BIOLOGY AND ECOLOGY OF FEW SELECTED SPECIES OF BUTTERFLIES IN THE NATURAL HABITATS OF PAVAGADH HILL, PANCHMAHAL DISTRICT, GUJARAT

EXECUTIVE SUMMARY

LAKSHMI S PILLAI
Department of Zoology
The Maharaja Sayajirao University of Baroda

DECEMBER 29, 2020

Table of Contents

Chapter 1

Introduction

1.1 Lepidopterans

Lepidoptera is an order of class Insecta which includes both moths (Heterocera) and butterflies (Rhopalocera). Lepidoptera is an ancient Greek word, coined by Linnaeus in 1735 which is derived from lepis means to scale and pteron means wing respectively. Approximately, 1,74, 250 species of Lepidoptera were described, of which 17,950 are butterflies and the rest are moths (Sidhu et al., 2012). There are 17,200 species of butterflies reported worldwide, and out of which 1,501 species of them are inhabiting India (Kunte, 2000). The order Lepidoptera contains about 1,80,000 species of insects like skippers, moths, and butterflies. Following the order Coleoptera i.e., the order of beetles, Lepidopterans form the second-largest order amongst the arthropods. This order comprises of bright coloured butterflies found majorly during the day along with the night-flying moths that are dull in appearance, while skippers act as bridging organisms in the order Lepidoptera. Majorly all adult lepidopterans exhibit the presence of two wings. The order nomenclature is also based on wings since the word Lepidoptera meaning "scaly winged" as on the wings it is having small, microscopic dust-like scales.

Lepidopterans exhibit a well-defined life cycle consisting of four major stages: egg, larva (caterpillar), pupa (chrysalis), and adult (imago). The egg grows and metamorphoses to form the larvae which are voracious feeders mainly dependent on foliage, stem, roots, fruits, and flowers. Due to the aggressively feeding nature of them, the larvae of many moths and butterflies are considered a pest in agriculture and forestry. Following the larval stage is the pupal stage which is dormant wherein major structural and metabolic changes occur eventually resulting in the emergence of the adult aka the imago. Adults forms of these insects exhibit a major mutualistic character of pollinating the plants, as they depend on the flower nectar for nutrition. Lepidopterans also play an ecological role wherein they aid in transforming and recycling the plant matter into the animal matter which down the line serves as the food for a major group of animals. Organisms belonging to this phylum have been appealing to human imagination due to the unparallel beauty and delicately woven body architecture that they exhibit. They also provide references to various jewellery pieces, paintings, fabrics, postage stamps, etc. (Sule & Kumar, 2019).

Butterflies are marvellous Lepidopterans that play an important role in pollinating flowers and most of the crops because they visit flowers to feed their nectar. While feeding, the scales present on their bodies brush against the anthers and the pollens get stuck to these scales. When these butterflies visit the next flower, the pollens stuck on the scales get transferred to the stigma of the flower and pollination occurs. The butterflies are sensitive, and they are directly influenced by habitat change, weather conditions, atmosphere temperature. This makes them a good environmental indicator (Kunte, 1997). They offer a most diversified biological component of a forest ecosystem and have a great role in maintaining the cycling of nutrients, soil regeneration, and protection, pollination of flowering plants as well as natural regulation of pests (Ehrlich & Wilson, 1991). Among insects, butterflies are best suitable for ecological studies, as the taxonomy, geographic distribution, and status of many species are relatively well known. As many butterflies are bio-indicators of the environment, they can be used to identify ecologically important landscapes for conservation purposes (Sudheendrakumar et al., 2000). A distinct pattern of habitat utilization is shown by butterflies (Ehrlich & Raven, 1964).

1.2 Size range and distribution

A variety in size, developmental pattern, and the rate is seen in Lepidopterans. The tiniest organism here exhibiting a wingspan of about 4mm (0.13 inches) to largest having that of 30cm (1 foot).

These organisms also exhibit a variety in their rates of development wherein some fast-growing species complete the development in about three weeks while the slower metamorphosing organisms may require about two to three years for completing their life cycle. These organisms show a ubiquitous presence as they are present on all the continents except Antarctica. These insects are known to adapt well to all the different types of habitats from arid deserts to hills and mountains, from marshes to tropical rainforests. But of all the habitats, the most preferred ones are tropics, but polar vegetation reduces the proliferation of these individuals drastically. These organisms majorly tend to exhibit adaptations towards restricted ecological niches as they are often limited to a small group of plants, often just a single type of plant. Thus, they exhibit abundance in very specific habitats. But on the contrary, some individuals of this order exhibit peak in abnormal abundance and defoliation of large areas of forests and grasslands, lending the tag of injurious pests to the insects in agriculture and forestry.

Lepidopterans are also proven to damage human monetary sources of food, fabric, fodder, and timber. Speaking of the majority of damaging insects, moths top the chart, as they exhibit to be major pests at the larval stage itself. Yet, what is beneficial is the fact that these organisms do not act as carriers of plant diseases nor are parasites needing human hosts. Lepidopterans majorly damage all the plants including grains, sugar beets, sugarcane along with crops like cotton, tobacco, root and shoot crops, fruits, timber, shade trees, etc.

Some Lepidopterans benefit humans directly such as *Bombyx mori*, the domesticated silkworm; while there are other different types of silks like shantung and tussah produced by members of the family Saturniidae. Lepidopterans belonging to the family Megathymidae constituted by the giant skippers also provide a source of food, where larvae and even some adults are consumed as delicacies and also canned and exported. The larvae of moths like the South American cactus moth have been known to contribute to weed control. Thus, eventually, the caterpillars as well as the adults contribute to benefitting humans by the establishment of weed-eating caterpillars or flower pollination by adults. They also contribute to research studies in the fields of pure sciences such as ecology, biogeography, physiology; along with applications in interdisciplinary research in the dynamic fields like genetics, systematics, etc. since earlier times of research, silkworms have been major animal models to study the development of insects aided by the endocrine controls. Some organisms belonging here have also been used as models of evolutionary changes eg. the British peppered moth (*Biston betularia*) the profound model of industrial melanism produced on account of the industrial revolution.

A compiled checklist of 193 species of butterflies from different parts of Gujarat in the form of a book was published by Anand Agricultural University (Parasharya & Jani, 2007). Department of Zoology of The M S University of Baroda published a detailed project report on butterflies within Gujarat in 2015 and recorded 61 species of butterflies belonging to 40 genera and 5 families (Kumar, 2015). A total of 70 butterfly species belonging to 5 families and 49 genera were observed from the fragmented Habitats of Waghai Botanical Garden of The Dangs – Gujarat (Gandhi & Kumar, 2016). 61 species belonging to 43 genera in five families were reported from Vadodara (Bhatt & Nagar, 2017).

1.2.1 Feeding habits

Lepidopterans tend to exhibit a diversity of adaptations amongst different species depending upon the climate, environment, availability of host plants, feeding mechanisms, development patterns, etc. The hosts for members of Lepidoptera range from primitive mosses and liverworts to the advanced gymnosperms and angiosperms. These organisms depend on various plant parts such as flower consuming larvae such as the plume moths belonging to the family Pterophoridae. While some depend on nectar consumption by adults. The yucca moth belonging to the family Incurvariidae, leaf roller moths of family Tortricidae, etc. depend on plant products such as cones and their fruits and seeds for satisfying their nutritional requirements. While the highly adapted flour eating moths of genus Ephestia are household pests feeding on stored grains and cereals. Some of the members of Lepidoptera are known to bore the succulent stems or buds of the plants to derive nutrition. The pine moth (Rhyacionia) depends on the terminal shoots of conifers for food while some depend on the turf of grasses. Contrastingly, members of the families Cossidae, hepialidae, Sesiidae, etc are known to bore the woody stems. There are some families of Lepidopterans that depend on decaying plant matter for their major nutrition such as members of the family Tineidae, Blastobasidae, Pyralidae, etc. But as compared to other orders, Lepidopterans are less dependent on animal derived matter for their survival as some families are strictly plant miners such as the members of the families Gracillariidae, elachistidae, and Tischeriidae (Stefanescu & Traveset, 2009; Mukherjee et al., 2015; Bhakare & Ogale, 2018).

1.3 Behaviour

1.3.1 Food selection by the adult

Adult Lepidopterans are the ones that exhibit maximum mobility, wherein they may travel short or long distances in search of food or a suitable environment to reproduce. Thus, the adults tend to have a well-developed ability to navigate through sight and scent both, wherein diurnal (insects active during the daytime) mainly depend on their vision, while nocturnal insects (the ones active during the night time) utilize their olfactory abilities.

Figure 1: Foraging behaviour of butterfly

The chief food source for adult Lepidopterans is floral nectar, sap, ripened fruits, honeydew, etc. majorly all the insects here exhibit varying animal interactions that eventually converge to mutualistic relations, wherein in exchange for food insects derive, they pollinate the plants in an exchange thus show an established beneficial interaction of mutualism. The mutualism may either be specific obligatory or facultative. These insects tend to exhibit certain characteristics that help them establish mutualistic relations such as members of the family Sphingidae display the presence of proboscis, a long tubular tongue that helps derive nectar and pollinate the plants with tubular flowers (Figure 1). While obligatory interactions are displayed by the yucca plants and yucca moths, where the moths depend on yucca fruits for the developmental stages whereas the fruits develop exclusively from the moth pollinated flowers. This phenomenon of obligatory mutualism also illustrates coevolution wherein the female moth exhibits the presence of tentacles on the mouthparts which aids in gathering pollens during the process of procuring nutrition (Ehrlich & Raven, 1964; Stefanescu & Traveset, 2009).

1.3.2 Courtship and mating

The phenomenon of mating amongst insects is majorly initiated by the females which send out pheromonal signals to attract the males while it is still in the pupal stage. The male antennae show the presence of scent sensilla which helps detect the pheromonal signals from the females (Honda et al., 1998). Some males display a prolific courtship behaviour where they detect the presence of females at a distance of about 5 to 6 kilometres using their large feathery antennae and eventually form courtship swarms to lure the females (Figure 2).

Some organisms also exhibit the presence of dancing swarms eg. European ghost moth (*Hepialus humuli*), the males then locate the females which then exhibit an elaborate courtship between the two individuals. While some butterflies display bright colouration and characteristic pattern formation to initiate mating. Male pheromones also play a role in establishing courtship, wherein androconia, the scent scales on the body majorly wings and legs induce receptivity of the females for mating. Post courtship follows mating where the external genitalia fit together mechanically such that they stimulate the sensory nerve organs on the female. Some butterflies exhibit elaborates active courtship behaviours eg. the sulphurs, wherein the male and female partners fly high in air, where they display elaborate behavioural patterns that provide stimuli for the next action in the course. Such highly specific actions help structure barriers to intraspecies hybridization.

Figure 2: Courtship behaviour of butterfly

Some males also exhibit territoriality, where they defend particular areas from intruding males or males who pass out at the other females commonly seen in butterflies such as admirals, coppers, and the asterocampa. Similarly, some butterfly species show congregations of males established that travel to hilltops exhibiting territory marking and pre-mating rituals (Honda et al., 1998).

1.3.3 Migration

Lepidopterans are fascinating migrators that exhibit varying patterns of transport. For instance, the Monarch butterfly, *Danus plexipus* is one of the butterflies which exhibits an annual long-distance to and fro migration where adults move southwards in autumn and then relocate to the north during spring. Monarchs are also known to colonize Hawaii, Australia and occasionally reaching Africa and Europe too making a long flight of crossing the Pacific Ocean. *Vanessa cardui* exhibits something known as mass flights which occur everywhere the organisms are found. However, for major Lepidopterans, one-way flights or emigrations hold more importance than migration due to their short life cycles or extremely cold conditions that they emigrate to. The painted lady, cloudless sulphur (*Phoebis sennae*), owlet moths, and pierid butterflies are the best-known examples of mass movements which usually occur for extending the range that the species sprawls in. radar technologies-based studies have revealed that migratory lepidopterans travel as fast as about 100 km/hour when they happen to select fast blowing wind currents nearer to the ground which helps directionalize their movement. They maintain their path of flight by fine-tuning their direction in response to the crosswinds. This pattern of flight along with the wind currents minimizes the energy inputs required from the metabolic aspects of the organism.

1.4 Ecology

1.4.1 Environmental hazards

Lepidopterans establish the first trophic level of the ecological pyramid, as these organisms are major primary consumers that depend directly on plants and plant products, due to their abundance, large variety of species, and the diversity of their food habits. In turn, they establish the food chain and food web when they act as prey for the hosts of predators, parasites, and scavengers. All life cycle stages of these insects are subjected to predatory attacks. The prominent predators depending directly on Lepidopteran insects are centipedes, spiders, mantids, bugs, beetles, ants, wasps, frogs, tree frogs, lizards, birds, rodents, bats, monkeys, etc. herein the invertebrate predators locate the Lepidopterans based on vision and scent while vertebrates mainly depend on sight, one exception is the bats that exhibit echolocation (use of ultrasonic sound to locate objects and preys). There is a group of parasites that attack Lepidopterans are known as parasitoids, which are known to have a greater impact on caterpillar populations. Female parasitoids display a scent-based selection of suitable hosts then lay their eggs, eventually which hatch to larvae that feed on almost all the tissues exhausting the host completely. To combat the parasitoid attacks, the Lepidopterans seem to have evolved defences such as toxic repellent secretions that caterpillars release, along with the high reproductive rates that help eliminate the risk of diminishing numbers due to parasitoid attack. Apart from this, Lepidopterans are also subjected to attacks from other organisms such as small protozoans, roundworms, bacteria, viruses, fungal infections, etc. which damage the most due to the abundance and crowding they exhibit. But humans seem to have derived benefits from here wherein they tend to use Lepidopteran parasites to control injurious pests (Kunte, 2000).

1.4.2 Threats to their Existence

The deterioration of natural surroundings with climate change and excessive collection for trading is mainly responsible for the shrinkage and depletion in the number and population of species of butterflies and their areas. The diversity, abundance, and omnipresence of butterflies form an important part of the food chain. Various destructive agents like birds, lizards, spiders may destroy them depending upon butterfly species. Over 95% of them are destroyed before reaching adulthood. Butterflies are neither nasty nor tasty, so they are not hunted by human beings. But still, some beautiful butterfly species are hunted and collected by human beings in large numbers for ornamental purposes. Their different stages like eggs, caterpillars, and pupae are used for the purpose of breeding. Though In India illegal trading is very rare, it is a challenge to the existence of butterflies. The only places in India where a considerable number of butterfly trading has been reported from the Himalayas and northeastern part of India, from where very beautiful and attractive swallowtails are caught and illegally exported (Kunte, 2000).

1.4.3 Habitat Destruction, Degradation, and Fragmentation

These are the major cause of the vulnerability and extinction of butterfly species. In India habitat loss, degradation, and fragmentation of habitats take place due to river valley projects, expansion of agricultural lands for agricultural practices, construction of new buildings, deforestation, rural development, urbanization, industrialization, settlements, motorways, development of tourism for raising revenue, etc.

1.4.4 Grazing

It affects the existence of butterflies in two ways, one is trampling, where early life stages of butterflies get killed. Trampling would affect almost all butterflies whose caterpillars feed on herbs and grasses. On the other hand, grazing may bring changes in the vegetation composition completely or alter the vegetation which is suitable to certain butterflies.

1.4.5 Forest Fires

It is a very strong destructive agent that can cause a serious impact in a short period. This can destroy habitats. Fires destroy annual grasses, herbs, grasslands, dry deciduous forests, etc. It desiccates the evergreen forests and increases the proportion of deciduous trees in them. At the ground level, they disturb the microclimate of the herbs growing on the forest floor and make it suitable only for weeds. Thus, nectar plants, as well as larval host plants of butterflies, are destroyed.

1.4.6 Application of Pesticides and Weedicides

Unscientific usage of weedicides removes larval host plants of butterflies and pesticides destroy the early stages of them. Sometimes it becomes a secondary problem caused by habitat reduction and fragmentation due to agriculture.

1.4.7 Protection against danger

As Lepidopterans are subjected to varying hunts and predatory pressures, Lepidopterans over time have developed multiple defence mechanisms. Some examples are some skippers, hawk moths, underwig moths, and others display speedy, erratic flights. They also mimic playing dead or fall and become immobile to escape predatory attacks. Camouflage is also one technique employed by Lepidopterans to avoid falling under the predatory eyes. The larvae of Lepidopterans have also been known to develop predatory escape strategies, wherein some drop to the ground upon getting disturbed while those of owlet moths can jump up to several inches too. Some Lepidopterans exhibit the presence of dense hair and scales on the exoskeleton which helps avoid predation for instance escaping the spiderwebs. Certain species of moths have been known to develop kills to perceive navigational sound pulses from the bats which aid in escaping by performing radical evasive maneuvers when the predator is closer or diving to the ground when the signal pulse is weak indicating the distant presence of bats. *Galleria mellonella* is known to perceive ultrasonic frequencies of about 3, 00, 000 hertz greater than bats echolocation capacity (2, 12,000 hertz). Yet predators have also developed mechanisms to catch the prey. One such mechanism is targeting prominent coloured eyespots or tails and hindwings of organisms that exhibit seizure, but the organism is known to escape without any vital injuries.

Another effective measure employed to escape predation is hiding away. For instance, many caterpillars like cutworms, hide in the litter, and forage at night. Some moths and butterflies are known to have flattened bodies that help them hide in crevices or under loose barks to avoid predation. Hibernating butterflies are known to hide in hollow trees or dried leaves lying immobile. Many lepidopteran larvae exhibit individual nests of rolled, folded, or webbed leaves and grasses to protect themselves, while some even become wood borers as seen in Cerura and Acronicta. Some larvae like tent caterpillar moths, ermine moth, Mexican social white butterfly, and others display the formation of communal nests; while larvae of the members of family Psychidae and Coleophoridae exhibit masking of larvae by twigs and leaves.

Another potent form of self-defence shown by lepidopterans is camouflage. It confers a cryptic appearance as the colouration pattern of individuals blends with their background. It is aided by prevalent immobility that makes it very difficult for predators to spot these individuals. Leaf dependent larvae exhibit colouration and stripes on their body such as to blend with the leaf colour and pattern, eg. Nerice displays an outline that mimics the elm leaf. Some lepidopterans exhibit twig-like slender bodies as seen amongst inchworms. While some Lepidopterans exhibit disruptive markings on their bodies so as to make them appear as different individuals. Some butterflies show startling colouration which helps cause a delay in the attack from predators. Some moths and butterflies also have different colouration patterns on and under the wings, thus upon flight danger signals are viewed which temporarily delay the predatory attack as commonly seen in Catocala. Whereas butterflies such as morphos, hairstreaks, and anglewings upon disturbance take sudden flights exposing the brightly coloured wings which initially seem cryptic as a result may escape predation. The larvae also show the presence of dark spots on their bodies which make them look scary and provide the ‘startle effect’.

Audio tricks are also employed by certain lepidopterans as an escape mechanism. As seen in hawkmoth caterpillars and pupae of gossamer-winged butterflies grating and squeaking noises; while *Acherontia atropos* makes chirping sounds and Ageronia makes a clicking sound on a flight. These sounds help delay the predatory attacks. Tiger moths which are inedible, make high-pitched grating sounds, not audible to humans but can be perceived by bats as a warning of inedibility which prevents predation of the moths.

Lepidopterans also display the use of toxins and repellents to get protection like members of family Nymphalidae show the presence of high concentrations of toxic glycosides which they acquire from the host plants from where they derive nutrition. Yet most of the time, toxins are produced by the insect themselves and stored, thus direct interaction of the predator is required to determine the presence of toxins eg burnet moths exhibit presence of hydrogen cyanide. Insects show the presence of specialized glands that release toxins at the time of attack such as members of the family Arctiidae release repellents from the prothorax. While some insects show autohemorrhization from joints in the body upon being subjected to predators. The snowtail butterflies and tussock moth larvae possess specialized glands that release volatile repellents, whereas larvae of other species spray formic acid from the prothorax upon disturbances. Some larvae and adults exhibit the presence of barbed hair that introduce toxins in the body of predators causing an inflammatory response for example members of family Limacodidae, Megalopygidae, etc. *Arctia cajal* directly injects toxins into the predator's body through sharp spines on the hindlimbs. Usually, lepidopterans send visual threat signals where they exhibit specific patterns, shapes, and markings to frighten the predators which are then memorized. The evolution of such resemblances is known as mimicry, which helps them escape predation by mimicing organisms that are originally toxic.

Lepidopterans are also known to exhibit various morphs i.e., hereditary variants that show different adaptive values with respect to various physiological features to adapt to an environment. Investigations on the peppered moth (*Biston betularia*) provide the basis for the evolution of industrial and natural melanism with respect to the environment where the organisms are found. Some Lepidopteran species exhibit polymorphism where the individuals become mimetic towards various organisms that have geographically and physiologically survived certain external environments.

1.5 Form and function

Lepidopterans are versatile where they a diversity of size structures and other characteristics instilled with evolution, where some individuals are known to show extremely primitive features, while some species have become extremely evolved and gained specialized characteristics which can be seen evidently amongst all the stages of the life of an organism.

1.5.1 The adult

Adults of lepidopterans commonly exhibit scales and hair-like projections coming out from the single layer of epidermal cells. Most insects tend to display scales on the external body, whereas internally the body is divided into distinct body segments also known as tagmata, namely the head, thorax and abdomen. The head specializes in exhibiting major sensory organs and structures required for feeding and ingestion. Thorax mainly specializes in imparting locomotory abilities. While the abdomen deals with organs concerned for digestion, excretion, and reproduction (Figure 3).

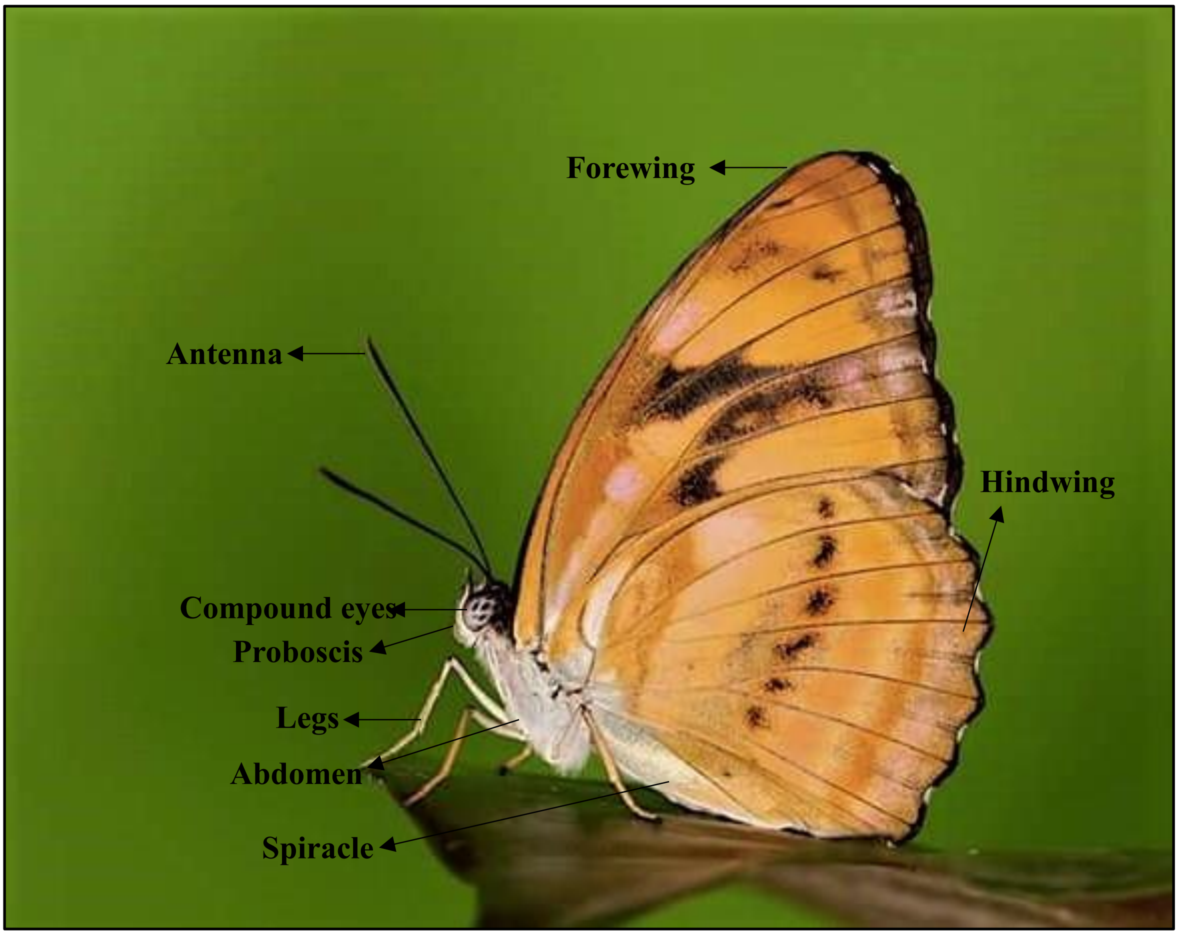


Figure 3: Labelled image of an adult butterfly

1.5.2 Head

The anterior-most segment of the body of any organism is the head, specialized with sensory and nervous tissue accumulation. Evolutionarily, it is evolved from the first six primitive body segments or somites or metameres. It also houses the antennae, which are prominent multi-segmented structures with sensilia which act as olfactory receptors. Moths are known to have long, slender, antennae with anterior portion either comb-like or featherlike, while skippers and butterflies are known to have club-shaped anterior-most tips of antennae which the house majority of the sensilia. Some of these also exhibit the presence of a cluster of sensory bristles on each side of the head near the eye. The head also houses the photoreceptors developed to well-functioning eyes also called the ommatidia. Some Lepidopterans are known to have a pair of small eyes called ocelli along with ommatidia which exhibit light-sensing abilities but are incapable of forming any images. The compound eyes efficiently distinguish movements but cannot resolve images (Figure 4).

Diurnal species especially those of butterflies are known to be able to distinguish flower shapes and courting individuals based on wing patterns which are species specific. Some individuals also exhibit colour perception, though in the blue-violet segments of visible light, while moths being nocturnal perceive ultraviolet light. Some organisms also exhibit strong olfactory abilities, along with an acute sense of taste brought about through palpi and tarsi. While the head also houses chewing mouthparts for example members of the family Micropterigidae.

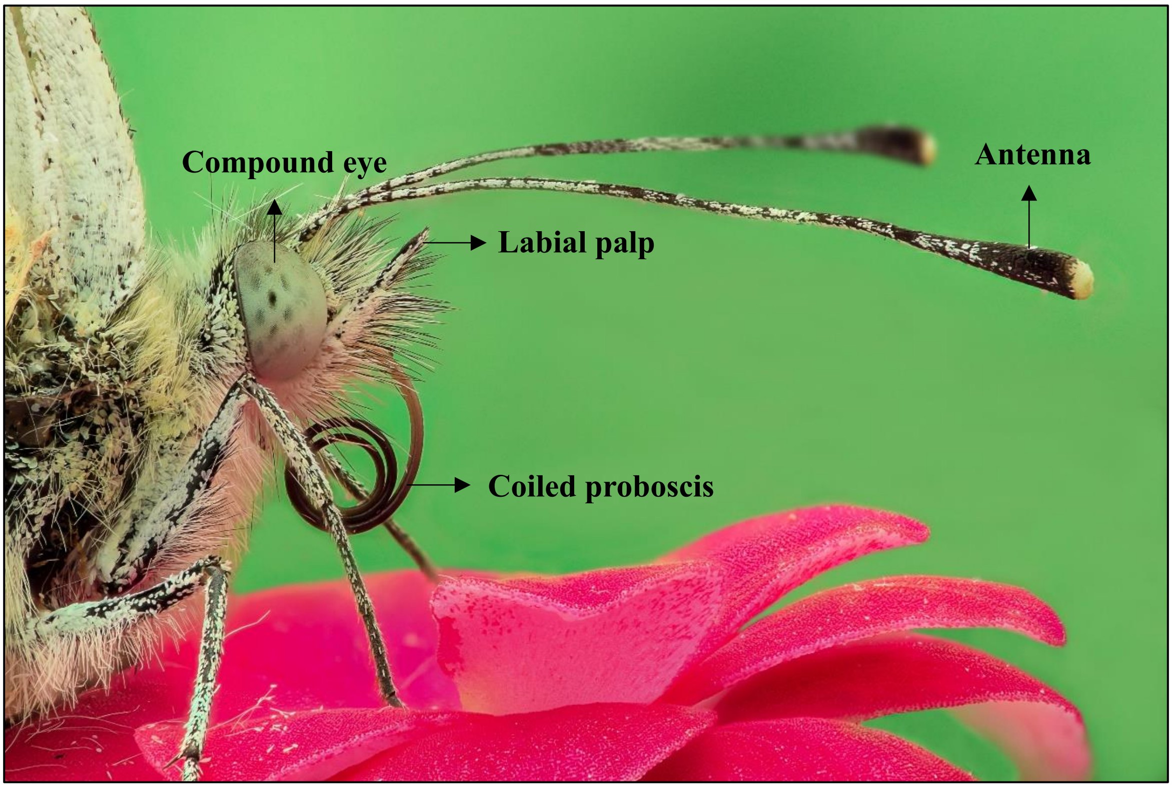


Figure 4: Labelled parts of the adult butterfly head

Caterpillar mouthparts mainly comprise of the anterior flap or labrum, along with chewing jaws or mandibles that help with mastication, followed by two pairs of maxillae which join behind the mouth forming the labium. Maxillae are known to bear jointed sensory appendages also called palpus. All these mouthparts aid chewings and modifications of the solid food. Some individuals have the first pair of maxillae modified to form the tubular proboscis also known as the haustellum which aids consume liquid products. Maxillae also bear the sensory palpi which appear segmented. Over the due course of evolution, haustellum and palpi have become redundant in some lepidopterans, thus eventually permitting only larvae to exhibit the character of voracious feeding and restricting the adults to aid reproduction and dispersal.

1.5.3 Thorax

The second major body segment is known as the thorax, bifurcated into the prothorax, mesothorax, and metathorax derived from the primitive segments. Prothorax bears the first pair of limbs and spiracles, mesothorax houses the second pair of limbs and spiracles along with the pair of forewings, while the metathorax bears the third pair of legs and the pair of hindwings. For some individuals, metathorax also houses the tympana i.e., the auditory organs which serve as receptors for high-frequency echolocation or as receptors for mate location calls. Certain sound signals are perceived by timbal organs that sense mechanical clicking. The wings begin development in the maturing larvae via epidermal invaginations. Then the pupa is formed by evagination becoming large and flat with subsequent development of tracheae and tubular veins. Slowly as the pupa grows, the adult emerges with fully formed wings which later expand to full size. The wings exhibit the presence of scales and hair-like tufts which aid in courtship as they may house the scent glands of the androconia, or through the display of various colours and patterns. The pigmentation is brought about by pigments such as melanin, uric acid derivatives, and flavones. These pigments also help provide the microstructure of hair and scales that refract differently producing visually varying patterns. Multiple visual effects are brought about by combinations of pigmental and structural colours. The wings also display specific venations and sizes amongst different individuals, wherein mostly the hindwings are shortened and reduced in size as compared to the forewings. The anterior/ leading/ costal end of the forewings is thickened with stronger veins as compared to the posterior/ anal end which is thinner and weaker. The pattern of wings also depends on the families and species. Some families show extremely diminished wings, or some are even absent.

1.5.4 Abdomen and genitalia

The posterior-most major body segment is the abdomen which houses about 10 segments. First eight abdominal segments bear one pair of spiracles each. Segmental appendages are absent in most varieties except for the condition wherein vestiges form genitalia. The abdomen also bears specialized structures that function in producing pheromones. Apart from this, the abdomen houses spines, teeth, setae, and scale tufts which aid in courtship and mating. Males have ring-like attachment surfaces for holding the dorsal structures in position along with a pair of lateral clasping organs. During copulation, males everse the aedeagus through the vesica to inseminate the female. These structures are derived from segments 8 and 10 of the vestigial abdominal appendages. Females house genitalia with internal ducts and openings, which are so peculiar that lepidopterans can be classified based on these traits along with mouthparts, wings, and early development stages. The testis is paired in primitive Lepidopterans but eventually fuse to form one organ in due course of evolution but, sperm ducts remain paired in both cases. In some insects, sperms pass from the testes to vasa deferentia to be stored in the seminal vesicles. Nourishment to the sperms is provided by fluids secreted from the accessory glands.

The female reproductive system comprises of the ovaries, paired accessory glands that provide yolk, along with a system of receptacles and ducts for obtaining, storing and passing the sperms to the egg to bring about fertilization. Females have individual oviducts which fuse to form the common oviduct that ends into the vagina. During copulation, the receptacle acts as a bearer for depositing the sperm capsule from which sperms are released which then swim through the seminal receptacle where sperms are stored until egg laying which may occur hours/ days/ months after mating.

1.5.5 The egg

The egg is enclosed the protective chorion, through which a system of tiny canals, micropyle. The eggs pass along the oviduct and end up in the vagina. Before laying eggs, they come into contact with the droplets of seminal fluid stored in the female receptacle where fertilization takes place. The eggs that laid are mostly spherical but mostly flat, long, and tapering for certain families. Their surfaces may be sculpted with pits, projections, and ridges (Bhakare & Ogale, 2018) (Figure 5; Table 1).

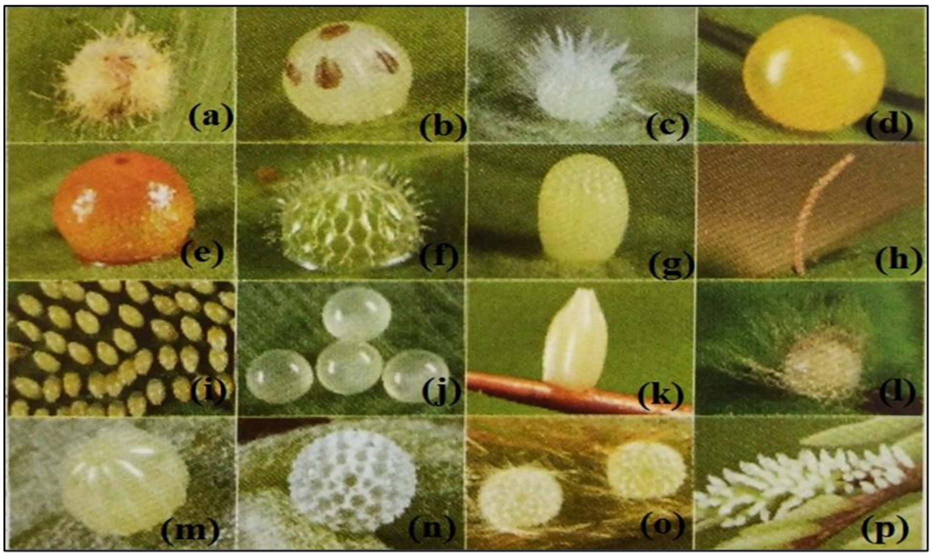


Figure 5: Variations in color and shape of Eggs belonging to different families of the order Lepidoptera (Source: Bhakare & Ogale, 2018)

Sr. No.	Family of the Butterfly	Common Name
a.	Hesperiidae	Common Redeye
b.	Nymphalidae	Black Prince
c.	Nymphalidae	Common Castor
d.	Papilionidae	Southern Bluebottle
e.	Papilionidae	Southern Birdwing
f.	Nymphalidae	Baron
g.	Nymphalidae	Malabar Tree Nymph
h.	Nymphalidae	Tamil Yeoman
i.	Pieridae	Common Jezebel
j.	Nymphalidae	Dark Evening Brown
k.	Pieridae	White-Orange Tip
l.	Hesperiidae	Water Snow Flat
m.	Nymphalidae	Chocolate Pansy
n.	Lycaenidae	Indian Sunbeam
o.	Lycaenidae	Banded Blue Pierrot
p.	Pieridae	Three-Spot Grass Yellow

Table 1: Eggs of Different Butterfly Families

1.5.6 The larva, or caterpillar

The larvae are structurally simple and primitive, which aid in classifying organisms into suborders, superfamilies, and families. The traits aid in making speculations about relationships amongst taxa. The head of the larvae bear short antennae and a pair of minute eyes called stemmata. The mouth bears a liplike labrum with paired mandibles that are short, broad, and allow consumption of plant materials. The next is the first pair of maxillae that house segmented palps along with a nearly connected labium-hypopharynx from which silk is spun. Each of the thoracic segments bears short, segmented legs. While the remaining 10 segments constitute the abdomen. Abdominal segments 3 to 6 and 10 bear the prolegs homologous to primitive segmental appendages. Each proleg bears minute hooklets which help hold the larvae onto surfaces. Hooklets are extended by the body fluids moving into those structures, following which placement on the surface happens, which leads to retraction of the body and reduction in the cuticle elasticity as a result gripping happens to the surface. The prothorax and abdominal segments 1 to 8 bear a pair of spiracles each. The larval epidermis also bears bristles known as primary setae, wherein the number of primary setae vary according to the species thus aid in classification. The hairy looking caterpillars possess secondary setae. While larvae which live as borers, burrowers and miners are plain devoid of any projections whereas, the ones living in open show diversity in shape, colour, pattern, and ornamentation. Some larvae also show modifications or absence of prolegs as seen in larvae of family Gracillariidae, while in the puss moth caterpillars, the last pair evolves into long eversible stemmatopoda.

Sr. No.	Name of Butterfly	Larval Host Plant	Family of Larval Host Plant	Type of Plant
1.	*Eurema hecabe* Linnaeus, 1758	*Cassia tora*	Caesalpiniaceae	Herb
2.	*Hypolimnas misippus* Linnaeus, 1764	*Justicia betonica*	Acanthaceae	Herb
3.	*Junonia lemonias* Linnaeus, 1758	*Hygrophilan auriculata*	Acanthaceae	Herb
4.	*Vanessa cardui* Linnaeus, 1758	*Echinops echinatus*	Asteraceae	Herb
5.	*Junonia orithya* Linnaeus, 1758	*Sida rhombifolia*	Malvacaeae	Herb
6.	*Belenois aurota* Fabricius, 1793	*Cadaba fruticosa*	Capparaceae	Shrub
7.	*Danaus chrysippus* Linnaeus, 1758	*Calotropis gigentea*	Apocynaceae	Shrub
8.	*Catopsilia pomona* Fabricius, 1775	*Bauhinia racemosa,*	Fabaceae	Shrub
9.	*Euploea core* Cramer, 1780	*Nerium oleander*	Apocynaceae	Shrub
10.	*Symphaedra nais* Forster, 1771	*Mangifera indica*	Anacardiaceae	Tree
11.	*Catopsilia pyranthe* Linnaeus, 1758	*Cassia fistula*	Caesalpiniaceae	Tree
12.	*Curetis thetis* (Drury, 1773)	*Pongamia pinnata,*	Fabaceae	Tree

13.	*Euploea core* Cramer, 1780	*Ficus benghalensis*	Moraceae	Tree
14.	*Catochrysops strabo* Fabricius, 1793	*Butea monosperma*	Fabaceae	Tree

Table 2: List of Larval Host Plants Identified from Pavagadh Hill

Anatomically the larvae are simplified, with an overall well-developed digestive system. Some possess paired silk glands, extending far into the abdomen. The gonad development which begins during the embryonic stage proceeds through the larval form along with the wing development. Some larvae possess specific repellents or toxins which circulate in the blood as a defence mechanism. They exhibit limited visual capacities wherein differentiation between light and dark can be done. While they exhibit an acute sense of taste with alarming receptors

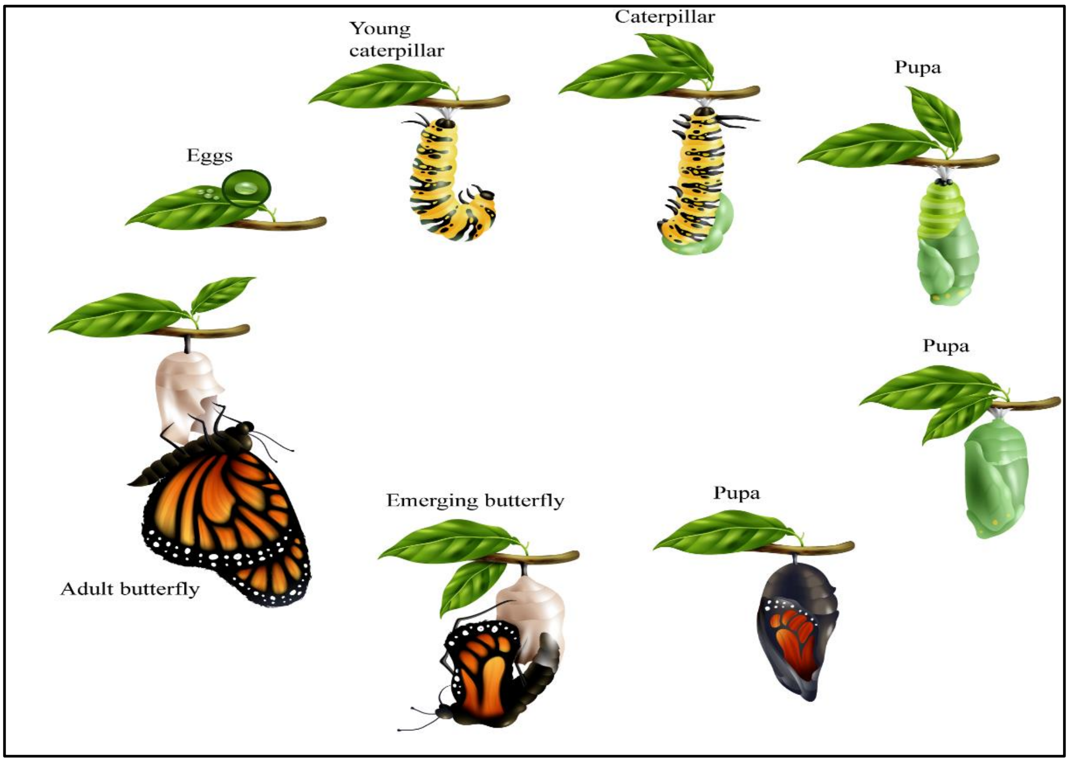


Figure 6: Lifecycle of Butterfly

present on the antennae and palpi as discrimination of food to edible and nonedible groups is requisite. They also possess a sense of touch due to the receptors present on the setae. Some of them also react to certain human sounds or disturbances. Some of the identified larval host plants from the study area are enlisted in Table 2.

1.5.7 The pupa, or chrysalis

Pupae of lepidopterans have also shown an evolutionary gradation, such as primitive mandibulate moths have free pupae with movable mandibles but advanced higher moths and butterflies have tightly grasping body walls which restrict movements making the pupal stage mostly sedentary or exhibit minor movements such as wriggling. Few pupae have stridulating rasps for sound production. Pupae exhibit adults to a very larger extent. Wherein they display a prominent presence of wings, proboscis, legs, antennae, etc. pupae exhibit a slight water loss and a minor respiratory exchange, apart from which they are self-sufficient. Pupae exhibit a tissue breakdown i.e., histolysis and remodelling aided by apoptosis and proliferation which eventually leads to the development of adult structures from the pupae (Kehimkar, 2008; Bhakare & Ogale, 2018).

1.5.8 Growth, moulting, and metamorphosis

A major characteristic of insects is metamorphosis, which is brought about by moulting that eventually causes growth. These processes are mainly brought about by the hormones- juvenile hormone and ecdysone- released from the corpora allata and the paired prothoracic glands in insects. The major role in ecdysis is played by the prothoracic gland, inducing metamorphosis from egg to larvae to pupae eventually to adults. The interplay between these moulting hormones namely juvenile hormone and ecdysone and alterations in their levels and peaks eventually help the organism to exhibit moulting, eventually metamorphosis. The lifecycle is of the buteerfly is represented in the figure 5.

1.6. Co-evolutionary Relationship among butterflies and plants

Insects have shown amazing evolutionary adaptability, as evidenced by their wide distribution and enormous diversity of species. Most of their structural modifications are in their wings, legs, antennae, mouthparts, and alimentary canals. Such a wide diversity enables this vigorous group to use all available food and shelter resources. Some of them suck the sap of plants, some are predaceous, some chew the foliage of plants, some are parasitic, and some live on the blood of various animals. Specialization happens in them to enable insects to eat a variety of food as per their habit, like leaves of only one kind of plant. This specificity of eating habits lessens competition with other species and to a great extent accounts for their biological diversity.

Coevolution is what occurs between pairs of species or among groups of species and is a process of reciprocal evolutionary change. The concept of coevolution was first developed by Charles Darwin. Darwin mentioned evolutionary interactions between flowering plants and insects in his book ‘On the Origin of Species’ published on 24th Nov 1859. Coevolution term was coined by Paul R. Erlich, Peter H. Raven in 1964. Animal life is not possible, or they cannot exist in the absence of plants. The mouthparts of insects have adapted themselves to different modes of ingestion of food. The mouthpart of a butterfly is of siphoning and sucking type, which is best suited to draw nectar from the flowers. The Labium is reduced to a triangular plate bearing palps. Mandibles and hypopharynx are absent. Both the palps-maxillary and labial are in a reduced condition. The galea of the first maxillae in the only well-developed structure. They feed on a liquid diet during the adult stage by feeding on nectar which contains dissolved sugar, salts, and other minerals from a variety of sources ranging from flowers, tree sap, rotting fruit, feces, and so on. When a butterfly finds a potential food source it unfurls its proboscis and uses the tip to feed on fluids.

Due to the importance of butterflies as indicators of environmental quality and their usefulness as model systems to address ecological and evolutionary questions butterfly biology has become a focus of research. In this study, a trial was conducted to examine proboscis length and its importance in carrying out butterfly processes concerning the nectar plants. To study the corolla proboscis interrelationship, we have studied the coexistence of butterflies and different flowering plants.

The interrelation between insects and flowering plants probably existed from the Cretaceous period (over 125 Million Years Ago). The early spermatophytes were largely dependent on the wind to carry their pollen from one plant to another. It was believed that around 125 million years ago a new pollination strategy developed, and angiosperms (flowering plants) first appeared. Previously, the involvement of insects in pollination was as "pollination assistants". Insects carried the pollen between plants merely by their movements. The actual relation between plants and insects began in the Cretaceous, with beetle pollinating the gymnosperms. The morphology of the first fossil-based angiosperms is similar to modern-day plants that are also fertilized by beetles. It seems that beetles led the way in insect pollination, followed by flies.

Insect pollination or Entomophily is a form of pollination where the insects distribute pollen grains. Features of flowers pollinated by insects are bright colors, sometimes patterns, and leads to rewards of pollen and nectar. Also, an attractive scent is present that sometimes mimics insect pheromones. Wind and water pollination require the production of vast quantities of pollen because pollen grains are deposited by chance. So completely depending on wind or water pollination is not economical. To overcome that plants, need pollinators to move their pollen grains from one plant to another. The need is to have pollinators consistently choose the same species of flowers, such that they must encourage specific pollinators to maintain the same species fidelity.

The attractions offered are mainly nectar, pollen, fragrances, and oils. The ideal pollinating insect is hairy so that pollen adheres to it, and spends time exploring the flower so that it comes into contact with the reproductive structures. Insects involved in pollination are bees, butterflies and moths, wasps, flies, ants, and beetles. Entomophilous plant species have evolved strategies to make themselves more appealing to insects like appealing shapes and pattern brightly colored, scented flowers, nectar. Entomophilous plants have pollen grains which are generally larger than that of anemophilous plants. The process is energetically costly and entomophilous plants bear the energetic costs of nectar production.

Butterflies and moths have hairy bodies and long proboscises that can probe deep into tubular flowers. Butterflies are attracted to pink, mauve, and purple flowers which mostly fly by day. The flowers are often large and scented, and the stamens are positioned such that pollen is deposited on the insects while they feed on the nectar (Ehrlich & Raven, 1964). Nectar is secreted for feeding the visiting insects. The position of Nectar glands is for an insect to touch both the stigmas and the anthers. They usually open during the day as butterflies are active during daytime. It possesses a tubular corolla which allows the proboscis to enter and collect the nectar. Flowers are usually in clusters and it provides a landing platform for the butterflies.

1.7 Classification

1.7.1 Distinguishing taxonomic features

There are various distinguishing characters which Lepidopterans use mouthparts, venation pattern, the anatomy of various systems, etc. which aid in distributing to ordinal, subordinal and family-level characteristics. Mouthparts to distinguish different Lepidopterans are mandibulate or haustellate or degenerate. Venation maybe homoneurous or heteroneurous or aculeate or nonaculeate or coupling. Venation patterns also derive differences and similarities between organisms. The most primitive groups depict maximum veins and branches in each wing, increased in forewings and comparatively reduced in hindwings. The genitalia and its structures also help in classifying insects such as female ducts can be bifurcated based on the internal ducts and openings that aid different patterns of insemination and oviposition.

1.7.2 Annotated classification

The lepidopteran classification follows Neils P Kristensen (1999) varying in categorizing taxonomic groups. The traditional taxonomy dealt with gathering superfamilies and families into suborders, while the recent advances in taxonomy promote organizing suborders to clades.

1.7.3 Order Lepidoptera

Characteristic features exhibited by lepidopterans:

1) These insects display complete metamorphosis
2) Wings are covered with flat scales
3) These insects exhibit mandibulate larval mouthparts
4) Adult mouthparts appear from being mandibulate to haustellate which sometimes become vestigial
5) Venation of wings ranges from being complex in primitive lepidopterans to exhibit a considerable reduction in adults
6) Almost all these organisms are phytophagous

1.8 Rationale of the Study

According to the Gadgil, 1996 report, India is one of the top twelve mega countries of the world, sheltering 5, 00,000 species of living organisms. Environmental factors also influence and affect species diversity. A correlation has been observed between species diversity and the structural complexity of habitats. Species diversity generally increases when a greater variety of habitat types are present (Ried et al., 1993). The present study was conducted in Pavagadh hill and its surrounding area,

The literature survey reveals that most of the research works were carried out in the area of geochemical stratigraphy, its conservation strategies, a study on flora, and taxonomical study of spiders. Though it is a world heritage site and having ecological importance, many of the areas remain unexplored by researchers. The increased industrialization and urbanization have serious effects on the ecology of this heritage site. These activities rapidly causing environmental damage and degradation of natural resources. So it is time to awake ourselves and protect our natural resources. Looking into the ecological and biological importance of the area, the present study aimed to investigate the diversity, biology, and ecology of the butterflies of Pavagadh Hill. This study will help to assess the diversity and status of butterflies in the Pavagadh hill so that appropriate conservation strategies could be developed.

1.9 Objectives of the Study

The abundance of butterflies usually indicates a healthier ecosystem (Fernandes et al., 2016). Butterflies hold an important position in the food chain. Since no work was done in this area on butterfly diversity, this study was taken up for a period of three years from January 2017 to December 2019. Hence the objectives of this research work entitled, Biology and Ecology of few selected species of Butterflies in the Natural Habitats of Pavagadh Hill, Panchmahal district, Gujarat are as follows:

i. To study the abundance, diversity, and biology of butterflies in Pavagadh.
ii. To establish the co-evolutionary responses of butterflies with plants.
iii. To study the phenology of plants in Pavagadh.

Chapter 2

Materials and methods

In compliance with the proposed objectives, the following materials and methods were followed. The details of the study area, materials used, methodology applied, and the measures which were taken have been discussed in this chapter.

2.1 Study area

Pavagadh Hill is situated in Panchmahal district of Gujarat at 50 km north-east of The M. S. University of Baroda, Vadodara. At the base of the hill, the historic city of Champaner is located. With Champaner and Pavagadh Hill, the Champaner-Pavagadh Archaeological Park is formed. It is one of the 38 World Heritage Sites of India which has been inscribed by UNESCO on the World Heritage List as Tangible Cultural Property of Universal value in the UNESCO's 28th session held at Beijing in China on 7th July 2004. Inscription on this confirms the exceptional and universal value of a cultural site that requires protection for the benefit of all humanity. The architecture of Champaner is one of the superb examples of the pre-Mughal township. The elegant monuments present in the area stand testimony to the harmonious synthesis of the local tradition of ornamentation and Islamic building traditions.

Champaner-Pavagadh Archaeological Park is a 16th century Medieval Sultanate capital city which was buried beneath a thick forest cover and is a highly complex heritage site whose landscape characterized by mounds, plateaus, and streams (Modi, 2008). An area of Core Zone of approx. 14 sq. km and Buffer Zone of 30 sq. km is covered by it. The famous temple of Kalimatha is situated at the top of Pavagadh hill, which is a well-known religious destination visited by lakhs of pilgrims throughout the year. It is also a place of historic importance having palaces, temples, monuments, mosques, arches, stepwells, and agricultural fields. The magnificent view of the Pavagadh hill invites an innumerable number of tourists from various places. The main Pavagadh hill is the highest point in the district, rising to a height of 823 m surrounded by several small hillocks of height ranging from 200m-300m. From the hill, it can be viewed Baroda on one side and Godhra on the other side. Naulakhi, Mauliya, Bhadrakali, Machi, and Atak are the five successive plateaus. The district is drained by seven major rivers and amongst them, the Mahi is the longest river. The river Vishwamitri originates from Pavagadh hills and flows through Halol Taluka before entering the Vadodara district.

2.2 Climate

The climate of the study area is hot and dry except in the monsoon season. The year may be divided into four seasons- summer season, monsoon season, post-monsoon, and winter. Essentially, the rainfall in the area is by the south-west monsoon during monsoon months. Rainfall is very irregular and erratic. Total rainfall received varies widely from year to year and from place to place. In the months of January to May humidity reaches around 30-40 %. Climatic conditions affect the diversity and ecology of butterflies. Ecological studies of butterflies help to know the environmental changes and if any disturbances occur in the area. Rainfall of 700 mm to 1024 mm range occurs here annually. The relative humidity is high during the monsoon season and in months like July and August it reached up to 50% to 80%. It became around 30- 40 % in the months of January to May.

2.3 Soil

The composition and constitution of the soil vary in the study area. It was chiefly sandy loam and black in nature. The Pavagadh Hill area has generally very shallow and poor soils and was totally devoid of soils at many places (Revdandekar, 2014).

2.4 Study Period

The study was carried out for a period of 3 consecutive years i.e., January 2017 to December 2019 in all four seasons of the year. Butterflies were mostly found in all habitats like forest areas, garden areas, agricultural fields, near the monuments, and hilly areas. Butterflies are diurnal in nature except for a few species like Common Evening Brown which are usually active at dusk. Thus, for the collection of the butterflies daytime was preferred. The sampling was done in the morning hours from 8:00 am to 12:00 pm under suitable weather conditions

2.5 Sampling Sites

To carry out the diversity studies of butterflies in the Pavagadh Hill, the entire study area was divided into different sub-study sites, depending on the type of vegetation, habitat structure, and convenience of data collection. The co-ordinates and elevation of each site were taken with the help of the Global positioning system (GPS: Garmin Oregon 550). Pavagadh's total area is 6356.98 ha and legally constitutes a reserve forest. Forest area, which is situated at the foot area of the Pavagadh hill of Pavagadh falls under Halol Range of Godhra Division. The total forest area of Pavagadh is 2100.35 ha, where 2099.63 ha is considered as a Reserved Forest area and 0.72 ha is coming under Protected or Unclassed Forest (Revdandekar, 2014). The majority of the forest area had a mixed type of vegetation which includes herbs, shrubs, trees, and climbers (Annexure). A public garden is also present at the base of Pavagadh Hill. This area also constitutes cultivated, ornamental as well as wild plants. Some of the plants were *Chrysanthemum, Ixora coccinea, Ocimum sanctum, Jasminum sambac, Vinca rosea, Nerium oleander*, etc. It was also surrounded by forest and has monuments and mosques. The garden area was more exposed to human interference because lakhs of tourists visit this area annually. The study of the diversity of butterflies along the slope was carried out in order to see the relationship between species diversity and height. The Pavagadh hill was divided into three altitudes starting from the base to the top of the hill i.e., lower altitude (230m to 430m), Middle altitude (430 to 630 m), and higher altitude (630 m to 830m). Each altitude was selected for 200 m in height.

2.6 Sampling Protocol

2.6.1 Field Survey

A systematic approach was followed to monitor the diversity of butterflies in the study area. The study was conducted from January 2017 to December 2019. The butterflies and plants were observed directly in the field and for documenting the butterflies Pollard Walk method was utilized with modification. The Pollard Walk method is a predominant type of monitoring of butterflies. At a site butterflies are recorded along a fixed-route walk is established on a regular basis under favourable conditions of weather (Pollard, 1997). Each path is walked through for 2-3 hours continuously at a slow and equal pace and kept visibility of 10 meters at both the sides and front side of the recorder. The same method is repeated for all the seasons and visits were made at least twice a month. The selected paths were visited from 08:00 am to 12:00 pm as it was the peak time for the butterfly activities. Repetition of counting butterflies more than once was avoided. The hilly areas were studied with a modification in the method. We explored along with the steps which are already present for the pilgrims to climb and reach the temple and the other sides of the hill were not accessible. So, we followed the same path and studied diversity in three different altitudes for a period of 2-3 hours continuously keeping the visibility of 10m. This sampling method is formed a very crucial step in achieving the objectives of this study.

2.6.2 Collection of Data

Collection of butterflies were restricted to those which could not be identified in the field with the help of field guides. The butterflies were captured with the help of a butterfly net (insect trapping net) and after taking photographs they were released back into the same habitat. Selected species of butterflies were captured for morphometric analysis. After taking measurements they were released.

2.6.3 Photography

Photographs were clicked with the help of a Canon EOS 750D camera. Most of the butterflies were photographed in live conditions from the study sites during their flight or nectaring time for identification.

2.6.4 Taxonomic Identification of Butterflies

Taxonomic identification of butterflies was done using multiple pictorial guides and standard books. The pictorial guide of (Kunte, 2000), (Kehimkar, 2008), and (Bhakare & Ogale, 2018) was used for the species-level identification of butterflies.

2.6.5 Taxonomic Identification of Plants

Details of the plants visited by butterflies to feed most frequently were observed. The plants are identified with the help of field guides. Flowering season, flower colour, corolla shape, and type of plant were observed. The host plants and nectar plants were identified by faculty members of the Department of Botany, Faculty of Science, The M. S. University of Baroda.

2.6.6 Seasonal Distribution of Butterflies

To study the effect of different seasons on the abundance and diversity of butterflies, monthly visits were made to the selected study area. The entire year was divided into four seasons depending on availability of rainfall and temperature fluctuation (Table 3). The study was carried out for the seasons of three consecutive years starting from January 2017 to December 2019.

2.6.7 Climatological Details

Sr. No.	Season	Months
1	Summer	March, April, May
2	Monsoon	June, July, August
3	Post-monsoon	September, October, November
4	Winter	December, January, February

Table 3: Climatological details considered during the study

2.6.8 The abundance of Butterflies

To study the abundance of butterflies, the observed butterflies were categorized into 5 different groups on the basis of their presence or absence of sightings during each visit in the study area. They are grouped as

VC- Very Common	(Above 75 sightings)
C-Common	(75-50 sightings)
UC- Uncommon	(50-25 sightings)
R-Rare	(25-10 sightings)
Very Rare	(Below 10 Sightings)

This categorization of butterflies was completely dependent on the local availability of them.

2.6.9 Morphometry of Butterflies

To study the coevolutionary relationship between butterflies and plants, morphometry of proboscis of selected species of butterflies were done with the help of Vernier calliper. Flowers that were frequently visited by the butterflies have identified. Most preferred flowers were only taken into consideration for performing morphometric analysis. To facilitate the morphometry of butterflies, five species each from the families Pieridae, Nymphalidae, Papilionidae, and Lycaenidae were selected based on their occurrence in the two habitats. To measure the length of the proboscis of butterflies they were captured with the help of a butterfly net. After that, they were removed from the net, and the length of proboscis was measured by inserting a needle into the centre of the coiled proboscis and straightening them out. With the help of Vernier callipers, proboscis length was measured as proboscis tip and labial palp base distance. After measurement butterflies were released into the same habitat without much damage. Measurements were made of body length (in mm), wingspan (in mm), and proboscis length (in mm).

2.6.10 Morphometry of Corolla of Flowers

To study the corolla tube length of the preferred nectar flower, morphometry of the corolla tube was done. It was characterized by the measurement of the length of the corolla tube with the help of Vernier Calliper of flowers of the preferred nectar plants.

2.7 Statistical Analysis of the Data

To study the Diversity, Species Evenness, and Richness different statistical parameters were used.

2.7.1 Species Diversity

It is an information index and is the most commonly used diversity index in ecology. The Shannon-Wiener Index does the quantification of the uncertainty associated, it predicts the identity of new taxa, given a number of taxa and also evenness in abundances of individuals in each taxon. Values of H′ typically range from 1.5 to 3.5, but it can range from 0 to 5. The Shannon-Wiener index assumes that the sample for the site was collected randomly.

$$H' = -\sum (ni/N \times \ln ni/N)$$

Where

ni= is the number of individuals of amount (biomass) of each of the i species

N = is the total number (or biomass) of individuals for the site.

2.7.2 Species Evenness

Pielou's Evenness Index (J'): The distribution of individuals over species is called evenness. The values of Evenness describe how evenly the individuals are distributed among the different species. It is calculated as:

Pielou's Evenness Index J = H' / InS

Where S = number of species, at the site

To study the co-evolutionary relationship among butterflies and plants, correlation of the length of proboscis of butterflies, and length of the corolla of the preferred nectar plant. The strength of the relationship between two variables can be found through correlation. It is a method in which one can establish the relationship between two variables. Values of the correlation coefficient always lie between -1 to +1. If the value is positive, then it is positively correlated, and the value of X increases with the corresponding Y value. If the value is negative means the value of X decreases with the corresponding value of Y. The value 0 indicates there is no correlation between the two corresponding variables.

2.7.3 Karl Pearson's Coefficient of Correlation

It is also known as the Product Moment correlation of coefficient. It is used to measure the magnitude of the relationship between two variables. It measures the level of relation between linear related variables. The letter 'r' represents the coefficient of correlation.

2.7.4 Regression Analysis

It is a mathematical measure to show the average relationship between the two variables. It indicates the cause-and-effect relationship between the variables and establishes a functional relationship between them

$Y = a + b X + \epsilon$

Where: Y – Dependent variable

X – Independent (explanatory) variable

a – Intercept

b – Slope

ϵ – Residual (error)

Chapter 3

Results

3.1 Identification of Butterfly species

An extensive investigation on ecology and diversity of butterflies was carried out in and around Pavagadh Hill. The study on butterflies in different habitats of Pavagadh Hill was carried out for three consecutive years i.e. from January 2017 to December 2019. The detailed study involved diversity, abundance, and seasonal variation of butterflies, coevolutionary relationship among butterflies and plants in various habitats of Pavagadh Hill. The entire study area was divided into different sub-study sites such as forest area, garden area and open scrub land depending on the type of vegetation and diversity of butterflies were observed. The different types of vegetation help the different stages of butterflies to survive and flourish. Hence it is an ideal place to study the ecology and biology of butterflies.

A total of 63 butterflies belonging to 5 families were identified from the study area during the entire study period of 3 years. Sub-study sites of Pavagadh Hill sustain high floral and faunal diversity of invertebrates as they provide sufficient microhabitats for their survival. The climatic condition of Pavagadh Hills helps in sustaining butterflies.

Looking into the percentage distribution of butterflies of Pavagadh Hill, a total of 63 butterfly species were found belonging to 5 families and 48 genera. Table 4 clearly depicts that family Nymphalidae showed the maximum species percentage i.e., 41.266% distribution as compared to all other families followed by Lycaenidae i.e., 22.22%, then Pieridae i.e., 20.64% followed by Papilionidae (9.524%) and least being family Hesperiidae (6.35%). Whereas family Nymphalidae and Lycaenidae showed visible genus percentage occurrence i.e., 39.583% and 27.09% respectively. Family Pieridae, Hesperiidae and Papilionidae showed 18.75%, 8.33% and 6.25% respectively.

3.2 Butterfly Species Abundance in study area of Pavagadh Hill

Butterfly species abundance was studied along with the species distribution in the study area. Butterfly abundance studies were categorized into Very common, Common, Uncommon and Rare. Amongst total of 63 species of butterflies, 24 butterfly species were uncommon, followed by 17 butterfly species being very common and common and 5 species were rare as shown in Table 5. Observing the individual families, within family Papilionidae 3 species namely *Graphium doson*, *Graphium agamemnon* and *Pachliopta aristolochiae* were found to be very common and *Pachliopta hector*, *Papilio polytes* and *Papilio demoleus* were found to be common species of butterflies.

Within family Nymphalidae, the members of genus *Danaus* i.e *D. chrysippus* and *D. genutia* were found to be very common in the study area (Table 5). Whereas in case of genus *Hypolimnias*, *H. bolina* was found to be common and *H. misippus* to be very common. Amongst 6 different Pansies i.e genus *Junonia*, *Junonia lemonias* i.e. Lemon Pansy was found to be very common,whereas Peacock Pansy (*Junonia almana*), Chocolate Pansy (*Junonia iphita*) and Blue Pansy (*Junonia orithya*) were uncommon and Grey Pansy and Yellow Pansy were rare.

Amongst the family of Whites and Yellows i.e family Pieridae, Emigrants i.e *Catopsilia pomona* and *Catopsilia pyranthe* and Grass yellows i.e., *Eurema brigitta* and *Eurema hecabe* were found to be very common as shown in Table 5. Within the family of Blues i.e., family Lycaenidae, Table 5 clearly states that Lime Blue (*Chilades lajus*), Dark grass Blue (*Zizeeria karsandra*), Lesser Grass Blue (*Zizina otis*) and Tiny Grass Blue (*Zizula hylax*) were found to be very common whereas *Talicada nyseus* (Red Pierrot) and *Chilades parrhasius* (Small Cupid) were rare.

Mentioning about family Hesperiidae, Indian Palm Bob (*Suastus gremius*) was rare whereas Table 5 also gives the clear picture that the other three species i.e Common Banded Owl (*Hasora chromus)*, Small Branded Swift (*Pelopidas mathias*) and Dark Palm Dart (*Telicota bambusae*) were uncommon.

3.3 Seasonal Occurrence of Butterflies in the study area of Pavagadh Hill

The entire study period was divided into four seasons namely: Summer, Monsoon, Post Monsoon and Winter. The summer months are from March to May, monsoon months ranges from June to August, post monsoon months include September to November and December, January, February forms the winter months.

During the post monsoon season, as shown in Table 6, the study area showed the maximum number of 63 butterfly species belonging to 5 different families. Whereas looking into the other seasons, minor difference in occurrence in no. of species was observed in Monsoon and winter season. During monsoons, total of 34 species of butterflies were observed whereas 35 species of butterflies were observed in winters. The least i.e only 15 species were observed during summer months.

Winters in Pavagadh Hill are quite chilly. Depicted in Table 6, within the total of 35 butterfly species observed during winter mornings- 5 species belong to family Papilionidae, Family Nymphalidae comprises of 16 species, 11 species from family Pieridae, Family Lycaenidae holds 3 butterfly species where no members were noted from Hesperiidae family.

Monsoons are full of humidity and foggy at Pavagadh hill. Out of 35 species documented in the study area, family Papilionidae comprises of 6 species, 13 species from family Nymphalidae, 7 species from family Pieridae, 6 species from family Lycaenidae and 2 species from family Hesperiidae (Table 6).

During summer months, 15 species of butterflies were observed in the study area. Table 6 clearly states that out of 15 species, family Nymphalidae holds 8 species of butterflies, Pieridae family comprises of 5 species and 2 species from family Papilionidae. None of members of family Lycaenidae and Hesperiidae were observed during summers in the study area.

Among the family Papilionidae, *Graphium doson* and *Graphium agamemnon* were observed throughout the year and in all seasons (Table 6). Whereas *Pachliopta aristolochiae, Pachliopta hector* and *Papilio polytes* except for summers, were found in all other seasons i.e., monsoon, post-monsoon and winters.

Table 6 clearly states that within family Nymphalidae, Plain Tiger (*Danaus chrysippus*), Common Castor (*Ariadne merione),* Black Rajah (*Charaxes solon),* Great Eggfly (*Hypolimnas bolina*) and Danaid Eggfly (*Hypolimnas misippus*) were found throughout the year. While among the 6 pansies observed in the study area, Lemon Pansy *Junonia lemonias* was observed throughout the year.

Looking into the details of seasonal occurrences of butterflies in the study area of Pavagadh Hill, Table 6 states that in the family of whites and yellows, emigrants namely *Catopsilia pomona* and *Catopsilia pyranthe* are found throughout the year. Whereas amongst the grass yellows, *Eurema hecabe* and *Eurema brigitta* were observed throughout the year. *Delias eucharis* i.e., Common Jezebel was found commonly throughout the year but was not found during the monsoon months.

As shown in Table 6, amongst the total species observed, all species of family Lycaenidae were observed during the post monsoon season of the year whereas in case of family Hesperiidae, Small Branded Swift *Pelopidas mathias* and Dark Palm Dart *Telicota bambusae* were documented during the monsoon and post monsoon months of the year. But none of the Hesperid species were observed during summer and winter months.

3.4 Species distribution in the selected different habitats of Pavagadh Hill

During the entire study period of three years, a total of 63 butterfly species were observed in selected different habitats of Pavagadh Hill. Amongst 63 species, family Papilionidae comprises of 6 butterfly species, family Nymphalidae comprises of 25 butterfly species, family Pieridae holds 13 butterfly species, 15 species from the family of Blues i.e., Lycaenidae and finally 4 species of skippers from family Hesperiidae.

During the study period, different habitats were selected in the Pavagadh Hill namely Forest Area, Open Scrub Land and Garden Area. As shown in Table 7 maximum number of 63 species were observed in forest area, followed by 49 butterfly species from the open scrub land and the last 36 species of butterflies were observed from the garden area.

Table 7 clearly depicts that total 63 species of butterflies observed during the study period were found in forest area too. Whereas in garden area, amongst the total of 63 species, 36 species were observed from the garden area. Out of 36 butterfly species, 6 species belong to family Papilionidae, 12 species each make up the family Nymphalidae and Pieridae and family Lycaenidae holds 6 butterfly species. None of the members of family Hesperiidae were observed in Garden Area. Hence, out of the total 5 families of butterflies, members of only 4 different families were observed in garden area.

Open Scrub Land showed the presence of 49 different butterfly species belonging to 5 different families as depicted in tabulated form in Table 7. Out of 49 species, 6 species of butterflies belong to family Papilionidae, Family Nymphalidae comprises of 18 species, family of whites and yellows i.e., Pieridae holds 13 different species whereas 10 species were found from family Lycaenidae and 2 species were observed from family Hesperiidae.

While looking into detail the Table 7 clearly shows that *Charaxes solon* and *Vanessa cardui* from family Nymphalidae was observed in forest land and open scrub land but was not found in garden area. Amongst the pansies, *Junonia iphita* and *Junonia lemonias* were found in all the three selected different habitats, whereas *Junonia almana, Junonia hierta* and *Junonia orithya* were found in forest area but were not observed in either open scrub land or the garden area. Similarly, *Ypthima huebneri* and *Ypthima baldus* were observed in forest area but not in open scrub land or the garden area. Within family Nymphalidae, *Euploea core, Euthalia aconthea, Hypolimnas bolina* and *Hypolimnas misippus* were documented in all 3 selected different habitats of Pavagadh Hill.

Amongst 13 species of family Pieridae, least difference of occurrence was observed (Table 7) except *Leptosia nina* i.e., Psyche was observed in forest area and open scrub land but was not observed in garden area.

From the family of Blues i.e., Lycaenidae - *Chilades lajus, Curetis thetis, Euchrysops cnejus, Zizeeria karsandra, Zizina otis* and *Zizula hylax* were found in all three selected habitats under study of Pavagadh Hill. Whereas *Catochrysops strabo, Spindasis vulcanus, Azanus ubaldus* and *Tarucus nara* were found in forest area and open scrub land but were absent in garden area (Table 7).

3.5 Diversity Indices of Various Seasons

The diversity indices Shannon-Weiner Diversity Index and Pielou's Evenness Index were calculated for all the four seasons (Table.8). Shannon-Weiner Index (H) for the study area ranged between 2.523 and 3.871. The least value was noticed during summer season and the highest value was observed during post-monsoon season followed by monsoon season. The values specify that highest butterfly species diversity occurred during post-monsoon season and least diversification of species occurred during summer season. In Pavagadh Hill there is a trend of increase in the diversity of butterflies after monsoon season. The rainfall supports the growth of nectar host plants and larval food host plants which is a reason that diversity of butterflies increases during post monsoon months. The higher value of Pielou's Evenness index signifies an increase in richness and evenness of species and lower value indicates decrease in richness and evenness of the species. The values ranged between 0.9432 to 0.9591. The value signifies that during post-monsoon season evenness is higher due to the presence species in similar proportions. But during summer season low evenness is reported as the distribution of species not similar due to less diversification of butterfly species. Which is concluded that maximum diversity of butterflies is correlated with availability of sufficient food plants.

3.6 Diversity Indices of Habitats

The study site of Pavagadh Hill was again classified into three different sub-study sites on the basis of the type of vegetation present. They are Garden, Forest and Scrubland. The garden constitutes ornamental and cultivated plants. The Shannon index increases when the richness and the evenness of the community increases, and Shannon index decreases when richness and evenness of the community decreases. The higher value of Shannon Weiner was recorded in the forest habitat (3.871) and least value was recorded in the garden area (3.352). When calculated Pielou's Evenness Index, the values ranged between 0.9432 and 0.9524. This index showed that lowest evenness was in Garden area, so the diversity of butterfly species was also low. Highest evenness is existing in Forest area due to the presence of diversified species with similar proportion (Table 9).

Graph 1 shows that highest number of butterflies belonged to the family Nymphalidae and least number of representatives were observed from the family Hesperiidae. The graphical representation of seasonal variations of butterflies in all the four seasons had been given in Graph 2 and distribution of butterflies in different habitats had given in Graph 3. It shows that after monsoon there is an increase in the number of species and their abundance. Post monsoon is the most favourable season for the existence of butterflies in Pavagadh Hill. The availability of rainfall plays an important role in diversity and survival of butterflies. Pavagadh is a dry deciduous forest. During summer the maximum average temperature reaches around 38°C and at times more than that. The plants in the area during summer season got dried up so the availability of nectar plans also reduced. Some of the common nectar plants like *Lantana camara*, *Tridax procumbens* which bear flowers throughout the year and many of the butterflies depend on them for the food. But on the onset of monsoon, the vegetation starts reappearing and the area gets flourished with different types of plants. This also impacts the butterfly diversity.

3.7 Co-evolutionary relationship among Butterflies and Plants

Co-evolution is the reciprocal evolutionary change that occurs between species when they interact each other through the process of natural selection. The mouthparts of insects are adapted themselves to different modes of ingestion of food. The mouthparts of a butterfly is of siphoning and sucking type, which is best suited to draw nectar from the flowers. They feed on liquid diet during the adult stage by feeding on nectar which contains dissolved sugar, salts and other minerals from a variety of sources ranging from flowers, tree sap, rotting fruit, faeces and so on. When a butterfly finds a potential food source it unfurls its proboscis and uses the tip to feed.

In this study an attempt was made to examine proboscis length and its significance in carrying out activities of the butterflies in relation to their nectar plants. In order to study the corolla proboscis interrelationship, we have examined the morphological features of butterflies and their preferred nectar host plants (Table 10 & 11). Also, a corelation study was carried out between the corolla length of nectar host plants and the proboscis length of the frequently visiting butterflies. A significant positive correlation ($r=0.824$; $R^2=0.679$) in the number of species was detected between the experimental groups (Graph 4). Taking the positive corelation into consideration, it can be concluded that if there's any variation in the corolla length (mostly due to evolutionary processes), it will be reflected in the butterflies' proboscis length too. Moreover, Table 13 shows the frequency of visit of selected butterflies on the nectar host plants. The data substantiates the correlation between nectar host plants and the butterflies and shows a regression fit of 67%. The remainder percentage can be entitled to the factors like colour, fragrance and morphology of the flower that are preferred by the butterflies.

To study the morphology of butterflies, 5 species each from four families Papilionidae, Nymphalidae, Pieridae and Lycaenidae were selected (Table. 10). Butterflies were selected on the basis of their abundance in the study area. The butterflies having the status Very Common and Common for e.g., Common Jay, Plain Tiger, Lemon Pansy, Common Emigrant and Lime Blue (Table. 5) were only considered for performing morphometry. Family Hesperiidae was not considered because of a smaller number of representatives and uncommon trend of butterflies (Table.5). To measure the length of proboscis of butterflies they were captured with the help of insect net. Then they were removed from the net and measurements were taken with the help of Dial Caliper. The measurements of proboscis length, body length and wingspan were taken and after the measurement they were released. Five individual butterflies from each species were selected for morphometric parameters such as proboscis length, body length and wingspan of butterflies. A total of 20 butterflies, 5 each from four families were observed in the study area. The proboscis length of butterflies varied from species to species, refer Table.10.

The proboscis length of Papilionidae ranged from 18.0 mm to 25.96 mm (Table 10). Out of the five species examined, *Graphium agamemnon* (25.96 mm) had got the long proboscis and *Papilio polytes* (18.0 mm) had got the small proboscis. They were larger butterflies with large wingspan. The body length was also measured higher than the proboscis. They were present throughout the year. They visited *Lantana camara* of corolla length 9.96 mm, Ixora coccinea (25.5) and *Catharanthus roseus* of corolla length 23.5 which bore flowers throughout the year (Table 11 &12).

In Nymphalidae the proboscis length varied between 12.14 mm and 23.96 mm. The body length was double the length of proboscis (Table 10). They preferred to visit *Lantana camara* (9.96 mm), *Chromolaena odorata* (10.06 mm), *Sida acuta* (3.75 mm) and *Wedelia trilobata* (2.5mm) (Table 11). All the selected species of Nymphalidae family were sighted throughout the year. They had a preference of selecting nectar host plants of varying flowering period. They preferred to visit them according to the availability of the flowers.

Pierids were brightly colored butterflies. Among the five species examined from the family Pieridae, *Delias eucharis* was a common butterfly in the area had got a longer proboscis with a larger body length. The proboscis length of the selected species of the family ranged between 9.04 mm to 15.98 mm (Table 10). They preferred to visit nectar host plants such as *Tridax procumbens* (5.5 mm) which bore flowers throughout the year and *Chromolaena odorata* (10.06) was seasonal usually appeared after the monsoon (Table 11&12).

The proboscis length of butterflies selected from Lycaenidae were comparatively smaller. They were small sized butterflies with small proboscis compared to other families. The proboscis length of the selected species of the family ranged between 4.72 mm and 6.6 mm (Table 10). The nectar host plants preferred by the representatives of Lycaenidae were *Tridax procumbens* (5.5 mm), *Tephrosia purpurea* (3.06 mm), *Sida acuta* (3.75 mm), *Emilia sonchifolia* (2.2mm) and *Sida rhombifolia* (5.28 mm). They also preferred nectar host plants of varying flowering seasons. Most of them were low flying butterflies so mostly preferred to visit herbs (Table 11&12).

The area of Pavagadh is composed of a mixed vegetation where all kinds of plants such as grasses, herbs, shrubs and trees were present (Table 11). They act as excellent larval host plants as well as nectar resources for the butterflies (Table 2&11). The diversity of flowering plants in each sub-study sites was observed and identified twenty-two prominent nectar plants belonging to ten families. Though the plant diversity of Pavagadh Hill is very high and a detailed checklist of plants was submitted by the Department of Botany, The M. S University of Baroda (Annexure 1), I have examined the nectar plants which were constantly visited by the butterflies only (Table 11). The phenological components like flower color, corolla shape, type of plant and the cyclicity of their flowering and non-flowering period were observed and noted (Table 11). Out of these twenty-two nectar plants, ten most frequently visited plants were selected for morphometric analysis. In morphometric analysis the length of corolla tube was measured with the help of Dial Caliper. For each plant species five individual flowers from different plants were selected and noted their corolla length (Table 12). The longest corolla length was observed in *Ixora coccinea* and Catharanthus roseus (27.5 mm) (Table 11) which was preferred by Papilionid butterflies. Papilionid butterflies had got comparatively longer proboscis. The smallest corolla length was measured in *Emilia sonchifolia* which were visited by short, tongued butterflies belonging to the family Lycaenidae. Lantana camara was found to be the most preferred nectar host plant of three families namely Papilionidae, Nymphalidae and Pieridae. Most of the herbs were visited by low flying butterflies (Table 12). Flower colour was found to be an important factor determining the foraging activity. Though butterflies visit flowers with different colors, but most of the preferred nectar plants had got white, red, yellow or pink flowers (Table 11).

Butterflies depend on different types of plants for nectar. They mostly prefer herbs and shrubs for the nectar. The forest area of Pavagadh Hill is a dry deciduous type and hence during summer the area became dried up and most of the vegetation also got disappeared especially the herbs and shrubs. So, butterflies prefer to forage on plants which bear flowers during summer season and also there are plants which bloomed throughout year. The unavailability or the decrease in the availability of nectar plants directly affected the diversity and abundance of butterflies. It was observed that during summer season the number of sights as well as the diversity went down. On the onset of monsoon, the plants start reappearing and flourish after that and bear flowers. Accordingly, there was an increase in the number of sightings as well as diversity of butterflies.

Sr. No	Family	No. of Genus		No. of Species	
		Number	%	Number	%
1	Papilionidae	3	6.25	6	9.524
2	Nymphalidae	19	39.583	26	41.266
3	Pieridae	9	18.75	13	20.64
4	Lycaenidae	13	27.09	14	22.22
5	Hesperiidae	4	8.33	4	6.35
TOTAL		**48**	**100**	**63**	**100**

Table 4: Percentage distribution of Butterfly genus and species in Pavagadh Hill

Sr No	Common Name	Scientific Name	Abundance
Family: Papilionidae			
1	Common Jay	*Graphium doson* Felder & Felder, 1864	VC
2	Tailed Jay	*Graphium agamemnon* Linnaeus, 1758	VC
3	Common Rose	*Pachliopta aristolochiae* Fabricius, 1775	VC
4	Crimson Rose	*Pachliopta hector* Linnaeus, 1758	C
5	Common Mormon	*Papilio polytes* Linnaeus, 1758	C
6	Lime Butterfly	*Papilio demoleus* Linnaeus, 1758	C
Family: Nymphalidae			
7	Tawny Coster	*Acraea terpsicore* Linnaeus, 1758	UC
8	Common Castor	*Ariadne merione* Cramer, 1777	UC
9	Black Rajah	*Charaxes solon* Fabricius, 1793	C
10	Painted Lady	*Vanessa cardui* Linnaeus, 1758	C
11	Plain Tiger	*Danaus chrysippus* Linnaeus, 1758	VC
12	Striped Tiger	*Danaus genutia* Cramr, 1779	VC
13	Common Indian Crow	*Euploea core* Cramer, 1780	C
14	Common Baron	*Euthalia aconthea* Cramer, 1777	UC

15	Great Eggfly	*Hypolimnas bolina* Linnaeus, 1758	C
16	Danaid Eggfly	*Hypolimnas misippus* Linnaeus, 1764	VC
17	Peacock Pansy	*Junonia almana Linnaeus,1758*	UC
18	Grey Pansy	*Junonia atlites Linnaeus,1763*	R
19	Yellow Pansy	*Junonia hierta Fabricius, 1798*	R
20	Chocolate Pansy	*Junonia iphita Cramer, 1779*	UC
21	Lemon Pansy	*Junonia lemonias* Linnaeus, 1758	VC
22	Blue Pansy	*Junonia orithya* Linnaeus, 1758	UC
23	Common Evening Brown	*Melanitis leda* Linnaeus, 1758	C
24	Common Bushbrown	*Mycalesis perseus* Fabricius, 1775	UC
25	Common Sailer	*Neptis hylas* Linnaeus, 1758	UC
26	Glassy Tiger	*Parantica aglea* Stoll, 1782	UC
27	Common Leopard	*Phalanta phalantha* Drury, 1773	UC
28	Baronet	*Symphaedra nais* Forster, 1771	UC
29	Blue Tiger	*Tirumala limniace Cramer, 1775*	VC
30	Common Four Ring	*Ypthima huebneri* Kirby, 1871	UC
31	Common Five Ring	*Ypthima baldus* Fabricius, 1775	UC
Family: Pieridae			
32	Common Emigrant	*Catopsilia pomona* Fabricius, 1775	VC
33	Mottled Emigrant	*Catopsilia pyranthe* Latreille,1758	VC
34	Small Grass Yellow	*Eurema brigitta* Stoll, 1780	VC
35	Common Grass Yellow	*Eurema hecabe* Linnaeus, 1758	VC
36	Common Jezebel	*Delias eucharis* Drury, 1773	C
37	Common Gull	*Cepora nerissa* Fabricius, 1775	C
38	Pioneer	*Belenois aurota* Fabricius, 1793	C
39	White Orange Tip	*Ixias marianne* Cramer, 1779	UC
40	Yellow Orange Tip	*Ixias pyrene* Linnaeus, 1764	UC
41	Crimson Tip	*Colotis danae* Fabricius, 1775	UC
42	Small Salmon Arab	*Colotis amata* Fabricius, 1775	UC
43	Common Wanderer	*Pareronia hippia* Fabricius, 1787	UC
44	Pysche	*Leptosia nina* Fabricius, 1793	UC
Family: Lycaenidae			

45	Forget-me-not	*Catochrysops Strabo* Fabricius, 1793	UC
46	Common Pierrot	*Castalius rosimon* Fabricius, 1775	C
47	Lime Blue	*Chilades lajus* Stoll, 1780	VC
48	Indian Sunbeam	*Curetis thetis* Drury, 1773	UC
49	Gram Blue	*Euchrysops cnejus* Fabricius, 1798	C
50	Common Silverline	*Spindasis vulcanus* (Fabricius, 1775)	C
51	Dark Grass Blue	*Zizeeria karsandra* Moore, 1865	VC
52	Lesser Grass Blue	*Zizina otis* Fabricius, 1787	VC
53	Tiny Grass Blue	*Zizula hylax* Fabricius, 1775	VC
54	Bright Babul Blue	*Azanus ubaldus* Stoll, 1782	C
55	Common Shot Silverline	*Spindasis ictis* Hewitson, 1865	C
56	Grass Jewel	*Freyeria trochylus* Freyer, 1845	VC
57	Red Pierrot	*Talicada nyseus* Guerin-Meneville, 1843	R
58	Small Cupid	*Chilades parrhasius* Fabricius, 1793	R
59	Striped Pierrot	*Tarucus nara* Kollar, 1848	C
Family: Hesperiidae			
60	Common Banded Awl	*Hasora chromus* Cramer, 1780	UC
61	Small Branded Swift	*Pelopidas mathias* Fabricius, 1798	UC
62	Dark Palm Dart	*Telicota bambusae* Moore, 1878	UC
63	Indian Palm Bob	*Suastus gremius* (Fabricius, 1798)	R

Table 5: Abundance of Butterflies in the Study Area ((VC= Very Common, C= Common, UC=Uncommon, R=Rare)

Sr. No	Common Name	Scientific Name	S	M	PM	W
Family: Papilionidae						
1	Common Jay	*Graphium doson* Felder & Felder, 1864	+	+	+	+
2	Tailed Jay	*Graphium agamemnon* Linnaeus, 1758	+	+	+	+
3	Common Rose	*Pachliopta aristolochiae* Fabricius, 1775	-	+	+	+
4	Crimson Rose	*Pachliopta hector* Linnaeus, 1758	-	+	+	+

5	Common Mormon	*Papilio polytes* Linnaeus, 1758	-	+	+	+
6	Lime Swallowtail	*Papilio demoleus* Linnaeus, 1758	-	+	+	-
Family: Nymphalidae						
7	Tawny Coster	*Acraea terpsicore* Linnaeus, 1758	-	+	+	-
8	Common Castor	*Ariadne merione* Cramer, 1777	-	+	+	+
9	Black Rajah	*Charaxes solon* Fabricius, 1793	-	+	+	-
10	Painted Lady	*Vanessa cardui* Linnaeus, 1758	-	+	+	-
11	Plain Tiger	*Danaus chrysippus* Linnaeus, 1758	+	+	+	+
12	Striped Tiger	*Danaus genutia* Cramr, 1779	-	+	+	-
13	Common Indian Crow	*Euploea core* Cramer, 1780	-	+	+	-
14	Common Baron	*Euthalia aconthea* Cramer, 1777	-	+	+	-
15	Great Eggfly	*Hypolimnas bolina* Linnaeus, 1758	+	+	+	+
16	Danaid Eggfly	*Hypolimnas misippus* Linnaeus, 1764	+	+	+	+
17	Peacock Pansy	*Junonia almana Linnaeus,1758*	-	-	+	-
18	Grey Pansy	*Junonia atlites Linnaeus,1763*	-	+	+	-
19	Yellow Pansy	*Junonia hierta Fabricius, 1798*	-	+	+	-
20	Chocolate Pansy	*Junonia iphita Cramer, 1779*	+	+	+	-
21	Lemon Pansy	*Junonia lemonias* Linnaeus, 1758	+	+	+	+
22	Blue Pansy	*Junonia orithya* Linnaeus, 1758	-	+	+	
23	Common Evening Brown	*Melanitis leda* Linnaeus, 1758	-	+	+	-
24	Common Bushbrown	*Mycalesis perseus* Fabricius, 1775	-	+	+	-
25	Common Sailer	*Neptis hylas* Linnaeus, 1758	-	-	+	+
26	Glassy Tiger	*Parantica aglea* Stoll, 1782	-	+	+	-
27	Common Leopard	*Phalanta phalantha* Drury, 1773	-	-	+	-
28	Baronet	*Symphaedra nais* Forster, 1771	-	-	+	-
29	Blue Tiger	*Tirumala limniace Cramer, 1775*	-	-	+	+
30	Common Four Ring	*Ypthima huebneri* Kirby, 1871	-	-	+	+
31	Common Five Ring	*Ypthima baldus* Fabricius, 1775	-	-	+	-
Family: Pieridae						

32	Common Emigrant	*Catopsilia pomona* Fabricius, 1775	+	+	+	+
33	Mottled Emigrant	*Catopsilia pyranthe* Latreille,1758	+	+	+	+
34	Small Grass Yellow	*Eurema brigitta* Stoll, 1780	+	+	+	+
35	Common Grass Yellow	*Eurema hecabe* Linnaeus, 1758	+	+	+	+
36	Common Jezebel	*Delias eucharis* Drury, 1773	+	-	+	+
37	Common Gull	*Cepora nerissa* Fabricius, 1775	-	-	+	+
38	Pioneer	*Belenois aurota* Fabricius, 1793	-	+	+	+
39	White-Orange Tip	*Ixias marianne* Cramer, 1779	-	+	+	-
40	Yellow-Orange Tip	*Ixias pyrene* Linnaeus, 1764	-	+	+	-
41	Crimson Tip	*Colotis danae* Fabricius, 1775	-	+	+	-
42	Small Samon Arab	*Colotis amata* Fabricius, 1775	-	+	+	-
43	Common Wanderer	*Pareronia hippia* Fabricius, 1787	-	+	+	-
44	Pysche	*Leptosia nina* Fabricius, 1793	-	+	+	-
Family: Lycaenidae						
45	Forget-me-not	*Catochrysops strabo* Fabricius, 1793	-	+	+	-
46	Common Pierrot	*Castalius rosimon* Fabricius, 1775	-	-	+	-
47	Lime Blue	*Chilades lajus* Stoll, 1780	-	+	+	-
48	Indian Sunbeam	*Curetis thetis* Drury, 1773	-	-	+	-
49	Gram Blue	*Euchrysops cnejus* Fabricius, 1798	-	+	+	+
50	Common Silverline	*Spindasis vulcanus* (Fabricius, 1775)	-	-	+	-
51	Dark Grass Blue	*Zizeeria karsandra* Moore, 1865	-	+	+	-
52	Lesser Grass Blue	*Zizina otis* Fabricius, 1787	-	+	+	+
53	Tiny Grass Blue	*Zizula hylax* Fabricius, 1775	-	-	+	-
54	Bright Babul Blue	*Azanus ubaldus* Stoll, 1782	-	-	+	+
55	Common Shot Silverline	*Spindasis ictis* Hewitson, 1865	-	-	+	-
56	Grass Jewel	*Freyeria trochylus* Freyer, 1845	-	+	+	-
57	Red Pierrot	*Talicada nyseus* Guerin-Meneville, 1843	-	-	+	-
58	Small Cupid	*Chilades parrhasius* Fabricius, 1793	-	-	+	-
59	Striped Pierrot	*Tarucus nara* Kollar,1848	-	-	+	-

Family: Hesperiidae						
60	Common Banded Awl	*Hasora chromus* Cramer, 1780	-	-	+	-
61	Small Branded Swift	*Pelopidas mathias* Fabricius, 1798	-	+	+	-
62	Dark Palm Dart	*Telicota bambusae* Moore, 1878	-	+	+	-
63	Indian Palm Bob	*Suastus gremius* Fabricius, 1798	-	-	+	-

Table 6: Seasonal Distribution of Butterflies in the Pavagadh Hill (S=Summer, M=Monsoon, PM=Post-Monsoon, W=Winter)

Sr No.	Species Name	Garden Area	Forest Area	Open Scrubland
Family: Papilionidae				
1	*Graphium doson* Felder & Felder, 1864	+	+	+
2	*Graphium agamemnon* Linnaeus, 1758	+	+	+
3	*Pachliopta aristolochiae* Fabricius, 1775	+	+	+
4	*Pachliopta hector* Linnaeus, 1758	+	+	+
5	*Papilio polytes* Linnaeus, 1758	+	+	+
6	*Papilio demoleus* Linnaeus, 1758	+	+	+
Family: Nymphalidae				
7	*Acraea terpsicore* Linnaeus, 1758	+	+	+
8	*Ariadne merione* Cramer, 1777	+	+	+
9	*Charaxes solon* Fabricius, 1793	-	+	+
10	*Vanessa cardui* Linnaeus, 1758	-	+	+
11	*Danaus chrysippus* Linnaeus, 1758	+	+	+
12	*Danaus genutia* Cramr, 1779	-	+	+
13	*Euploea core* Cramer, 1780	+	+	+
14	*Euthalia aconthea* Cramer, 1777	+	+	+
15	*Hypolimnas bolina* Linnaeus, 1758	+	+	+
16	*Hypolimnas misippus* Linnaeus, 1764	+	+	+
17	*Junonia almana Linnaeus,1758*	-	+	-
18	*Junonia atlites Linnaeus,1763*	-	+	+

19	*Junonia hierta Fabricius, 1798*	-	+	-
20	*Junonia iphita Cramer, 1779*	+	+	+
21	*Junonia lemonias* Linnaeus, 1758	+	+	+
22	*Junonia orithya* Linnaeus, 1758	-	+	-
23	*Melanitis leda* Linnaeus, 1758	-	+	+
24	*Mycalesis perseus* Fabricius, 1775	-	+	+
25	*Neptis hylas* Linnaeus, 1758	-	+	+
26	*Parantica aglea* Stoll, 1782	+	+	-
27	*Phalanta phalantha* Drury, 1773	-	+	-
28	*Symphaedra nais* Forster, 1771	+	+	+
29	*Tirumala limniace Cramer, 1775*	+	+	+
30	*Ypthima huebneri* Kirby, 1871	-	+	-
31	*Ypthima baldus* Fabricius, 1775	-	+	-
Family: Pieridae				
32	*Catopsilia pomona* Fabricius, 1775	+	+	+
33	*Catopsilia pyranthe* Latreille,1758	+	+	+
34	*Eurema brigitta* Stoll, 1780	+	+	+
35	*Eurema hecabe* Linnaeus, 1758	+	+	+
36	*Delias eucharis* Drury, 1773	+	+	+
37	*Cepora nerissa* Fabricius, 1775	+	+	+
38	*Belenois aurota* Fabricius, 1793	+	+	+
39	*Ixias marianne* Cramer, 1779	+	+	+
40	*Ixias pyrene* Linnaeus, 1764	+	+	+
41	*Colotis danae* Fabricius, 1775	+	+	+
42	*Colotis amata* Fabricius, 1775	+	+	+
43	*Pareronia hippia* Fabricius, 1787	+	+	+
44	*Leptosia nina* Fabricius, 1793	-	+	+
Family: Lycaenidae				
45	*Catochrysops strabo* Fabricius, 1793	-	+	+
46	*Castalius rosimon* Fabricius, 1775	-	+	-
47	*Chilades lajus* Stoll, 1780	+	+	+
48	*Curetis thetis* Drury, 1773	+	+	+

49	*Euchrysops cnejus* Fabricius, 1798	+	+	+
50	*Spindasis vulcanus* (Fabricius, 1775)	-	+	+
51	*Zizeeria karsandra* Moore, 1865	+	+	+
52	*Zizina otis* Fabricius, 1787	+	+	+
53	*Zizula hylax* Fabricius, 1775	+	+	+
54	*Azanus ubaldus* Stoll, 1782	-	+	+
55	*Spindasis ictis* Hewitson, 1865	-	+	-
56	*Freyeria trochylus* Freyer, 1845	-	+	-
57	*Talicada nyseus* Guerin-Meneville, 1843	-	+	-
58	*Chilades parrhasius* Fabricius, 1793	-	+	-
59	*Tarucus nara* Kollar, 1848	-	+	+
Family: Hesperiidae				
60	*Hasora chromus* Cramer, 1780	-	+	-
61	*Pelopidas mathias* Fabricius, 1798	-	+	+
62	*Telicota bambusae* Moore, 1878	-	+	+
63	*Suastus gremius* Fabricius, 1798	-	+	-

Table 7: Distribution of butterflies in different habitats of Pavagadh Hill (+ stands for presence of species, - stands for absence of species)

Diversity Index	Summer	Monsoon	Post Monsoon	Winter
Shannon-Weiner Index (H)	2.523	3.318	3.871	3.271
Simpsons's Index of Diversity (1-D)	0.9156	0.9616	0.9776	0.9587

Table 8: Diversity indices of seasons

Diversity Index	Garden	Forest	Scrubland
Shannon-Weiner Index (H)	3.352	3.871	3.637
Simpsons's Index of Diversity (1-D)	0.963	0.9776	0.9721

Table 9: Diversity indices of habitats

Sr. No.	Scientific Name	Proboscis Length (mm)	Body Length (mm)	Wingspan (mm)
Papilionidae				
1.	*Graphium doson* C. & R. Felder, 1864	22.58 ± 0.601	27.2	79.9
2.	*Graphium agamemnon* Linnaeus, 1758	25.96 ± 0.114	28.28	85.6
3.	*Pachliopta aristolochiae* Fabricius, 1775	18.94 ± 0.906	21.9	85.0
4.	*Papilio polytes* Linnaeus, 1758	18.0 ± 0.158	22.8	95.1
5.	*Papilio demoleus* Linnaeus, 1758	23.4 ± 0.589	25.7	84.8
Nymphalidae				
6.	*Danaus chrysippus* Linnaeus, 1758	12.94 ± 0.449	29.2	76.4
7.	*Hypolimnas misippus* Linnaeus, 1764	13.96 ± 0.114	22.4	83.5
8.	*Junonia lemonias* Linnaeus, 1758	12.04 ± 0.230	23.4	57.3
9.	*Danaus genutia* Cramer, 1779	12.14 ± 0.151	25.5	77.6
10.	*Tirumala limniace* Cramer, 1775	12.24 ± 0.270	28.2	95.6
Pieridae				
11.	*Catopsilia pomona* Fabricius, 1775	15.92 ± 0.164	19.1	63.5
12.	*Catopsilia pyranthe* Linnaeus,1758	15.06 ± 0.089	20.4	60.1
13.	*Eurema brigitta* Stoll, 1780	13.02 ± 0.083	17.8	44.5
14.	*Eurema hecabe* Linnaeus, 1758	9.04 ± 0.114	16.2	45.46
15.	*Delias eucharis* Drury, 1773	15.98 ± 0.109	22.2	73.7
Lycaenidae				

16.	*Chilades lajus* Stoll, 1780	5.58 ± 0.238	8.7	28.1
17.	*Zizina otis* Fabricius, 1787	5.12 ± 0.192	6.7	19.1
18.	*Zizula hylax* Fabricius, 1775	6.6 ± 0.336	7.2	18.2
19.	*Freyeria trochylus* Freyer, 1845	4.72 ± 0.164	6.8	9.9
20.	*Zizeeria karsandra* Moore, 1865	5.3 ± 0.158	8.7	22.02

Table 10: Butterfly Species examined with their Morphological Measurements

Sr. No.	Name of the Nectar Host Plant	Family	Flowering Season	Flower Color	Corolla Shape	Type of Plant
1.	*Lantana camara*	Verbenaceae	throughout year	Yellow, Orange, Red & Pink	Tubular	Shrub
2.	*Nerium oleander*	Apocynaceae	throughout year	Pink	Tubular	Shrub
3.	*Jatropha pandurifolia*	Euphorbiaceae	Throughout Year	Red with yellow centre	Tubular	Shrub
4.	*Caesalpinia pulcherrima*	Fabaceae	throughout year	Red	Non-Tubular	Shrub
5.	*Tamarindus indica*	Caesalpiniaceae	May to Aug	Pale Yellow	Non-Tubular	Tree
6.	*Bougainvillea spectabilis*	Nyctaginaceae	throughout year	Pink	Tubular	Shrub
7.	*Murraya koenigii*	Rutaceae	Apr-May	White	Non-Tubular	Tree
8.	*Chromolaena odorata*	Asteraceae	Sept-Dec	White	Tubular	Shrub

9.	*Tridax procumbens*	Asteraceae	Throughout Year	Yellowish White	Tubular	Herb
10.	*Tectona grandis*	Verbenaceae	June-Sept	White	Non-Tubular	Tree
11.	*Tephrosia purpurea*	Fabaceae	Sept-Oct	Purple	Non-Tubular	Shrub
12.	*Allamanda cathartica*	Apocynaceae	Throughout year	Yellow	Tubular	Shrub
13.	*Cassia occidentalis*	Fabaceae	July-Dec	Yellow	Tubular	Shrub
14.	*Sida acuta*	Malvaceae	Aug-Dec	Yellow	Tubular	Herb
15.	*Catharanthus roseus*	Apocynaceae	Throughout year	Pink	Tubular	Shrub
16.	*Calotropis procera*	Apocynaceae	Aug-Dec	White with purple crown	Non-Tubular	Shrub
17.	*Tabernaemontana gamblei*	Apocynaceae	Throughout year	White	Tubular	Shrub
18	*Wedelia trilobata*	Asteraceae	Almost throughout the year	Yellow	Non-Tubular	Herb
19	*Emilia sonchifolia*	Asteraceae	Aug-Dec	Purple	Tubular	Herb
20	*Ixora coccinea*	Rubiaceae	Throughout year	Pink	Tubular	Shrub
21	*Sida rhombifolia*	Malvaceae	Aug-Dec	Yellow	Tubular	Herb
22	*Sida cordifolia*	Malvaceae	Aug-Dec	Yellow	Tubular	Herb

Table 11: Prominent Nectar Plant Species found in the Study Area

Sr. No.	Name of the Nectar Host Plant	Corolla Length Mean±SD (mm)	Visited Butterflies
1.	*Lantana camara*	9.96 ± 0.114	Common Jay
			Tailed Jay
			Common Rose
			Common Mormon
			Lime Swallowtail
			Common Emigrant
			Mottled Emigrant
			Common Jezebel
			Plain Tiger
			Danaid Eggfly
			Striped Tiger
			Blue Tiger
			Lemon Pansy
2.	*Chromolaena odorata*	10.06 ± 1.277	Common Emigrant
			Mottled Emigrant
			Common Grass Yellow
			Plain Tiger
			Danaid Eggfly
3.	*Tridax procumbens*	5.5 ± 0.070	Common Emigrant
			Mottled Emigrant
			Common Grass Yellow
			Small Grass Yellow,
			Lime Blue
			Tiny Grass Blue
4.	*Tephrosia purpurea*	3.06 ± 0.396	Grass Jewel
			Lesser Grass Blue
			Tiny Grass Blue
			Lime Blue
			Dark Grass Blue
5.	*Catharanthus roseus*	23.0 ± 1.083	Common Jay
			Lime Swallowtail

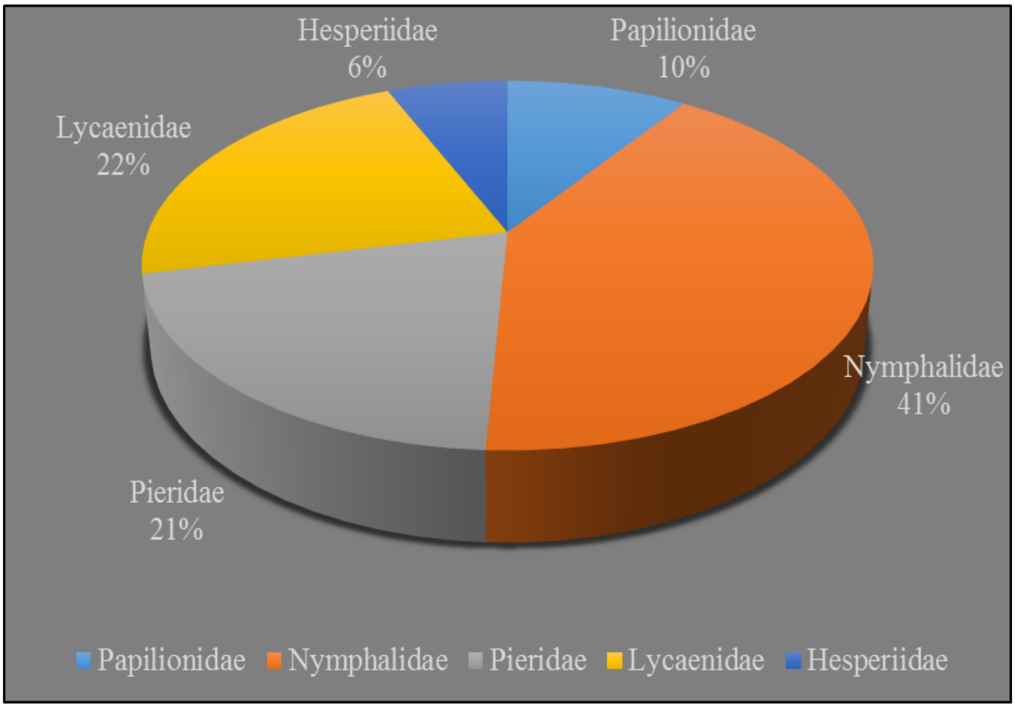
			Tailed Jay
			Common Rose
			Common Mormon
6.	*Sida acuta*	3.75 ± 0.250	Lemon Pansy
			Lime Blue
			Lesser Grass Blue
			Tiny Grass Blue
			Grass Jewel
			Dark Grass Blue
7.	*Wedelia trilobata*	2.5 ±0.207	Lemon Pansy
			Plain Tiger
			Danaid Eggfly
8.	*Emilia sonchifolia*	2.2 ±0.148	Lime Blue
			Lesser Grass Blue
			Tiny Grass Blue
			Grass Jewel
			Dark Grass Blue
9.	*Ixora coccinea*	25.5 ±1.204	Common Jay
			Tailed Jay
			Common Mormon
			Lime Swallowtail
			Common Rose
10.	*Sida rhombifolia*	5.28 ± 0.258	Lime Blue
			Lesser Grass Blue
			Tiny Grass Blue
			Grass Jewel
			Dark Grass Blue

Table 12: Corolla length of preferred nectar plants and their visited butterflies

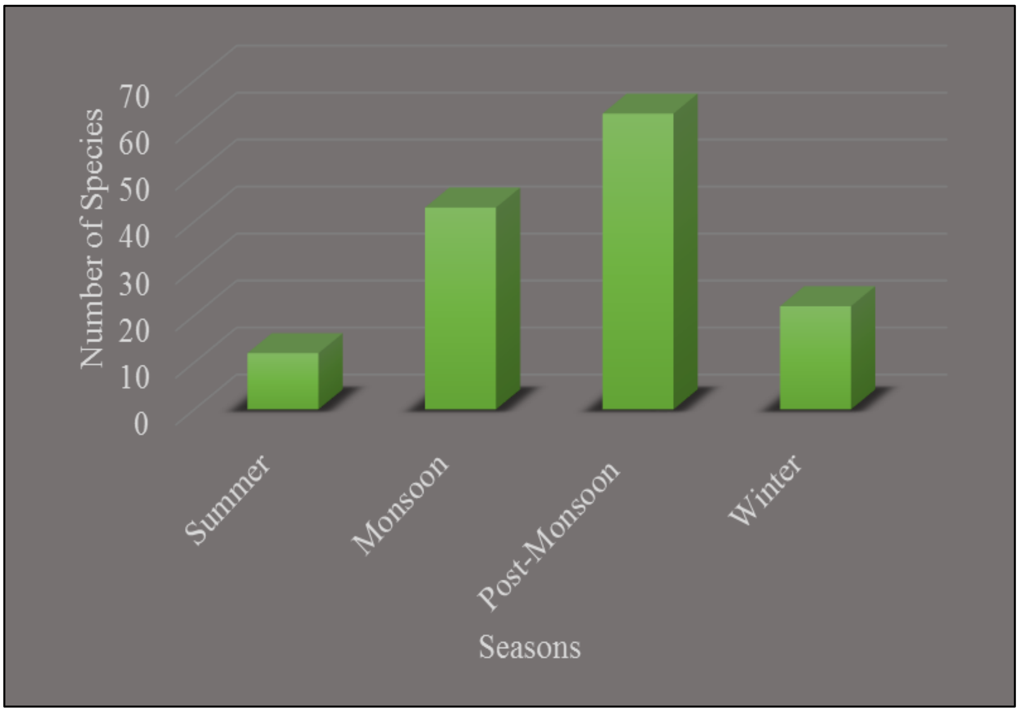
Sr. No.	Name of the Nectar Host Plant	Corolla Length Mean±SD (mm)	Visited Butterflies	Frequency of Visits/Hour
1.	*Lantana camara*	9.96 ± 0.114	Common Jay	4
			Tailed Jay,	12
			Common Rose,	6
			Common Mormon	14
			Lime Swallowtail	6
			Common Emigrant	10
			Mottled Emigrant	10
			Common Jezebel	10
			Plain Tiger	16
			Danaid Eggfly	14
			Striped Tiger	14
			Blue Tiger	14
			Lemon Pansy	12
2.	*Chromolaena odorata*	10.06 ± 1.277	Common Emigrant	12
			Mottled Emigrant,	12
			Common Grass Yellow	2
			Plain Tiger	14
			Danaid Eggfly	12
3.	*Tridax procumbens*	5.5 ± 0.070	Common Emigrant	6
			Mottled Emigrant	6
			Common Grass Yellow	12
			Small Grass Yellow,	10
			Lime Blue	16
			Tiny Grass Blue	16
4.	*Tephrosia purpurea*	03.06 ± 0.396	Grass Jewel	16
			Lesser Grass Blue	12
			Tiny Grass Blue	10
			Lime Blue	10
			Dark Grass Blue	10

5.	*Catharanthus roseus*	23.0 ± 1.083	Common Jay	6
			Lime Swallowtail	16
			Tailed Jay	8
			Common Rose	10
			Common Mormon	6
6.	*Sida acuta*	3.75 ± 0.250	Lemon Pansy	8
			Lime Blue	14
			Lesser Grass Blue	12
			Tiny Grass Blue	10
			Grass Jewel	16
			Dark Grass Blue	12
7.	*Wedelia trilobata*	2.5 ±0.207	Lemon Pansy	8
			Plain Tiger	6
			Danaid Eggfly	4
8.	*Emilia sonchifolia*	2.2 ±0.148	Lime Blue	12
			Lesser Grass Blue	12
			Tiny Grass Blue	12
			Grass Jewel	16
			Dark Grass Blue	14
9.	*Ixora coccinea*	25.5 ±1.204	Common Jay	16
			Tailed Jay	2
			Common Mormon	2
			Lime Swallowtail	12
			Common Rose	15
10.	*Sida rhombifolia*	5.28 ± 0.258	Lime Blue	18
			Lesser Grass Blue	16
			Tiny Grass Blue	14
			Grass Jewel	4
			Dark Grass Blue	12

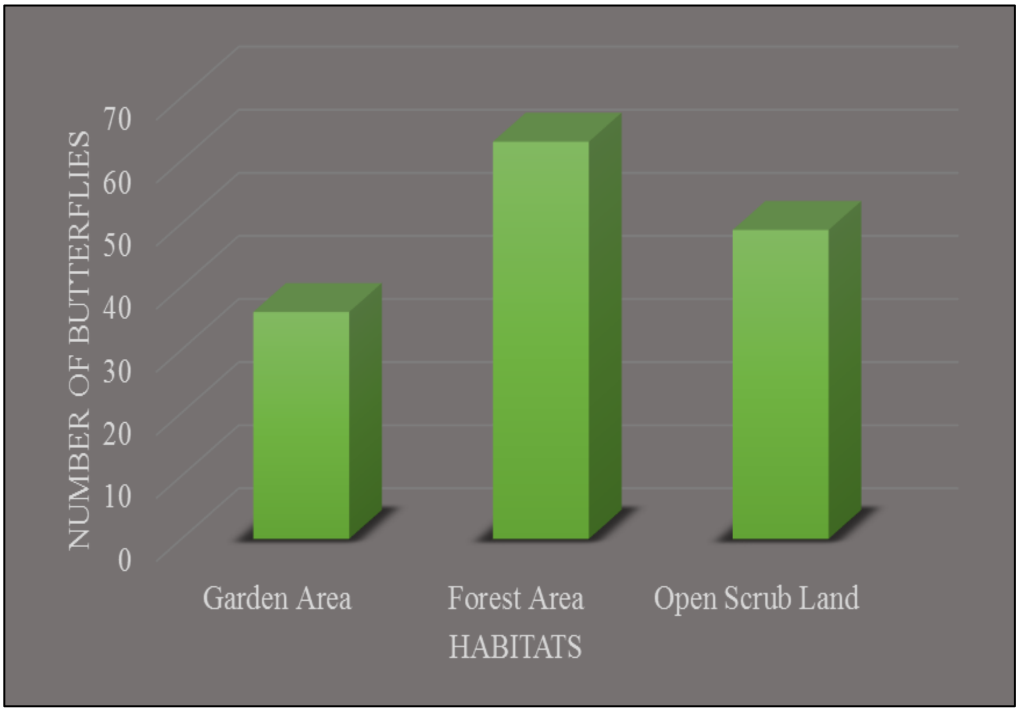
Table 13: Frequency of flowers visited by butterflies during the study period at Pavagadh Hill



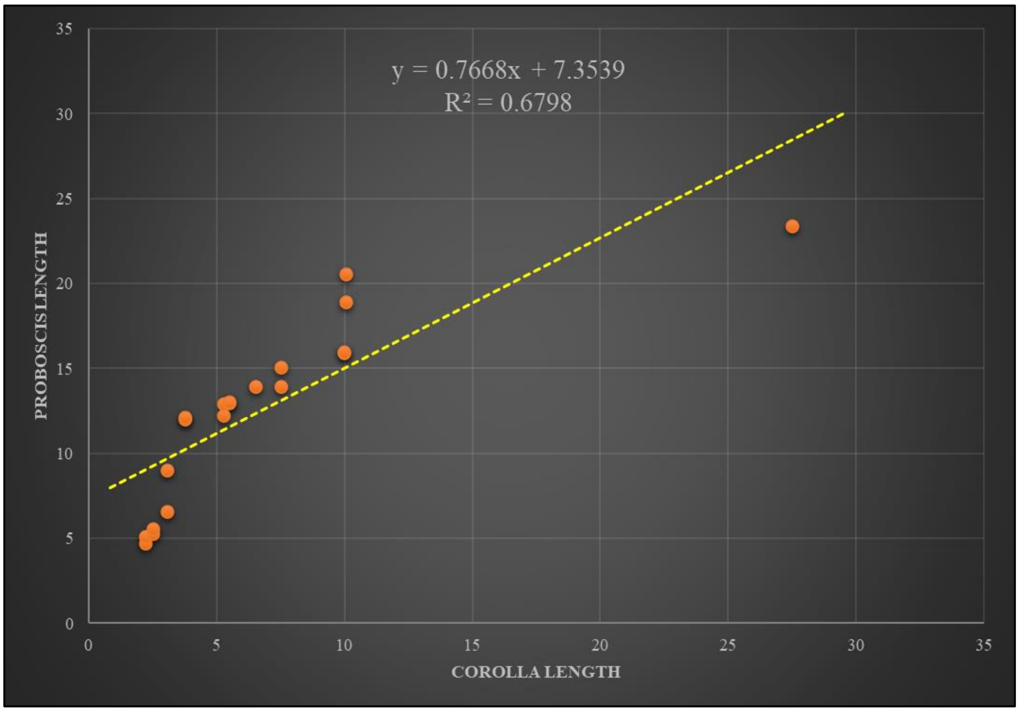
Graph 1: Composition of Different Butterfly Families in Pavagadh Hill



Graph 2: Seasonal Variation of Butterflies in Pavagadh Hill



Graph 3: Distribution of Butterflies in Different Habitats of Pavagadh Hill



Graph 4: Co-evolutionary relationship among Butterflies and Plants. The values are in mm.

Chapter 4

Significant Findings & Conclusion

- This research work was on species diversity, abundance, seasonal variation, nectar plant preference and the co-evolutionary relationship between butterflies and plants in Champaner-Pavagadh Archaeological Park, a UNESCO recognized world heritage site.
- Champaner-Pavagadh Archaeological Park is a healthy ecosystem having varied habitats such as Forest area, Agricultural fields, Garden area and concrete structures and thus provides a healthy environment for the growth and development of different stages of butterflies.
- The occurrence status of butterfly species is associated with the availability of host plants and their flowering season (Table 5 and Table11).
- Flora of Pavagadh has been studied by the Department of Botany, The M.S.University of Baroda and flora of Pavagadh has also been extensively listed by in the Working plan of the Forest Department Godhra (2008) (Annexures I&II) and a separate list of host plants of butterflies have also been identified by us in this work (Table 12).
- A gradual increase in the number of species was observed in monsoon season June, July and August to post-monsoon i.e., September, October and November.
- There were some butterfly species present throughout the year (Table 6) because the preferred nectar plants by them used to bear flowers throughout the year for example *Lantana camara* (Lantana) and *Tridax procumbens*.
- During the study period, a total of 63 butterfly species were identified belonging to 48 genera and 5 families (Table 6).
- Amongst 63 species, 06 species were Papilionids, 26 species were Nymphalids, 13 species were Pierids, 14 were Lycaenids and 4 were Hesperiids.
- Family Nymphalidae showed the highest number of butterfly species, followed by Lycaenidae and Pieridae while Family Hesperiidae showed least diversity of butterfly species.
- Depending on the availability of butterfly species they become common, uncommon or rare.

- *Lantana camara* was found to be the most preferred nectar plant by wide range of butterflies (Table 12&13). The diversity and abundance of butterflies were maximum in Forest area followed by Scrubland and Garden area.
- The foraging strategy of butterflies was positively correlated with their preferred nectar plants because the selection of flowers strongly favored shape of corolla (tubular), corolla length, texture, color of corolla and frequency of flower visits. For example, the frequency of flower visits was more on *Lantana camara* by *Danaus chrysippus* (Plain Tiger) that is 16 times per hour but the same species was visited on *Wedelia trilobata* 6 times per hour. *Graphium agamemnon* (Tailed Jay) visited *Catharanthus roseus* 8 times per hour but visited *Ixora coccinea* only 2 times per hour (Table 13).
- The study reveal that the floral morphology and the structure of butterfly proboscis are correlated which lead to the existence of the co-evolutionary relationship with their pollinators. They often prefer bright colored flowers with tubular corolla. The visits were more on flowers of *Lantana camara* (red colour) *Sida acuta* (yellow colour) and *Tridax procumbens* (pink colour) Catharanthus *roseus* (white colour) flowers. If we plot a graph between the depth of flowers and the length of proboscis of butterflies, there was a positive correlation. The result of the correlational study shows that the length of corolla and length of proboscis are correlated. Butterflies with shorter proboscis restrict their visits to flowers with deep corolla.

Family	Preferred Nectar Plant	Scientific Name of Butterfly	Common Name of Butterfly
Papilionidae	*Lantana camara* (Lantana)	*Graphium doson* C. & R. Felder, 1864	Common Jay
		Graphium agamemnon Linnaeus, 1758	Tailed Jay
		Pachliopta aristolochiae Fabricius, 1775	Common Rose
		Papilio polytes Linnaeus, 1758	Common Mormon
		Papilio demoleus Linnaeus, 1758	Lime Swallowtail
	Ixora coccinea (Ixora)	*Graphium doson* C. & R. Felder, 1864	Common Jay
		Pachliopta aristolochiae Fabricius, 1775	Common Rose
		Papilio demoleus Linnaeus, 1758	Lime Swallowtail
	Catharanthus roseus (Periwinkle)	*Papilio demoleus* Linnaeus, 1758	Lime Swallowtail
Nymphalidae	*Lantana camara* (Lantana)	*Danaus chrysippus* Linnaeus, 1758	Plain Tiger
		Hypolimnas misippus Linnaeus, 1764	Danaid Eggfly
		Danaus genutia Cramer, 1779	Striped Tiger
		Tirumala limniace Cramer, 1775	Blue Tiger

		Junonia lemonias Linnaeus, 1758	Lemon Pansy
	Chromolaena odorata (Siam Weed)	*Danaus chrysippus* Linnaeus, 1758	Plain Tiger
		Hypolimnas misippus Linnaeus, 1764	Danaid Eggfly
	Lantana camara (Lantana)	*Catopsilia pomona* Fabricius, 1775	Common Emigrant
		Catopsilia pyranthe Linnaeus,1758	Mottled Emigrant
		Delias eucharis Drury, 1773	Common Jezebel
	Chromolaena odorata (Siam Weed)	*Catopsilia pomona* Fabricius, 1775	Common Emigrant
		Catopsilia pyranthe Linnaeus,1758	Mottled Emigrant
	Tridax procumbens (Coat Buttons)	*Eurema hecabe* Linnaeus, 1758	Common Grass Yellow
		Eurema brigitta Stoll, 1780	Small Grass Yellow
Lycaenidae (Monsoon and Post monsoon)	*Tephrosia purpurea* (Wild Indigo) *Sida acuta* (Common Wireweed) *Emilia sonchifolia* (Purple Sow Thistle) *Sida rhombifolia* (Cuban Jute)	*Chilades lajus* Stoll, 1780	Lime Blue
		Zizina otis Fabricius, 1787	Lesser Grass Blue
		Zizula hylax Fabricius, 1775	Tiny Grass Blue
		Freyeria trochylus Freyer, 1845	Grass Jewel
		Zizeeria karsandra Moore, 1865	Dark Grass Blue

Table14: Butterflies and their Preferred Nectar Plants from Pavagadh (some examples)

CONCLUSION

The butterfly fauna depends mainly on the floristic elements, humidity, rainfall, and temperature. Type of vegetation determines the survival of the organisms. Butterflies are highly sensitive to changes in the environment. Plantation of the right flora in any habitat invites a large number of butterflies throughout the year. It is highly recommended that the public garden on the foothill of Pavagadh can be uplifted to a Butterfly Park by planting more nectar host plants as well as other larval host plants which promote the survival of different developmental stages of butterflies.

Chapter 5

Bibliography

Baker, H. G., & Baker, I. (1973). Amino-acids in Nectar and their Evolutionary significance. *Nature*, 241, 543–545

Bhakare, M., & Ogale, H. (2018). *A Guide to the Butterflies of Western Ghats (India) Milind Bhakare and Hemant Ogale First Edition* (First). Milind Bhakare-354, Somwar Peth, Satara, 354pp

Bhatt, U. M., & Nagar, P. S. (2017). Diversity of butterflies in an arboretum of Vadodara, Gujarat, India. *Check List the Journal of Biodiversity Data*, 13(2), 1–15

Ehrlich, P. R., & Raven, P. H. . (1964). Butterflies and Plants : A Study in Coevolution. *Evolution*, 18(4), 586–608

Ehrlich, P. R., & Wilson, E. O. (1991). Biodiversity Studies: Science and Policy. *Science*, 253(5021), 758–762

Fernandes, B., Kini, A., Varkey, J., Subramanian, S., & Achary, P. (2016). Study of Diversity and Current Status of Butterflies (Rhopalocera) at Vasai Fort, Dist-Palghar, India. *International Research Journal of Biological Sciences*, 5(3), 11–19

Gadgil, M. (1996). Documenting diversity: An experiment. *Current Science*, 70(1), 36–44.

Gandhi, S., & Kumar, D. (2016). Seasonal diversity of butterflies in the fragmented habitats of Waghai Botanical Garden of The Dangs - Gujarat. *International Journal of Biological Research*, 4(2), 237–244

Gandhi, S., & Kumar, D. (2015). Studies on Butterfly diversity, abundance and utilization of plant resources in urban localities of Banyan city-Vadodara, Gujarat, India. Journal of Entomology and Zoology Studies, 3(4), 476-480

Hammond, P. C., & Miller, J. C. (1998). Comparison of the Biodiversity of Lepidoptera Within Three Forested Ecosystems. *Annals of the Entomological Society of America*, 91(3), 323–328

Honda, K., Ômura, H., & Hayashi, N. (1998). Identification of floral volatiles from Ligustrum japonicum that stimulate flower-visiting by cabbage butterfly, Pieris rapae. *Journal of Chemical Ecology*, 24(12), 2167–2180

Kehimkar, I. (2008). *The Book of Indian Butterflies* (1st ed.). Bombay Natural History Society. 497pp

Krenn, H. W., Plant, J. D., & Szucsich, N. U. (2004). Mouthparts of flower-visiting insects. *Arthropod Structure and Development*, 34(1), 1–40

Kristensen, N. P. (1999). Lepidoptera, Moths and Butterflies. Vol. 1: Evolution, Systematics, and Biogeography. Handbook of zoology, 4, 1-491

Kunte, K. (2000). *India- A Lifespace Butterflies of Peninsular India* (1st ed.). University Press (India) Private Limited, Hyderabad 254pp

Kunte, K. J. (1997). Seasonal patterns in butterfly abundance and species diversity in four tropical habitats in northern Western Ghats. *Journal of Biosciences*, *22*(5), 593–603.

Modi, S. M. (2008). Champaner-Pavagadh - Managing conflicts - A conservation challenge. *Structural Analysis of Historic Construction*, *5*(1), 175–179

Mukherjee, S., Banerjee, S., Basu, P., Saha, G. K., & Aditya, G. (2015). Lantana camara and butterfly abundance in an urban landscape: Benefits for conservation or species invasion. *Ekologia*, *34*(4), 309–328

Oza, G. M. (1961). Flora of Pavagadh. Ph. D. Thesis Submitted to The M. S.University of Baroda, Vadodara Gujarat, India, 572pp

Parasharya, B. M., & Jani, J. J. (2007). *Butterflies of Gujarat* (First, Vol. 2000). Anand Agricultural University 138pp.

Pollard, E., Greatorex-Davies, J. N., & Thomas, J. A. (1997). Drought reduces breeding success of the butterfly Aglais urticae. Ecological Entomology, 22(3) 315-318

Reid, W. V., McNeely, J. A., Winograd, M., Bryant, D. A., & Tunstall, D. B. (1993). Biodiversity indicators for policy-makers, 42pp

Revdandekar, A. V. (2014). Ecologically sustainable development plan for Pavagadh forest area using satellite data. Ph. D Thesis Submitted to The M. S. University of Baroda, Vadodara Gujarat, India, 156pp

Sheth, H. C., & Melluso, L. (2008). The Mount Pavagadh volcanic suite, Deccan Traps: Geochemical stratigraphy and magmatic evolution. *Journal of Asian Earth Sciences*, *32*(1), 5–21

Sidhu, A. K., Chandra, K., & Palot, J. (2012). Observations on the status and biodiversity of butterflies in the fragile ecosystem of Ladakh (J&K). *Records of the Zoological Survey of India*, *112*(3), 101–112

Singh, A. P. (2012). Lowland forest butterflies of the Sankosh River catchment, Bhutan. *Journal of Threatened Taxa*, *4*(12), 3085–3102

Sinha, A. (2018). Conservation of historic water systems in Champaner-Pavagadh, Gujarat, India. *Landscape Research*, 44(5): 588–599

Sinha, A. (2004). Champaner-Pavagadh Archaeological Park: A Design Approach. *International Journal of Heritage Studies*, *10*(2), 117–128

Stefanescu, C., & Traveset, A. (2009). Factors influencing the degree of generalization in flower use by Mediterranean butterflies. *Oikos*, *118*(7), 1109–1117

Sudheendrakumar, V. V, Binoy, C. F., Suresh, P. V, & Mathew, G. (2000). Habitat Associations of Butterflies in the Parambikulam Wildlife Sanctuary, Kerala, India. *Journal of the Bombay Natural History Society*, *97*(2), 193–201

Sule, R., & Kumar, D. (2019). Insecticide resistance studies of Cypermenthrin 25EC and Chlorpyriphos 20EC against Spodoptera litura fabricius, 1775 (Lepidoptera: Noctuidae). *Indian Journal Of Agricultural Research*, *53*(4), 453–457

Swihart, C. A. (1970). Colour discrimation by the butterfly Heliconius charitonius linn. *Animal Behaviour*, *19*(1), 156–164

Tiple, A. D., Deshmukh, V. P., & Dennis, R. L. (2006). Factors influencing nectar plant resource visits by butter fl ies on a university campus : implications for conservation. *Nota Lepidopterologica*, *3*(4), 213–224

Waser, N. M. (1986). Evaluating the impact of pollution on plant-Lepidoptera relationships. *The American Naturalist*, *127*(5), 357–373

Yadav, A. (2019). Diversity and Ecology of Spiders in Champaner-Pavagadh Archaeological

Park a World Heritage Site in Gujarat. Ph. D. Thesis Submitted to The M. S.University of Baroda, Vadodara Gujarat, India, 219pp.

Annexure I

Publication from thesis

62

Environment and Ecology 38 (1) : 62—70, January—March 2020
ISSN 0970-0420

Seasonal Variations in the Diversity and Abundance of Butterflies in the Forest of Champaner-Pavagadh, Gujarat

Lakshmi S. Pillai, Dolly Kumar

Received 29 October 2019 ; Accepted 13 December 2019 ; Published on 4 January 2020

ABSTRACT

Butterflies are one of the most potent pollinators and ecological indicators existing today. Their presence indicate the health of an ecosystem. Thus a research work was conducted in the forest area of Champaner-Pavagadh to study the diversity, abundance and seasonal distribution of butterflies. Champaner - Pavagadh is a UNESCO recognized world heritage site which attracts number of pilgrims and tourists throughout the year. Pavagadh hill comprises forest vegetation with different types of flowering plants. A total of 52 butterfly species belonging to 5 different families namely Nymphalidae, Pieridae, Papilionidae, Lycaenidae and Hesperidae were recorded during the study period July 2016 to June 2018. Maximum diversity of species were observed in Nymphalidae and Pieridae. Least diversity of species was observed in Hesperidae. The maximum favorable season for flourishing of butterflies were post-monsoon and the post-monsoon season includes months of September, October and November because of the frequent rains received during monsoon period promotes the growth of the flowering plants which provide nectar resource for the butterflies. Some butterflies such as *Catopsilia pomona*, *Catopsilia pyranthe*, *Eurema brigitta*, *Delias eucharis*, *Belenois aurota*, *Ixias marianne*, *Acraea terpsicore*, *Ariadne merione*, *Danaus chrysippus*, *Hypolimnas misippus*, *Euchrysops cnejus* were existed throughout the year while species like *Curetis thetis*, *Hasora chromus*, *Pelopidas mathias*, *Telicota bambusae*, *Colotis danae* were observed only during post-monsoon and winter seasons.

Keywords Butterfly, Diversity, Pavagadh, Seasonal variation.

INTRODUCTION

Butterflies are one of the most fascinating insects belonging to the order Lepidoptera. Members of this group are attracted by their peculiar coloration and beauty. Approximately 17, 200 species of butterflies have been reported worldwide and out of which 1,501 species of them are inhabiting in India (Kunte 2000). Adults and larvae of butterflies depend on specific host plants for foliage, nectar and pollens. The occurrence of butterflies is seasonal and their appearance become common for only a few months and remain rare or absent for rest of the year. They become rare or inactive as adults and usually spend their life either as caterpillar or pupae during unfavorable seasons.

Lakshmi S. Pillai, Dolly Kumar*
Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara 390002, India
Email : dollymsu@gmail.com
*Corresponding author