು (ಶಾನನ್, ಸಿಂಪ್ಸನ್, ಚಾವೊ–1, ಸಮಾನತೆ) ಪ್ರತಿ ಸ್ಥಳಕ್ಕೆ, ತಿಂಗಳು/ಋತುವಿನ ಪ್ರಕಾರ ಲೆಕ್ಕಹಾಕಲಾಗಿದೆ. ಬೀಟಾ ವೈವಿಧ್ಯತೆಯನ್ನು ಬ್ರೇ–ಕರ್ಟಿಸ್, ನಾನ್–ಮೆಟ್ರಿಕ್ ಡೈಮೆನ್ಷನ್ ಸ್ಕೇಲ್ (ಎನ್.ಎಂ.ಡಿ.ಎಸ್.), ಹೈರಾರ್ಷಿಯಲ್ ಕ್ಲಸ್ಟರ್ ವಿಶ್ಲೇಷಣೆ (ಎಚ್.ಸಿ.ಎ.) ಮೂಲಕ ವಿಶ್ಲೇಷಿಸಲಾಗಿದೆ ಹಾಗೂ ವೈವಿಧ್ಯತೆಯ ಪರಸ್ಪರ ಸಂಬಂಧ ಮತ್ತು ಹವಾಮಾನ ನಿಯತಾಂಕಗಳನ್ನು ಲೆಕ್ಕಹಾಕಲಾಗಿದೆ.

ಅಧ್ಯಯನದ ಸಮಯದಲ್ಲಿ, ಎಲ್ಲಾ ಅಧ್ಯಯನ ಪ್ರದೇಶಗಳಿಂದ ಆರು ಕುಟುಂಬಗಳಿಗೆ ಸೇರಿದ 183 ಪ್ರಭೇದಗಳ ಚಿಟ್ಟೆಗಳನ್ನು ವೀಕ್ಷಿಸಬಹುದು. ವಿವಿಧ ಅಧ್ಯಯನ ತಾಣಗಳು ಮತ್ತು ಋತುಗಳಲ್ಲಿ ವೈವಿಧ್ಯತೆಯ ನಿಯತಾಂಕಗಳಲ್ಲಿ ಸ್ಪಷ್ಟ ವ್ಯತ್ಯಾಸಗಳಿರುವುದನ್ನು ಕಾಣಬಹುದು. ಆಗುಂಬೆಯಲ್ಲಿ ಅತಿ ಹೆಚ್ಚು ಅಂದರೆ 111 ರೀತಿಯ ಪ್ರಭೇದಗಳು, ಮಂಗಳೂರಿನಲ್ಲಿ 105 ಪ್ರಭೇದಗಳು, ಬೆಂಗಳೂರು ಪ್ರದೇಶದಲ್ಲಿ 84 ಪ್ರಭೇದಗಳು, ಧಾರವಾಡದಲ್ಲಿ 80 ಪ್ರಭೇದಗಳು ಮತ್ತು ಗುಲ್ಬರ್ಗ ಪ್ರದೇಶದಲ್ಲಿ 69 ಪ್ರಭೇದಗಳು ದಾಖಲಾಗಿವೆ. ಆಗುಂಬೆ ಮತ್ತು ಮಂಗಳೂರಿನಲ್ಲಿ ಪ್ರಭೇದಗಳ ಸಂಪತ್ತು ಹೆಚ್ಚಿದ್ದರೂ, ಬೆಂಗಳೂರು ನಂತರ ಗುಲ್ಬರ್ಗದಲ್ಲಿ ಹೇರಳವಾಗಿದೆ. ಹೆಚ್ಚಿನ ಜಾತಿಯ ಸಮಾನತೆಯಿಂದಾಗಿ ಗುಲ್ಬರ್ಗದಲ್ಲಿ ಹೆಚ್ಚಿನ ಶಾನನ್ ಮತ್ತು ಸಿಂಪ್ಸನ್ ಸೂಚ್ಯಂಕವನ್ನು (ಕಡಿಮೆ ಜಾತಿಯ ಸಂಪದ್ಭರಿತೆಯನ್ನು ಹೊಂದಿದ್ದರೂ) ಅಧ್ಯಯನವು ಗಮನಿಸಿದೆ. ಹಂತ 2ರ ಅಧ್ಯಯನದಲ್ಲಿ ಒಟ್ಟಾರೆ ಪ್ರಬಲ ಪ್ರಭೇದವೆಂದರೆ *ಕ್ಯಾಟೊಪ್ಸಿಲಿಯಾ* ಪ್ರಭೇದ, *ಯುಪ್ಲೋಯಾ* ಪ್ರಭೇದ ಎರಡನೇ ಸ್ಥಾನದಲ್ಲಿದ್ದರೆ, *ಡೆಲಿಯಾಸ್ ಯೂಕಾರಿಸ್* ಮೂರನೇ ಸ್ಥಾನ, *ಜುನೋನಿಯಾ ಲೆಮೊನಿಯಾಸ್* ನಾಲ್ಕನೇ ಮತ್ತು *ಟ್ಯುಫಾ ಎರಿಮಾಂತಿಸ್* ಪ್ರಾಬಲ್ಯದಲ್ಲಿ ಐದನೇ ಸ್ಥಾನದಲ್ಲಿವೆ. ಹಂತ 2ರ ಅಧ್ಯಯನದ ಇತರ ಪ್ರಬಲ ಪ್ರಭೇದಗಳು ಹಂತ 1ರ ಅಧ್ಯಯನದ ಮೊದಲ 10 ಪ್ರಭೇದಗಳಲ್ಲಿ ಸೇರಿವೆ. ವಲಯವಾರು ಪ್ರಬಲ ಪ್ರಭೇದಗಳು ಹಂತ 1 ರಲ್ಲಿರುವಂತೆಯೇ ಹೆಚ್ಚಾಗಿವೆ.

ಎಲ್ಲಾ ವಲಯಗಳಲ್ಲಿ ಚಳಿಗಾಲ ಮತ್ತು ಮಳೆಗಾಲದಲ್ಲಿ ಪ್ರಭೇದಗಳ ಸಂಪದ್ಭರಿತತೆ ಮತ್ತು ಸಮೃದ್ಧಿ ಅಧಿಕವಾಗಿದ್ದು, ವೈವಿಧ್ಯತೆಯ ಸೂಚ್ಯಂಕಗಳು (ಶಾನನ್ ಮತ್ತು ಈವನ್‌ನೆಸ್) ಸಹ ಚಳಿಗಾಲ ಮತ್ತು ಮಳೆಗಾಲಗಳಲ್ಲಿ ಅತ್ಯಧಿಕ

ಮೌಲ್ಯಗಳೊಂದಿಗೆ ಇರುವುದನ್ನು ತೋರಿಸುತ್ತವೆ. ಬೇಸಿಗೆಯಲ್ಲಿ ಧಾರವಾಡ ಮಾತ್ರ ಅತ್ಯಧಿಕ ಮೌಲ್ಯವನ್ನು ತೋರಿಸಿದೆ. ವಿವಿಧ ಅಧ್ಯಯನ ವಲಯಗಳಲ್ಲಿ ಜಾತಿಗಳ ಸಂಯೋಜನೆಯು ವ್ಯಾಪಕವಾಗಿ ಬದಲಾಗಿದ್ದು, ಮಂಗಳೂರು ಮತ್ತು ಆಗುಂಬೆ ಶೇ.47ರಷ್ಟು ಇದೇ ಮಾದರಿಯನ್ನು ತೋರಿಸಿದೆ. ಬೆಂಗಳೂರು ಮತ್ತು ಧಾರವಾಡ ಕೂಡ ಇದೇ ರೀತಿಯ ಜಾತಿಯ ಸಂಯೋಜನೆಯನ್ನು ತೋರಿಸಿದೆ (48%), ಆದರೆ ಗುಲ್ಬರ್ಗವು ಅತಿ ಹೆಚ್ಚು ತಾಪಮಾನ ಮತ್ತು ಕಡಿಮೆ ಆರ್ದ್ರತೆಯ ಪ್ರೊಫೈಲ್‌ಗಳಂತಹ ವಿಭಿನ್ನ ಹವಾಮಾನ ಅಂಶಗಳನ್ನು ಹೊಂದಿರುವ ಕೆಲವು ಪ್ರಭೇದಗಳನ್ನು ಇತರ ವಲಯಗಳೊಂದಿಗೆ (15% ಆಗುಂಬೆಯೊಂದಿಗೆ) ಹಂಚಿಕೊಂಡಿದೆ.

ಪರಿಸರ–ಹವಾಮಾನ ವಲಯದಲ್ಲಿನ ಕಾಲೋಚಿತ ವ್ಯತ್ಯಾಸವನ್ನು P1 ಅಧ್ಯಯನದ ದತ್ತಾಂಶದೊಂದಿಗೆ ಹೋಲಿಸಲಾಗಿದೆ. ಅಧ್ಯಯನದ ಎರಡೂ ಅವಧಿಯಲ್ಲಿ (2016–17 ಮತ್ತು 2021–22) ಮಂಗಳೂರು ಹೊರತುಪಡಿಸಿ (ಮಳೆಗಾಲದಲ್ಲಿ ಶ್ರೀಮಂತಿಕೆ ಅಧಿಕವಾಗಿತ್ತು) ಚಳಿಗಾಲದಲ್ಲಿ ಜಾತಿಯ ಸಂಪದ್ಭರಿತೆಯು ಅತ್ಯಧಿಕವಾಗಿದೆ ಎಂದು ಗಮನಿಸಲಾಗಿದೆ. ನಾಲ್ಕು ವರ್ಷಗಳ ನಂತರವೂ ಪ್ರಭೇದಗಳ ಸಂಪದ್ಭರಿತತೆಯ ಮಾದರಿಯಲ್ಲಿ ಹೆಚ್ಚಿನ ವ್ಯತ್ಯಾಸವಿರುವುದಿಲ್ಲ ಎಂದು ಇದು ಸೂಚಿಸುತ್ತದೆ. P1 ಮತ್ತು P2 ಎರಡರಲ್ಲೂ ಆಗುಂಬೆ, ಬೆಂಗಳೂರು ಮತ್ತು ಮಂಗಳೂರಿನಲ್ಲಿ ಸಮೃದ್ಧಿಯು ಹೋಲುತ್ತದೆ. ಗುಲ್ಬರ್ಗ ಮತ್ತು ಧಾರವಾಡದಲ್ಲಿ ಚಳಿಗಾಲದಲ್ಲಿ P2 ಮತ್ತು ಮಳೆಗಾಲದಲ್ಲಿ P1 ರ ಸಮಯದಲ್ಲಿ ಹೇರಳವಾಗಿತ್ತು.

2016–2017 ಮತ್ತು 2021–2022ರಲ್ಲಿ ನಡೆಸಲಾದ ಹಂತ 1 ಮತ್ತು 2 ಅಧ್ಯಯನದಿಂದ, ಕರ್ನಾಟಕದ ವಿವಿಧ ಪರಿಸರ–ಹವಾಮಾನ ವಲಯಗಳ ಐದು ಅಧ್ಯಯನ ಪ್ರದೇಶಗಳಿಂದ ಒಟ್ಟು 206 ಚಿಟ್ಟೆ ಪ್ರಭೇದಗಳನ್ನು ದಾಖಲಿಸಲಾಗಿದೆ. P2 ಅಧ್ಯಯನದಲ್ಲಿ ಕುಟುಂಬ ಲೈಕೆನೈಡ್ ಮತ್ತು ನಿಂಫಾಲಿಡೆ ಪ್ರಬಲವಾದವುಗಳಾಗಿವೆ. P1 ನಲ್ಲಿ ನಿಂಫಾಲಿಡೆ ನಂತರ ಲೈಕೆನೈಡ್ ಪ್ರಾಬಲ್ಯವನ್ನು ಹೊಂದಿತ್ತು. P1 ಮತ್ತು P2 ನ ಸಂಗ್ರಹ ಮಾಡಲಾದ ದತ್ತಾಂಶದಲ್ಲಿ, ಫ್ಯಾಮಿಲಿ ನಿಂಫಾಲಿಡೆ ಮತ್ತು ಲೈಕೇನಿಡೇ ಅತಿ ಹೆಚ್ಚು ಪ್ರಭೇದಗಳನ್ನು ಪ್ರತಿನಿಧಿಸುತ್ತದೆ (ಅಂದರೆ 30% ಮತ್ತು 29.6%) ನಂತರ ಹೆಸ್ಪೆರಿಡೆ (18%), ಪಿಯೆರಿಡೆ (12.6%), ಪ್ಯಾಪಿಲಿಯೊನಿಡೆ (9.2%) ಮತ್ತು ರಿಯೋಡಿನಿಡೆ ಕುಟುಂಬದಿಂದ ಕೇವಲ ಒಂದು ಪ್ರಭೇದ ಪ್ರತಿನಿಧಿಸಲಾಗಿದೆ. ಒಟ್ಟು 125 ಕುಲಗಳು 206 ಪ್ರಭೇದಗಳ ಚಿಟ್ಟೆಗಳನ್ನು ಪ್ರತಿನಿಧಿಸುತ್ತವೆ, ಇದರಲ್ಲಿ ಪ್ಯಾಪಿಲಿಯೊ ಕುಲವು ಹೆಚ್ಚಿನ ಸಂಖ್ಯೆಯ ಪ್ರಭೇದಗಳನ್ನು (10) ನಂತರ ಜುನೋನಿಯಾ 6 ಪ್ರಭೇದಗಳೊಂದಿಗೆ ಪ್ರತಿನಿಧಿಸುತ್ತದೆ. 4 ಕುಲಗಳು ತಲಾ 5 ಪ್ರಭೇದಗಳನ್ನು, 2 ಕುಲಗಳು 4 ಪ್ರಭೇದಗಳನ್ನು, 10 ಕುಲಗಳು 3 ಪ್ರಭೇದಗಳನ್ನು, 21 ಕುಲಗಳು 2 ಪ್ರಭೇದಗಳನ್ನು ಮತ್ತು 84 ಕುಲಗಳು ಒಂದೇ ಪ್ರಭೇದದೊಂದಿಗೆ ಪ್ರತಿನಿಧಿಸುತ್ತವೆ.

ಈ ವರದಿಯು ವರ್ಷದ ಮೂರು ಋತುಗಳಲ್ಲಿ ಕರ್ನಾಟಕದ ಪರಿಸರ–ಹವಾಮಾನ ವಲಯಗಳ ಪ್ರತಿಯೊಂದು ಐದು ಅಧ್ಯಯನ ಕ್ಷೇತ್ರಗಳಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆಯ ಎರಡನೇ ಸೆಟ್ ದತ್ತಾಂಶವನ್ನು ನೀಡುತ್ತದೆ. ಪ್ರಸ್ತುತ ಅಧ್ಯಯನವು ಹಂತ 1ರ ದತ್ತಾಂಶದೊಂದಿಗೆ ಹೋಲಿಕೆಗಾಗಿ ಡೇಟಾಬೇಸ್ ಅನ್ನು ರಚಿಸಿದೆ. ನಾಲ್ಕು ವರ್ಷಗಳ ಅಧ್ಯಯನದ ನಂತರ ಪರಿಸರ ಪ್ರದೇಶಗಳಲ್ಲಿ ಚಿಟ್ಟೆಗಳ ಸಂಪದ್ಭರಿತತೆ ಮತ್ತು ಸಮೃದ್ಧಿಯಲ್ಲಿ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸಗಳಿಲ್ಲ ಎಂದು ಕಂಡುಬಂದಿದೆ. ಎಲ್ಲಾ ಪ್ರದೇಶಗಳಲ್ಲಿ ಚಳಿಗಾಲ/ಮಳೆಗಾಲವು ಹೆಚ್ಚಿನ ವೈವಿಧ್ಯತೆಯನ್ನು ಬೆಂಬಲಿಸುತ್ತದೆ. ಋತುಮಾನದ ವ್ಯತ್ಯಾಸಗಳು ಹವಾಮಾನದ ಅಂಶಗಳು ಚಿಟ್ಟೆ ವೈವಿಧ್ಯತೆಯ ಮೇಲೆ ಸ್ಪಷ್ಟವಾದ ಪ್ರಭಾವವನ್ನು ಹೊಂದಿವೆ ಎಂಬುದಕ್ಕೆ ಸ್ಪಷ್ಟ ಸೂಚನೆಯಾಗಿದೆ. ಅಧ್ಯಯನದ ಎರಡೂ ಹಂತಗಳಲ್ಲಿ, ಇಡೀ ಕರ್ನಾಟಕದಲ್ಲಿ (ನಿರ್ದಿಷ್ಟ ಅಧ್ಯಯನ ಪ್ರದೇಶಗಳು) ಮತ್ತು ಪ್ರತಿ ಪರಿಸರ ವಲಯದಲ್ಲಿ ಪ್ರಬಲವಾದ ಪ್ರಭೇದಗಳು ಹೆಚ್ಚು ಕಡಿಮೆ ಒಂದೇ ಆಗಿದ್ದು, ಕುಟುಂಬದ ಹಂಚಿಕೆ ಮತ್ತು

ಪ್ರಾಬಲ್ಯದಲ್ಲೂ ಕೂಡ ಹೆಚ್ಚು ವ್ಯತ್ಯಾಸವಿಲ್ಲ. ಕಳೆದ ಐದು ವರ್ಷಗಳಲ್ಲಿ ಹವಾಮಾನ ವೈಪರೀತ್ಯಗಳು ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆಯ ಮಾದರಿಯನ್ನು ಬದಲಾಯಿಸುವಲ್ಲಿ ಹಾನಿಕಾರಕ ಅಥವಾ ಪ್ರಭಾವಶಾಲಿಯಾಗಿಲ್ಲ ಎಂಬುದನ್ನು ಇದು ಸೂಚಿಸುತ್ತದೆ. ಇಂತಹ ಅಧ್ಯಯನಗಳು ಮತ್ತು ದಾಖಲಾತಿಗಳನ್ನು ಮುಂಬರುವ ವರ್ಷಗಳಲ್ಲಿ ವಾರ್ಷಿಕವಾಗಿ ಅಥವಾ ನಾಲ್ಕು ಅಥವಾ ಐದು ವರ್ಷಗಳ ಮಧ್ಯಂತರದಲ್ಲಿ ಮಾಡಬಹುದಾಗಿದೆ, ಇವುಗಳಲ್ಲಿ ಹವಾಮಾನ ಬದಲಾವಣೆಗಳಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಚಿಟ್ಟೆಗಳ ವೈವಿಧ್ಯತೆ ಮತ್ತು ಸಮೃದ್ಧಿಯಲ್ಲಿ ಯಾವುದೇ ಬದಲಾವಣೆ ಇದೆಯೇ ಎಂದು ನೋಡಲು ಮತ್ತು ಚಿಟ್ಟೆ ವೈವಿಧ್ಯತೆಯ ಮೇಲೆ ಹವಾಮಾನ ಬದಲಾವಣೆಯ ಸಂಭವನೀಯ ಪರಿಣಾಮಗಳನ್ನು ವಿವರಿಸಲು ಪ್ರಾದೇಶಿಕ ಮತ್ತು ತಾತ್ಕಾಲಿಕ ಪ್ರಮಾಣದಲ್ಲಿ ಡೇಟಾಬೇಸ್ ಅನ್ನು ಪಡೆಯಬಹುದು.

ಅಧ್ಯಯನವನ್ನು ಬಲಪಡಿಸಲು ಭವಿಷ್ಯದ ವಿಧಾನವಾಗಿ, ಪರಿಸರ ಮತ್ತು ಹವಾಮಾನ ಬದಲಾವಣೆಯ ಸೂಚಕಗಳಾಗಿ ಚಿಟ್ಟೆಗಳ ಪ್ರಾಮುಖ್ಯತೆಯನ್ನು ಪ್ರದರ್ಶಿಸಲು ಸಾರ್ವಜನಿಕ (ನಾಗರಿಕ ವಿಜ್ಞಾನ) ಸಹಾಯದಿಂದ ಕರ್ನಾಟಕದ ಎಲ್ಲಾ ಜಿಲ್ಲೆಗಳಲ್ಲಿ ಅಧ್ಯಯನವನ್ನು ಮುಂದುವರಿಸಲು ಉದ್ದೇಶಿಸಲಾಗಿದೆ. ಈ ಅಧ್ಯಯನದ ಸಂದರ್ಭದಲ್ಲಿ ಅಭಿವೃದ್ಧಿಪಡಿಸಿದ ಮತ್ತು ಪರೀಕ್ಷಿಸಿದ ಫೀಲ್ಡ್ ಗೈಡ್ ಹಾಗೂ ಬಟರ್‌ಫ್ಲೈ ಐಡೆಂಟಿಫಿಕೇಶನ್ ಅಪ್ಲಿಕೇಶನ್ (ಬಿ.ಐ.ಎ.) ಅನ್ನು ಬಳಸಿಕೊಂಡು ಭಾಗವಹಿಸುವ ಆಸಕ್ತ ಅನನುಭವಿಗಳಿಗೆ ಚಿಟ್ಟೆಗಳನ್ನು ಗುರುತಿಸಲು ತರಬೇತಿ ನೀಡಬಹುದು. ಶಾಲಾ ವಿದ್ಯಾರ್ಥಿಗಳು, ಅರಣ್ಯ ಕ್ಷೇತ್ರ ಸಿಬಂದಿಗಳು ಹಾಗು ರೇಂಜ್ ಫಾರೆಸ್ಟ್ ಅಧಿಕಾರಿಗಳು, ಮತ್ತು ಚಿಟ್ಟೆಗಳನ್ನು ಗುರುತಿಸಬಲ್ಲ ಸ್ಥಳೀಯರು ಪ್ರತಿದಿನ ಟ್ರಾನ್ಸೆಕ್ಟ್ ನಡಿಗೆಯಲ್ಲಿ ಭಾಗವಹಿಸಬಹುದು ಮತ್ತು ಅಂತಹ ದತ್ತಾಂಶವನ್ನು ನಿರ್ವಹಿಸಲು ವಿನ್ಯಾಸಗೊಳಿಸಲಾದ ಆನ್‌ಲೈನ್ ಪೋರ್ಟಲ್‌ಗೆ ವರ್ಗಾಯಿಸಬಹುದಾದ ದತ್ತಾಂಶವನ್ನು ಸಂಗ್ರಹಿಸಬಹುದು ಮತ್ತು ಸಕಾಲಿಕ ವಿಶ್ಲೇಷಣೆಯನ್ನು ಎಂಪ್ರಿ ಮತ್ತು ಇತರ ವೈಜ್ಞಾನಿಕ ಸಂಸ್ಥೆಗಳು ಮಾಡೆಲಿಂಗ್ ಮತ್ತು ಪ್ರೊಜೆಕ್ಷನ್‌ಗಳಲ್ಲಿ ಸಹಾಯಕವಾಗಬಹುದು. ಚಿಟ್ಟೆ ಡೇಟಾಬೇಸ್ ಡೈನಾಮಿಕ್ ಆಗಿರಬೇಕು ಮತ್ತು ಹವಾಮಾನ ಬದಲಾವಣೆಗಾಗಿ ಕರ್ನಾಟಕ ರಾಜ್ಯ ಜ್ಞಾನ ಪೋರ್ಟಲ್‌ನಲ್ಲಿ ಇರಿಸಲಾಗುತ್ತದೆ. ಹಂತ 1 ಮತ್ತು ಹಂತ 2 ಅಧ್ಯಯನಗಳ ಮೂಲಕ ಅಭಿವೃದ್ಧಿಪಡಿಸಿದ ಮೂಲ ದತ್ತಾಂಶವು ಭವಿಷ್ಯದ ದತ್ತಾಂಶದೊಂದಿಗೆ ಹೋಲಿಸಲು ಮತ್ತು ಚಿಟ್ಟೆಗಳ ಜೀವವೈವಿಧ್ಯತೆಯ ಮೇಲೆ ಹವಾಮಾನ ಬದಲಾವಣೆಯ ಪರಿಣಾಮಗಳನ್ನು ಅರ್ಥೈಸಲು ಸಹಾಯ ಮಾಡುತ್ತದೆ. ಅಂತಹ ದೃಷ್ಟಿಕೋನದಿಂದ, ಈ ಅಧ್ಯಯನವು ಒಂದು ಮಹತ್ವದ ಸಂಶೋಧನೆಯನ್ನು ರೂಪಿಸುತ್ತದೆ.

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Dr. O. K. Remadevi
Principal Investigator

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Abbreviations

Acronyms

BIA	Butterfly Identification Application
C	Common
EMPRI	Environmental Management and Policy Research Institute
HCA	Hierarchical Cluster Analysis
IMD	India Meteorological Department
KSNDMC	Karnataka State Natural Disaster Monitoring Centre
NMDS	Non-Metric Dimensional Analysis
P1	Phase I Study
P2	Phase II Study
PAST	PAleontological STatistics
R	Rare
R	Rainy
RH	Relative Humidity
S	Summer
TO	Total
VC	Very Common
VR	Very Rare
W	Winter

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Chapter 1: Introduction

Climate Change impacts both the floral and faunal diversity. It is projected to have devastating effects on different macro and micro ecosystems. A small change in pattern of climate has severe impact on the biodiversity, altering the habitats of the species and presenting a threat for their survival (Prakash and Srivastava, 2019). The two important aspects of climate variability are variation in precipitation and temperature which are likely to have a direct and significant effect on India's biodiversity (Soni and Ansari, 2017). In this context, it is very essential to study the impacts of climate change on the biodiversity in the different ecosystems.

Diversity, distribution and bio ecology of insects, especially butterflies reflect the health of environment and the impact of climate on them. Butterflies are dependent on the host plants for completion of their life cycle. The adult lays eggs and the larvae feed on the leaves of the host plants for their nutrition. As the butterflies act as pollinators and act as a source of food, they contribute to ecosystem functioning and restoration. An increase in plant diversity and other pollinator groups within restored areas is indicated due to increased butterfly populations (Ghazanfar *et al.*, 2016). Since the availability and phenology of host plants change due to climatic variability and change, the diversity of butterflies also get affected and hence they are the best bio indicators of climate change.

Butterflies are considered as the umbrella species in nature conservation and are usually the key taxa in biodiversity monitoring (New, 1997). They bear a history of long-term coevolution with plants. The faunistic survey of butterflies, their occurrence and characteristics provide crucial information on the ecology of a particular region (Ghazoul, 2002). Monitoring the butterfly populations is an essential component of conservation efforts (Taron and Ries, 2015). Studying the biodiversity and distribution in a specific locality will enable us to monitor their occurrence in relation to climate variability and climate change. To monitor them it is essential that they should be correctly identified in the field itself. Hence routine field surveys are essential in the selected areas.

Background

EMPRI, the nodal agency for climate change in Karnataka, conducted a project in 2015-16 on "Butterflies as Indicators of Climate Change, a baseline study in Bangalore city". As there were no detailed studies from the past to compare the current data on butterfly diversity from

Bengaluru city, we were not able to assign any climate change reason on a temporal scale for the current butterfly diversity. Hence during 2016-17 we extended the study to five different study areas located in different eco-climatic regions in Karnataka with varying climate regimes (temperature, relative humidity and rain fall etc.) so that the climate variability in different locations and diversity of butterflies can be compared. This study helped to indirectly point out the effect of climate change on butterfly diversity. In this Phase II project conducted during 2021 to 2022, the study is repeated after a gap of more than four years. The variability/ change in climate and the current diversity could be documented through this study. This type of monitoring can build up diversity database from different areas and enable us to use butterflies as climate change bio-indicators.

Objectives

The present study undertaken after about four years from the Phase I study under a small hike in temperature studies, the variation of diversity in relation to same eco-climatic regions and correlates diversity and climatic factors. It indicates some of the changes in species distribution and abundance in specific areas located in different eco-climatic zones in Karnataka. To elucidate the above features and aspects, Phase II study is planned with the following objectives:

1. Study the diversity of butterflies in green spaces of the selected districts in different eco-climatic zones of Karnataka.
2. Seasonal variance in the diversity and abundance of butterflies in the study area.
3. Comparison of diversity data with the data generated in the study conducted during 2016-17.
4. Correlation of the diversity with climatic parameters in the study areas.

Chapter 2: Review of Literature

2.1 Bio-Ecology of Butterflies

Butterflies are taxonomically well studied group, which have received reasonable amount of attention throughout the world. They are the most beautiful creatures and are regarded as flagship species. They are a well-known insect group and extensive studies are carried out on diverse aspects. Heppner (1998) has documented approximately 19,238 butterfly species throughout the world.

Worldwide, there are reports of more than 28,000 species of butterflies, with about 80 percent in tropical regions. Their survival depends on the availability of specific host plants and nectar that is produced in flowers and also on extra-ripe fruits. The butterfly plays a very important role in ecosystems, gathering pollen on their long, thin legs while drawing nectar from a flower and pollinating flowers that open during the day time. Many butterfly species migrate over long distances as many as 3,000 miles. These migrations allow for pollination across long distances.

Many eco-climatic factors govern the diversity, abundance and seasonal occurrence of butterflies in a particular area. Larval food plants of Lycaenidae and Riodinidae are of particular interest for several reasons. Many of these species feed as larvae on the flower buds, flowers, and fruits of plants (Downey, 1962) and thus may exert stronger selective forces on their food plants than foliage feeders (Breedlove and Ehrlich, 1968). Plants and animals are shifting their home ranges either at higher altitudes or higher latitudes in order to combat the stress of warming. The behavioural aspects of Lepidoptera towards light, temperature, and habitat requirements have been quantitatively assessed (Warren, 1985; Thomas and Harrison, 1992; Oostermeijer and Swaay, 1998; Pollard *et al*., 1998). Demonstration of their correlations with changes in ecosystem conditions has been done (Bowman *et al*., 1990; Thomas and Harrison, 1992; Hill *et al*., 1995; Pullin, 1996; Spitzer *et al*., 1997; Pollard *et al*., 1998; Swengel, 1998).

Ecologist use butterflies as model organisms to study the impact of climate change and habitat loss. Butterflies, together with birds and vascular plants, are the most frequently monitored taxonomic groups in Europe (de Heer *et al*., 2005; Thomas, 2005), due mostly to their high popularity among amateur naturalists. If populations of butterfly diminish, then population of birds, mice and other animals that rely on them as food source will also reduce.

Some butterfly species migrate over long distance and share pollens across plants which are far away from one another. Monitoring the change in abundance and assessing the distribution of butterflies have been suggested as a potential tool for assessing large scale biodiversity trends (van Swaay *et al*., 2008).

2.2 Diversity of Butterflies in India

India has nearly 1,800 species and subspecies (Kehimkar, 2008), the peninsular region recorded approximately 350 species (Kunte, 2000b). North eastern part of India has reported 962 species (Evans, 1932). The Lepidopterists Gupta and Mridula (2012), Varshney and Peter (2015), Isaac Kehimkar (2016) and many others have contributed extensively to Indian butterflies by documenting diversity along with their seasonal variation, morphology, butterflies and their host plants, effect of abiotic factors on butterfly community, effect of deforestation and effect of anthropogenic disturbances on population of butterflies. Numerous works has also been carried out to deal with regional butterfly diversity.

Since early 18th century butterflies have been studied systematically. In 1758, Carl Linnaeus initiated the systematic study of Indian butterflies in his publication Carl Linnaeus's Systema Naturae, and established the naming of species. Further Pieter Cramer and Johan Christian Fabricius who were his students described 350 butterflies from the Indian region. During 18th century the naming of Indian butterflies was started by Thomas Horsfield and Frederic Moore and they described over 500 taxa from different region and a Catalogue of the Lepidopterous Insects in the Museum of the Honorary East-India Company was published in the 1820s (Moore 1892, 1896, 1899, 1900, 1903, 1905). Hence this period was called the golden period of taxonomic discovery of Indian butterflies.

During the 19th century, Evans (1927) provided essential keys to the identification of Indian butterflies. Some of the most beautiful butterflies in the world are found in Indian region (Wynter-Blyth, 1957). Bets (1950) recorded 170 species of butterflies in the Northern Assam, India.

Butterflies have attracted many researchers from more than a hundred years. A chronological account of the studies on Indian butterflies is presented below. Bell (1909-1927) reported on the common butterflies on the plains of India. Best (1951) reported 70 species of butterflies from Bombay and Salssetter regions of India. In India region (India, Pakistan, Ceylon, Burma, Andamans and Nicobar) about 1400 species have been found and some of them are most beautiful in the world (Wynter-Blyth, 1957). From Palani Hills 224 species of butterflies were recorded by Ugarte and Rodricks (1960). At a more local level, Larsen (1987) carried out intensive studies of butterfly fauna of Nilgiris and reported 300 species, which may well be representative of the South Indian region.

Haribal (1992) listed nearly 103 species from Sikkim and provided a considerable body of work on the butterflies of the Sikkim and their natural history. Diversity and habitat utilization of butterflies in different forest types of Hosur forest Division of Southern India was documented by Kathikeyan (1999). Kunte (2000a) conducted a study on "Butterfly Diversity of Pune City along the Human Impact Gradient" in 1997 and identified 103 species present in the area belonging to 5 families. Out of this 32 species belonged to Lycaenidae, 30 species in Nymphalidae, 20 in Pieridae, 13 in Hesperiidae and 8 in Papilionidae. Kunte, (2000b) mentioned about 1501 species of butterflies found in India, of which 321 are Skippers, 107 Swallowtails, 109 Whites and Yellows, 521 Brush-footed butterflies and 443 Blues.

A study in Government College Campus, Madappally, Kozhikode District, Kerala was conducted by Nair (2002) and recorded 73 species of butterflies out of which 32 belonged to the family Nymphalidae followed by 13 species belonging to the family Papilionidae, 12 species belonging to Lycaenidae, 8 species each belonging to Pieridae and Hesperiidae. Singh and Bhandari (2003) studied the butterfly diversity in tropical moist deciduous forests of Dehra Dun valley. A total of 183 species of butterflies belonging to 128 genera and 5 families were recorded from the study area. The index significantly declined during the monsoon. It again increased significantly during post-monsoon. The species diversity was highest during autumn and lowest during winter.

Singh and Pandey (2004) evolved a model for estimating butterfly species richness of areas across the Indian subcontinent using papilionids as indicators. The proportion of species in many of the five butterfly families found across the Indian sub-continent show a relatively invariant relationship with the overall butterfly species richness at both local and regional scales. This relationship suggests that it is possible to use the species total of a single butterfly family to estimate the overall species richness of all other butterflies in an area. Family Papilionidae is the logical choice over others for ease of sampling. Also, there is a positive correlation between Papilionid species richness and the overall species richness of all other butterflies across all the other areas, and the proportion of this family is reasonably invariant. Sreekumar and Balakrishnan (2006) studied the occurrence and diversity of butterfly populations in different altitude levels in a tropical rain forest ecosystem of Aralam Wildlife Sanctuary in Kerala. A total of 71 species of butterflies were recorded.

India has a rich butterfly fauna comprising of about 1504 species (Kehimkar, 2008). He published, 'The book of Indian butterflies', which contains illustrations of 735 species of butterflies occurring in the Indian subcontinent. He described in detail on distribution, biology, host plants and importance of butterfly gardens. Tiple *et al.,* (2009) studied the diversity, habitat and seasonal distribution of butterflies in and around Nagpur city, Central India during 2006-08 and recorded a total of 145 species of butterflies, out of which 62 species were new records. 51 species belonging to the Nymphalidae with 17 new records followed by 46 species of Lycaenidae with 29 new records, 22 species of Hesperiidae with 14 new records, 17 of Pieridae species with 4 new records and Papilionidae with 9 species were observed. Most species were recorded between monsoon and early winter and thereafter a trend in decline in number were observed till March. 28% were very common, 27% were common, 6% were not rare, 26% were rare and 13% were very rare.

In a study by Singh (2009) entitled, "Butterflies of Kedarnath Musk Deer Reserve, Garhwal Himalaya, India", he recorded 147 species during May and September 2006. Nymphalidae dominated with 68 species followed by 30 species of Lycaenidae, 17 of Hesperiidae, 14 of Pieridae, 13 of Papilionidae and 5 of Riodinidae. Raut and Pendhakar (2010) studied the Butterfly Fauna of Maharashtra Nature Park, Mumbai, India and recorded 53 species of Butterflies, out of which 23 belonged to the family Nymphalidae (43%), 13 to Pieridae (25%), 10 to Lycaenidae (19%), 5 to Papilionidae (9%) and 2 to Hesperiidae (4%). Gogoi (2012) studied, butterflies (Lepidoptera) of Dibang Valley, Mishmi Hills, Arunachal Pradesh and recorded 294 species dominated by Nymphalidae with 115 species followed by 61 species of Hesperiidae, 59 of Lycaenidae, 33 species of Papilionidae and 26 species of Pieridae.

Tiple (2011) surveyed on the butterflies of Vidarbha region, Maharashtra State, central India, and documented a total of 166 species which was dominated by Nymphalidae with 50 species followed by 48 by Lycaenidae, 34 by Hesperiidae, 23 by Pieridae and 13 by Papilionidae. Kunte *et al.,* (2012) studied the butterflies of the Garo Hills and recorded 298 species of butterflies dominated by Nymphalidae with 121 followed by 72 species of Lycaenidae, 48 of Hesperiidae, 28 of Papilionidae, 24 of Pieridae and 5 of Riodinidae. Smitha *et al.,* (2012) enlisted 84 species of butterflies in south Indian states of Karnataka, Kerala, Andhra Pradesh and Tamil Nadu, out of which 33 species were represented by the family Nymphalidae, 13 by Pieridae, 17 by Lycaenidae, 14 by Papilionidae and 7 by Hesperiidae. Murugesan *et al.*, (2013) recorded 63 species of butterflies belonging to 5 families in and around Oussudu Bird Sanctuary in Puducherry, India. The family Nymphalidae was dominant with 21 species followed by Pieridae with 14 species, Lycaenidae with 10 species followed by Papilionidae and Hesperiidae with 9 species each. A study by Prabakaran *et al.*, (2014) in Thiruvallur district, Tamil Nadu, India recorded a total of 97 species, out of which 31 species belonged to Nymphalidae, 25 to Hesperiidae, 20 to Pieridae, 14 to Lycaenidae and 7 species to Papilionidae. Narasimmarajan *et al.*, (2014) identified 66 species of butterflies in Gugamal National Park, in Melghat Tiger Reserve, Maharashtra, Central India. The family Nymphalidae was dominant with 31 species followed by Pieridae with 16 species, Papilionidae with 8 species, Lycaenidae with 7 species and Hesperiidae with 4 species.

2.3 Distribution of Butterflies in Western Ghats Region

Western Ghats is the biodiversity hot spot in South India, which harbours many species of butterflies which were recorded across diverse landscapes and time periods. Extensive studies on butterflies of Western Ghats, Southern India was carried out by Gaonkar (1996), which was the first study that took into account of all 330 species in 166 genera belonging to 5 families recorded from this mountain range and the adjacent areas. He recorded 317 species from the southern Western Ghats, 316 from the central Western Ghats and 200 from the northern Western Ghats. As per Kunte (2000b), Western Ghats harbour about 334 species of butterflies including 37 endemics.

Kunte (2008) analysed the Wildlife (Protection) Act and conservation prioritization of butterflies of the Western Ghats, and reported the presence of 333 butterflies out of which 33 are endemic to Western Ghats and 8 shared between Western Ghats and Sri Lanka. Kunte (2011) studied the biogeographic origins and habitat use of of 332 species of butterflies belonging to six families and 164 genera in Western Ghats. Study by Padhye *et al.*, (2012) revealed that 270 species belonging to 6 families were present; out of which 81 species were represented by the family Nymphalidae, 82 by Lycaenidae, 59 by Hesperiidae, 28 by Pieridae, 19 by Papilionidae and one by Riodinidae within the Western Ghats of Karnataka. A total of 334 species was recorded in the entire Western Ghats landscape.

2.4 Diversity of Butterflies in Karnataka

Butterfly diversity in different parts of Karnataka was studied by many researchers. Yates (1933) had reported 140 species of butterflies from Bangalore. Kathikeyan (1999) revealed the occurrence of about 153 species of butterflies in Bangalore, of which 12 species belonged to the family Papilionidae, 23 to Pieridae, 42 to Nymphalidae, 51 to Lycaenidae and 25 to Hesperiidae. Mohandas and Ramadevi (2019) documented 142 species of butterflies belonging to 5 families in Kudremukh National Park, Mookambika Wildlife Sanctuary and Someshwar Wildlife Sanctuary. Nymphalidae dominated with 53 species followed by 28 species of Lycaenidae, 24 species of Hesperiidae, 19 species of Papilionidae and 18 species of Pieridae. Kumar *et al.,* (2007) studied the butterflies of Tiger-Lion Safari, Thyavarekoppa, Shimoga, and Karnataka and reported the presence of 57 species; 28 species of Nymphalidae, 10 species of Papilionidae, 8 species each of Lycaenidae and Pieridae and 3 species of Hesperiidae. Tamang (2010) reported 42 species of butterflies in Bannerghatta National Park. Butterflies belonging to subfamily Danainae are observed to migrate in the outskirts of Bangalore (Kunte 2006, 2017). Kumar *et al.,* (2004) reported the presence of 64 species of butterflies in bio park of Bangalore University, 18 species belonged to the family Lycaenidae followed by 17 of Nymphalidae, 14 of Pieridae, 7 of Papilionidae, 4 of Danainae, 2 of Satyrinae and one each of Acraeini and Hesperiidae (Shashikumar and Venkatesh, 2010).

Raghavendra Gowda *et al.,* (2011) made a study on Butterfly Diversity, Seasonality and Status in Lakkavalli Range of Bhadra Wildlife Sanctuary, Karnataka and recorded a total of 52 species out of which 16 belonged to the family Nymphalidae, 10 Papilionidae, 8 Pieridae, 7 Lycaenidae, 4 of Danainae, Satyrinae and Hesperiidae and one belonging to the family Acraeini. A rare species, *Apharitis lilacinus* was reported in Hesaraghatta Lake of Bangalore by Sheshadri *et al.,* (2013). A study by Jeevan *et al.,* (2013) at Mandagadde of Shivamogga, Karnataka, India recorded a total of 52 species of butterflies belonging to 5 families. Family Nymphalidae represented the highest number of species with 23 followed by Papilionidae with 9 species, Pieridae and Lycaenidae with 8 and Hesperidae with 4 species. Dayananda (2014) recorded a total of 115 species of butterflies in and around Gudavi bird sanctuary, Sorab, Karnataka during 2009 to 2011. 40 species of Nymphalidae, 25 species of Lycaenidae, 18 species of Hesperiidae and 16 species each of Papilionidae and Pieridae were recorded. Sayeswara (2014) documented 33 species belonging to 5 species in Sahyadri College Campus, Shivamogga, Karnataka, India in the year 2013. Family Nymphalidae dominated with 9 species followed by 8 species of Papilionidae and Pieridae each and 4 species of Hesperiidae and Lycaenidae each.

Ankalgi *et al.,* (2014) in 2012-13 studied the diversity of butterflies from Ankalga village, Gulbarga district, Karnataka, and identified 31 species out of which 11 species belonged to Nymphalidae, 10 of Pieridae, 5 of Lycaenidae, 4 of Papilionidae and 1 species belonging to the family Hesperiidae. A preliminary study by Nijavalli (2015) around the Kundavada Lake, Davangere district, Karnataka recorded a total of 51 species of Butterflies belonging to 5 families with 17 species (33%) contributed by Nymphalidae followed by 14 (27%) by Pieridae, 11 (22%) by Lycaenidae, 6 (12%) by Papilionidae and 3 (6%) by Hesperiidae. Checklists of butterflies have documented a total of 137 species in and around Mysore city belonging to 5 families (www.mysorenature.org). Butterfly species were highest in number belonging to the family Nymphalidae representing 43 species followed by 39 by Lycaenidae, 22 by Pieridae and Hesperiidae each and 11 species of Papilionidae.

During the systematic survey done in 2015-16 by Saraf and Jadesh (2016), a total of 52 species of butterflies belonging to 29 genera and 5 families were recorded from Uplaon Nature Camp, Kalaburagi district, Karnataka. Nymphalidae and Pieridae dominated the list with 18 species followed by, Lycaenidae with 8 species, Papilionidae with 6 species and Hesperidae with 2 species.

Naik and Mustak (2016) reported 172 species of butterflies from Dakshina Kannada district, belonging to 117 genera under six families. Nymphalidae with 57 species was the dominant followed by Hesperiidae 37 species, Lycaenidae 45 species, Papilionidae 17 species, Pieridae 15 species and Riodinidae one species. Sammilan Shetty and other volunteers at Sammilan Shetty's Butterfly Park, Belvai, Mangalore, Karnataka, have recorded a total of 147 butterfly species representing 6 families of order Lepidoptera during 2011 to 2017. A study done by Umapati *et al*., (2016) recorded a total of 36 species belonging to 25 different genera under five families from Karnatak University Campus, Dharwad. Of these, individuals of Nymphalidae family were found to be dominant with 16 species under 11 genera followed by Pieridae (8), Papilionidae (6), Lycaenidae (4) and Hesperiidae (2). During the year 2015-16, a total of 108 species of butterflies were recorded from the 6 green spaces of the Bangalore city (Remadevi *et al.,* 2018a). Out of the 108 species, ten butterfly species come under the protection category of the Indian Wildlife Protection Act 1972; six falls under Scheduled I, three under Schedule II and one under Schedule IV. It was found that 19 species were very common, 37 species were common, 21 were rare and 31 were very rare. As per our studies Common Grass Yellow (Euremahecabe) is the most common butterfly in Bangalore city and at the same time, twenty species of butterflies were recorded only once. A Field guide was developed for assisting the identification of 153 species of butterflies reported from Bengaluru (Remadevi *et al.,* 2018b)

Ugare *et al*., (2019) documented the lepidopteran diversity within the Karnatak University campus, Dharwad, which revealed the occurrence of 48 species belonging to 11 families. The family Nymphalidae was the most dominant one with 13 species, followed by Erebidae (9) and Papilionidae (6) family whereas Pterophoridae and Uraniidae families represented single species each and were rarely seen during the study.

A study by Harisha and Hosetti (2021) at Kuvempu University Campus, Karnataka recorded a total of 115 species of butterflies in 77 genera, belonging to five families. The family Nymphalidae dominated with 38 species (33% of total species) recorded, followed by Lycaenidae with 28 species (24%), Pieridae with 23 species (20%), Papilionidae with 15 species (13%), and Hesperiidae with 11 species (10%). Extensive studies in different eco-climatic areas of Karnataka facilitated the preparation of a field guide for 323 species reported from Karnataka (Remadevi *et al.,* 2020). A Butterfly Identification App is also prepared for helping butterfly identification and database creation of butterflies in Karnataka (Remadevi *et al.,* 2022).

2.5 Effects of Climate Change on diversity of insects/butterflies

Global warming and consequent changes in climate in a specific area with a set of biotic components drive very many changes in the diversity, distribution, and composition of flora and fauna including insects. Insects especially butterfly, very sensitive to the floral characteristics and climatic conditions in an area get impacted faster. How climate changes affect butterfly diversity is a major concern of all biologists. Researchers and environmentalists also look up to butterflies which can serve as flagship organisms to indicate climate change and environmental health. Climate Change research in recent years from all around the world specifically from temperate countries has shed light on the impact of climate change on biodiversity in diverse ecosystems. Parmesan and Yohe (2003), Root *et al.,* (2003), and Parmesan and Hanley (2015) offer interesting overviews of climate change drivers and its impact on species distribution, range shifts, altered population structure, and disturbed phenology cycles. Climate changes have drastic impacts on the economy of agriculture-based, biodiversity-rich countries like India (Sharma, 2010; Dhaliwal *et al.,* 2004). Research data on the phenology and range shift of forestry and agricultural species and the impact of climate change on biodiversity from India are very scarce.

Insects are cold-blooded, most speciose animals (Coviella and Trumble, 1999) and the temperature is probably the single most important environmental factor influencing insect behaviour, distribution, survival and reproduction. It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998). Moisture and CO2 effects on insects can potentially have important considerations in a global climate change setting (Hamilton *et al.,* 2005; Coviella and Trumble, 1999; Hunter, 2001; Sharma, 2010; Dhaliwal *et al.,* 2004, 2010). Higher temperature lead to an earlier infestation of Helicoverpa armigera (Hub.) in North India (Sharma, 2010), resulting in increased crop loss. Increased levels of CO_2 will enhance plant growth, but may also become vulnerable to select phytophagous insects (Gregory *et al.,* 2009). There is a general paucity of long-term climatic data and its impact on pollinators in developing countries especially India (Inoue, 1993). Sudden outbreaks of insect pests can wipe out certain crop species and encourage the invasion by exotic species (Kannan and James, 2009). Biodiversity is continually transformed by the changing climate. The type of climate change brought about by human activities is threatening to accelerate the loss of biodiversity (Peters and Lovejoy, 1992).

Climate change has three main impacts on Lepidopteran species: 1.Changes in abundance; 2.Changes in range, distribution or area; 3.Changes in phenology (Woiwod, 1997). According to Jaimes Nino *et al*., (2019) the most significant climatic factor explaining differences in butterfly richness and abundance throughout the year in Ecuadorian Amazonia was the temperature. Porter *et al.,* (1991) and Logan *et al.*, (2003) suggest that the following possible impacts can be expected in the near future: increasing rate of overwintering, prolonged development stage, changes in the synchronization of host plant and pest, changes in interspecific interactions including modifications in the relation of Lepidoptera and their natural enemies, increasing severity of invasions of migrant pests, changes in the frequency of damages due to gradation and general decrease in biodiversity. This reinforces the need for temporal studies to better predict how tropical butterfly populations will respond to predicted climate change.

2.6 Butterflies as Indicators of Climate Change

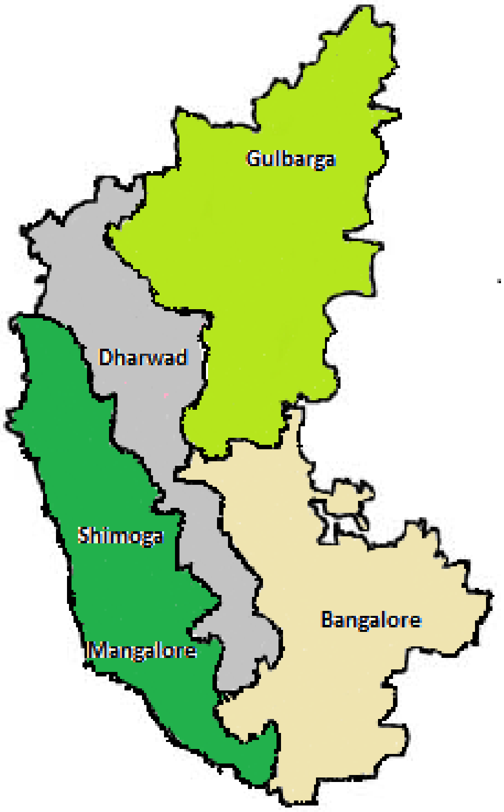
Butterflies are paid more attention to, because of their important service in environmental quality assessment under terrestrial ecosystem (Ghazoul, 2002) and they serve as potential ecological indicator of forest condition. Indicator species are thought to either signal the presence/abundance of other species, or to signal chemical/physical changes in the environment through changes in their own presence or abundance (Landres *et al.*, 1988; Simberloff, 1998). The second of these types of indicators is referred to as an ecological indicator (McGeoch, 1998).

Lepidoptera are widely accepted as ecological indicators of ecosystem health in many regions of the world (Rosenberg *et al.,* 1986; Beccaloni and Gaston, 1995; Oostermeijer and van Swaay, 1998). To study the impact of climate change and habitat loss, ecologist use butterflies as model organisms. Butterflies are known to be sensitive to climate change (Parmesan *et al*., 1999). The Butterfly Climate Change Atlas shows the expected changes in the distribution of European butterflies under different climate scenarios. Several ecological characteristics also make butterflies promising biodiversity indicators (Settele *et al.,* 2008). A potential tool for assessing large scale biodiversity trends is by monitoring the change in abundance and assessing the distribution of butterflies (van Swaay *et al.,* 2008).

According to Ronkay (2004) the taxon list of a given area provides an extremely detailed view of the environmental conditions of the site, and this is also true vice versa: butterflies and moths show a sensitive reaction to the change of abiotic factors. Thus, butterflies and moths can be considered as good indicator species in monitoring climate change.

Chapter 3: Methodology

The methodology followed was same as in Phase I study conducted in the same study sites located in different ecoclimatic zones of karnataka during 2016-2017.



Mangalore - 24 - 38^{0}C

Shimoga - 15 -35^{0}C, (highest rainfall)

Dharwad- 15 - 40^{0} C

Gulbarga- 15 - 50^{0} C

Bangalore - 12 - 38^{0}C

Fig.1: Map of eco-climatic zones in Karnataka (Lele *et al*., 2005 quoting Nadkarni, 1990)

3.1 Ecoclimatic Zones

Several different ways of classifying Karnataka into agro-climatic or eco-climatic zones have been proposed. The ecoclimatic zonation adopted by Nadkarni (1990) and mentioned by Lele *et al*., 2005 was followed for selecting the ecoclimatic zones and delineating the study areas in the present study.

3.2 Study areas

Field work was carried out in study areas located in five districts of different eco-climatic zones of Karnataka. In each zone we have selected different districts and areas in the city premises and the same transects surveyed in Phase I were resurveyed (Fig.2B, C, D, E & F) In the ecoclimatic zone with the costal boundary, two areas (Shimoga and Mangalore) depicting diverse climatic features were selected to conduct the studies. Five Districts selected for the study were the same selected in Phase I i.e. Agumbe, Bengaluru, Dharwad, Gulbarga and Mangalore (Fig.1 & 2A)).

Agumbe - Agumbe (Shivamogga District) which falls under the hottest hotspots of the world is called the Chirapunji of the South India, as it receives one of the highest rainfalls in Southern India (previously the highest). Since it is present in the heart of the Western Ghats, it has a variation in temperature between 35+ degrees in its peak and as low as 15 degrees in the winters. The uniqueness in this landscape is that it receives an excess rainfall of over 7000 mm rainfall per annum and is a host of some of the most unique life systems not seen anywhere else in the world.

Bengaluru - Bengaluru urban and rural areas fall between the Western and the Eastern Ghats region which makes it a unique landscape to carry out the work. With burgeoning population and environmental changes, it makes a case very much strong to prove whether the populations of the butterflies are really affected by the climatic changes or not.

Dharwad - Dharwad District falls on the downward side of the Western Ghat towards its east. The temperature fluctuation in this area has is about 40+ degrees in the summers and as cool as 15 degrees in winters. With the presence of Dandeli Tiger Reserve and a vast Dharwad University campus, it provides a unique opportunity to study Butterflies which are poorly documented so far in the area.

Gulbarga (Kalaburgi) - Gulbarga district is one of the hottest districts in Karnataka. The temperature peaks to almost 50 degrees in the summer and gets as cold as 10 degree during winter and comes under the Deccan Plateau region of Southern India

Mangalore -Mangalore District is an area which is present below the Western Ghats towards the west Coastal region. The temperature varies from 37-38 degrees in the summer and as cool as 24 degrees in the post monsoon, with high humidity during monsoon season.

Table 1: Latitudes and Longitude of the study sites

Agumbe

Sites	Lat.	Long.
ARRS	13.5184	75.0886
MR	13.5095	75.1027
KA	13.5334	75.1055
AR	13.5143	75.1153

Bengaluru

Sites	Lat.	Long.
LP	12.9487	77.5887
CP	12.9798	77.5968
DRF	12.8971	77.5905
IISc	13.0173	77.5712
GKVK	13.0808	77.5677

Gulbarga

Sites	Lat.	Long.
KG	17.2791	76.8574
PG	17.3319	76.835
GL	17.336	76.8302

Mangalore

Sites	Lat.	Long.
MU	12.8162	74.9172
NB	12.8343	74.8608
IA	12.9165	74.8183
PN	12.93	74.8992

Dharwad

Sites	Lat.	Long.
KU	15.44	74.9864
KL	15.4615	74.9685
AU	15.4903	74.9816

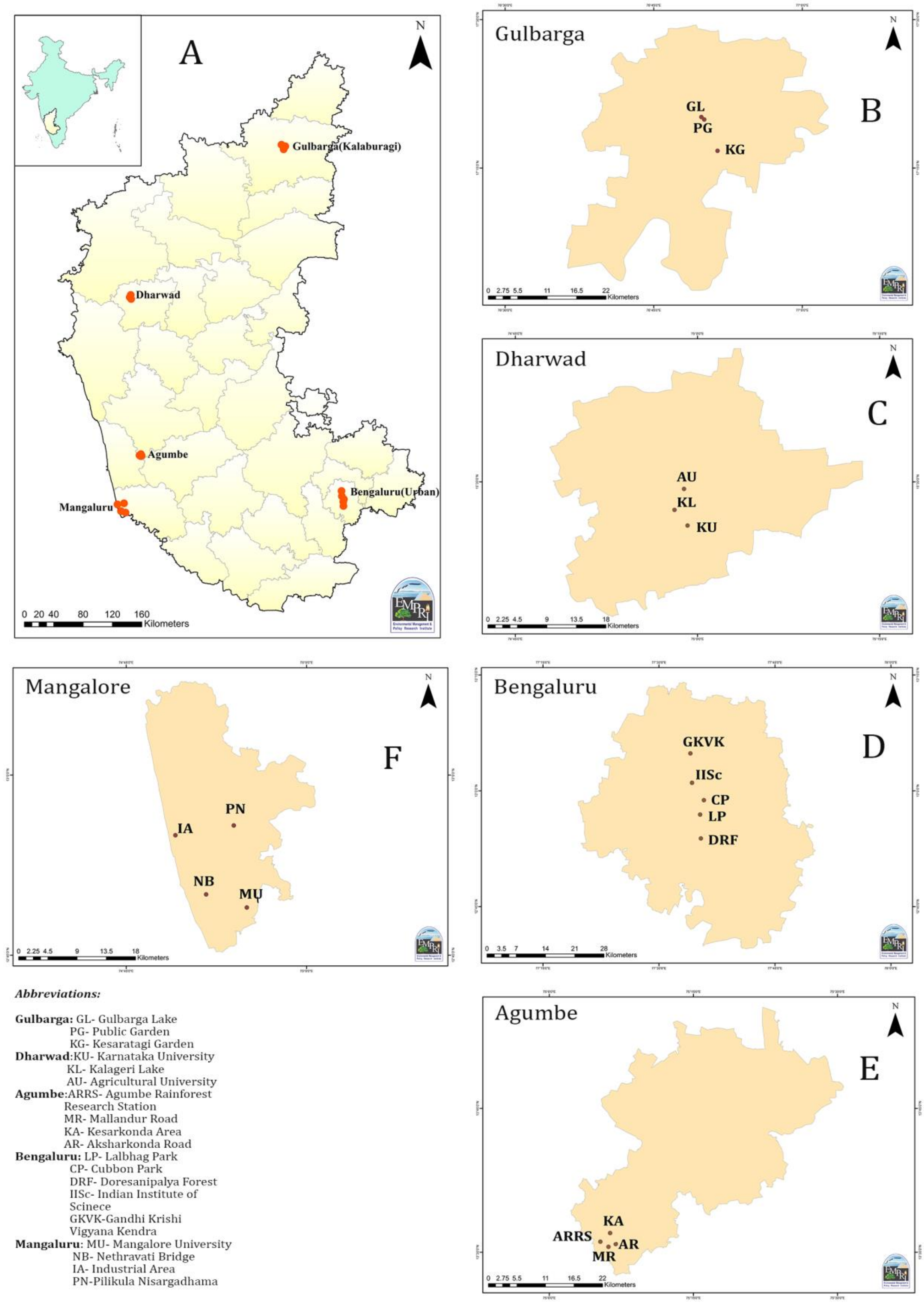


Fig.2: Map showing the locations of different study sites in different eco-climatic zones of Karnataka. The taluk boundaries and study sites have been highlighted. **A.**Representing Karnataka state, **B.**Gulbarga taluk, **C.**Dharwad taluk, **D.**Bengaluru Urban, **E.**Agumbe (Thirthahalli taluk), **F.**Mangalore taluk.

3.3 Seasons of Study

The seasons are categorized as summer (February to May), rainy (June to September) and winter (October to January). The climatic factors vary from one place to another in Karnataka.

3.4 Data on Temperature and Relative humidity

The information on temperature and relative humidity of five study areas in different eco-climatic zones of Karnataka (Bengaluru, Mangalore, Gulbarga, Agumbe and Dharwad) between 2021 and 2022 was collected from the website of Karnataka State Natural Disaster Monitoring Center (KSNDMC) and India Meteorological Department (IMD).

The overall average temperature observed during summer season was high in Gulbarga and Dharwad, followed by Mangalore and lowest in Agumbe and Bengaluru. During the rainy season the overall average temperature was high in Gulbarga, followed by Mangalore and Dharwad and lowest in Agumbe and Bengaluru. Agumbe, Bengaluru and Gulbarga had low overall average temperature during winter season compared to Dharwad and Mangalore. The overall average relative humidity was highest in Mangalore and lowest in Gulbarga in all the three seasons (Fig.3).

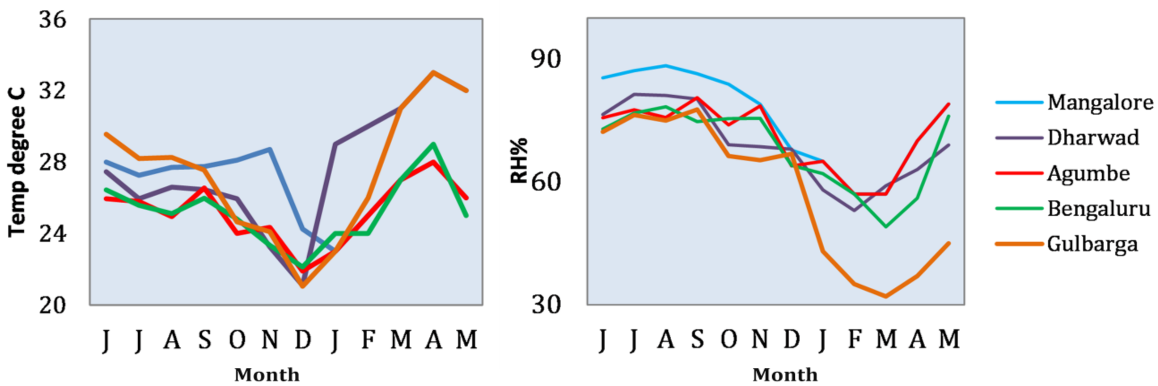


Fig.3: Graphs showing the temperature and relative humidity in study sites of eco-climatic zones of Karnataka in 2021-22.

3.5 Survey Method

A permanent line transects of 500m length was laid in different green spaces of eco-climatic regions with the help of GARMIN eTrex 20x GPS and SUUNTO KB-20 compass. Along the transect, butterfly counts were taken into account in order to understand the abundance and species occurrence in a green space. During the count two observers moved in fixed transect and recorded butterflies on both side (2.5m) and 5m above the eye level (Fig.4). The field work was carried out periodically once in a month in each location. Maps for the study areas with transects were generated for the area using ArcGIS 10.3.1.

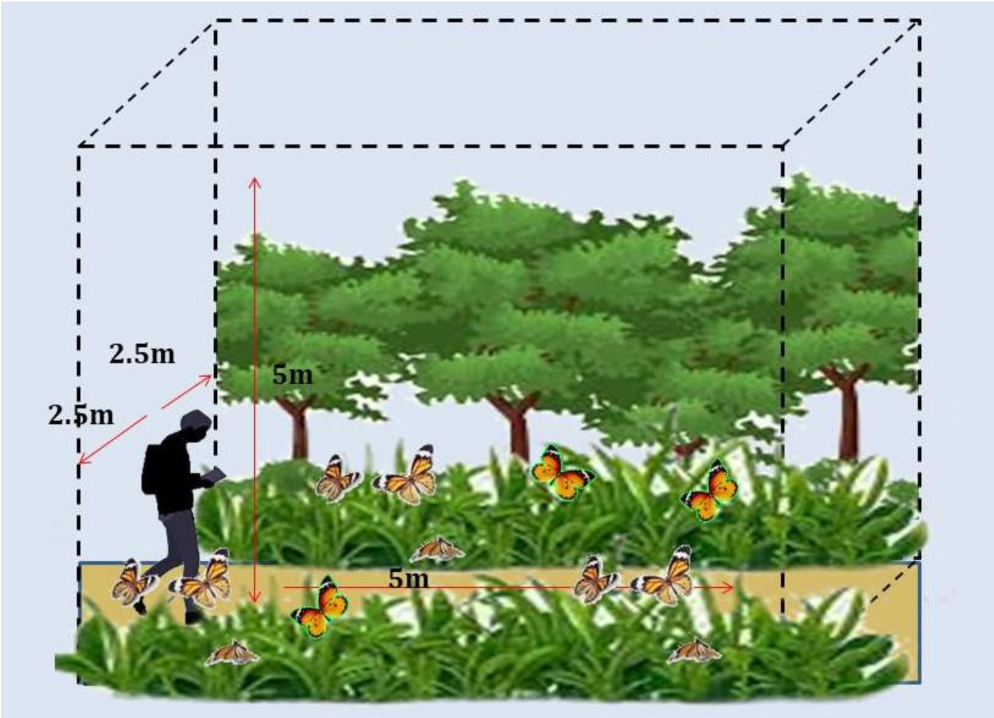


Fig.4: Figure depicting the transect survey and observations.

3.6 Identification of butterflies

Individual butterflies were identified on the move and noted to the species level using field guides and research papers (Gunathilagaraj *et al*., 1998; Kehimkar, 2008; Kunte, 2000b; Kunte *et al*., 2020; Naik, Vishwas and Deviprasad, 2014; Naik and Mustak, 2016; Remadevi *et al*., 2018b; Remadevi *et al*., 2020).The butterflies were identified till species; few were identified till genus level due to difficulty in distinguishing at species level in the field. Updated taxonomic nomenclature was followed according to peer-reviewed website viz., Indian Foundation for Butterfly (Kunte *et al*., 2020).

A mobile application known as Butterfly Identification App (BIA) developed by us in Environmental Management and Policy Research Institute (EMPRI) was also used to identify butterflies in the field. It is a colour-based identification application, which can be used by anyone having an android mobile phone. There is no necessity to capture the butterflies; the photos are taken and compared with the photos in the colour based groups in the BIA database and are then identified.

3.7 Data Analysis

Species richness

Chao-1 index is a nonparametric method for estimating the number of species in a community. The Chao richness is based on the concept that rare species infer the most information about the number of missing species.

$$\mathbf{R=S_0 + a_0}$$

Where S_0 is the number of taxa observed at least once in a sample and a_0 is the unknown number of species present in the community but not observed.

Diversity and Abundance

The total number of species in each area was calculated for the entire study period location wise and month wise.

The α-diversity for the habitat and seasons were calculated using a formula,

Shannon's H^'=-∑p_i *ln(pi)

Simpson's 1-D=∑(n/N)^2,

Where pi is the proportion of i^{th} species, n is the frequency of n^{th} species, and N is the total frequency within a habitat and season (Magurran, 1988).

Species evenness within a habitat and season was calculated as

$$\mathbf{E= H/H_{max}}$$

Where H'max = ln(S) and S is the number of species.

Further, the extent of species dominance within a habitat and season was calculated as D = 1 – Simpson's index of diversity. Diversity indices were calculated using the PAST (version 3.26) software (Hammer *et al*., 2001).

For each habitat, species were sorted based on the decreasing proportion of individuals and a rank abundance curve was plotted.

Beta diversity

Hierarchical Cluster Analysis (HCA) and Non-Metric Dimensional Analysis (NMDS) were performed to visualize the relation or similarities among study habitat and season based on species assemblage, or butterfly species based on habitat and season preferences. HCA was constructed based on Bray-Curtis similarity coefficient (a measure of β diversity). NMDS was performed on the correlation matrix of the data in R software using basic package. All statistical analysis was performed using basic package of PAST software and MS excel.

Butterflies were also categorized as Very Common (VC), Common (C), Rare (R) and Very Rare (VR) based on observations made during the field visits. Butterflies which were observed 100 times or more were classified as Very Common, between 30 and 99 were classified as Common, between 6 and 29 as Rare and 5 and below as Very Rare. The correlation analysis was performed to compare the Phase I and II environmental parameters (temperature and relative humidity) and also the species diversity and climate variables.

Chapter 4: Results

4.1 Species richness, abundance and diversity of butterfly species in five study areas

A total of 17702 individuals belonging to 183 species of butterflies were recorded in the present study of Phase II (Table 2). The highest number of species was recorded in Agumbe i.e. 111 species followed by 105 species in Mangalore, 84 species in Bengaluru region, 80 species in Dharwad and 69 species in Gulbarga region (Fig.5A & B). The abundance observed is high in Bengaluru (5141) followed by Gulbarga (4361), Mangalore (3373), Agumbe (2704) and lowest in Dharwad (2123) (Fig.5A & C).

Table 2: Checklist of butterflies recorded in five study sites in different eco-climatic zones of Karnataka during Phase II [numbers in table represent the abundance of species in five study areas and color represent gradation - red-high abundance; yellow-intermediate; green-low abundance].

High — Low

	Places	Agumbe	Bengaluru	Dharwad	Gulbarga	Mangalore		Total	Category	IWPA 1972
	Family/Species									
	Hesperiidae									
1	*Aeromachus pygmaeus*	14				15		29	**R**	-
2	*Ampittia dioscorides*			1				1	**VR**	-
3	*Badamia exclamationis*		3	2				5	**VR**	-
4	*Baoris farri*					8		8	**R**	**IV**
5	*Borbo cinnara*		7	5		2		14	**R**	-
6	*Burara jaina*	1						1	**VR**	-
7	*Caltoris kumara*					1		1	**VR**	-
8	*Celaenorrhinus fusca*	1						1	**VR**	-
9	*Halpe porus*					1		1	**VR**	-
10	*Hasora badra*				10			10	**R**	-
11	*Hasora chromus*		44	18	29			91	**C**	-
12	*Iambrix salsala*	33	42	21		28		124	**VC**	-
13	*Matapa aria*					1		1	**VR**	-
14	*Notocrypta paralysos*					4		4	**VR**	-
15	*Oriens goloides*		6	1		6		13	**R**	-
16	*Parnara* sp.	1						1	**VR**	-
17	*Pelopidas agna*				10			10	**R**	-
18	*Pelopidas mathias*				5			5	**VR**	-
19	*Potanthus* sp.	1				3		4	**VR**	-
20	*Pseudocoladenia dan*	1						1	**VR**	-

21	*Sarangesa dasahara*	1				1	2	**VR**	-
22	*Spialia galba*		4	3		1	8	**R**	-
23	*Suastus gremius*					2	2	**VR**	-
24	*Tagiades gana*	6				7	13	**R**	-
25	*Tagiades japetus*		3				3	**VR**	-
26	*Tagiades litigiosa*	23				58	81	**C**	-
27	*Taractrocera ceramas*	9		10		3	22	**R**	-
28	*Taractrocera maevius*			17			17	**R**	-
29	*Telicota bambusae*	1	1			3	5	**VR**	-
30	*Udaspes folus*		3				3	**VR**	-
	Lycaenidae								
31	*Acytolepis puspa*	16	38	2		12	68	**C**	-
32	*Anthene emolus*					1	1	**VR**	-
33	*Anthene lycaenina*	4					4	**VR**	**II**
34	*Arhopala alea*	1					1	**VR**	-
35	*Arhopala amantes*		8	2			10	**R**	-
36	*Arhopala bazaloides*					1	1	**VR**	**II**
37	*Arhopala centaurus*	5	6			16	27	**R**	-
38	*Azanus jesous*			2	20		22	**R**	-
39	*Azanus ubaldus*				22		22	**R**	-
40	*Azanus uranus*				46		46	**C**	-
41	*Bindahara moorei*	3					3	**VR**	-
42	*Caleta decidia*	3				4	7	**R**	-
43	*Castalius rosimon*	10	224	36	95	95	460	**VC**	-
44	*Catapaecilma major*	1					1	**VR**	-
45	*Catochrysops panormus*				78		78	**C**	-
46	*Catochrysops strabo*	3	7	5	56		71	**C**	-
47	*Celastrina lavendularis*	3					3	**VR**	-
48	*Cheritra freja*	3				13	16	**R**	-
49	*Chilades lajus*		15			1	16	**R**	-
50	*Chilades pandava*		36	12	79	18	145	**VC**	-
51	*Chilades parrhasius*				24		24	**R**	-
52	*Curetis siva*	1					1	**VR**	-
53	*Curetis thetis*	4				1	5	**VR**	-
54	*Deudorix epijarbas*	3			45		48	**C**	-
55	*Discolampa ethion*	6	11			66	83	**C**	-
56	*Euchrysops cnejus*		47	1	42		90	**C**	**II**
57	*Everes lacturnus*				38		38	**C**	-
58	*Freyeria trochylus*			8	93		101	**VC**	-
59	*Hypolycaena othona*	1		1			2	**VR**	**II**
60	*Jamides alecto*		1				1	**VR**	-
61	*Jamides bochus*	4	17	21	29	1	72	**C**	-

62	*Jamides celeno*	26	95	20		138	279	**VC**	-
63	*Lampides boeticus*		52	10	127	3	192	**VC**	**II**
64	*Leptotes plinius*		147	14	72		233	**VC**	-
65	*Loxura atymnus*					26	26	**R**	-
66	*Megisba malaya*	1					1	**VR**	-
67	*Nacaduba kurava*					25	25	**R**	-
68	*Nacaduba pactolus*	1					1	**VR**	-
69	*Neopithecops zalmora*	5				6	11	**R**	-
70	*Prosotas dubiosa*	1	3			2	6	**R**	-
71	*Prosotas nora*	9	15		38	52	114	**VC**	-
72	*Pseudozizeeria maha*		15	13			28	**R**	-
73	*Rapala manea*	4	1			2	7	**R**	-
74	*Rathinda amor*	1	2			24	27	**R**	-
75	*Spalgis epius*					1	1	**VR**	-
76	*Spindasis elima*				3		3	**VR**	**II**
77	*Spindasis ictis*				16		16	**R**	-
78	*Spindasis lohita*	1					1	**VR**	**II**
79	*Spindasis* sp.	4	1	2	36		43	**C**	-
80	*Surendra quercetorum*	2				3	5	**VR**	-
81	*Talicada nyseus*	21	3	10		4	38	**C**	-
82	*Tarucus nara*				31		31	**C**	-
83	*Virachola isocrates*			7			7	**R**	-
84	*Zizeeria karsandra*		14	13		67	94	**C**	-
85	*Zizina otis*	15	31	19	6	165	236	**VC**	-
86	*Zizula hylax*	127	53	36		21	237	**VC**	-
	Nymphalidae								
87	*Acraea terpsicore*		38	18	139	197	392	**VC**	-
88	*Ariadnesp.*	82	126	19	109	64	400	**VC**	-
89	*Athyma ranga*	4				7	11	**R**	**II**
90	*Athyma selenophora*	1					1	**VR**	-
91	*Cethosia mahratta*	2					2	**VR**	-
92	*Charaxes agrarius*			5			5	**VR**	-
93	*Charaxes bharata*					3	3	**VR**	-
94	*Charaxes solon*				1		1	**VR**	-
95	*Cirrochroa thais*	24				49	73	**C**	-
96	*Cupha erymanthis*	319				128	447	**VC**	-
97	*Cyrestis thyodamas*	2					2	**VR**	-
98	*Danaus chrysippus*		45	43	164	65	317	**VC**	-
99	*Danaus genutia*		33	31	151	2	217	**VC**	-
100	*Doleschallia bisaltide*					5	5	**VR**	-
101	*Dophla evelina*	4				1	5	**VR**	**II**
102	*Elymnias caudata*	17	67	22		26	132	**VC**	-

103	*Euploea klugii*					1	1	VR	IV
104	*Euploea* sp.	138	273	56	42	424	933	VC	-
105	*Euthalia aconthea*	1	20	12		5	38	C	-
106	*Euthalia lubentina*			3			3	VR	IV
107	*Hypolimnas bolina*	8	20	29	134	50	241	VC	-
108	*Hypolimnas misippus*	3	11	10	92	2	118	VC	I
109	*Idea malabarica*	34					34	C	-
110	*Junonia almana*	1	9	18	26	1	55	C	-
111	*Junonia atlites*	46	3	44	2	49	144	VC	-
112	*Junonia hierta*		16	6	51		73	C	-
113	*Junonia iphita*	199	328	146		109	782	VC	-
114	*Junonia lemonias*	14	187	83	157	4	445	VC	-
115	*Junonia orithya*		3	5	85		93	C	-
116	*Kallima horsfieldii*	2				1	3	VR	II
117	*Lethe europa*		2			3	5	VR	-
118	*Lethe rohria*		2				2	VR	-
119	*Libythea lepita*	2					2	VR	II
120	*Melanitis leda*	2	3	7	87	3	102	VC	-
121	*Moduza procris*	7	3	2		15	27	R	-
122	*Mycalesis junonia*	41				2	43	C	-
123	*Mycalesis* sp.	8	96	30		22	156	VC	-
124	*Neptis hylas*	32	101	69		45	247	VC	-
125	*Neptis jumbah*	3	20	4		19	46	C	-
126	*Orsotriaena medus*	6		3		12	21	R	-
127	*Pantoporia* sp.	8	2			34	44	C	-
128	*Parantica aglea*	230		11		72	313	VC	-
129	*Parthenos sylvia*	6				10	16	R	-
130	*Phalanta phalantha*	11	89	21	28		149	VC	-
131	*Rohana parisatis*	11					11	R	-
132	*Symphaedra nais*		16	4			20	R	-
133	*Tanaecia lepidea*	23				12	35	C	II
134	*Tirumala limniace*	2	3	6	39	7	57	C	-
135	*Tirumala septentrionis*	26	46	27	34	85	218	VC	-
136	*Vanessa cardui*				9		9	R	-
137	*Vindula erota*	19					19	R	-
138	*Ypthima asterope*				42		42	C	-
139	*Ypthima baldus*	41				64	105	VC	-
140	*Ypthima huebneri*	265	628	149		162	1204	VC	-
141	*Zipaetis saitis*	1					1	VR	II
	Papilionidae								
142	*Graphium agamemnon*	27	51	59	129	79	345	VC	-
143	*Graphium antiphates*	12					12	R	-

144	*Graphium doson*	13			99	5	117	**VC**	-
145	*Graphium teredon*	89	4	7		20	120	**VC**	-
146	*Pachliopta aristolochiae*		36		133	43	212	**VC**	-
147	*Pachliopta hector*	1	18	15	73	8	115	**VC**	**I**
148	*Pachliopta pandiyana*	7					7	**R**	-
149	*Papilio buddha*	1				8	9	**R**	**II**
150	*Papilio clytia*	2	2			4	8	**R**	-
151	*Papilio demoleus*	3	34	7	137	2	183	**VC**	-
152	*Papilio dravidarum*	7				1	8	**R**	-
153	*Papilio helenus*	35				13	48	**C**	-
154	*Papilio liomedon*	3					3	**VR**	**I**
155	*Papilio paris*	1				4	5	**VR**	-
156	*Papilio polymnestor*	62	22	21		34	139	**VC**	-
157	*Papilio polytes*	14	100	51	139	68	372	**VC**	-
158	*Troides minos*	6				8	14	**R**	-
	Pieridae								
159	*Appias albina*	34	23	7	60		124	**VC**	-
160	*Appias libythea*		7				7	**R**	**IV**
161	*Appias lyncida*					2	2	**VR**	**II**
162	*Belenois aurota*		84	8	90	2	184	**VC**	-
163	*Catopsilia* sp.	37	601	238	270	138	1284	**VC**	-
164	*Cepora nadina*	48					48	**C**	**II**
165	*Cepora nerissa*		3	41	104		148	**VC**	-
166	*Colotis amata*			78	86		164	**VC**	-
167	*Colotis aurora*			6	31		37	**C**	-
168	*Colotis danae*			11	105		116	**VC**	-
169	*Colotis etrida*				16		16	**R**	-
170	*Colotis fausta*			5	46		51	**C**	-
171	*Delias eucharis*	15	49	20	17	8	109	**VC**	-
172	*Eurema andersonii*	1					1	**VR**	-
173	*Eurema blanda*	55	483	47	10	48	643	**VC**	-
174	*Eurema brigitta*	2	30		45		77	**C**	-
175	*Eurema hecabe*	64	239	160	120	109	692	**VC**	-
176	*Eurema laeta*		42		22		64	**C**	-
177	*Hebomoia glaucippe*	47	82	29	3	4	165	**VC**	-
178	*Ixias marianne*			36	62		98	**C**	-
179	*Ixias pyrene*	75	11	50	58		194	**VC**	-
180	*Leptosia nina*		64	10	62	84	220	**VC**	-
181	*Pareronia hippia*	14	10	22	2	5	53	**C**	-
182	*Prioneris sita*	1					1	**VR**	**IV**
	Riodinidae								
183	*Abisara bifasciata*	2	1			4	7	**R**	-

Alpha diversity is calculated using Chao-1 index which showed that the highest unique species observed were in Agumbe region (138.3) followed by Mangalore (115.9), Bengaluru (85.7), Dharwad (80.9) and lowest in Gulbarga (69.0) (Fig.5D). Simpson and Shannon indices were high for Gulbarga (0.98, 3.91) and low for Bengaluru (0.94, 3.42) (Fig.5E & F). Both Simpson and Shannon index depends on evenness of species distribution; the species were more evenly distributed in Gulbarga (0.72) followed by Dharwad (0.51), Mangalore (0.40), Bengaluru (0.36), and Agumbe (0.33) (Fig.5G).

A

Places	Diversity index					
	Richness	Abundance	Chao-1	Simpson_1-D	Shannon_H	Evenness
Agumbe	111	2704	138.3	0.95	3.59	0.33
Bengaluru	84	5141	85.7	0.94	3.42	0.36
Dharwad	80	2123	80.9	0.96	3.71	0.51
Gulbarga	69	4361	69.0	0.98	3.91	0.72
Mangalore	105	3373	115.9	0.96	3.73	0.40
Total	183	17702	213.7	0.97	4.17	0.35

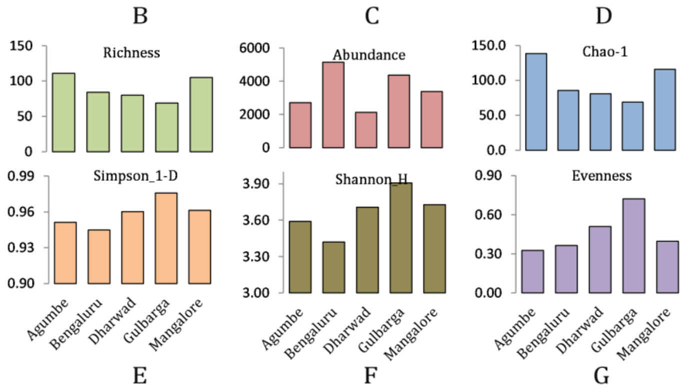


Fig.5: Diversity attributes of butterfly species present in five study areas in eco-climatic zones. **A.**Table represent diversity index; **B.**Richness; **C.**Abundance; **D.**Chao-1; **E.**Simpson index; **F.**Shannon; **G.**Evenness.

Family wise species distribution

Out of 183 species, the Lycaenidae and Nymphalidae species were most dominant (56 and 55 species) followed by Hesperiidae 30 species, Pieridae 24 species, Papilionidae 17 species and Riodinidae one species (Fig.6).

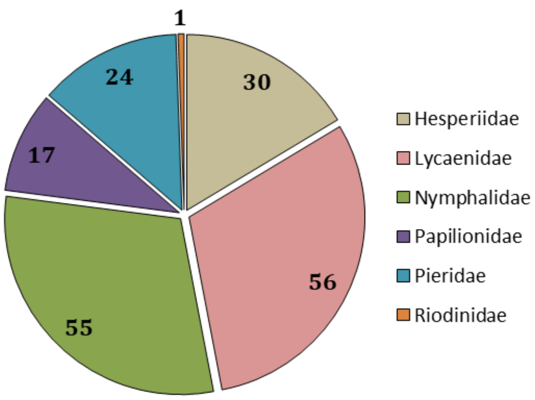


Fig.6: Family wise Distribution of species

Studies on species abundance

The rank abundance curve suggests that *Catopsilia* sp. (i.e. 7% of total population, 1284 individuals) was the most abundant species observed in the study. *Ypthima huebneri* is the second, *Euploea* sp. is third, *Junonia iphita* is fourth and *Eurema hecabe* is fifth in the dominance. For each zone the abundance of species varied, in Agumbe, *Cupha erymantis* (i.e. 12% of total population, 319 individuals) dominated, in Bengaluru *Ypthima huebneri* (i.e. 12% of total population, 628 individuals) and in Mangalore, *Euploea* sp.(i.e. 13% of total population, 424 individuals) dominated. In Dharwad (i.e. 11% of total population, 238 individuals) and Gulbarga (i.e. 6% of total population, 270 individuals) *Catopsilia* sp. was the most abundant species (Fig.7A &B).

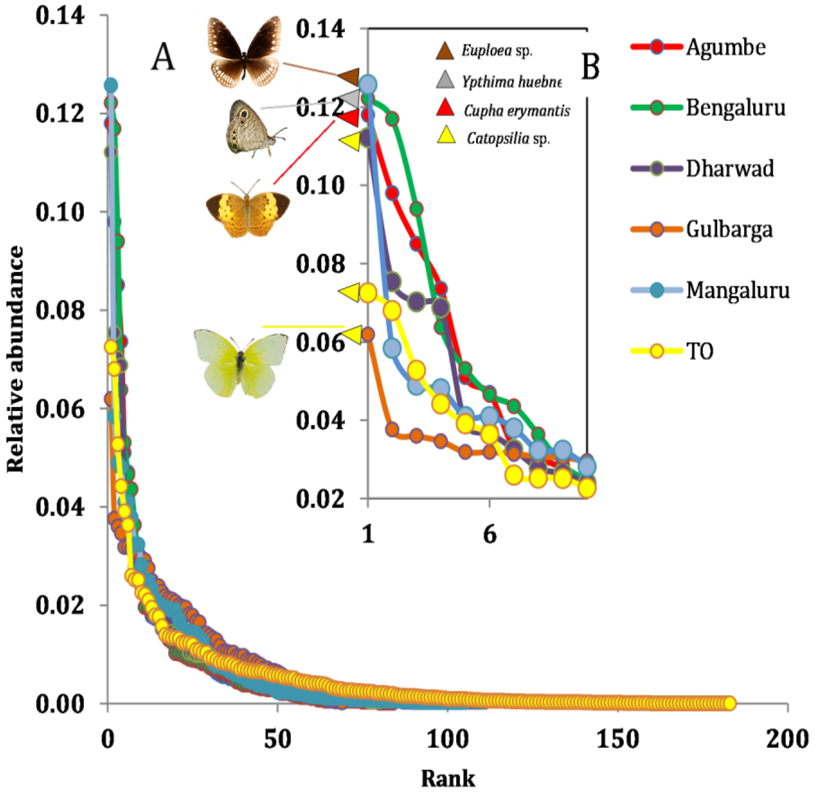


Fig.7: Rank abundance curve: **A.**Curve for all zones and TO (total) is pooled data; **B.**Zoomed section.

The distribution of abundant species was ranked for both P2 and P1 for each of the zones and also for the total of all zones and given in table below (Table 3). *Catopsilia* sp. dominated in both P1 and P2.

Table 3: Zone wise Heatmap on dominant species of P2 and P1

	P2	P1	P2	P1	
	Agumbe		**Gulbarga**		
1	*Cupha erymanthis*	*Cupha erymanthis*	*Catopsilia sp.*	*Catopsilia sp.*	1
2	*Ypthima huebneri*	*Parantica aglea*	*Danaus chrysippus*	*Graphium agamemnon*	2
3	*Parantica aglea*	*Euploea sp.*	*Junonia lemonias*	*Papilio demoleus*	3
4	*Junonia iphita*	*Ypthima huebneri*	*Danaus genutia*	*Danaus chrysippus*	4
5	*Euploea sp.*	*Junonia iphita*	*Acraea terpsicore*	*Eurema hecabe*	5
6	*Zizula hylax*	*Ariadne sp.*	*Papilio polytes*	*Papilio polytes*	6
7	*Graphium teredon*	*Junonia atlites*	*Papilio demoleus*	*Graphium doson*	7
8	*Ariadne sp.*	*Appias albina*	*Hypolimnas bolina*	*Pachliopta hector*	8
9	*Ixias pyrene*	*Ixias pyrene*	*Pachliopta aristolochiae*	*Pachliopta aristolochiae*	9
10	*Eurema hecabe*	*Neptis hylas*	*Graphium agamemnon*	*Danaus genutia*	10
	Bengaluru		**Mangalore**		
1	*Ypthima huebneri*	*Catopsilia sp.*	*Euploea sp.*	*Euploea sp.*	1
2	*Catopsilia sp.*	*Junonia lemonias*	*Acraea terpsicore*	*Delias eucharis*	2
3	*Eurema blanda*	*Ypthima huebneri*	*Zizina otis*	*Acraea terpsicore*	3
4	*Junonia iphita*	*Eurema hecabe*	*Ypthima huebneri*	*Catopsilia sp.*	4
5	*Euploea sp.*	*Danaus chrysippus*	*Jamides celeno*	*Cupha erymanthis*	5
6	*Eurema hecabe*	*Phalanta phalantha*	*Catopsilia sp.*	*Graphium agamemnon*	6
7	*Castalius rosimon*	*Belenois aurota*	*Cupha erymanthis*	*Ypthima huebneri*	7
8	*Junonia lemonias*	*Zizula hylax*	*Junonia iphita*	*Jamides celeno*	8
9	*Leptotes plinius*	*Ariadne sp.*	*Eurema hecabe*	*Castalius rosimon*	9
10	*Ariadne sp.*	*Euploea sp.*	*Castalius rosimon*	*Danaus chrysippus*	10
	Dharwad		**Total**		
1	*Catopsilia sp.*	*Catopsilia sp.*	*Catopsilia sp.*	*Catopsilia sp.*	1
2	*Eurema hecabe*	*Junonia lemonias*	*Ypthima huebneri*	*Euploea sp.*	2
3	*Ypthima huebneri*	*Eurema hecabe*	*Euploea sp.*	*Delias eucharis*	3
4	*Junonia iphita*	*Pachliopta aristolochiae*	*Junonia iphita*	*Junonia lemonias*	4
5	*Junonia lemonias*	*Danaus chrysippus*	*Eurema hecabe*	*Cupha erymanthis*	5
6	*Colotis amata*	*Mycalesis sp.*	*Eurema blanda*	*Ypthima huebneri*	6
7	*Neptis hylas*	*Hypolimnas bolina*	*Castalius rosimon*	*Danaus chrysippus*	7
8	*Graphium agamemnon*	*Papilio demoleus*	*Cupha erymanthis*	*Acraea terpsicore*	8
9	*Euploea sp.*	*Ixias marianne*	*Junonia lemonias*	*Eurema hecabe*	9
10	*Papilio polytes*	*Eurema laeta*	*Ariadne sp.*	*Graphium agamemnon*	10

H

L

Studies on Beta diversity

The similarity of the species composition in five study areas in different eco-climatic zones was studied using Cluster analysis, correlation matrix, bray-curtis matrix and NMDS analysis. In Bray-Curtis analysis Mangalore and Agumbe formed a cluster with 47% (ρ=0.53) of species similarity. Benagaluru and Dharwad formed another cluster with 48% (ρ =0.83) similarity. The species similarity was 15% (ρ=-0.03) in Gulbarga when compared to Agumbe. Gulbarga formed a distinct zone with very less similarity with other zones. Other places show lesser similarity in species composition (Fig.8A, B & C).

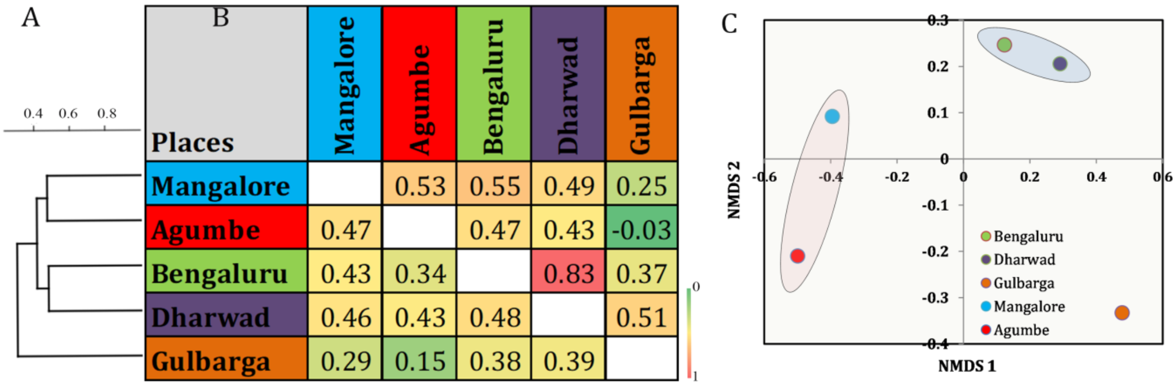


Fig.8: Beta diversity measures: **A.** Cluster analysis; **B.** Right above correlation and left below is Bray-Curtis similarity index; **C.**NMDS plot.

4.2 Seasonal pattern of butterfly species assemblage in five study

a. Agumbe

The abundance and richness observed was very high i.e. about 13% of total individuals during the December month (Fig.9A & B). The species richness and abundance observed was high during the winter season followed by rainy and summer season (Fig.9C & D). The Shannon diversity indices observed was high in winter, high evenness index was observed in rainy season and chao-1 index observed was high in summer (Fig.9E, F & G).

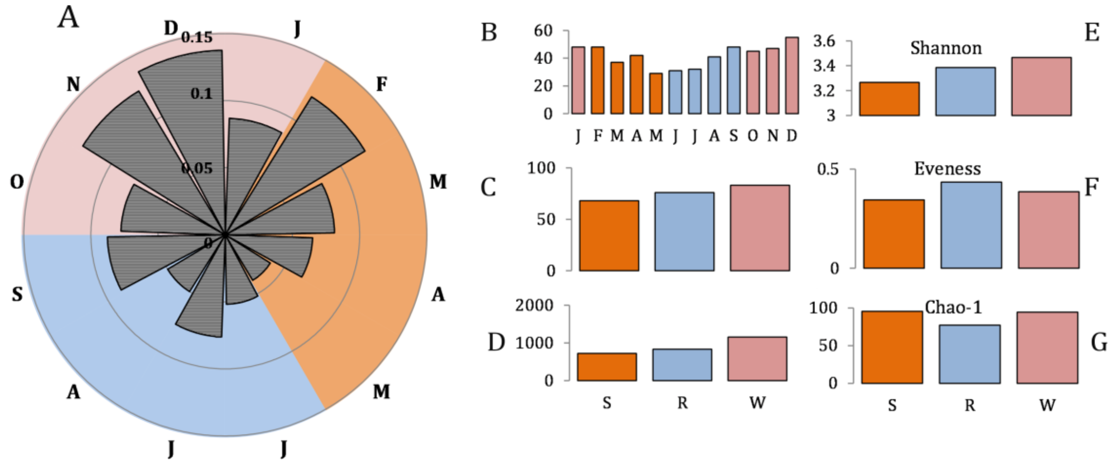


Fig.9: Seasonal pattern of butterfly communities in Agumbe. Month wise: **A.**Relative abundance; **B.**Species richness; Season wise: **C.**Species richness; **D.**Abundance; **E.**Shannon; **F.**Evenness; **G.**Chao-1.

b. Bengaluru

The richness observed was high during the month of August (Fig.10B), whereas abundance observed was very high i.e. about 17% of total individuals during the June month (Fig.10A). Overall species richness was high during winter and abundance observed was high during the rainy season (Fig.10C & D). The Shannon diversity indices observed was high in winter, high evenness index was observed in winter season and chao-1 index observed was high in rainy (Fig.10E, F & G).

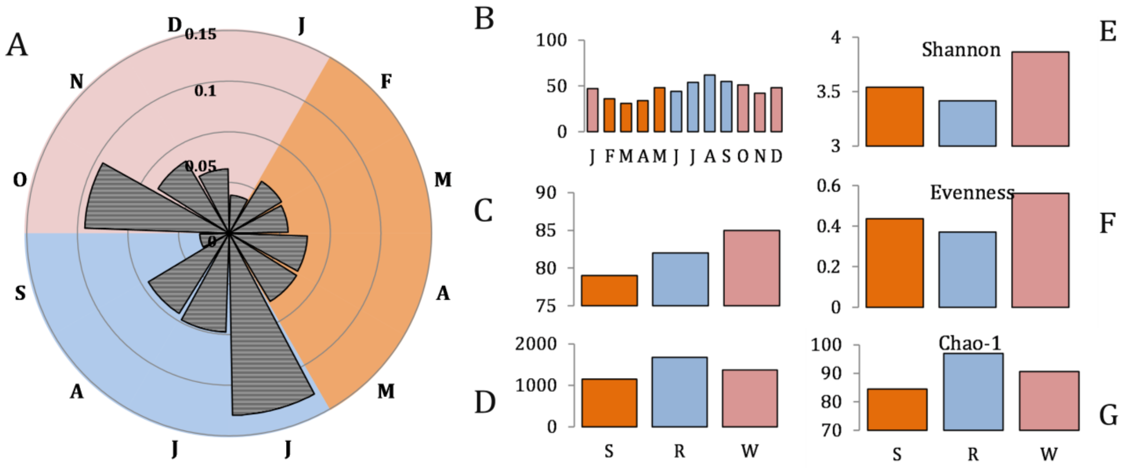


Fig.10: Seasonal pattern of butterfly communities in Bengaluru. Month wise: **A.**Relative abundance; **B.**Species richness; Season wise: **C.**Species richness; **D.**Abundance; **E.**Shannon; **F.**Evenness; **G.**Chao-1.

c. Dharwad

The richness observed was high during the month of December and April (Fig.11B), whereas abundance observed was very high i.e. about 11% of total individuals during the February and November month (Fig.11A). Overall species richness and abundance observed was high during the winter season followed by summer and rainy season (Fig.11C & D). The Shannon diversity indices observed was high in summer, high evenness index was observed in summer season and high chao-1 index was observed in winter (Fig.11E, F & G).

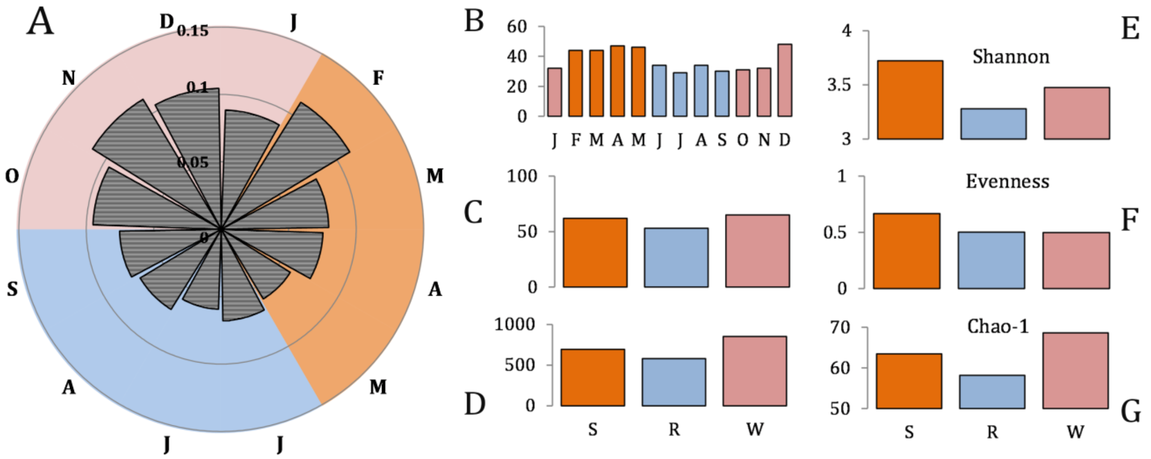


Fig.11: Seasonal pattern of butterfly communities in Dharwad. Month wise: **A.**Relative abundance; **B.**Species richness; Season wise: **C.**Species richness; **D.**Abundance; **E.**Shannon; **F.**Evenness; **G.**Chao-1.

e. Gulbarga

The richness observed was high during the month of December (60 species) and abundance observed were very high during September and December month i.e. 13% and 12% of total individuals respectively (Fig.12A & B). The species richness and abundance observed was high during the winter season followed by rainy and summer season (Fig.12C & D). The Shannon diversity indices observed was high in winter, high evenness index was observed in rainy season and chao-1 index observed was high in summer (Fig.12E, F & G).

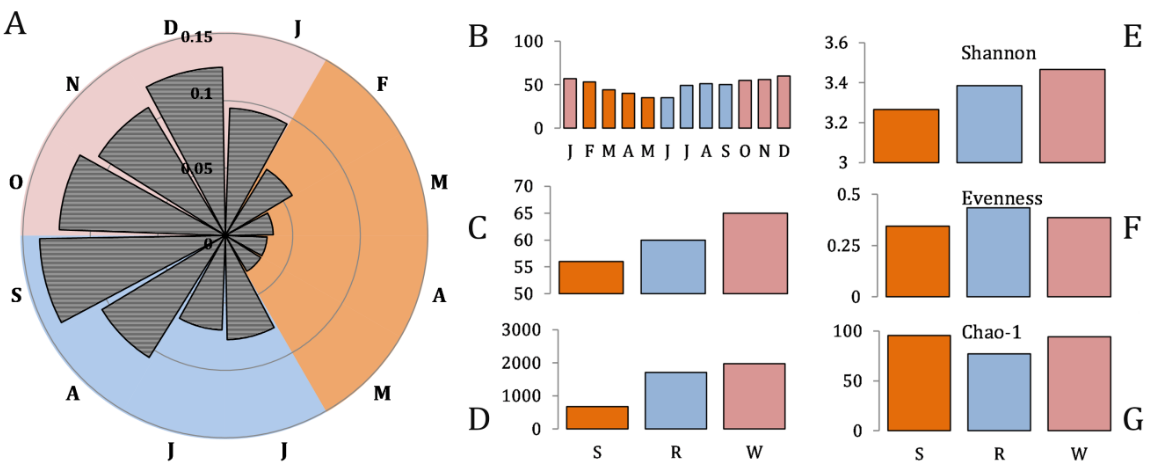


Fig.12: Seasonal pattern of butterfly communities in Gulbarga. Month wise: **A.**Relative abundance; **B.**Species richness; Season wise: **C.**Species richness; **D.**Abundance; **E.**Shannon; **F.**Evenness; **G.**Chao-1.

f. Mangalore

The richness observed was high during the month of August (Fig.13B) and abundance observed was high in month of December (i.e. about 13% of total individuals) (Fig.13A). Overall species richness and abundance observed was high during the rainy season followed by winter and summer season (Fig.13C &D). The Shannon diversity index was high in winter, high evenness index was observed in rainy season and high chao-1 index was observed in summer (Fig.13E, F & G).

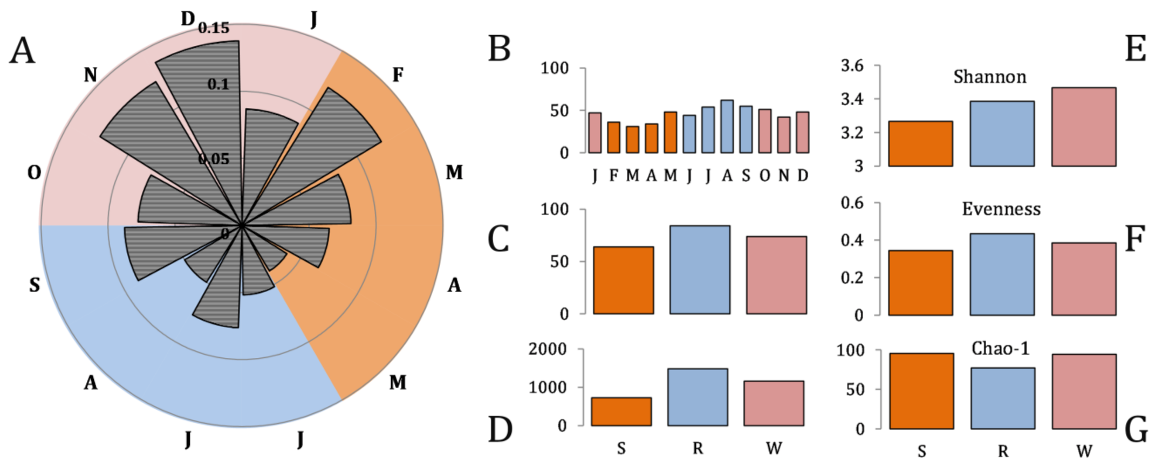


Fig.13: Seasonal pattern of butterfly communities in Mangalore. Month wise: **A.**Relative abundance; **B.**Species richness; Season wise: **C.**Species richness; **D.**Abundance; **E.**Shannon; **F.**Evenness; **G.**Chao-1.

4.3 Comparision of diversity data of P1 and P2

Comparison of diversity measures in P1 and P2 study

The butterfly diversity during P1 and P2 study period was compared with reference to different seasons (Table 4). It is evident that the species richness is highest in winter season in all regions except Mangalore (where it is rainy season) in both the periods. The abundance was similar during P1 and P2 in Agumbe, Bengaluru and Mangalore. While the highest abundance was in winter in Dharwad and Gulbarga during P2, it was during rainy season in the P1 study. The Shannon index was similar in Agumbe and Bengaluru (P1 and P2), but varied in Gulbarga and Mangalore. Unlike other areas, in Dharwad, Shannon and evenness index was higher in Summer during P2 study

Table 4: Comparison of highest values of diversity measures in P1 and P2.

	Richness		Abundnace		Shannon		Eveness	
	P2	P1	P2	P1	P2	P1	P2	P1
Agumbe	W	W	W	W	W	W	R	-
Bengaluru	W	W	R	R	W	W	W	W
Dharwad	W	W	W	R	S	S/W	S	W
Gulbarga	W	W	W	R	W	R	R	R
Mangalore	R	R	R	R	W	R	R	R

Correlation of butterfly population trend in relation with environmental parameters in five study areas

a. Bengaluru

The population trend showed that, as the relative humidity increases there is an increase in relative abundance observed in both Phases, i.e. during the late winter and early summer the relative abundance observed was low due to low RH (Fig.14A). The seasonal trend during the study period showed that the relative humidity and temperature had positive correlation (ρ =0.59, ρ =0.79 respectively) during the Phase I and II (Fig.14B & C).

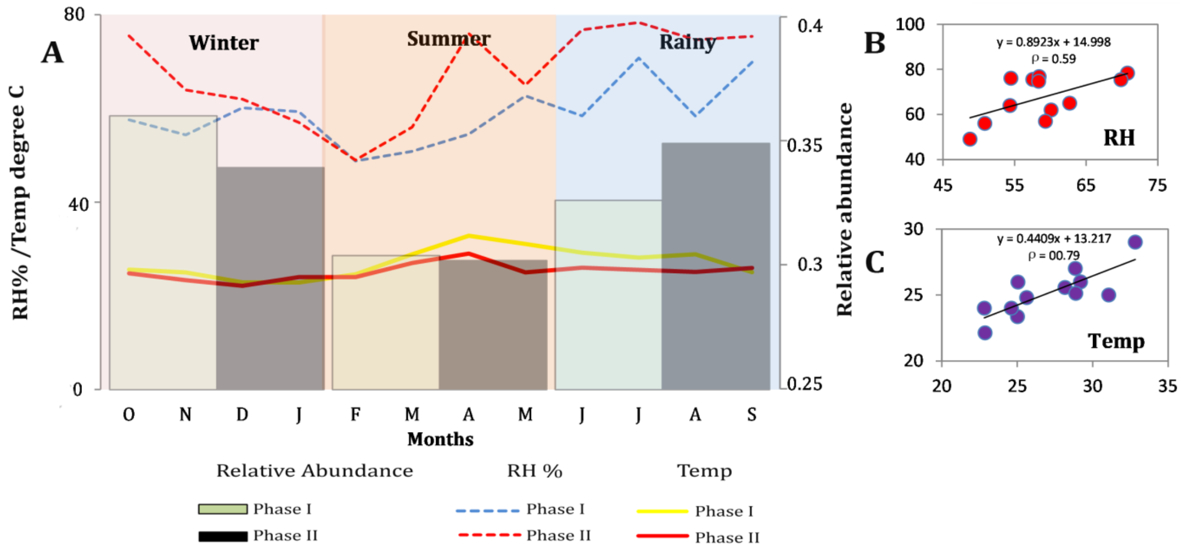


Fig.14: A. Population trend of two Phases with respect to relative humidity and average temperature of Bengaluru region; Correlation of environmental parameters between Phase I and II: **B.**Relative humidity; **C.**Temperature.

b. Dharwad

The population trend showed that when the relative humidity increases there is an increase in relative abundance observed in both Phases i.e. during the late winter and summer the relative abundance observed was low due to low RH in Phase II, whereas the temperature doesn't show much fluctuation in this region (Fig.15A). The seasonal trend observed during the study period showed that the relative humidity and temperature had positive correlation (ρ =0.92, ρ=0.76 respectively) when compared with Phase I and II (Fig.15B & C).

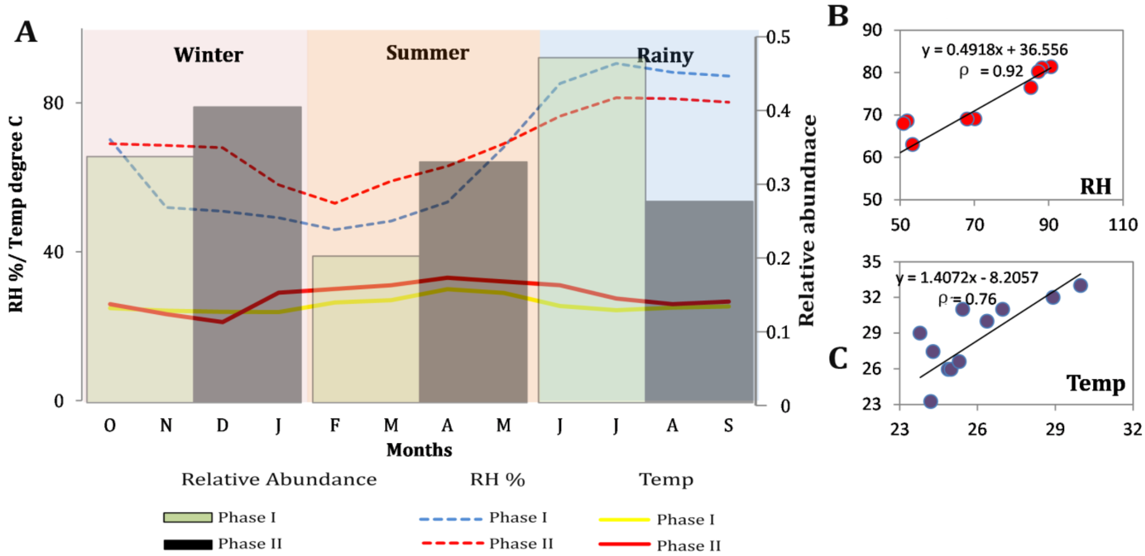


Fig.15: A. Population trend of two Phases with respect to relative humidity and average temperature of Dharwad region; Correlation of environmental parameter between Phase I and II: **B.**Relative humidity; **C.**Temperature.

c. Mangalore

The population trend showed that when the relative humidity increases there is an increase in relative abundance observed in both phase I and II, i.e. during the late winter and early summer the relative abundance observed was low due to low RH, whereas the temperature doesn't show much fluctuation in this region (Fig.16A). The seasonal trend observed during the study period showed that the relative humidity and temperature had positive correlation (ρ=0.67, ρ=0.16 respectively) when compared between Phase I and II (Fig.16B & C).

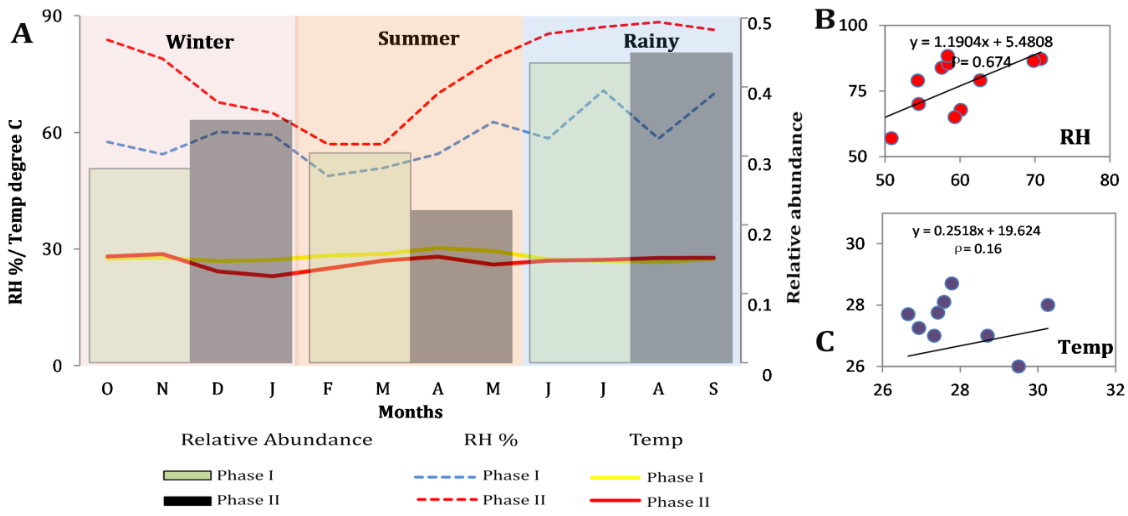


Fig.16: A. Population trend of two Phases with respect to relative humidity and average temperature of Mangalore region; Correlation of environmental parameter between Phase I and II: **B.**Relative humidity; **C.**Temperature.

Comparison of P1 (2016-2017) and P2 (2021-2022) butterfly data in Bengaluru region

Location wise comparison

To understand the similarity of species composition between Phase I and II, Bray-Curtis similarity index was calculated; result showed that species composition observed was similar within IISc (64%), Lalbagh (66%), Cubbon park (67%) and GKVK (63%) forming a cluster together. Doresanipalya (48%) showed less similarity within the site between Phase I and Phase II and cluster was formed apart from each other (Fig.17A & B).

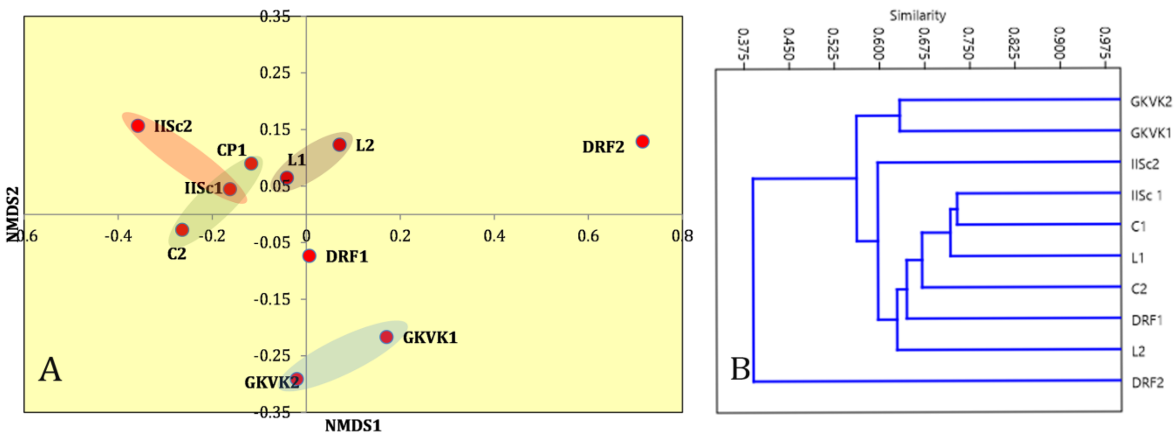


Fig.17: Similarity of species composition between Phase I and II in different sites of Bengaluru: **A.**NMDS plot; **B.**Cluster analysis.

Seasonwise comparison

In Bangalore region, the relative abundance pattern observed was high during October when both Phase I and II were combined, (Fig.18A), monthly trending pattern observed was different in both Phase I and II. The species richness and abundance pattern observed was high in Rainy season (Fig.18D & G).

The similarity of species composition observed between Phase I and II, showed that summer had 64% similarity, where as 52% similarity was seen between rainy seasons and 58% similarity between winter seasons (Fig.19).

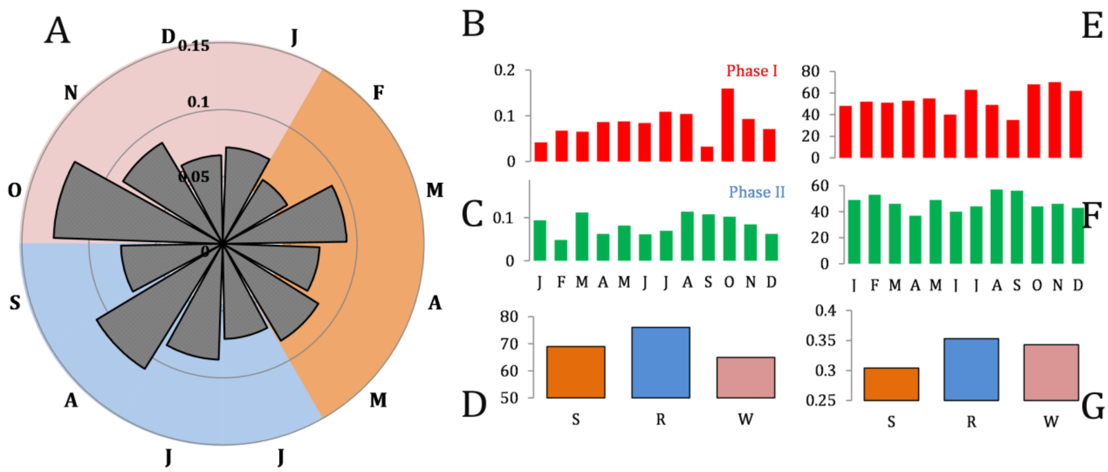


Fig.18: Seasonal species composition observed during Phase I & II in Bangalore region. Month wise: **A**.Relative abundance of Phase I &II combined; **B&E.**Relative abundance and species richness of Phase I; **C&F.**Relative abundance and species richness of Phase II; Season wise: **D.**Species richness; **G.**Relative abundance.

		Phase II			Phase I		
	Seasons	**Summer**	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**
Phase II	**Summer**		0.59	0.56	0.64	0.69	0.61
	Rainy	0.59		0.71	0.49	0.52	0.55
	Winter	0.56	0.71		0.44	0.43	0.58
Phase I	**Summer**	0.64	0.49	0.44		0.66	0.61
	Rainy	0.69	0.52	0.43	0.66		0.58
	Winter	0.61	0.55	0.58	0.61	0.58	

Fig.19: Similarity of species composition (Bray-Curtis) between seasons and Phase I and II in Bangalore region.

4.4 Correlation of the diversity with climatic parameters in the study areas

The correlation test performed with respect to diversity (Simpson index) and environmental parameters (RH and temperature) showed positive correlation that as the relative humidity (RH) increases; the butterfly diversity (Simpson index) also increases; whereas the low RH resulted in low butterfly diversity (Fig.20). The temperature influences much in relation to alpha diversity in the different zones; the lower temperature results in higher diversity. The diversity is lowest in the summer season in most of the places (Fig.21).

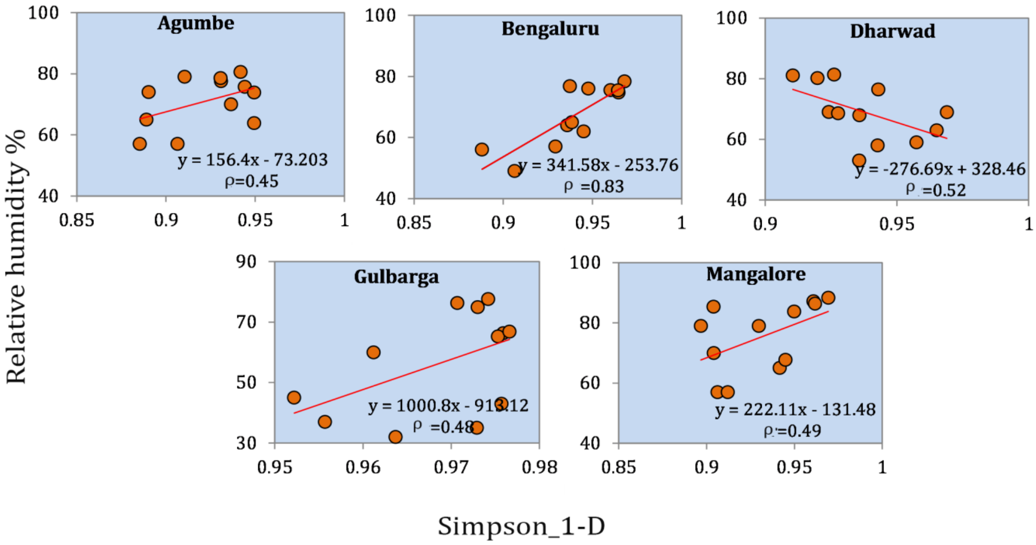


Fig.20: Correlation effect between relative humidity (%) and alpha diversity (Simpson index) in five study areas in eco-climatic zones.

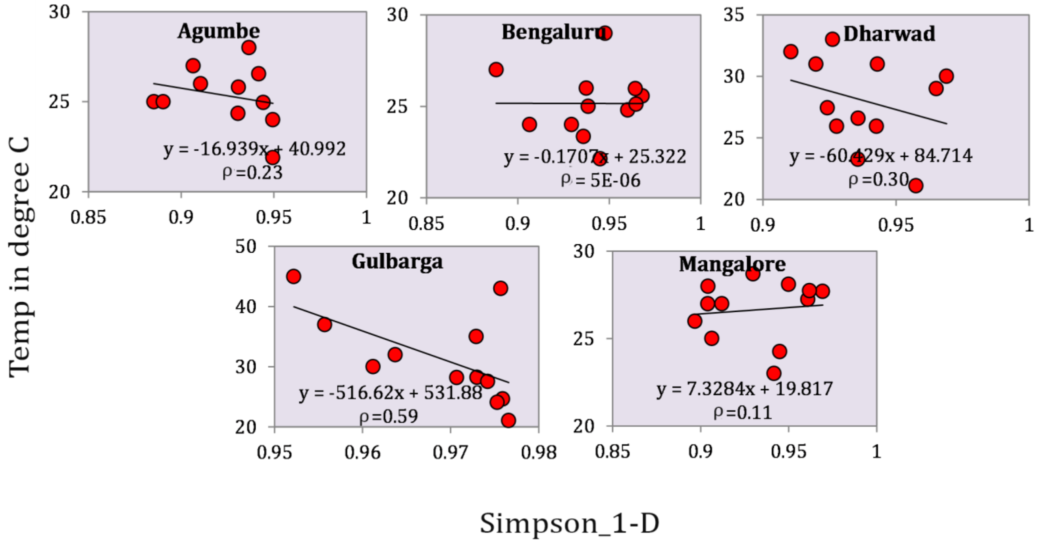


Fig.21: Correlation effect between temperature ($^{\circ}$C) and alpha diversity (Simpson index) in five different eco-climatic zones.

4.5 Compilation of list of butterfly recorded in five study areas of Karnataka during Phase I and Phase II

A total of 206 butterfly species were recorded from the five different eco-climatic zones of Karnataka during the period of Phase I and II study i.e. 2016-2017 and 2021-2022 respectively (Table 5). Out of these family Nymphalidae and Lycanidae represents highest number of species (i.e. 30% and 29.6%) followed by Hesperiidae (18%), Pieridae (12.6%), Papilionidae (9.2%) and one species represented from Riodinidae family (Fig.23A). A total of 125 genus represent 206 species of butterfly, where in genus Papilio represent high number of species (10) followed by Junonia represent 6 species, four genus represent 5 species, 2 genus represent 4 species, 10 genus represent 3 species, 21 genus represent 2 species, 84 genus represent single species (Fig.23B). The family wise distribution of species showed that Nymphalidae and Lycaenidae dominated in their distribution.

Table 5: Checklist of butterfly species from five study sites in eco-climatic zones of Karnataka compiled based on the Phase I and Phase II study.

	Common Name	Scientific Name
	Family: Hesperiidae	
1	Pygmy Scrub Hopper	*Aeromachus pygmaeus* (Fabricius, 1775)
2	Bush Hopper	*Ampittia dioscorides* (Fabricius, 1793)
3	Brown Awl	*Badamia exclamationis* (Fabricius, 1775)
4	Complete Paint-brush Swift	*Baoris farri* (Moore, 1878)
5	Rice Swift	*Borbo cinnara* (Wallace, 1866)
6	Common Orange Awlet	*Burara jaina* (Moore, [1866])
7	Karwar Swift	*Caltoris canaraica* (Moore, [1884])
8	Blank Swift	*Caltoris kumara* (Moore, 1878)
9	Dusky Spotted Flat	*Celaenorrhinus fusca* (Hampson, [1889])
10	Common Spotted Flat	*Celaenorrhinus leucocera* (Kollar, [1844])
11	Tricolour Pied Flat	*Coladenia indran*i (Moore, [1866])
12	Giant Redeye	*Gangara thyrsis* (Fabricius, 1775)
13	Bispot Banded Ace	*Halpe porus* (Mabille, [1877])
14	Common Awl	*Hasora badra* (Moore, [1858])
15	Common Banded Awl	*Hasora chromus* (Cramer, [1780])
16	Chestnut Bob	*Iambrix salsala* (Moore, [1866]
17	Common Branded Redeye	*Matapa aria* (Moore, [1866])
18	Common Banded Demon	*Notocrypta paralysos* (Wood-Mason & de Nicéville,1881)
19	Smaller Dartlet	*Oriens goloides* (Moore, [1881])
20	Swift sp.	*Parnara* sp.
21	Obscure Branded Swift	*Pelopidas agna* (Moore, [1866]
22	Small Branded Swift	*Pelopidas mathias* (Fabricius, 1798)
23	Large Branded Swift	*Pelopidas subochracea* (Moore, 1878)
24	Indian Dart	*Potanthus pseudomaesa* (Moore, 1881)
25	Dart sp.	*Potanthus* sp.
26	Fulvous Pied Flat	*Pseudocoladenia dan* (Fabricius, 1787)

27	Common Small Flat	*Sarangesa dasahara* (Moore, [1866])
28	Asian Grizzled Skipper	*Spialia galba* (Fabricius, 1793)
29	Indian Palm Bob	*Suastus gremius* (Fabricius, 1798)
30	Suffused Snow Flat	*Tagiades gana* (Moore, [1866])
31	Common Snow Flat	*Tagiades japetus* (Stoll, [1781])
32	Water Snow Flat	*Tagiades litigiosa* Möschler, 1878
33	Tawny Spotted Grass Dart	*Taractrocera ceramas* (Hewitson, 1868)
34	Grey-veined Grass Dart	*Taractrocera maevius* (Fabricius, 1793)
35	Dark Palm-dart	*Telicota bambusae* (Moore, 1878)
36	Pale Palm-Dart	*Telicota colon* (Fabricius, 1775)
37	Grass Demon	*Udaspes folus* (Cramer, [1775])
	Family: Lycaenidae	
38	Common Hedge Blue	*Acytolepis puspa* (Horsfield, [1828])
39	Common Ciliate Blue	*Anthene emolus* (Godart, [1824])
40	Pointed Ciliate Blue	*Anthene lycaenina* (R. Felder, 1868)
41	Sahyadri Rosy Oakblue	*Arhopala alea* (Hewitson, 1862)
42	Large Oakblue	*Arhopala amantes* (Hewitson, 1862)
43	Dusted Oakblue	*Arhopala bazaloides* (Hewitson, 1878)
44	Centaur Oakblue	*Arhopala centaurus* (Fabricius, 1775)
45	African Babul Blue	*Azanus jesous* (Guérin-Méneville, 1849)
46	Bright Babul Blue	*Azanus ubaldus* (Stoll, [1782])
47	Dull Babul Blue	*Azanus uranus* Butler, 1886
48	Blue Bordered Plane	*Bindahara moorei* Fruhstorfer, 1904
49	Angled Pierrot	*Caleta decidia* (Hewitson, 1876)
50	Common Pierrot	*Castalius rosimon* (Fabricius, 1775)
51	Common Tinsel	*Catapaecilma major* Druce, 1895
52	Silver Forget-me-not	*Catochrysops panormus* (C. Felder, 1860)
53	Forget me-not	*Catochrysops strabo* (Fabricius, 1793)
54	Plain Hedge Blue	*Celastrina lavendularis* (Moore, 1877)
55	Common Imperial	*Cheritra freja* (Fabricius, 1793)
56	Lime Blue	*Chilades lajus* (Stoll, [1780])
57	Plains Cupid	*Chilades pandava* (Horsfield, [1829])
58	Small Cupid	*Chilades parrhasius* (Fabricius, 1793)
59	Shiva Sunbeam	*Curetis siva* Evans, 1954
60	Indian Sunbeam	*Curetis thetis* (Drury, [1773])
61	Cornelian	*Deudorix epijarbas* (Moore, [1858])
62	Banded Blue Pierrot	*Discolampa ethion* (Westwood, [1851])
63	Gram Blue	*Euchrysops cnejus* (Fabricius, 1798)
64	Indian Cupid	*Everes lacturnus* (Godart, [1824])
65	Orange-spotted Grass Jewel	*Freyeria trochylus* (Freyer, 1845)
66	Orchid Tit	*Hypolycaena othona* Hewitson, [1865]
67	Silverstreak Blue	*Iraota timoleon* (Stoll, [1790])
68	Metallic Cerulean	*Jamides alecto* (C. Felder, 1860)
69	Dark Cerulean	*Jamides bochus* (Stoll, [1782])
70	Common Cerulean	*Jamides celeno* (Cramer, [1775])
71	Pea Blue	*Lampides boeticus* (Linnaeus, 1767)
72	Zebra Blue	*Leptotes plinius* (Fabricius, 1793)
73	Yamfly	*Loxura atymnus* (Stoll, 1780)
74	Malayan	*Megisba malaya* (Horsfield, [1828])
75	Transparent Six-lineblue	*Nacaduba kurava* (Moore, [1858])

76	Large Four-Lineblue	*Nacaduba pactolus* (C. Felder, 1860)
77	Quaker	*Neopithecops zalmora* (Butler, [1870])
78	Dingy Lineblue	*Petrelaea dana* (de Nicéville, [1884])
79	Tailless Lineblue	*Prosotas dubiosa* (Semper, [1879])
80	Common Lineblue	*Prosotas nora* (C. Felder, 1860)
81	Pale Grass Blue	*Pseudozizeeria maha* (Kollar, [1844])
82	Slate Flash	*Rapala manea* (Hewitson, 1863)
83	Monkey Puzzle	*Rathinda amor* (Fabricius, 1775)
84	Apefly	*Spalgis epius* (Westwood, [1851])
85	Scarce Shot Silverline	*Spindasis elima* (Moore, 1877)
86	Common Shot Silverline	*Spindasis ictis* (Hewitson, 1865)
87	Long Banded Silverline	*Spindasis lohita* (Horsfield, [1829])
88	Plumbeous Silverline	*Spindasis schistacea* (Moore, [1881])
89	Common Silverline	*Spindasis vulcanus* (Fabricius, 1775)
90	Common Acacia Blue	*Surendra quercetorum* (Moore, [1858])
91	Peacock Royal	*Tajuria cippus* (Fabricius, 1798)
92	Red Pierrot	*Talicada nyseus* (Guérin-Méneville, 1843)
93	Striped Pierrot	*Tarucus nara* (Kollar, 1848)
94	Common Guava Blue	*Virachola isocrates* (Fabricius, 1793)
95	Redspot	*Zesius chrysomallus* Hübner, [1819]
96	Dark Grass Blue	*Zizeeria karsandra* (Moore, 1865)
97	Lesser Grass Blue	*Zizina otis* (Fabricius, 1787
98	Tiny Grass Blue	*Zizula hylax* (Fabricius, 1775)
	Family: Nymphalidae	
99	Tawny Coster	*Acraea terpsicore* (Linnaeus, 1758)
100	Angled Castor	*Ariadne ariadne* (Linnaeus, 1763)
101	Common Castor	*Ariadne merione* (Cramer, [1777])
102	Common Sergeant	*Athyma perius* (Linnaeus, 1758)
103	Blackvien Sergeant	*Athyma ranga* Moore, [1858]
104	Staff Sergeant	*Athyma selenophora* (Kollar, [1844])
105	Joker	*Byblia ilithyia* (Drury, [1773])
106	Sahyadri Lacewing	*Cethosia mahratta* Moore, 1872
107	Anomalous Nawab	*Charaxes agrarius* Swinhoe, [1887]
108	Indian Nawab	*Charaxes bharata* C. & R. Felder, [1867]
109	Plain Tawny Rajah	*Charaxes psaphon* Westwood, 1847
110	Black Rajah	*Charaxes solon* (Fabricius, 1793)
111	Tamil Yeoman	*Cirrochroa thais* (Fabricius, 1787)
112	Rustic	*Cupha erymanthis* (Drury, [1773])
113	Map Butterfly	*Cyrestis thyodamas* Doyère, [1840]
114	Plain Tiger	*Danaus chrysippus* (Linnaeus, 1758)
115	Striped Tiger	*Danaus genutia* (Cramer, [1779])
116	Autumn Leaf	*Doleschallia bisaltide* (Cramer, [1777])
117	Redspot Duke	*Dophla evelina* (Stoll, [1790])
118	Tailed Palmfly	*Elymnias caudata* Butler, 1871
119	Common Crow	*Euploea core* (Cramer, [1780])
120	Brown King Crow	*Euploea klugii* Moore, [1858]
121	Double-branded Crow	*Euploea sylvester* (Fabricius, 1793)
122	Common Baron	*Euthalia aconthea* (Cramer, [1777])
123	Gaudy Baron	*Euthalia lubentina* (Cramer, [1777])
124	Great Eggfly	*Hypolimnas bolina* (Linnaeus, 1758)

125	Danaid Eggfly	*Hypolimnas misippus* (Linnaeus, 1764)
126	Malabar Tree-Nymph	*Idea malabarica* (Moore, 1877)
127	Peacock Pansy	*Junonia almana* (Linnaeus, 1758)
128	Grey Pansy	*Junonia atlites* (Linnaeus, 1763)
129	Yellow Pansy	*Junonia hierta* (Fabricius, 1798)
130	Chocolate Pansy	*Junonia iphita* (Cramer, [1779])
131	Lemon Pansy	*Junonia lemonias* (Linnaeus, 1758)
132	Blue Pansy	*Junonia orithya* (Linnaeus, 1758)
133	Sahyadri Blue Oakleaf	*Kallima horsfieldii* (Kollar, [1844])
134	Bamboo Treebrown	*Lethe europa* (Fabricius, 1775)
135	Common Treebrown	*Lethe rohria* (Fabricius, 1787)
136	Common Beak	*Libythea lepita* Moore, [1858]
137	Common Evening Brown	*Melanitis leda* (Linnaeus, 1758)
138	Commander	*Moduza procris* (Cramer, [1777])
139	Gladeye Bushbrown	*Mycalesis junonia* Butler, 1868
140	Dark-branded Bushbrown	*Mycalesis mineus* (Linnaeus, 1758)
141	Common Bushbrown	*Mycalesis perseus* (Fabricius, 1775)
142	Common Sailer	*Neptis hylas* (Linnaeus, 1758)
143	Chestnut-streaked Sailer	*Neptis jumbah* Moore, [1858]
144	Medus Brown	*Orsotriaena medus* (Fabricius, 1775)
145	Common Lascar	*Pantoporia hordonia* (Stoll, [1790])
146	Extra Lascar	*Pantoporia sandaka* (Butler, 1892)
147	Glassy Tiger	*Parantica aglea* (Stoll, [1782])
148	Clipper	*Parthenos sylvia* (Cramer, [1775])
149	Common Leopard	*Phalanta phalantha* (Drury, [1773])
150	Black Prince	*Rohana parisatis* (Westwood, [1851])
151	Baronet	*Symphaedra nais* (Forster, 1771)
152	Grey Count	*Tanaecia lepidea* (Butler, 1868)
153	Blue Tiger	*Tirumala limniace* (Cramer, [1775])
154	Dark Blue Tiger	*Tirumala septentrionis* (Butler, 1874)
155	Painted Lady	*Vanessa cardui* (Linnaeus, 1758)
156	Cruiser	*Vindula erota* (Fabricius, 1793)
157	Common Three-ring	*Ypthima asterope* (Klug, 1832)
158	Common Five-ring	*Ypthima baldus* (Fabricius, 1775)
159	Common Four-ring	*Ypthima huebneri* Kirby, 1871
160	Banded Catseye	*Zipaetis saitis* Hewitson, [1863]
	Family: Papilionidae	
161	Tailed Jay	*Graphium agamemnon* (Linnaeus, 1758)
162	Fivebar Swordtail	*Graphium antiphates* (Cramer, [1775])
163	Common Jay	*Graphium doson* (C. & R. Felder, 1864)
164	Spot Swordtail	*Graphium nomius* (Esper, 1799)
165	Narrow-banded Bluebottle	*Graphium teredon* (C. & R. Felder, [1865])
166	Common Rose	*Pachliopta aristolochiae* (Fabricius, 1775)
167	Crimson Rose	*Pachliopta hector* (Linnaeus, 1758)
168	Malabar Rose	*Pachliopta pandiyana* (Moore, 1881)
169	Malabar Banded Peacock	*Papilio buddha* Westwood, 1872
170	Common Mime	*Papilio clytia* Linnaeus, 1758
171	Common Banded Peacock	*Papilio crino* Fabricius, 1793
172	Lime Swallowtail	*Papilio demoleus* Linnaeus, 1758
173	Malabar Raven	*Papilio dravidarum* Wood-Mason, 1880

174	Red Helen	*Papilio helenus* Linnaeus, 1758
175	Malabar Banded Swallowtail	*Papilio liomedon* Moore, [1875]
176	Paris Peacock	*Papilio paris* Linnaeus, 1758
177	Blue Mormon	*Papilio polymnestor* Cramer, 1775
178	Common Mormon	*Papilio polytes* Linnaeus, 1758
179	Sahyadri Birdwing	*Troides minos* (Cramer, [1779])
	Family: Pieridae	
180	Common Albatross	*Appias albina* (Boisduval, 1836)
181	Plain Puffin	*Appias indra* (Moore, [1858])
182	Western Striped Albatross	*Appias libythea* (Fabricius, 1775)
183	Chocolate Albatross	*Appias lyncida* (Cramer, [1777])
184	Indian Pioneer	*Belenois aurota* (Fabricius, 1793)
185	Common Emigrant	*Catopsilia pomona* (Fabricius, 1775)
186	Mottled Emigrant	*Catopsilia pyranthe* (Linnaeus, 1758)
187	Lesser Gull	*Cepora nadina* (Lucas, 1852)
188	Common Gull	*Cepora nerissa* (Fabricius, 1775)
189	Small Salmon Arab	*Colotis amata* (Fabricius, 1775)
190	Plain Orange-tip	*Colotis aurora* (Cramer, [1780])
191	Crimson-tip	*Colotis danae* (Fabricius, 1775)
192	Little Orange-Tip	*Colotis etrida* (Boisduval, 1836)
193	Large Salmon Arab	*Colotis fausta* (Olivier, 1804)
194	Indian Jezebel	*Delias eucharis* (Drury, 1773)
195	One-spot Grass Yellow	*Eurema andersonii* (Moore, 1886)
196	Three-spot Grass Yellow	*Eurema blanda* (Boisduval, 1836)
197	Small Grass Yellow	*Eurema brigitta* (Stoll, [1780])
198	Common Grass Yellow	*Eurema hecabe* (Linnaeus, 1758)
199	Spotless Grass Yellow	*Eurema laeta* (Boisduval, 1836)
200	Great Orange-tip	*Hebomoia glaucippe* (Linnaeus, 1758)
201	White Orange-tip	*Ixias marianne* (Cramer, [1779])
202	Yellow Orange-tip	*Ixias pyrene* (Linnaeus, 1764)
203	Psyche	*Leptosia nina* (Fabricius, 1793)
204	Indian Wanderer	*Pareronia hippia* (Fabricius, 1787)
205	Painted Sawtooth	*Prioneris sita* (C. & R. Felder, [1865])
	Family: Riodinidae	
206	Double-banded Judy	*Abisara bifasciata* Moore, 1877

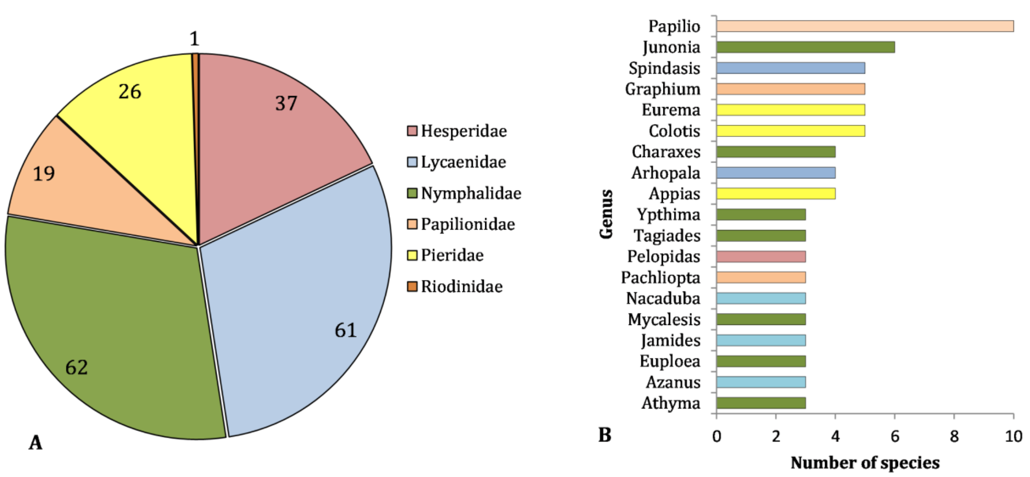


Fig.22: Species distribution: **A.** Family wise; **B.** Genus wise

Chapter 5: Discussion

A very few studies have explored the abundance and pattern of butterfly communities in Karnataka. Few studies have presented the abundance pattern (Santhosh and Basavarajappa, 2016; Kumar *et al*., 2019; Remadevi *et al*., 2021; Naik *et al*., 2021) from different regions of Karnataka. The urbanization is rapidly intensifying in various parts of Karnataka due to the socioeconomic progress which leads to serious threat to the local ecosystems. In view of the above, to assess the status of diversity of butterflies in the urban ecosystems, diverse eco-climatic areas were surveyed throughout the year covering the three seasons. Using the transect method as specified in our earlier P1 study; we collected the abundance pattern of butterflies in different eco-climatic zones (Urban/Forest habitat). Karnataka has ten agro eco-climatic zones and three eco-climatic zones; in our study we explored the five study areas in different Eco-climatic zones. Though species richness is higher in Agumbe and Mangalore, abundance is higher in Bengaluru followed by Gulbarga. The reason may be that Agumbe and Mangalore are rich with more plant diversity supporting many butterfly species. The occurrence of butterflies and family distribution observed are similar when compared with other studies (Nayak *et al*., 2004; Naik and Mustak, 2016; Mohandas and Remadevi, 2019; Remadevi *et al*., 2021; Naik *et al*., 2021). The study recorded 206 (63%) species out of already reported 325 species from Karnataka. However the present study provides a large dataset on butterflies from five different eco-climatic zones of Karnataka. Overall the species richness was lower in the open habitat (includes drier habitat) when compared with the Hilly zone (Agumbe). The species composition was highly variable within the five different zones of study, may be due to the influence of habitat preference, altitude, host plant availability and also other environmental factors (Kasangaki *et al*., 2012).

The study observed high Shannon and Simpson index (despite having low species richness) in Gulbarga due to the high species evenness. In this Phase II study the overall dominant species was *Catopsilia* sp., *Euploea* sp. was second, *Delias eucharis* was third, *Junonia lemonias* was fourth and *Cupha erymanthis* was fifth in dominance. The other dominant species of the P2 study were also among the first 10 species of P1 study. In the P1 study, the zone wise dominant species were mostly same as that in the P2. In our study in Bengaluru city in 2015-16 the *Catopsilia* sp. (*C. pomona* and *C. pyranthe*) and *Eurema* sp. (*E. core* and *E. sylvester*) were observed as most dominant species (Remadevi *et al*., 2021). In the P1 and P2 study also, *Catopsilia* sp. was found as the most abundant species.

The species composition widely varied in the different study zones. Similar pattern was observed in Mangalore and Agumbe, which are nearer to each other and moreover they are sharing more or less same eco-climatic factors. Similarly Bengaluru and Dharwad shows similar species composition may be due to similar in eco-climatic and geographical factors, whereas Gulbarga which has very distinct climatic factors like highest temperature and low humidity profiles shares very few species between other zones. In Bengaluru study region the survey carried out after four years, in most of study site the pattern remained similar with respect to species occurrence. The comparison of species composition in different study sites in Bengaluru during P1 and P2 indicate that there is no significant variation except for Doresanipalya RF, This shows that there is no much change in habitat structure since the habitat are well maintained in urban green spaces, but the composition varied in protected forest (Doresanipalya RF) where the habitats are untouched. This infers that the habitats which are less prone to anthropogenic activity may alter slowly with respect to the flora and thereby altering the butterfly diversity.

The species richness and abundance was high during winter and rainy seasons in all the zones. The seasonal variation in the eco-climatic zone was compared with the data of P1 study. It was observed that the species richness was highest during winter in all the places except Mangalore (richness was high in rainy season) in both the period of study (2016-17 and 2021-22). This indicates that there is no much variation in the species richness pattern even after four years. The abundance was also similar in Agumbe, Bengaluru and Mangalore in both P1 and P2. In the Gulbarga and Dharwad the abundance was higher in the winter season during P2 and in rainy season during P1.The diversity indices shows that winter and rainy seasons were with the highest values. Only Dharwad showed highest value in summer season. There are several other ecological factors like day length, temperature, humidity and precipitation and food source (Tiple *et al*., 2009; Shimadzu *et al*., 2013; Naik *et al*., 2022) which influences the species diveristy. The detailed account on habitat/phenological changes needs to be understood over a period of time to analyse the changes in species composition and distribution of butterfly communities. In order to understand the effect of climate change (Midgley *et al*., 2002) there is the need to setup a long-term monitoring scheme in different places.

Each and every landscape has its own unique composition in flora and fauna and directly depicts the diversity. During the study period we observed that the species with low conservation value (less abundant/unique species) was observed in Agumbe, which lies in

Western Ghats (Hill zone). Even the urban habitats including Bengaluru and Mangalore showed high number of species with low conservation value; this indicates that even the urban green patches is really in need of protection to maintain the urban forests.

In the present study we provided the baseline information of butterfly community assemblage in five different eco-climatic zones of Karnataka, which helps in understanding the current scenario. The study also provides the importance of urban green patches and need for preservation using butterfly as a model which indirectly reflect the other flora and fauna. The information helps in future conservation and management plan. To pinpoint the impacts of climate change, the study has to be repeated and reviewed for the status after 30years.

Limitations of the Study

1. Same study team could not conduct surveys in all the places. The varied levels of expertise of the field staff engaged in the identification of butterflies in different areas may cause some errors in species identity. Correction needs repetitive visits and confirmation of the species. Catching butterflies was prohibited in this study.
2. The anthropogenic intervention in the study areas may interfere in the richness and abundance of butterflies. The study cannot record all those changes.
3. The study did not encompass the floristics of the different areas which might have changed due to natural regeneration or due to plantation activities.
4. As the identification of different species of same genera was difficult due to the minute variations, which could not be verified from one quick sighting, they were represented as "genus sp." in the P2 study. But it was identified separately in earlier studies. This comparison might have slightly changed the dominant species grouping with respect to P1/ P2 study /zones and also over all dominance.

Deliverables

Research Publications

Remadevi, O. K., Vinaya Kumar, K. H., Kakkar, R. (2020). Butterfly monitoring programme for Karnataka. In: Building Climate Change Resilience. Remadevi *et. al*., (Ed) Excel India publishers. ISBN: 978-93-89947-17-5, 27-36.

Remadevi, O. K., Puranik, R. D., Sooraj, S., Shet, R. C., Naik, D. and Vinaya Kumar, K. H. (2021). Butterfly species assemblage and seasonal patterns in different urban green spaces of Bengaluru city, Karnataka, India. Annals of Entomology, 39(2): 85-98.

Remadevi, O. K., D Souza, J. M. and, Shet, C. R. (2022). Citizen Science for data creation on geographical and temporal variations of incidence of butterflies to serve as climate change indicators. In: Biodiversity, Ecosystem services and Climate change. Excel India publishers. ISBN: 978-93-91355-57-9, 153-159.

Remadevi, O. K., Vinaya Kumar, K. H., Kakkar, R. (2022). Impact of Climate Change on the Diversity of Butterflies, In: Climate Change | Biodiversity & Development Centre for Innovation in Science and Social Action, 1-25.

Remadevi O. K., Antony J. C., D Souza J. M. and Vinaya Kumar, K. H. (2022). Butterfly Identification App (BIA): A mobile application for identification and monitoring of butterflies in the state of Karnataka. Insect Environment, 25 (2), 207-216.

Conclusion and recommendations

Conclusion

How the climate changes affects butterfly diversity is a major concern of all biologists. Researchers and environmentalists also look up to butterflies which can serve as flagship organisms to indicate the climate change and environmental health. The present study was planned with this background. The study gave us vital information on the extent of the diversity, abundance and richness of butterflies in different eco-climatic zones of Karnataka pointing to the differential distribution of butterflies in relation to the climatic factors prevalent in the areas. The baseline data from these zones generated four years back (Phase I study) could be compared with reference to seasons and change in climatic factors.

The main objective of the study was to see whether the climatic conditions of the Phase I study and Phase II study are very different and if so how the butterfly diversity is influenced and altered. We surveyed the butterfly species in five study areas in different eco-climatic zones of Karnataka, with a record of 17702 individuals representing 183 species during the period of 2021 to 2022. The diversity varied in different areas with different species composition patterns. The more unique species composition was observed in Agumbe. The species belonging to *Catopsilia* sp. (*C.pomona* & *C. pyranthe*) and *Euploea* sp. (*E. core* and *E. sylvester*) were observed to be dominant with high abundance in all zones. The relationship of diversity with the temperature was analysed and it is found that higher the temperature lower is the diversity and the diversity of butterflies is positively correlated with relative humidity. The species richness and abundance was more in winter/rainy seasons and mostly similar as that in P1 study. The family wise distribution of species showed that Nymphalidae and Lycaenidae dominated in their distribution in both P1 and P2.

The P1 and P2 studies were conducted in a gap of about 4 years and the seasonal climatic parametres did not show significant changes .The species richness, distribution, abundance, seasonal preference etc. of the current study in different eco-climatic zones matched the findings of the P1 study to a high extent. The changes in abundance observed may be due to other anthropogenic activities or habitat succession. No much change in species composition was observed between locations in Bengaluru and also in the different study areas even after four years (between Phase I and Phase II period). Our study provides a base line data for the conservation of butterfly as well as future ecological monitoring.

Recommendations

Though there are many studies on the diversity of butterflies from a spatial and temporal perspective, there are no much specific studies to correlate the diversity with the changing climate. This requires continuous monitoring of an area season wise across many years. In order understand the crucial changes in species composition in different zones there is the need for a long-term monitoring programme. In each zone few indicator species are to be identified in order to understand the climate change impacts. The butterflies are the good models, species abundance purely depends on phenology of plants and the also the climatic conditions.

This requires the building of a base line data for each of the biodiversity hotspots which can be monitored in the coming years. The study recommends regular monitoring of butterfly diversity in selected specific locations in all districts of Karnataka through citizen science program. During the course of studies since 2015, an APP (BIA) for identification of butterflies is developed and its use is recommended extensively by identified groups (NGC schools, Range Forest officials) to build a database year after year so that the butterfly diversity is used as a bio indicator of climate variability /change. It is strongly recommended that a dynamic **Butterfly monitoring program for the state of Karnataka** is established to utilise butterfly diversity as a bio indicator of climate change. Following is the list of recommendations on future work to be carried out to increase the butterfly diversity and also to use butterflies as climate change indicators.

1. Data collection has to be continued for many years in the selected eco-climatic zones to validate the findings and correlate it with climate change.
2. Data on host plants is also to be collected from the field sites and regularly monitored to understand the change in their dynamics due to anthropogenic activity and/or micro climatic conditions in the area.
3. The school students (of NGC schools), locals and forest officials (from all Range Forest offices) who can identify butterflies can participate in regular surveys and identify the butterflies in their locality using field guides and BIA developed for field identification. BIA collected GPS linked data shall be transferred to the online Knowledge Portal on Climate Change designed under DST project.
4. A Butterfly Monitoring Program for the whole state including all the districts has to be initiated so that the data on diversity can be collected month after month and year after year to form a database along with the district wise Climate database. The database can

be used for long term monitoring of climate change using the butterflies as bio indicators.

5. Data and knowledge on butterflies can be shared with stakeholders and scientists to come up with better unskewed interpretations and results (similar to the European model).
6. Doresanipalya Forest Campus can be converted into a butterfly reserve or a park and can be made to host many more butterfly species by planting more host plant species.
7. Interested novice participants can be trained to identify butterflies using BIA and field guides.
8. The study also provides the information on the importance of urban green patches and recommends the need for preservation using butterfly as a model which indirectly reflect the other flora and fauna and also the environmental health.

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Team member description

Principal Investigator: **Dr. O.K. Remadevi,**
Consultant and Ex head,
Centre for Climate Change,
Environmental Management and Policy Research Institute,
Bengaluru

Co- Principal Investigator: **Ms. Jane Maria Dsouza**
Project Associate
Centre for Climate Change, EMPRI

Team Members:

a) **Dr. Deepak Naik**,
Project Associate
Centre for Climate Change, EMPRI

b) **Mr. Chaturved Shet**
Project Associate
Centre for Climate Change, EMPRI

Annexures

Fig.23 : Study sites in Agumbe

Fig.24: Study sites in Dharwad

Fig.25: Study sites in Gulbarga

Fig.26: Study sites in Mangalore

Fig.27: Study sites in Bengaluru

Sahyadri Lacewing (*Cethosia mahratta*)

Five-bar Swordtail (*Graphium antiphates*)

Malabar Tree-Nymph (*Idea malabarica*)

Lesser Gull (*Cepora nadina*)

Common Beak (*Libythea lepita*)

Long Banded Silverline (*Spindasis lohita*)

Fig.28: Butterflies of Agumbe

Blue Mormon (*Papilio polymnestor*)

Lime Swallowtail (*Papilio demoleus*)

Common Four-ring (*Ypthima huebneri*)

Plain Tiger (*Danaus chrysippus*)

Lemon Pansy (*Junonia lemonias*)

Zebra Blue (*Leptotes plinius*)

Fig.29: Butterflies of Bengaluru

Chocolate Pansy (*Junonia iphita*)

Common Sailer (*Neptis hylas*)

Common Mormon (*Papilio polytes*)

Dark Cerulean (*Jamides bochus*)

Small Salmon Arab (*Colotis amata*)

Yellow Orange-tip(*Ixias pyrene*)

Fig.30: Butterflies of Dharwad

Common Emigrant (*Catopsilia pomona*)

Common Gull (*Cepora nerissa*)

Indian Jezebel (*Delias eucharis*)

Common Rose (*Pachliopta aristolochiae*)

Great Eggfly (*Hypolimnas bolina*)

Crimson-tip (*Colotis danae*)

Fig.31: Butterflies of Gulbarga

Rustic (*Cupha erymanthis*)

Tamil Yeoman (*Cirrochroa thais*)

Chocolate Albatross (*Appias lyncida*)

Common Crow (*Euploea core*)

Malabar Banded Peacock (*Papilio buddha*)

Narrow-banded Bluebottle (*Graphium teredon*)

Fig.32: Butterflies of Mangalore

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Environmental Management & Policy Research Institute (EMPRI) is an autonomous institute established by Government of Karnataka under the Department of Forest, Ecology and Environment. It is registered under the Karnataka Societies Registration Act, 1960. The Institute undertakes applied and policy research and also endeavours to provide capacity building trainings on concurrent environmental issues relevant to the society. Research and assessments undertaken by the institute seek to encourage and enable government and other institutions, industry and civil society to safeguard and manage the natural resources effectively. Fresh capabilities on impact and carrying capacity assessment for sustainable development, and baseline data and modelling for air pollution and climate change are being augmented.

Environmental Management & Policy Research Institute

Department of Forest, Ecology and Environment, Government of Karnataka

https://empri.karnataka.gov.in

Circle Arch, Vinayaka Nagar, Sahyadri Layout, J. P. Nagar, Bengaluru, Karnataka 560078