

Discussion

Pavagadh hill is located in the Champaner-Pavagadh Archaeological Park which is a combination of forest, agricultural fields, hill, garden and concrete structures like monuments, temples, masjids, tombs, palaces and arches. This is an ideal site for studying the biodiversity as environmental conditions of the area and provide a conducive atmosphere for the growth of different types of flora and fauna.

The highlight of the study site is the presence of a hill measuring 823 meters in height. An effort was made to record the diversity of butterflies along the slope and have observed a decline in diversity as we go higher. Maximum diversity was observed in the lower elevations especially at the foothill up to a height of 600 meters. The lower altitude of Pavagadh hill nurture greater diversity of herbs and shrubs which attract a diverse group of butterflies. These plants constitute the nectar or larval host plants of butterflies. Thus, a positive correlation between flora and butterfly diversity was observed. At higher elevations floral richness has decreased significantly compared to lower areas. Similar results of butterfly diversity declining linearly with altitude were observed by Bhusal & Khanal, 2008 in the Eastern Siwalik of Nepal. They reported that diversity of butterflies increased with the increase in altitude but declined after reaching a height of 550 meters. The optimum altitudinal range for rich diversity was found in the range of 350 to 850 meters. The correlation coefficient between the altitude and species richness was found to be of negative significance.

Total rainfall received varies widely from year to year and from place to place. However, Champaner-Pavagadh Archaeological Park receives a rainfall of 700 mm to 1024 mm annually (Forest Department Godhra, 2008. Working plan for the forest of Panchmahal and Kheda for a period of 20 years. Panchmahal district, Gujarat). In the months of March to May humidity reaches around 30%-40%. Climatic conditions greatly affect the diversity and ecology of the species. Ecological studies of butterflies help to know the environmental changes and many other disturbances of the area. The relative humidity is high during the monsoon season and in months like July and August it reached up to 50-80% RH. The average annual rainfall received during the monsoon season is 823 mm (Sinha, 2018) . An average minimum and maximum

temperature ranged between 22-24⁰C and 28- 30⁰C respectively. The atmospheric humidity was recorded as 60- 83% RH during the same season. This weather condition supports excellent quality and quantity of larval food plants for caterpillars and nectar rich flowers for the adult butterflies. Moreover, significant amount of rainfall makes the soil fertile for the growth of plants. Hence, highest number (63) of butterfly species were observed during postmonsoon months i.e. September, October and November. (Deepika, 2014) from Kambalakonda Eco-Tourism Park, Vishakhapatnam revealed that temperature, humidity and rainfall collectively influence the abundance of butterflies. They reported that average temperature of 25- 26⁰C was the most favorable for the butterflies. Atmospheric humidity of 80%-90% RH was most preferred range followed by 60-80% for butterfly abundance. Daily rainfall of 50 mm was most favorable level followed by 50-100 mm rainfall. The forest area surrounding the Pavagadh Hill is a dry deciduous forest which usually receives annual rainfall from June to September. An average minimum temperature of 23⁰C-26⁰C and maximum temperature of 35⁰C - 40⁰C were experienced during summer months which dries up the land and thereby loss of leaves and flowers of the nectar and larval host plants. Hence there was a reduction in the number of butterflies observed during summer season compared to other seasons. It is because different stages of butterfly synchronize with the phenology of plants. After the monsoon the quality and quantity of the vegetation increases. Rainfall influences the area from dry deciduous to moist deciduous type for some months. Life cycle of butterflies is directly related to the temperature and humidity because all the stages of its development require suitable larval or nectar host plants. The diversity and abundance of vegetation depends on the rainfall and other ecological parameters. The flowering period of most of the identified nectar plants (Table.11) coincide with the post-monsoon season which could be a reason for the maximum abundance of butterflies observed in post-monsoon season.

A remarkable amount of rainfall makes the soil fertile and nutrient-rich which promotes the growth of nectar plants and larval food plants. (Wynter-Blyth, 1957) mentioned that the distribution of butterflies in a locality mainly depends on the amount of rainfall received in that region. Thus, the highest number of butterfly species were observed during post-monsoon and then in monsoon seasons as compared to other seasons. A study conducted by (Gandhi & Kumar, 2016) at Dangs of Gujarat also found that highest number of butterfly species was observed during the post-monsoon season as compared to other seasons. All these reports support the result of the present work that the most favorable season for the butterflies is

postmonsoon because of the frequent rains received during this period. It promotes the growth of the flowering plants which provide nectar resource for the butterflies. So, seasonality of butterfly species is synchronized with the seasonal presence of its food plants. Similar kind of study was conducted by Manwar & Wankhade, 2014 at Sawanga-Vithoba Lake region and found that maximum number of butterflies recorded during post-monsoon followed by monsoon season. During summer months the number of species observed was very less. They concluded that butterflies exhibit seasonal variation in their distribution and more species diversity observed in monsoon.

Another study of the similar type conducted by Serrat et al., 2015 in Mediterranean vegetation including forest and scrub land (Girona province, Spain) reported that environmental factors are known to influence the abundance and diversity of butterflies because any change in the ecological parameters like temperature and humidity affect the butterflies as they are very sensitive towards environmental conditions.

A total of 63 butterfly species belonging to 5 families were recorded during this study period from the three sub-study sites. Out of the 63 butterfly species recorded 35 species were common to all the three habitats. Butterflies show a seasonal trend in their appearance in all the three habitats. In all the three habitats family Nymphalidae had got the maximum diverse species of butterflies. The maximum species diversity was observed during post-monsoon season followed by monsoon season and winter season and least diversity of species was observed during the summer season. Most of the butterflies were encountered during monsoon and postmonsoon seasons because of the frequent rainfall which in turn promoted the growth of their favorite nectar host plants and larval food plants. More than half of the total butterfly species identified during this study were encountered during wet seasons. Diversity of a region generally increases when a greater variety of habitat types are present. A study conducted by Shobana et al., 2012 from Villupuram district of Tamil Nadu situated at the foothills of the eastern slope of the Western Ghats reported that butterfly species diversity increased in various habitats like agricultural fields, scrub land, urban area and undisturbed areas because of the presence of various types of vegetation.

The Pielou's Evenness Index close to "0" indicates low diversity while a high value close to "1" indicates high diversity. In this study, high Evenness Index was seen during post-monsoon season followed by monsoon season. This is an indicative of high butterfly diversity which was

evenly distributed during post-monsoon and monsoon seasons. In the present study, the Shannon-Wiener Index was also calculated. The highest Shannon Diversity Index was observed during post-monsoon followed by monsoon seasons. The least value was seen in the summer season. It was inferred that the occurrence of species of different families was highly diversified during post-monsoon followed by monsoon season and they were least diversified during the summer season. . A similar kind of study conducted by Revathy & Mathew (2014) in a butterfly garden maintained in the KFRI campus at Peechi found that the Shannon Weiner diversity index and species richness were higher in post-monsoon and monsoon seasons i.e. from August to November and butterfly population showed a decline in the month of February and in the months of March to April diversity reached to its least count. They also found that butterfly population showed highest population sightings during August to November and this may be related to flowering time of plants and the appropriate climatic conditions. (Chandrakar et al., 2007) reported that the abundance of butterflies reached a peak in the months from August to November while working in the selected habitats of Melghat region, Maharashtra namely Chikhaldadra Wildlife Sanctuary, Gugamal National Park, Melghat Tiger Reserve and Wan Sanctuary. The optimum temperature reported in Melghat region ranged between 13⁰C 22⁰C for the abundance of butterflies.

Various habitats of Pavagadh namely Forest, Scrub land and Garden always supported the growth of different types of plants. The abundance of butterflies was due to the presence of nectar resources. The list of larval host plants and a total of 22 prominent nectar plants along with its phenological details found in Pavagadh Hill are shown in Table 2 & 11. An elaborate list of plants present in the Pavagadh was published by the Department of Botany, The M. S. University of Baroda, Vadodara in the year, 2014 as well as in a report published by Forest Department, Godhra in the year 2008. Some prominent nectar plants and larval host plants from the study area (Table 2 & Table 11) have also been identified and the co-evolutionary relationship studied (Table 12 & Table 13). The identified nectar plant species belong to 10 families. It includes 5 plant species which belong to Apocynaceae, 3 in Malvaceae, 2 in Rubiaceae, 4 were from Asteraceae, 3 belonged to Fabaceae. Family Verbenaceae is represented by 2 plant species and 1 species each from Rutaceae, Nyctaginaceae, Caesalpinaceae and Euphorbiaceae. Pavagadh Hill has a complex habitat with varying types of plants like ornamental plants, wild plants, cultivated and invasive plants. The complexity in the floral diversity is a supporting factor for the diversity and abundance of butterflies. A research

study conducted at four different sacred forests Suryabinayak Sacred Forest, Dakshinkali Sacred Forest, Swyambhunath Sacred Forest and Pashupatinath Sacred Forest of Kathmandu valley, Nepal reported that high diversity and abundance of butterflies were always favored by the availability of nectar host plants and larval food plants. Less availability of nectars and larval food plants in both sacred forests might be another reason of sighting less butterfly richness. The presence of *Lantana camara* (Lantana) at the surrounding area served as the nectar resource for the butterflies throughout the year (Shrestha et al., 2018).

There was also an effort to see the correlations between proboscis (mouth parts of butterfly) and nectar host plants (corolla). The foraging strategy depends on the structure of proboscis and when this strategy match with the corolla structure, there exist a correlation between butterflies and plants. They may visit many flowers of the nectar plants available in a locality but not necessarily forage on them. The results obtained, indicate that the butterfly proboscis had a significant role in co-evolution between the butterfly species and the flowers of the nectar plants.

Same kind of co-relation was observed between butterflies and plants by (Sultana et al., 2017) who studied the proboscis length of butterfly and their functional relation with the nectar plants and reported that there is a significant role of co-evolution between butterfly species and the flowers of host plants. Only those flowers are foraged which remain within the range of its strategy. Many other factors also involved like the colour of the flower, shape of corolla (tubular/non-tubular), nectar content, floral texture in developing the strategy of foraging. It was also observed from the study site that butterflies used to visit flowers with tubular corollas more frequently than those with non-tubular corollas (Table 11&12). Butterflies also showed some colour preference towards nectar plants. The visits were more with flowers having red colour for example *Lantana camara* (Lantana), yellow colour for *Sida acuta* (Common Wireweed) and *Tridax procumbens* (Coat buttons) pink-coloured flowers in *Catharanthus roseus* (Periwinkle) and white color in *Chromolena odorata* (Siam Weed). While conducting a study, to see diversity of butterflies in relation to nectar food plants from by (Nimbalkar et al., 2011) reported that floral attributes influence nectar feeding behavior of butterflies. Butterflies visit different plants in order to meet their nutritional requirement. Because all the nutrients are not found in a single floral nectar source and hence butterflies have to visit different kinds of flowers to acquire all the nutrients required (Rani & Raju, 2016). Adult

butterflies essentially require considerable quantities of proteins, salts, vitamins etc. for longer life span and for the production of large number of eggs (Kunte, 2000).

From the result, it is clear that the occurrence status or abundance of butterflies is reflected in their feeding behavior. In other words, there is a relationship existing between the status of butterflies and the diversity of nectar host plants utilized by them. During the study period it was observed that almost all species from Lycaenidae for example *Zizeeria karsandra* Moore, 1865 (Dark Grass Blue), *Zizina otis* Fabricius, 1787 (Lesser Grass Blue), *Zizula hylax* Fabricius, 1775 (Tiny Grass Blue) completely disappeared during the summer season. Their preferred nectar plants were also found to be absent during the summer months. However some of the species from the family Pieridae like *Catopsilia pomona* Fabricius, 1775 (Common Emigrant), *Catopsilia pyranthe* Linnaeus, 1758 (Mottled Emigrant), *Eurema brigitta* Stoll, 1780 (Small Grass Yellow), *Eurema hecabe* Linnaeus, 1758 (Common Grass Yellow) and Nymphalid butterflies such as *Danaus chrysippus* Linnaeus, 1758 (Plain Tiger) and *Hypolimnas misippus* Linnaeus, 1764 (Danaid Eggfly), Papilionids namely *Graphium doson* C. & R. Felder, 1864 (Common Jay), *Graphium agamemnon* Linnaeus, 1758 (Tailed Jay), *Pachliopta aristolochiae* Fabricius, 1775 (Common Rose) were present throughout the year. The preferred nectar plants of these butterflies were either present throughout the year or these butterflies had a foraging habit of visiting different types of plants. So the availability of butterflies is directly associated with the presence of their larval or nectar host plants.

The presence of larval host plants is an important factor which determines the abundance of butterflies. *Graphium agamemnon* Linnaeus, 1758 (Tailed Jay), which is one of the very common butterflies found at the study sites, has *Annona squamosa* (Sugar Apple) serving as the larval host plant. *Calotropis gigantea* (Giant Milkweed) serves as a host plant for *Danaus chrysippus* Linnaeus, 1758 (Plain Tiger) which is a very common butterfly present in all three habitats. The presence of *Murraya koenigii* (popularly known as Curry tree) is the host plant for *Papilio polytes* Linnaeus, 1758 (Common Mormon). *Nerium oleander* (Oleander) serves as a host plant for *Euploea core* Cramer, 1780 (Common Indian Crow). *Eurema hecabe* Linnaeus, 1758 (Common Grass Yellow) utilizes *Cassia tora* (Sickle pod) as the larval host plant. *Justicia betonica* (White Shrimp Plant) is the larval host plant of *Hypolimnas misippus* Linnaeus, 1764 (Danaid Eggfly). In the same way presence of nectar host plants also were an important factor for the abundance of butterflies. *Ixora coccinea* (Jungle Geranium), a pink-flowered shrub is a common nectar resource for the Papilionid butterflies. Its presence in the habitat made them

very common in the habitat. The abundance of butterflies was due to the presence of nectar resources and even larval host plants increase during monsoon and post-monsoon seasons. While working in the Eastern Siwalik of Nepal, Bhusal & Khanal, 2008 reported that there is a significant correlation existing between species diversity and spring season. Spring season showed the abundance of diverse species which is positively affected by approaching warmer days, high relative humidity, and more rainfall. Diverse vegetation is aided by these factors, which are vital food sources for many butterfly species. The major flowering plants found in the study area are as follows. Trees like *Tectona grandis* (Teak tree) bear flowers during summer season (April-June) which attract butterflies like *Graphium agamemnon* Linnaeus, 1758 (Tailed Jay), *Catopsilia pyranthe* Linnaeus, 1758 (Mottled Emigrant) and *Azadirachta indica* (Neem tree) bloom from March to May attracting butterflies like *Danaus chrysippus* Linnaeus, 1758 (Plain Tiger) and *Hypolimnas misippus* Linnaeus, 1764 (Danaid Eggfly). These plants become the nectar resources for the butterflies during summer season when other plants do not bloom. Shrubs like *Lantana camara* (Lantana), *Jatropha pandurifolia* (Peregrina), *Bougainvillea spectabilis* (Bougainvillea) and herb like *Tridax procumbens* (Coatbuttons) were some of the common nectar plants found in the study area which bear flowers throughout the year and attract butterfly species of different families.

Thus, the butterflies which preferred to forage on these flowers get food throughout the year. The complexity in the vegetation of Pavagadh hill make the site best suitable for the life of butterflies. While studying the habitat association of five habitats viz., Garden, Scrub jungle, Riparian woods, Sandy area and Casuarina plantation with diversity pattern of butterflies within the campus of DAE, IGCAR, Kalpakkam, Tamil Nadu was reported by Ramesh et.al., 2010 who reported that diversity and abundance of butterflies is directly associated with the availability of food plants because of the presence of different types of preferred nectar as well as larval host plants namely *Catharanthus roseus* (Periwinkle), *Tridax procumbens* (Coatbuttons), *Ixora coccinea* (Jungle geranium), *Tephrosia purpurea* (Wild Indigo) etc.

The natural habitat of Pavagadh is healthy and not disturbed. But the weather condition during summer season dries up the vegetation to a large extent. Hence most of the nectar and larval host plants disappear during the summer season which could be the reason for the reduction of butterflies during this season. During the summer season, we have noted that the occasional occurrence of forest fires either artificial or natural in the study area is an additional reason for butterfly reduction as it severely damages the flora. Eggs, immature butterflies such as the

larval stages completely depend on plants and the leaves are used as substrate. Due to fire; butterflies die (especially the early stages like eggs) in large numbers along with the plants. (Ghorpadé & Kunte, 2010) while working in the South Western Ghats, Palani Hills reported that forest fires severely affect butterfly population causing reduction in the diversity and abundance of butterflies.

A total of 63 butterfly species during different seasons were recorded. It is a good sign for the health of habitat biodiversity. In order to maintain and further enhancement of biodiversity, it is necessary to conserve the existing biodiversity for achieving sustainable development. It is important to have all kinds of vegetation. All the stages namely egg, larvae, pupa and adults require a mixture of different kinds of plants. Presence of all such habitats and the favorable vegetation of different kinds of grasses, herbs, shrubs and trees make the study site unique. (Sharma & Sharma, 2017) while working in the Gir Wildlife Sanctuary found that butterflies require all kinds of vegetation for the survival of different stages of their life cycle. They reported that the ideal habitat should be a mixture of grasslands, herbs, shrubs, and flowering trees because butterflies require mixed vegetation for survival of larval, pupal, and adult stage.

In a nutshell any area which is a combination of various habitats like Garden area, Forest area, Agricultural fields and Scrubland is the best site for maintenance, sustenance and diversity of fauna and flora. Champaner-Pavagadh Archaeological Park a World Heritage Site is one such site.