Chapter 1

Introduction

1.1 Diversity of Insects

Insects represent vast majority of organisms in terrestrial as well as freshwater ecosystem. They are the most supreme creatures on the earth and exist everywhere from the equator to the arctic and from sea level to the snowfield of highest mountains, dry deserts, on land, in air and water. Lepidoptera is an order of class Insecta which includes both moths (Hetrocera) 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 important role played by butterflies and moths in the natural ecosystem are as pollinators and as food in the food chain. But some moths, particularly their caterpillars can be major agricultural pests. Caterpillar of gypsy moth is an invasive species in the northern United States that causes severe damage to the forests. *Spodoptera litura* is one of the important pests and causes considerable damage to the crop (Sule & Kumar, 2019). Unlike moths, butterflies are very useful to mankind and the ecosystem in several ways.

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[1] .2 Butterfly: The colorful lepidopterans

Butterflies are an important component of biodiversity and are ecologically important because of the role they play in the food chain of the forest ecosystem (Singh, 2012). Their larvae, caterpillars, and adults form the food for various other organisms including birds and reptiles. Their presence is an important factor in determining the health of the ecosystem as they are good biological indicators of environmental variation and quality.

Butterflies 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. Butterflies are good indicators of environmental changes as they are sensitive and are directly affected by changes in habitats, atmosphere temperature and weather conditions (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.

An important factor, which determines the dependence and survival of a species is the nature of vegetation. Butterflies undergo complete change or metamorphosis during their life cycle. Each butterfly species passes through four distinct stages namely egg, larva, pupa and adult. The female butterfly searches for an appropriate host plant to lay eggs soon after mating. Most butterfly species prefer a single plant species for laying eggs which are known as larval host plants. Many have only one species of plant and others prefer plants from one family and few butterflies have a wider range of host plants and may have different host plants in different regions (Bhakare & Ogale, 2018). Adults and larvae of butterflies depend on specific host plants for foliage, nectar and pollens. The occurrence of butterflies is seasonal and their appearance becomes common for only a few months and remains rare or absent for the rest of the year. They become rare or inactive as adults and usually spend their life either as caterpillar or pupae during unfavorable seasons. Seasonal changes are influenced by ecological and biological factors such as temperature, humidity, rainfall, photoperiod, availability of food plants and larval host plants.

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).

An extensive study on Lepidoptera on different aspects such as studies related to taxonomy, ecology, and biology of butterflies has already been carried out in different parts of Gujarat concerning protected areas, Wildlife Sanctuaries, National Parks, fragmented habitats like agricultural landscapes and industrial zones. But there is a void in the field of research in Pavagadh Hill which is a fragmented forest area as no records of butterflies has been recorded so far. It is a world heritage site announced by UNESCO in 2004 situated in Gujarat, which is home to many invertebrates as well as vertebrates. The present study deals with the biology and ecology of butterflies in Pavagadh Hill. The study gives a detailed insight into the diversity of butterflies, abundance, seasonal variation, their natural host plants and also the coevolutionary relationship between butterflies with their nectar host plants.

An in-depth study on the flora of Champaner- Pavagadh Archaeological Park has been conducted by the Department of Botany, The M S University of Baroda by (Oza, 1961) and (Revdandekar, 2014). The Forest Department of Godhra has also contributed in the form of reports on the plants and animals of Champaner-Pavagadh Archaeological Park have been mentioned (Annexure I). Modi, 2008 from People for Heritage Concern, Surat worked on managing conflicts of Champaner Pavagadh Archeological Park. Other studies conducted are geochemical stratigraphic and magmatic evolution studies from the Department of Earth Sciences, IIT Mumbai (Sheth & Melluso, 2008). (Sinha, 2004) from The University of Illinois, USA conducted a design approach to study Champaner Pavagadh. (Yadav, 2019) conducted a study on the diversity and ecology of spiders in Champaner-Pavagadh Archaeological Park. But no study has been conducted in this world heritage site to know about the butterflies. Hence there is a need to study them because it is a place whose 94% is covered with forest having different types of vegetation which can serve as the nectar and host plants for various butterfly species. Moreover, there is a public garden at the base of the hill where many ornamental plants are grown. The forest present there is a dry deciduous type having mixed vegetation which includes grasses, creepers, climbers, herbs, shrubs, and trees. This hill is surrounded by a dense forest having a large number of different types of plants. Though it is a semi-arid and deciduous forest, it harbors rich biodiversity of different invertebrates and vertebrates. Therefore, Pavagadh Hill is a potential site to carry out ecological as well as biodiversity studies. Pavagadh's total forest area cover which is legally constituted as a

reserve forest is 6356.98 ha. Champaner is situated at the base of the Pavagadh hill which is a historic city. Champaner along with Pavagadh popularly known as Champaner- Pavagadh Archaeological Park. It was declared as a world heritage site by UNESCO in July 2004 which is spread over an area of more than 1,329 hectares. Pavagadh hill is 823 meters high from the sea level. At the base of the hill, a public garden is also situated. Moreover, there are temples, monuments, temporary residential houses, and water installations such as step wells and tanks, mosques, palaces, and natural caves are also present.

1.3 Developmental Stages of Butterflies

The stages of development, growth, and reproduction of an organism referred to as the life cycle. The developmental stages that a butterfly undergoes are known as metamorphosis, which is a complete one. Each species passes through four distinct stages such as egg, a larval stage known as a caterpillar, pupa (chrysalis) and finally enter into the adult stage. The transformation from egg to beautiful adult is one of the wonders of nature. Different stages of development take different time to molt. Usually, the caterpillar stage is the longest and the egg stage is the shortest depending on the size of the butterfly. The caterpillar roughly takes 15 to 40 days depending on the time of the year and also the size of the butterfly. Caterpillars that grow in the monsoon season take a shorter period than those that grow in the summer season. The pupal stage lasts for about 6 to 15 days if the season is favorable. Adults live for a few to a couple of months and it is observed that larger species usually survive longer.

A) **Egg**: Eggs are laid by the female on a specific host plant or near the host plant. Eggs are laid singly, in groups, or in large masses. Usually, they are laid on the lower surface of leaves to escape from the predators but sometimes laid on buds, flowers, upper surface of leaves of any plant which is near the host plant or even on the ground also. Most of them lay eggs on the host plants because it is easy for the newly emerged larvae to feed upon them. They may lay eggs on one or more species of plants but they do not lay eggs on every plant. The shape, size, color, and texture of eggs vary greatly from species to species (Figure 2 & Table 1). It is an identifying feature of the species. Though they are specific the eggs of a particular family have got some specific features. For example, the eggs of the butterflies belong to the family Lycaenidae are generally tiny, turban shaped, or dome-like with a smooth surface or with notches like a golf ball. In Pieridae, eggs are tall, spindle-shaped, and often appear in white colour when they are laid but turn into red to orange

in a day or two (Bhakare & Ogale, 2018). The eggs have a thin hard-ridged protective outer layer known as chorion, which has a thin wax coating that prevents the eggs from drying out before the larva develops fully. The eggs stick to the leaf surface with an adhesive coating on the egg surface (Kehimkar, 2008). Egg contains several tiny funnel-shaped openings or holes present at one end, which is known as micropyles. The function of micropyle is to allow the sperm to enter the egg and to fertilize the egg as well as gas exchange for the developing larva. There is a nutrient fluid inside each egg that nourishes the developing larva (Bhakare & Ogale, 2018). When it is time to hatch, the larva opens the eggshell from within with its jaws and comes out.

Figure 1: Representative image showing butterfly laying eggs

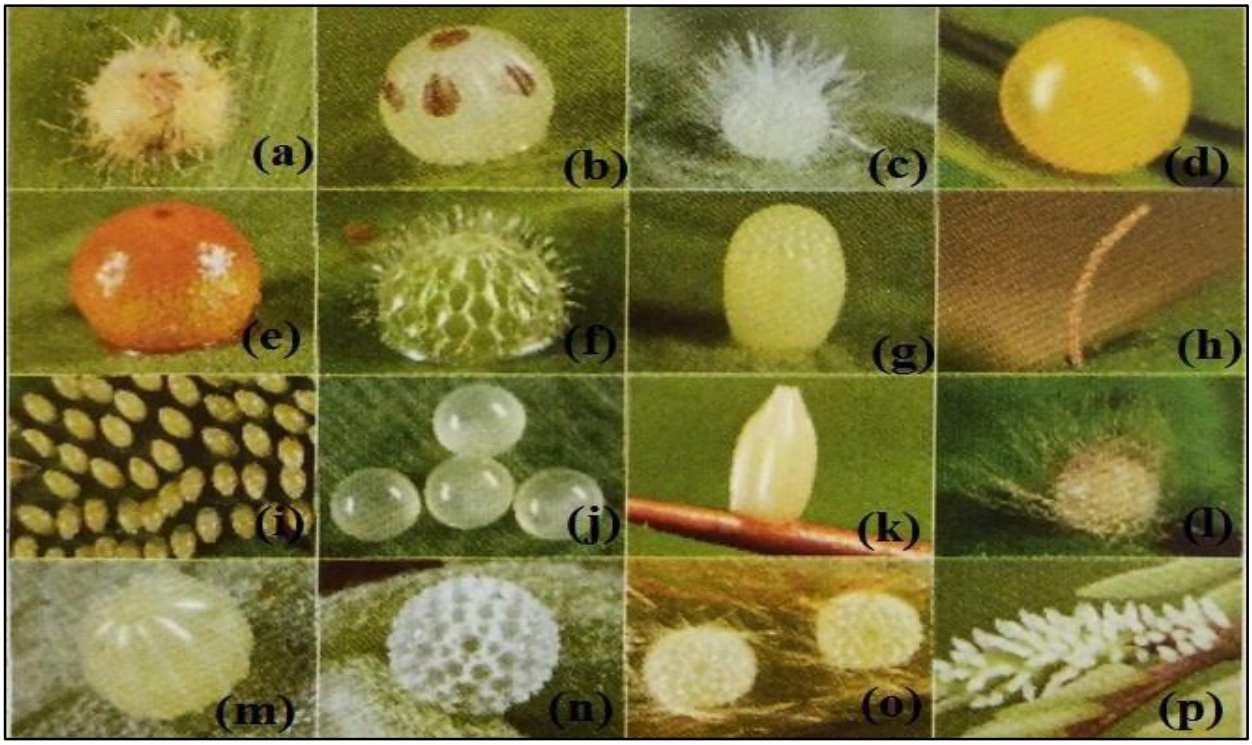

Figure 2: Variations in color and shape of Eggs belonging to different families of the order Lepidoptera (Source: Bhakare & Ogale, 2018)

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

B) Larva (Caterpillar): Caterpillar is the larval stage of butterflies. The duration of the stage is from two weeks to a month. The larval stage is the main feeding stage of the butterfly life cycle. Most of them prefer to eat the tender leaves of a particular plant species, known as larval host plants. They are multi-legged, voracious feeders, spend all of their time in search of plant leaves, and consume food. The larva grows rapidly but the skin doesn't grow. When the skin gets stretched, the larva stops eating for a while and new skin is formed under the old skin and it sheds and enters into the next stage of growth called instars. This process of shedding skin is known as molting. Caterpillars mature through a series of stages known as instars. The larva is the only growing stage in the life cycle and accumulates some resources for reproduction.

Butterfly larva consists of 14 segments. The first segment is the head which is joined to the body by the neck. Head bears two antennae placed on either side. The larvae have six true legs located on the 3 thoracic segments. These legs are primarily used for holding and manipulating the leaves on which they feed. Four pairs of false legs are present on the abdominal segments called prolegs, which helps to maintain a grip on the twigs or leaves while moving. There is the presence of a pair of anal claspers at the tail end of the body, which helps while walking. Most of the butterfly larvae prefer to eat only a single type of plant throughout their larval stage. When it reaches the final instar, it stops eating and search for a suitable substrate to pupate. Some of the identified larval host plants from the study area are enlisted in Table 2.

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

C) The Head: It has a central groove, separating its two lobes. The lobes may be produced on top into small points or longhorns. At the base are the biting and chewing type of mouthparts, with jaws that work sideways. The silk-spinning organ known as the spinneret is present behind the jaw. Simple eyes are present on the sides of the cheeks.

D) The Thoracic Segments: The second segment of the body may be narrow and form a neck that can twist and turn to a great extent. A pair of small true legs are present on each thoracic segment. The legs help to hold on to the leaves which they eat.

E) The Abdominal Segments: Segments from 7 to 10, each of them has a pair of fleshy prolegs which help in holding the silk threads on the surface on which the caterpillar rests. An additional pair of fleshy prolegs are present at the 14th segment called claspers. It acts as the strongest hold on the surface and also helps the caterpillar suspends for pupation. The surface of the body may be tubercled and each tubercle may bear a spine or hairy outgrowth. Spiracles are situated on the 2nd and 5th to 14th segments at the lower side of the body. These are small pores that open inside through a network of microscopic tubes. It helps in communicating with the various parts of the body. The caterpillar and adult butterfly breathe through the spiracles.

F) Pupa (Chrysalis): Once the larva gets a suitable place to pupate it spins a pad of silk, with the help of anal claspers it hangs on it freely. It is a dormant stage of the life cycle where metamorphosis takes place within it and forms an adult butterfly. Once the metamorphosis is complete, the adult one crawls and comes out of the pupal case. It hangs itself to the pupal case or a nearby firm surface like a perch. The newborn butterfly is a fully formed adult and remains the same size throughout its remaining life.

G) Adult: the fourth and the last stage of the life cycle is the adult. Once the metamorphosis is complete, it cracks open the pupal case and emerges out. Then it tries to expand its wings. Once the wings got expanded to the fullest, the butterfly tries to dry them in the sun. Butterflies generally emerge from the pupal case during pre-dawn darkness or at dawn because they use the earlymorning sunlight to dry their wings. As it is the reproductive stage of the life cycle, they eventually mate and lay eggs thus the life cycle continues. All the above given developmental stages can be visualized in figure 3.

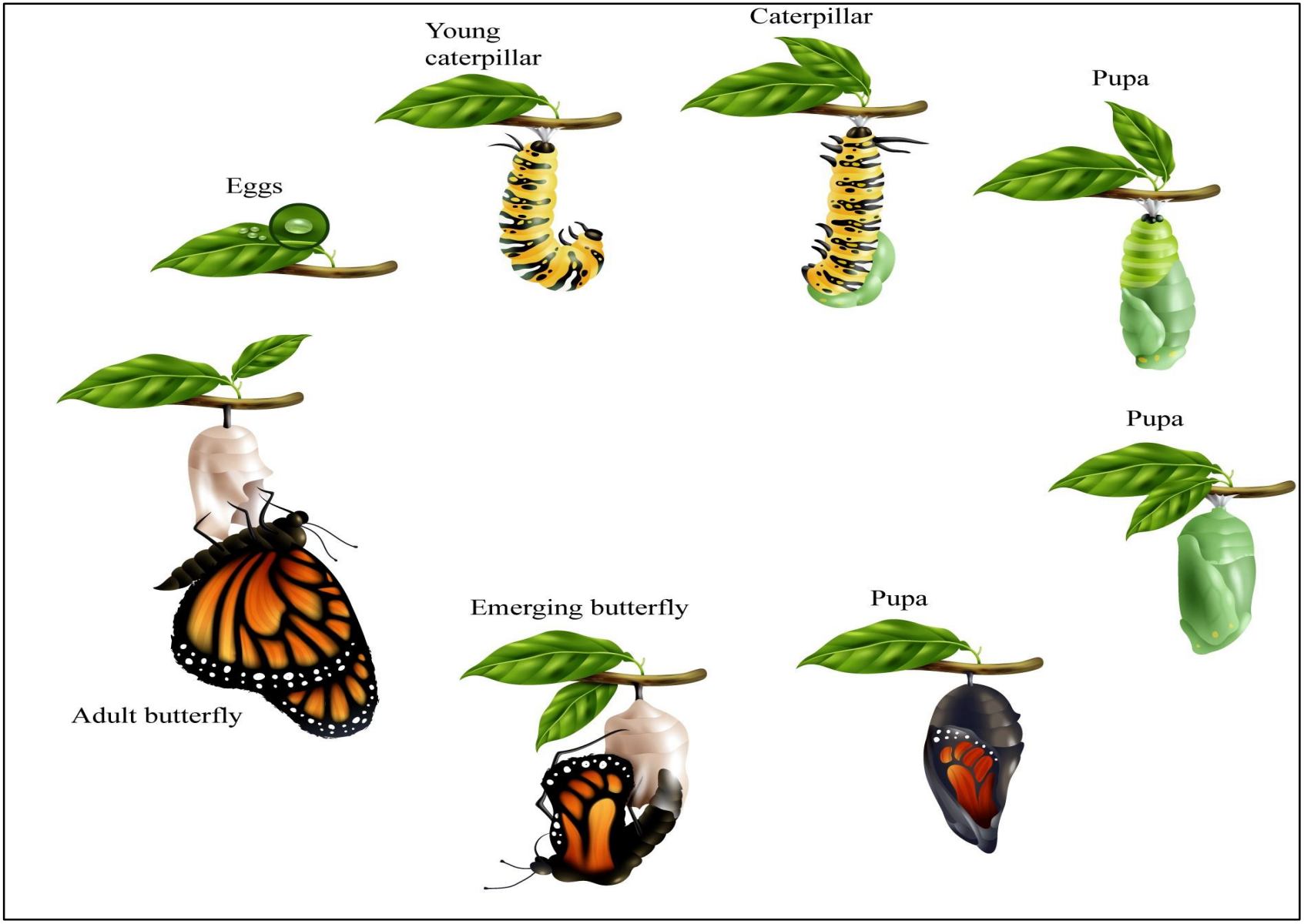

Figure 3: Lifecycle of Butterfly

1.4 Morphological Features of Butterflies

The body of an adult butterfly is made up of three parts namely the head, thorax, and abdomen. The head bears two antennae, two compound eyes, the proboscis, and a pair of hairy palpi.

A) Antennae: The butterfly has a pair of segmented antennae that project forward and located between the eyes. The type of antennae present in butterflies is capitate antennae which means that antennae are abruptly clubbed at the end. These are long, straight movable feelers projecting from the forehead between the eyes. The basic shape is clubbed, knobbed, or slender because the segments increase in size as it gets further away from the head and this usually creates a club-like appearance on the tip of the antenna. They are the sensory appendages attached to the head of butterflies. For assessing the physical and chemical properties of the surrounding, butterfly use antennae which have chemoreceptors. These are similar to the taste buds on our tongues. The primary function is olfaction as the surface of the antennae is covered with large numbers of olfactory scales, hairs, or pits and is very sensitive. The secondary function is balance and orientation during flight. To detect nectar-producing plants, butterflies use their antennae. Males use the antennae for recognition and the location of their mates. In addition to that, they serve other functions like pheromone detection. It can also detect the odors of various flowers. Near the base of the antennae, in the second antennal segment exists an organ called Johnston's organ, used for balance and orientation during flight. The shape of antennae differs from family to family.

Senses Present in Butterflies

Butterflies use their different senses such as sight, hearing, smell and touch to survive in the world, to find food and mates, lay eggs in an appropriate place, migrate and of course keep themselves from predators. They use color vision when searching for flowers. The retina of butterflies has six or more photoreceptors with distinct spectral sensitivities. The eyes are furnished with six classes of spectral receptors such as UV, violet, blue, green, red, and broadband. Combined intracellular electrophysiology, anatomy, and molecular biology studies revealed that these six classes of receptors are situated in the ommatidia in three fixed combinations. Several units called ommatidia make the compound eyes. An ommatidium contains some photoreceptor cells and each one bears visual pigments. The colors and patterns on the wings of butterflies serve as important means of recognizing members of the same species. Adult butterflies do not possess any complex hearing organs but they do respond to sounds that are sensed by the sacs present at the base of the wings

in some groups and by leg bristles and abdominal organs. Complex organs of hearing are absent in butterflies but the sense of smell is well developed. This is used to help locate flowers, larval host plants on which the females lay their eggs as well as sources of other needs such as amino acids and mineral acids.

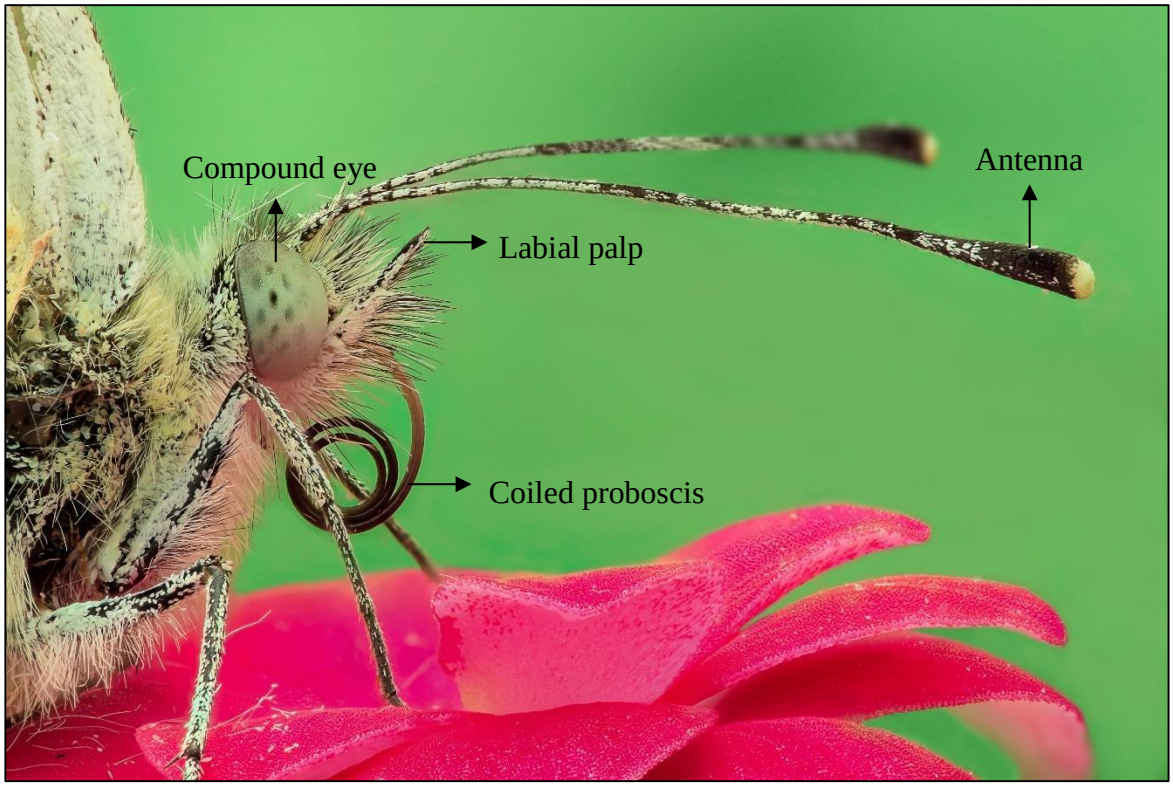

Figure 4: Image depicting head anatomy of a butterfly

Two different types of eyes, single and compound, are present in butterflies. Ocelli are one pair of simple eyes that are single-chambered and primarily for determining light brightness. They are unable to focus on an individual object. The compound eyes are multifaceted and are used for their main eyesight. The light starts from one facet and is perceived by one rhabdom, similar to human retinas. A wavelength range from 254 to 600 nm can be seen by butterflies which includes ultraviolet light, a light that we are unable to see. Human can see only 450 to 700 nm.

B) Eyes: The compound eye of a butterfly consists of thousands of visual elements known as ommatidia which unitedly work as one unit and produce an image of the site around them. Each ommatidium receives light from a single angle and is connected by an optic nerve that transmits visual signals to the brain. Eyes are immovable. The vision of butterflies is blurred they are capable of differentiating light and dark.

Vision of butterflies

A butterfly can see the colors and patterns that are invisible to man. The colors of flowers, the patterns of color on its wings appear much different to a butterfly. The reason being the butterfly able to see ultraviolet light. UV (ultraviolet) light comes from the Sun. It causes sunburns in man. Butterfly uses UV in different ways, for example, its vision and navigation. A pair of eyes is present on its head. Thousands of images forming minute eyes are called ommatidia. These compound eyes are very characteristic of insects. This aids the butterfly to enjoy a wide field of vision. This is facilitated by the ommatidia. The ommatidium is a minute sensory structure with a lens, crystalline cone, and retinal cells. Every ommatidium is directed at different angles. Collectively they are directed in all directions. This aids to see simultaneously in every direction. Such a vision is called Omni vision and the image seen by the butterfly is mosaic.

C) Proboscis: Butterflies possess a specialized straw-like structure used to feed the nectar of flowers and moisture known as a proboscis. Two long and tubular structures known as galea comprise the proboscis. When not in use the proboscis is coiled like a spring. It is coiled under the head at rest and is extended when butterflies probe food. In the resting position, the proboscis is coiled between 3.5 and 7 times depending on its total length (Krenn et al., 2004). The coil is having interlocking structures on both the dorsal and ventral sides of the galea tubes. The galeae when applied and locked together along the length, form a long tubular proboscis. The long proboscis allows them to reach deep into the flowers for nectar. The coils are tightly packed and touch each other for the entire length. The coiled proboscis is held between the labial palps and contacts the labium on the ventral side of the head. Olfactory sensors are also present on them which help in selecting the food. As adults, butterflies consume only liquids and these are sucked employing the proboscis.

D) Palpi: They are present on either side of the proboscis, which coiled under the head and curves up in front of the face between the eyes, sometimes separated, but independently movable. Formed of three joints, the first two are covered with scales and often with long hairs and the third one is naked.

E) Wings: Butterfly has two pairs of wings, namely forewings and hind wings. Each wing consists of two layers of transparent membrane, connected by minute fibers and structurally strengthen by a system of thickened hollow ribs called veins as represented in figure 5 (Bhakare

& Ogale, 2018). These transparent membranes are covered with rows of minute, colored scales. The movement of wings is possible by the rapid muscular expansion and contraction of the thorax.

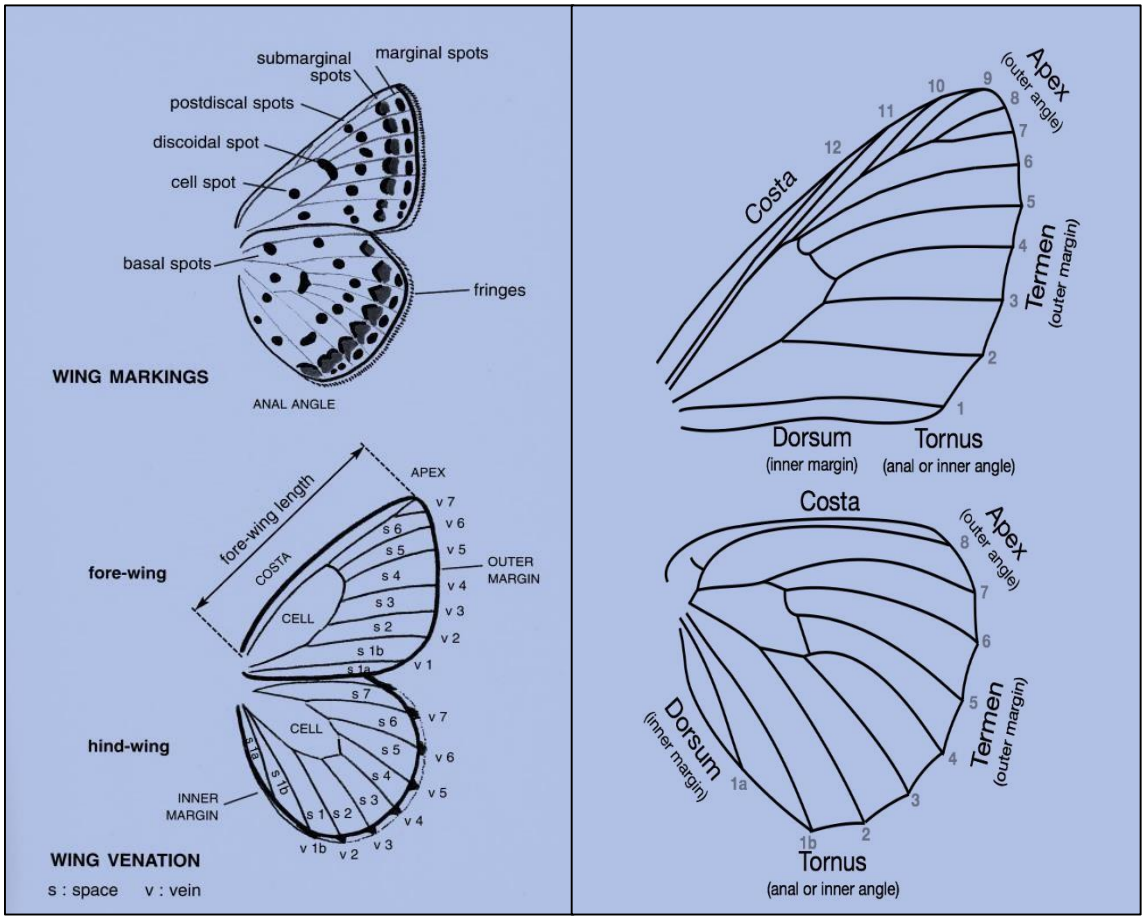

Figure 5: Anatomy of butterfly wing. Source: www.wikiwand.com

F) The coloration of Wings: Butterfly colors are produced by colored scales or pigmentary colors, structural or combination of both. In Lepidoptera, the wing surfaces are covered by scales, each of which has developed as a flattened outgrowth from a single cell. Color patterns are formed from a mosaic of individual pigmentary scales, each of which has only a single color. Variations in shade and intensity are attained by the mixing of different proportions of each type of scale.

G) Legs: Adult butterflies have three pairs of jointed legs. Each leg is divided into parts namely coxa, trochanter, femur, tibia, and tarsus. Forelegs show considerable variation between families and hence are used in classification. In families Hesperiidae, Papilionidae, and Pieridae, the forelegs are well developed and are similar in male and female. In other families Lycaenidae, Nymphalidae, and Riodinidae the tarsus and claws are reduced, at least in the males and the

structure of male and female legs differ. The legs especially the tarsus also have olfactory organs and taste receptors, helping in taste and smell out the food plants.

1.5 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 have to 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 day time. 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.

1.6 Flower Foraging Behavior of Butterflies

The majority of the flower-visiting insects include wasps, flies, butterflies, moths, etc. they obtain nutrition from the floral nectar and pollen. Butterflies depended on plants for their survival. The larvae mostly feed on tender leaves and the adults utilize nectar for their sustenance. Thus, butterflies have an inseparable and complex feeding relationship with plants that result in a coevolutionary relationship among butterflies and plants (Ehrlich & Raven, 1964).

In addition to food, flowers are visited frequently by insects to seek shelter, prey, larval hosts, and mates. A sugary liquid produced by plants called nectar in nectary glands attract pollinators. Flower signals such as colors and scents assist this recognition process. The composition of nectar is sugars, amino acids, and water, for attracting pollinators. The activities of adult butterflies are fufilled by nectar gathered from flowers and the energy reserves stored as a larva.

Butterflies need to be efficient foragers and recognize the flowers which reward. Flower signals such as colors and scents assist them in this recognition process. Butterflies can taste the nectar and judge its content. The ability to associate colors with food rewards is highly developed in butterflies (Stefanescu & Traveset, 2009). In addition to floral color, floral scent plays a central role (Honda et al., 1998). Plants that specialize in attracting butterfly pollinators often display brightly colored flowers with long narrow spurs (Mukherjee et al., 2015).

Food searching butterflies and other insects do not visit all plant species in a given area but restrict their visits to certain species and develop flower constancy to these. There are two views on how floral constancy is maintained. One is constancy develops from memory constraints which limit the number of plant species that an insect can learn to handle and the other constancy is based on the ability to associate certain floral signals with rewarding plants which require insects to recognize and memorize more than one species at a time and to compare rewards between them (Waser, 1986).

Figure 6: Foraging behavior of butterfly

1.7 Locating and Identification of Flowers by Butterflies

The flowers are exploited by the butterflies for nectar as it is the only source of carbohydrates for them. The butterfly nectars tend to have sucrose dominance and are not very viscous (Baker & Baker, 1973). The nitrogen requirement is met from the amino acids in nectar therefore the butterfly nectars are normally rich in amino acids (Tiple et al., 2006). Nectar can fulfill the water needs of butterflies. It is observed that a great increase in the number of butterfly visits to flowers during drought to overcome the need for water.

Butterflies are diurnal in their activities and visit many flowers that open in the morning using innate and imprinted search images (Swihart, 1970). Butterflies rely entirely or exclusively on floral color for locating, identifying, and feeding on the flower. Most species have innate color preferences and show constancy to color variations. Experience and training can cause modifications in some. Scents may act as nectar markers when the butterflies are attracted by the

flower colours, where there will be a change in the quantity and quality of the scent (Krenn et al., 2004).

1.8 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). Apart from that other challenges also existing which are as follows:

A) 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.

B) 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.

C) 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.

D) Application of Pesticides and Weedicides: Unscientific usage of weedicides remove 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.

1.9 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. Studies have demonstrated that a correlation exists between the structural complexity of habitats and species diversity.

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, 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.

1.10 Objectives of the Study

The abundance of butterflies usually indicates a healthier ecosystem (Fernandes et al., 2016). They are an important component of a 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.