SYSTEMATICS OF SWALLOWTAIL BUTTERFLIES (LEPIDOPTERA: PAPILIONIDAE) OF KERALA, INDIA

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For the Award of the Degree of

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by

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DECLARATION

I hereby declare that the thesis entitled **"Systematics of Swallowtail Butterflies (Lepidoptera: Papilionidae) of Kerala, India"** submitted to the University of Calicut, Thenhipalam, Kerala for the award of degree of 'Doctor of Philosophy' in Zoology (Faculty of Science) is a record of original and independent research work carried out by me under the supervision and guidance of Dr. George Mathew, Emeritus Scientist, Forest Health Division, KFRI, Peechi. This thesis has not been submitted elsewhere for the award of any degree, diploma, associateship or other similar title.

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CERTIFICATE

This is to certify that the thesis entitled **"Systematics of Swallowtail Butterflies (Lepidoptera: Papilionidae) of Kerala, India"** submitted to the University of Calicut, Thenhipalam, Kerala in partial fulfillment for the award of the degree of 'Doctor of Philosophy' in Zoology (Faculty of Science) is a record of original research work carried out by **Ms. Revathy V. S.** under my supervision and guidance at Kerala Forest Research Institute, Peechi, Thrissur. This thesis has not been submitted elsewhere for the award of any degree, diploma, associateship or any other similar title to any candidate of this or any other University or Institute.

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Dedicated to

My loving husband, Biju

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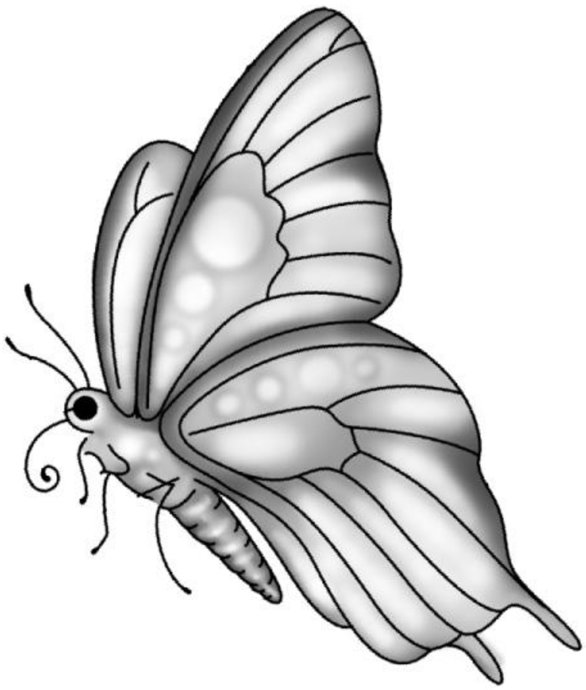


INTRODUCTION

Chapter 1: Introduction

The most exhilarating aspect of the world of life is its diversity and the uniqueness of its components. The scientific study of the kinds and diversity of organisms and of any and all relationships among them is termed systematics (Mayr, 1969). It covers biology, ecology and classification pertaining to organisms and thus provides complete information of an organism and those associated with it. Systematics not only supplies the urgently needed information about species integration in the organic world but, more importantly it cultivates a way of thinking, a way of approaching the biological problems which are tremendously important for the balance and well-being of biology as a whole. Systematics is the study of the pattern of relationships among taxa. It is an important component in our endeavors to achieve sustainable use of biological resources/biodiversity and to secure the future of humankind and the organisms with which we share the environment. In other words, systematics provides the basic framework, by which biologists can communicate information about organisms. The present research work falls within the domain of the basic discipline of systematics.

Among all organisms, butterflies constitute some of the most beautiful and fascinating taxa distributed all over the world. They belong to the order Lepidoptera (Gk. *lepis* = scale, *pteron* = wing), the second largest insect order, coming under the phylum Arthropoda (Gk. *arthro* = jointed or segmented, *poda* = feet or appendages), of the class Hexapoda (Gk. *hexa* = six, *poda* = legs) or Insecta. The order Lepidoptera is divided into two suborders *viz.,* Heterocera and Rhopalocera. The former constitutes the moths and the latter, the butterflies. So far, about 1, 40,000 species of Lepidoptera have been described globally (Kunte, 2000). There are about 18,000 species of butterflies in the world and India has 1,501 species of butterflies (Kehimkar, 2008). The Western Ghats harbours around 330 species butterflies (Gaonker, 1996) and 316 species have been reported from Kerala (Palot *et al.,* 2012).

1.1 Classification of butterflies

As per the recent classification, butterflies are classified into two superfamilies, Hesperioidea and Papilionoidea. Of these, Hesperioidea includes the skippers while Papilionoidea includes the rest, the true butterflies. Hesperioidea consists of a single family *viz.,* Hesperiidae (Skippers), whereas Papilionoidea comprises of four families: Papilionidae (Swallowtails), Pieridae (Whites and Yellows), Nymphalidae (Brush-footed butterflies) and Lycaenidae (Blues) (Kehimkar, 2008). Among various groups of butterflies, the Papilionids, which contain some of the largest and colourful butterflies, are very important.

1.2 Papilionid / Swallowtail butterflies

The butterflies of the family Papilionidae are generally known as 'Swallowtails' because of their characteristic tail-like extension on the hind wings which recall the forked tail of a swallow. The precise function of the tail is not clear and whether they assist in flight or have some other function is yet to be worked out (Collins and Morris, 1985). This group of butterflies includes some of the charismatic, spectacular and most endangered butterflies of the world. With their fabulous colours and delicate flight, the beauty of Swallowtails is appreciated by all ages and races of people. Papilionidae is the smallest butterfly family in the world and it contains just 701 species which represent just 4% of global butterfly diversity. In India, there are about 107 species of Papilionid butterflies, of which 19 species are present in Kerala (Kunte, 2000; Kehimkar, 2008). The Papilionids show high degree of endemism compared to the members of other families. Out of 19 species, five are exclusively endemic to the Western Ghats and Peninsular India and three species are shared endemics of Peninsular India and Sri Lanka (Gaonker, 1996).

1.3 Distribution and classification of Swallowtails

The Swallowtails have worldwide distribution, occurring in all the major continents except for the polar areas (Kehimkar, 2008). Their maximum diversity is recorded from the tropical areas. The family Papilionidae is divided into 3 subfamilies- Zerynthiinae (=Baroniinae), Parnassiinae and Papilioninae (Talbot, 1939). Of these, the subfamily Zerynthiinae is essentially a Palaearctic group. The only representative of this subfamily in the Indian region is the genus *Armandia*, which is not found in Kerala. The subfamily Parnassinae which includes the Apollo butterflies is represented by two genera *viz.*, *Parnassius* and Hypermnestra in the Indian region. Both these genera are not so far recorded from Kerala. The subfamily Papilioninae which contains about 650 species of butterflies under seven genera is the largest subfamily (Kunte, 2000). Butterflies coming under this subfamily alone occur in Kerala. The Papilioninae is divided into four tribes *viz.,* Troiidini, Papilionini, Leptocercini and Teinopalpini. A brief account of the Papilionid butterflies present in Kerala is given below.

1.3.1 Genus *Troides* Hübner (Birdwings)

The genus *Troides* belongs to the tribe Troiidini. Species belonging to this genus are popularly known as Birdwings and only one species of this genus *viz., Troides minos* Cramer (Southern Birdwing) occurs in Kerala. It is the largest Indian butterfly and is endemic to the Western Ghats. Because of its large wing span and extreme size it resembles a bird and hence the popular name Birdwing. Forewings are deep black in colour and the hindwings are golden yellow with black borders. It has a black coloured body and the female is similar to the male except that it has a row of large triangular spots on the yellow areas of its tailless hindwings. They inhabit diverse habitats from the evergreen forests to mixed or moist deciduous forests and agricultural lands. It is restricted to southern India and is very common in monsoon and post monsoon seasons.

1.3.2 Genus *Atrophaneura* Reakirt (Roses)

The Roses belong to the tribe Troiidini and genus *Atrophaneura.* Kerala harbours three species *viz., Atrophaneura aristolochiae* Fabricius (Common

Rose), *A. pandiyana* Moore (Malabar Rose) and *A. hector* Linnaeus (Crimson Rose). The Roses have crimson red body and their hindwings are tailed. Both sexes are similar in all Roses. In *A. aristolochiae*, the forewing is black in colour and the hindwing has a large white area with a series of red spots present on the outer margin. *A. pandiyana*, which is an endemic to the Western Ghats, has black forewings and relatively much larger white patches on its hindwings. *A. hector* is very similar to other Roses but it is larger, glossy black and has two white bands in the centre of forewings. The tailed hindwings have two series of crimson red spots. This butterfly which is endemic to Western Ghats and Sri Lanka is a protected species under Schedule I of the Indian Wildlife Protection Act (GOI, 1972). The Roses have slow fluttering steady flight. While feeding at flowers, they beat their forewings continuously and the hindwings have little movement. The flying pattern of some butterflies especially the Swallowtails are quite interesting because the long forewings are used to propel the body and hindwings mainly for balancing and steering (Kunte, 2000). This flight style is distinctly evident from the Roses. They are commonly found in open cultivated areas, deciduous forests and agricultural lands. The Crimson Rose occurs mainly in dry deciduous forests and evergreen forests and in thick scrub jungles.

1.3.3 Genus *Graphium* Scopoli (Jays, Bluebottles and Swordtails)

The Jays, Bluebottles and Swordtails belong to the tribe Leptocercini and the genus *Graphium.* There are two species of Jays, *Graphium doson* C&R Felder (Common Jay) and *Graphium agamemnon* Linnaeus (Tailed Jay), one Bluebottle, *Graphium sarpedon* Linnaeus (Common Bluebottle) and two species of Swordtails, *Graphium nomius* Esper (Spot Swordtail) and *Graphium antiphates* Fabricius (Five-bar Swordtail) recorded from Kerala. These are very nervous, restless butterflies, settling only very seldom and their flight is very straight and dashing. Most of these are swift, powerful fliers and occur in all vegetation layers. The Jays and Bluebottles have black wings with green or blue spots and short tails and are found in evergreen, wet semi-evergreen, moist deciduous as well as thick, riparian forests. Due to the availability of larval host plants, the Jays and Bluebottles are often noticed in urban areas also. They are also found in mud puddling aggregation but the Tailed Jays are never noticed in mud puddling groups.

Swordtails have white wings with black bands and with red and green spots. The hindwings have sharp, pointed sword-like tails. Spot Swordtails inhabit dry deciduous forests. Five-bar Swordtails are found in evergreen, wet semi-evergreen, moist deciduous as well as thick riparian forests. They are common during the dry months.

1.3.4 Genus *Papilio* Linnaeus (Mormons and Peacocks)

The genus *Papilio* which contains nine species is the largest genus of Papilionids in Kerala. They belong to the tribe Papilionini. Among these, two of them are Mormons, *viz., Papilio polymnestor* Cramer (Blue Mormon) and *Papilio polytes* Linnaeus (Common Mormon), three species of Peacocks *viz.*, *Papilio crino* Fabricius (Common Banded Peacock), *Papilio buddha* Westwood (Malabar Banded Peacock) and *Papilio paris* Linnaeus (Paris Peacock) and the rest of them are *Papilio dravidarum* Wood-Mason (Malabar Raven), *Papilio liomedon* Moore (Malabar Banded Swallowtail), *Papilio helenus* Linnaeus (Red Helen) and *Papilio demoleus* Linnaeus (Lime Butterfly).

P. polymnestor is the second largest among the South Indian butterflies and it is endemic to Sri Lanka and the Western Ghats. It is a black butterfly with glistening pale blue colour on the tailless hindwing. It is common along the forest paths and sides of streams. *P. polytes* is a good example for sexual polymorphism and Batesian mimicry. It has four forms- three female forms and one male form; the female form *cyrus*, is similar to the male form both in colouration and the form, *stichius* mimics the Common Rose and *romulus* mimics the Crimson Rose. The males generally participate in mud puddling along with other species of butterflies and both sexes show the habit of basking. They usually inhabit home gardens, deciduous forests, riparian forests and evergreen forests.

P. crino is a black butterfly with a bluish green discal band on both wings and with a tail which is metallic green at the tip. It is endemic to Sri Lanka and Western Ghats. It generally prefers to fly fast along the sides of streams, in the canopy and it usually inhabit dry deciduous forests. *P. paris* which is largest among the Peacocks, is found in evergreen forests and its distribution extends over the entire Oriental region. It is also black in colour dusted with green and the hindwing has a large metallic blue spot, a crimson coloured tornal spot and three sub-marginal spots. *P. buddha*, another Peacock found in Kerala, is also black with a broad metallic greenish blue band in the central part of both wings. By depending on the angle of reflection of light, the colour of the band appears varied (usually the shades of blue). *P. buddha* is endemic to the Western Ghats and is protected under Schedule II of the Indian Wildlife Protection Act (GOI, 1972) and is restricted to the lowland evergreen and semi evergreen forests. All Peacocks fly fast and straight and they can easily avoid the barriers while flying, hence they may possibly soar fast even in the dense canopy. *P. liomedon*, also a butterfly endemic to the Western Ghats, is protected under Schedule I of the Indian Wildlife Protection Act (GOI, 1972). Similarly, *P. dravidarum,* a black butterfly having a white spot in the forewing cell, is endemic to the Western Ghats.

1.3.5 Genus *Chilasa* Moore (Mimes)

The only one species of Mime reported from Kerala *viz.*, *Chilasa clytia* Linnaeus and its form *commixtus* is a protected species under Schedule I of the Indian Wildlife Protection Act (GOI, 1972). It is a tailless Swallowtail, which appears in two forms, the *clytia* form and the *dissimilis* form. *C. clytia clytia* is dark brown in colour with two rows of white spots on the edges of both wings and shows resemblance with the Common Indian Crow (*Euploea core* Cramer) which is a case of Batesian mimicry. Similarly, *C. clytia dissimilis* with whitish wings having numerous black coloured striations on the entire area shows resemblance with Blue Tiger (*Tirumala limniace* Cramer) which is also a case of Batesian mimicry. Both forms have a row of yellow spots on the underside of the hindwing which help them to distinguish this species from others.

1.4 Behaviour

1.4.1 Flight

Swallowtails are strictly diurnal and their flight may be of two kinds- fluttering or gliding. Butterflies that characteristically fly by fluttering the wings usually possess broad wings which they beat up and down. Gliding is a passive flight performed by butterflies either during migration or while moving from the canopy to the ground. The Birdwings generally soar slowly and royally on the tops of trees, the Jays skip quickly and suddenly from flower to flower, the Peacocks fly swiftly in the canopy and others such as the Red Helen and Mormons have a lazy flight. However, all of them have the ability for rapid progression if any danger threatens them.

1.4.2 Basking

Swallowtails, being 'cold-blooded' organisms, bask in the sun with open wings to keep the thoracic muscles warm for flight. Basking may be dorsal or lateral. In the former, the wings are kept spread out while in the latter, the wings are held together above the body with the ventral surface kept perpendicular to the sun when the dark pigments on the underside of the wings absorb radiant energy warming the flight muscles of the thorax efficiently. The black areas near the wing bases absorb the heat efficiently which is then directly transferred to the flight muscles. In the tropics, the flight activity lasts longer because of the longer duration of warm day hours. Several species of Papilionids such as Red Helen, Paris Peacock, Common Mormon and Lime Butterfly are fond of basking in the sunshine, especially those having significant spots on the hind wings.

1.4.3 Migration

Butterflies migrate to tide over the unfavourable conditions such as overcrowding, scarcity of food, unfavourable weather conditions etc. The classical example of butterfly migration is that of the Monarch butterfly (*Danaus plexipus* Linnaeus) from Canada to Mexico, traversing a distance of about 3200 km. About 250 species of butterflies in the world and about 60 species in India are reported to be migratory. The members of the family Papilionidae are generally non-migrants, but certain species such as the Lime Butterfly and Crimson Rose occasionally form migratory swarms.

1.4.4 Mud puddling

Adult butterflies frequently aggregate on damp soil mainly for their salt requirement. The males exhaust their sodium reserves during spermatogenesis while the female replenish their sodium reserve through the sperms received from the males during copulation. The mud puddling aggregations usually comprise of a large congregation of many species of butterflies. Only the male butterflies take part in mud puddling. The Papilionids like Common Jay, Bluebottle, Spot Swordtail, Fivebar Swordtail, Lime Butterfly and Peacocks usually form large mud puddling congregations.

1.4.5 Polymorphism

Swallowtails also exhibit polymorphism, in which one species exist in more than two forms. *Papilio polytes* is one of the classic examples of sexual polymorphism in which the female has three forms and the male has one form. The three female forms include the form *cyrus,* a male-like female form; form *stichius*, mimicking the Common Rose and form *romulus* mimicking the Crimson Rose. No other Papilionids have the polymorphism. Seasonal variations in form and colouration are usually absent among Swallowtails.

1.4.6 Patrolling

Male butterflies patrol for females in different ways. Among the Swallowtails, the Southern Birdwing (*Troides minos*) fly along the linear pathways such as forest paths or in butterfly gardens in search of mates. These flights are slow and steady and they chase away rival males. So the defense of landmark territories seems to be a common mate locating tactic among Papilionid butterflies. In some others, like *Atrophaneura pandiyana* and *A. aristolochiae,* males keep circling around food plants where female butterflies are likely to emerge from pupae.

1.5 Adaptations of Swallowtails

Since butterflies have many predators and parasitoids posing threats to their life stages, many species have developed various adaptations to overcome these threats. A variety of natural enemies such as spiders, praying mantis, ants, wasps, parasitic wasps, parasitic flies, birds, rats, toads, lizards and snakes have been reported to affect natural populations of butterflies. Since butterflies do not have any specialised organs of defense they have developed various strategies to keep away from the predators. Warning coloration, camouflage, accumulation of toxic materials in the body etc., are some of the adaptations found in butterflies.

Unpalatability and mimicry are some of the imperative survival strategies of butterflies especially Swallowtails. Palatable butterflies copy the appearance and behaviour of unpalatable ones and the predators are fooled into thinking that these are unpalatable. The Batesian mimicry in which the palatable butterflies mimic the unpalatable ones is more common among the Swallowtails. The Malabar Raven (*Papilio dravidarum*) and the Common Mime (*Chilasa clytia*) which mimics the Common Crow (*Euploea core* Cramer), the Common Mormon (*Papilio polytes*, form *romulus*) which mimics the Crimson Rose (*Atrophaneura hector*) and Common Mormon (*Papilio polytes,* form *stichius*) which mimics the Common Rose (*Atrophaneura aristolochiae*) are examples of Batesian mimicry. In Mullarian mimicry, the unpalatable species mimic each other, as in Common Rose (*Atrophaneura aristolochiae*) and Malabar Rose (*Atrophaneura pandiyana*).

1.6 Significance and role of Swallowtail butterflies

Butterflies have important ecosystem roles including pollination, as indicators of environmental quality and they are used in studies of population and community ecology. A brief review of significant roles of Swallowtails is summarized below.

1.6.1 Pollination of phanerogamic plants

Butterflies being important pollinators of several wild and domesticated plant species assist in the succession of plant communities. Depletion of butterfly population could adversely affect the regeneration of plants they pollinate and the healthy presence of butterflies ensures the healthy status of an ecosystem.

1.6.2 As bioindicators of environmental quality

A variety of features of the butterflies make them good candidates as indicator, umbrella or flagship species. They are strongly influenced by weather conditions and are highly sensitive to environmental changes. Besides being charismatic insects that could attract the public attention, they enjoy a wide distribution occurring in fairly large numbers both as individuals and as species in different ecosystems and are relatively easy to sample and identify. As a result, they have been looked upon as good ecological indicators of environmental quality.

1.6.3 Swallowtails and research

Because of their short life span, butterflies are good candidates for research on genetics, insect-plant interactions and co-evolution. Different types of vegetation show different butterfly species composition. Hence, the butterfly assemblages may be used to characterize different habitats. Their distribution is related with the phenological stages of the plants and the three types of plant population categories, *viz.,* are larval food plants, nectar plants and shade plants are needed to complete their lifecycle (Manzoor *et al.,* 2013). As a result, butterflies are widely used to study the insect-plant interactions and co-evolution.

1.6.4 Role in food web

The adult butterflies mostly feed on nectar at the flowers of phanerogamic plants and the caterpillars feed on the foliage of specific host plants. All stages of butterflies in turn are fed upon by various higher groups of animals like birds, bats and mammals. The caterpillars form the primary herbivores in the ecosystem and play an important role in the transfer of solar energy contained in plants and making it available to higher groups of organisms which feed on the caterpillars and butterflies. Butterflies thus form more than on link in the food web.

1.6.5 Swallowtails for exhibitory

Apart from their ecological significance, they have great aesthetic value. They constitute important objects for display in Natural History Museums and Zoos. Butterfly exhibits are also key attractions in many museums and biodiversity parks. Efforts are also being made to sustain many natural populations of butterflies in carefully landscaped areas termed as butterfly gardens, parks or safaris.

1.7 Economic significance of Swallowtail butterflies

As the immature stages of Swallowtails are phytophagous in habit they occasionally cause severe damage to plants and hence they have great economic importance as pests of various agricultural and forestry crops. For instance, the Lime Butterfly, *Papilio demoleus*, which is a well-known pest of citrus in the Oriental Region (Wyniger, 1962) and also in the New World (Eastwood *et al.*, 2006), often cause severe defoliation of seedlings in nurseries and young plantations. Yunus and Munir (1972) reported that *P. demoleus* larvae feed on the leaves of at least 19 citrus species or varieties but show some differences in larval consumption rates, developmental times and mortality. Narayanamma *et al.*, (2001) have reported up to 83% defoliation of young grove trees in Andhra Pradesh and Thakare and Borle (1974) reported severe outbreak leads to the skeletonisation of the entire citrus garden.

Other Papilionids having economic significance include *G. agamemnon*, which feeds on soursop (*Annona muricata* Linnaeus) in Vietnam. Larvae of *G. agamemnon* were found to damage soursop trees throughout the year but damage was more common in the middle of the wet season, which lasts from May to October (Vu *et al.*, 2008). *G. agamemnon* is distributed in India, South-East Asia to Australia including the nearby Pacific islands, where it feeds primarily on custard apple (*Annona reticulata* Linnaeus) and Soursop (*Annona muricata* Linnaeus) (Braby, 2000). Similarly, *Chilasa clytia* is a serious pest of Cinnamon and Chinese cassia and its larvae feed voraciously on the tender and partly mature leaves, leaving only the midrib and veins. Both young plants in nurseries and plants in plantations are affected by this pest. Heavy infestation of this butterfly adversely affects the plant growth (Anandaraj and Devasahayam, 2004, Rajapakse and Kumara, 2007).

1.8 Threats for the survival of Swallowtails

Butterflies being highly diversified in their habits require specific ecological conditions for their survival. Natural forests, grasslands, canopies of trees as well as wet areas along the banks of rivers and streams are the typical butterfly habitats. However, due to various reasons, particularly due to human intervention, the habitats of many butterflies have been altered. Consequently many species of butterflies that were once very common in our locality and country sides have vanished. It has been stated that extinction of a single species would eventually lead to extinction of about a dozen or more species that are linked with it. Biological diversity is now increasingly recognized as a vital parameter to assess global and local environmental changes and sustainability of developmental activities (Rajagopal *et al.,* 2011). Butterflies are potentially useful ecological indicators of urbanization because they are sensitive to changes in microclimate, temperature, solar radiation, and the availability of host plants for ovipositing and larval development (Thomas *et al.*, 1998; Fordyce and Nice, 2003).

The four main aspects that threaten Swallowtails are habitat alteration and destruction, pollution, introduction of exotic species and commercial exploitation. In general, these threats are either the direct result of increasing human population pressure or else are enhanced by it (Collins, 1984).

1.8.1 Habitat alteration and destruction

The most critical threat to a wild species is the destruction and alteration of biotopes and habitats in which they live (Ford, 1944; Groombridge and Wright, 1982; Lucas and Synge, 1978). All species depend upon the integrated network of physical and biological factors that make up their environment for survival. Most species are able to withstand a small degree of disturbance and manipulation, but human activities have steadily modified wilderness areas into man-made landscapes of settlement, agriculture and industry that are altered to an extent that precludes coexistence with many wild creatures. In the case of Swallowtails, the significant forms of habitat alteration that affect their existence are 1) deforestation, 2) agricultural conversion and intensification, 3) alteration of pastures and 4) industrialization and urbanization. These factors often lead to habitat alteration leading to changes in weather parameters like temperature, humidity and rainfall, resulting in diminution of butterfly wealth. Prevalence of unfavourable weather conditions often affect habitat fitness leading to local extinction of butterflies (Van der Made, 1987; Pollard, 1979; Dempster and Hall, 1980; Ehrlich *et al.*, 1980; Thomas, 1980).

1.8.2 Pollution

The excessive use of pesticides and weedicides adversely affects various butterfly populations and habitats. Usually, in the agricultural fields and in estates, toxic pesticides are generally used to control pests which will affect all kinds of life forms wherever they are sprayed. This may affect both the larval host plants and the immature forms which may be killed. Although not well documented, the increasing use of pesticides is a cause of serious concern for Swallowtails especially where drift of chemicals into neighbouring natural habitats such as forest edges, occurs from low level aerial applications to crops.

1.8.3 Introduction of exotic species

To some extent, exotic introduction of animals and plants inevitably upsets the equilibrium of natural communities. There are no documented cases of severe effects on Swallowtail butterflies but the occurrence of various exotic species may adversely affect the survival of native species of butterflies.

1.8.4 Commercial exploitation

The most important threat to butterflies, especially the Swallowtails is the collection of adults for trade. The world wide trade in butterflies is a big business, running into tens of millions of dollars annually. The precise amount is controversial although there have been reports that butterfly trade in a small country like Taiwan exceeds US $20-30 million per year (Collins and Morris, 1985). The effect of commercial collection on butterfly populations is controversial due to lack of data. However, its impact seems to be largely dependent on the biology of the species. Invertebrates can frequently, but not invariably, withstand a considerable level of harvest because of their high reproductive capacities. However, heavy exploitation can have serious effects under three circumstances: 1) if the population is already critically depleted by other factors like habitat destruction, 2) if the population is small and have a high value per individual 3) if the species has a low reproductive rate and low juvenile recruitment. Irresponsible over collection of a species can cause a permanent decline.

1.8.5 Butterfly trade

Butterflies are mostly traded for the curio market (Collins and Morris, 1985; New and Collins, 1991). At least 34 species are traded with the most common genera traded being *Troides* (170,000 individuals/year) and *Ornithoptera* (129,000 individuals/year). The increase in breeding farms as to produce the high-quality specimens demanded in trade has, at least in some countries, led to a significant decrease in the capture of wild-caught specimens. In the 1980s, Collins and Morris (1985) reported that globally, 10% of trade volumes were derived from captive-breeding or ranching operations, but levels seem to have increased considerably in recent years. Nijman (2010) gave an overview of international wildlife trade from Southeast Asia. He reported that a total of 306,000 butterflies were traded with 13,000 being wild-caught individuals, 109,000 originating from ranging operations, and a further 184,000 from captive-breeding facilities. Until around 2002, numbers of ranch-raised, captive-bred and wild caught were in a similar order of magnitude, but from 2003 onwards the number of butterflies derived from ranching operations doubled annually followed in 2004 by the doubling of export from captive-breeding facilities.

1.9 Conservation strategies

Various attempts have been made to conserve butterflies in different parts of the world. Some of the strategies adopted for butterfly conservation are as follows.

1.9.1 Legislation and international conventions

The first step in any effective conservation is the documentation of threats to wildlife and conservation through legislative action against hunting or collection of rare and endangered species at international and national levels. The most important International agreement on wildlife trade is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which controls and monitors import and export of some listed species. CITES recognizes a few Swallowtails in Appendix I and II. *Ornithoptera alexandrae*, *Papilio chikae* and *P. homerus* are included in Appendix I. The butterflies listed on Appendix II are the Birdwings (*Ornithoptera* spp., *Troides* spp. and *Trogonoptera* spp.), Apollo butterfly (*Parnassius apollo*), *Teinopalpus* spp., *Papilio hospiton*, *Bhutanitis* spp., *Atrophaneura pandiyana* and *A. jophon* (Collins and Morris, 1985; http://www.cites.org). The IUCN Invertebrate Red Data Book (Wells *et al.*, 1983) included seven species of Swallowtails and a number of other butterflies. IUCN Red list of threatened species included around 84 species of Swallowtails as threatened in the world, of which, *Teinopalpus imperailis* (Kaiser-I-Hind) and *Bhutanitis lidderdalii* (Bhutan glory) are found in India (Kehimkar, 2008). The Government of India (GOI), under the Wildlife (Protection) Act (GOI, 1972) lists butterfly species that have been extended legal protection against their collection and exportation. Under the act, nearly 129 species and subspecies of butterflies are listed in Schedule I; 306 species in Schedule II and 18 species in Schedule IV. The Schedule I list three Papilionid butterflies that are found in Peninsular India and one in Schedule IV. They are Common Mime (*Chilasa clytia*), Malabar Banded Swallowtail (*Papilio liomedon*) and Crimson Rose (*Atrophaneura hector*) in Schedule I and Malabar Banded Peacock (*Papilio buddha*) in Schedule IV. As per Section 40 (92) of the Act, no person can acquire, receive, to keep in control, custody or possession, any of the species included in the above Schedules without previous permission in writing of the Chief Wildlife Warden or his authorized officer. Nevertheless, illegal trade in butterflies continues. A strict evaluation of the survival status of various species would lead to inclusion of many more species under the protected category.

1.9.2 Ranching and farming of Swallowtails

Farming of Swallowtails on a large scale is relatively rare but perfectly possible, particularly since the technique of hand-mating has been perfected for *Papilio* (Collins and Morris, 1985). 'Ranched' Swallowtails are captured as young stages of wild parentage and reared to the adult stage in captivity. In Papua New Guinea, the Insect Farming and Trading Agency (I.F.T.A.) of the Department of Primary Industry sells high quality specimens of Birdwings ranched locally, returning three quarters of all profits to the ranchers (National Research Council 1983). The I.F.T.A. demonstrates the method to enrich the habitat of the Birdwings by planting food plants and nectar plants around the gardens of the ranchers, and provides basic equipment for rearing the pupae in cages, killing the adults and storing them safely for later setting and sale. Butterfly ranching in Papua New Guinea shows how the trade and conservation of butterflies can go on simultaneously with mutual benefit.

1.9.3 Role of butterfly gardens in conservation

Since public communication is an important element of environmental education, butterfly gardens are ideal means by which visitors can observe and study butterflies in a recreated environment. At present there are no institutions in India for undertaking research on rare or endangered butterflies, to monitor their population status and to maintain stock cultures through habitat enrichment. However, this is going to be a tremendous task with several challenges. Research on the Birdwing butterflies has demonstrated that indepth knowledge of breeding biology and general ecology are required to pay dividends in terms of both conservation and rational exploitation (National Research Council, 1983). Further, carefully directed research could be of great benefit in the conservation of this family as a whole.

1.10 Significance of the present study

The Swallowtails are widespread Holarctic species, which are iconic organisms that have great ecological, economic, cultural and aesthetic values. The

Swallowtail is one of about 15 target species in a new campaign of research and conservation of British butterflies currently being run by WWF (U.K.). The management and research on these threatened taxa has now become the responsibility of various research Institutes dealing with biodiversity coursework. Establishment of the correct species identity is very essential in any conservation programme. The current morphological schemes of classification of Swallowtail butterflies based on wing venation and colouration have not been very successful in resolving the sub-specific status of many taxa (Talbot, 1939). So far, no major taxonomic revision on the butterflies of family Papilionidae of Kerala has been made. Recently, there has been a shift in taxonomic methodologies in which emphasis has been given to the morphological details of the external genitalia for understanding intrinsic variations between species and for breaking complex species groups. In, the present study, an attempt has been made to reexamine the taxonomy of the Swallowtail butterflies of Kerala along with data generated on their biological, ecological and behavioural aspects, which will go a long way in conserving these beautiful organisms from destruction.

1.11 Objectives of the study

The major objectives of this study are the following:

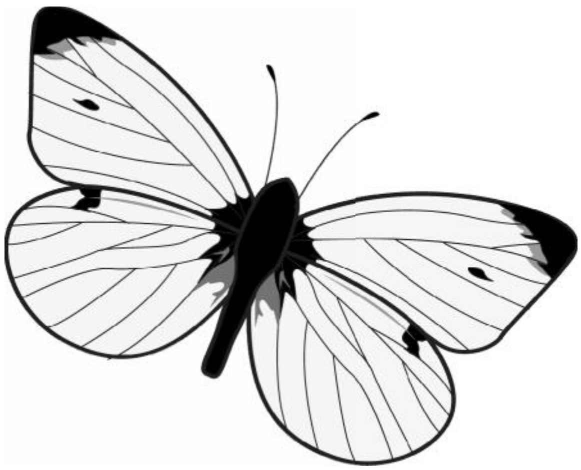
1. To make a taxonomic study of the Swallowtail butterflies of Kerala based on the morphology of their external genitalia and,
2. To generate information on the biology and ecology of the species found in Kerala.

1.12 Organization of thesis

The thesis is presented in six chapters. In the first chapter, a general introduction to the Swallowtail butterflies including the classification, distribution, behaviour, adaptations, economic significance, role in the ecosystem, threats for the survival, conservation strategies as well as the objectives of the study are given. The second chapter on review of literature includes the history of Lepidopteran classification, contributions from India, classification and nomenclature of Papilionidae, biological studies, ecological monitoring and conservation studies. The chapter on materials and methods includes detailed descriptions of the study area as well as the methods adopted in this study. The fourth chapter on general external morphology of Papilionidae and the descriptions of head, thorax, abdomen, wing venation and genitalia. The fifth chapter on results covers the detailed descriptions of the major aspects of the study *viz.,* taxonomic studies including butterfly survey, descriptions of the external genitalia of different Papilionids, key for the identification of species, phenetic and phylogenetic analysis; biological studies including descriptions of each instar of different species; ecological monitoring including butterfly fauna, population trends, seasonal patterns of abundance, weather correlations and behavioural observations of Papilionids. The sixth chapter discussion covers a discussion of the major findings of the study *viz.*, taxonomic studies including the comparative morphology of male genitalia, female genitalia, morphological similarities and dissimilarities of the external genitalia in different tribes, phenetic and phylogenetic analysis; biological studies and ecological monitoring including the population abundance, seasonal population trends and weather correlations. Illustrations, tables, graphs and figures pertaining to various topics covered in this study are given in the middle or end of the respective chapters. This is followed by summary, which gives a sum total of the topics covered in this study *viz.,* taxonomy, biology and ecology of Papilionidae of Kerala. This is followed by Plates and Appendices. A list of literature cited in this study is given under references.

REVIEW OF LITERATURE

Revathy V. S “Systematics of swallowtail butterflies (Lepidoptera: Papilionidae) of Kerala, India ” Thesis. Kerala Forest Research Institute, University of Calicut, 2014



REVIEW OF LITERATURE

Chapter 2: Review of literature

2.1 Background

Lepidoptera is one of the few insect orders that have received sufficient attention and quite a large number of studies have been made on the taxonomy of this group. Published work on Lepidopteran natural history dates back to Aristotle (384-322 BC). Later several workers particularly Albertus Magnus, Marcello Malpighi, Jan Swammerdam, Rene Reaumur and Charles De Geer have made significant contributions to our knowledge of Lepidoptera. Pioneering studies have been made by Linnaeus (1758), Denis & Schiffermuller (1775), Herrich-Schaffer (1843-1856), Meyrick (1895) and Hubner (1819). It was Linnaeus (1758) who made significant contribution on this group of insects. Besides describing various taxa, he also presented a scheme of classification which forms the basis of modern taxonomy. The system of biological nomenclature and scheme of classification presented by him has been accepted by the *International Code of Zoological Nomenclature*. Linnaeus recognized three main divisions of the Lepidoptera- *Papilio*, *Sphinx*, and *Phalaena* and the *Phaleana,* of which the latter was divided into seven subgroups. This classification was based on features of the antennae, mouth parts and the wings, particularly the position of the wings at rest and on whether the insects flew by day or by night. Linnaeus also included a considerable variety of larval and adult features in his species descriptions. He noted that the antennae of butterflies were clubbed, and that some members of what he called 'Bombyces' lacked tongue. The classification proposed by Linnaeus was accepted by the subsequent workers who made several modifications so as to include numerous additional species subsequently. For this, Linnaeus' divisions and subdivisions were further divided and several formal categorical ranks were established. In additions to this, several supra specific taxa were added to those introduced by Linnaeus. Primary types of many Linnaean Lepidoptera species have been preserved and are available even today, for study. Linnaeus' own collection is housed in the Linnaean Society of London (http://www.linnean.org/).

Prior to Linnaeus' death, and just under twenty years after the publication of *Systema Naturae,* Denis & Schiffermuller (1775) produced a work on the Lepidoptera of the Vienna area. Their classification was based on Linnaeus' system of classification, but they used additional characteristics of adult and immature stages and further subdivided many Linnaean groups. Based on these studies, the Danish Entomologist Fabricius, who was a student of Linnaeus, described several new species and named some of the Linnaean subgroups (Fabricius, 1775). The contribution of Fabricius on Lepidopteran taxonomy was tremendous. Later, Latreille (1796) added more supra specific groups, most of which represent genera. The concept of the genus taxon in Lepidoptera was provided by Schrank (1801). The Lepidopteran genus was firmly established by Ochsenheimer (1807–1835), in a series of works, later it was completed by Treitschke (1825), in his synthesis of the Lepidopteran fauna of Europe. Newman (1834) attempted to divide the insects into natural orders on the similarity and dissimilarity of their early stages. Many of the higher taxa of Lepidoptera that we still accept in a recognizable form emerged from the impressive and very influential six volume study by Herrich-Schaffer. The work was published at regular intervals between 1843 and 1856 (Herrich-Schaffer, 1843-1856). To a significant extent, Herrich-Schaeffer established the taxa on wing venation. He provided numerous morphological illustrations, which are remarkable in their detail and execution. With collections being made from beyond Europe, a further dimension to the classification was added.

Apart from describing numerous new genera and species, Edward Meyrick (particularly for microlepidopterans) and Sir George Hampson (particularly for macrolepidopterans) have contributed a lot on the higher classification of this order. Meyrick (1895) proposed that the Lepidoptera could be divided into ten phyla. Meyrick, like Herrich-Schaffer, relied to a significant extent on the wing venation since he considered the pattern to be of low adaptive ('physiological') value and thus to be less altered by external factors. Hampson's contribution to the higher classification of Lepidoptera focused mainly on the superfamilies Noctuoidea, Pyraloidea, and Thyridoidea. Since the mid nineteenth century, many other taxonomists have caused the earlier classifications to be modified and expanded. Some workers emphasized other character sets either from larvae (Fracker 1915) or pupae (Mosher 1916).

Subsequently various workers including Borner (1925, 1939), Hinton (1946), Hennig (1953), Ehrlich (1958), Munroe and Ehrlich (1960), Vane-Wright (1978) and Ackery (1984) have contributed to the detailed description of the adult and early stages of a number of species from different parts of the world. Some landmark works were done by Borner (1925, 1939) who proposed a fundamental division of the Lepidoptera into Monotrysia and Ditrysia on the basis of the structure of female genitalia. The Monotrysia, which included only 5 percent of Lepidoptera, are not monophyletic. But Borner's recognition of the Ditrysia as a natural group was an important step in understanding the phylogenetic structure of this order. So, it was his appreciation of the systematic value of many morphological characters in the classification and diagnosis of Lepidopteran families and superfamilies. Based on the works of Borner as well as of Hinton (1946), Hennig (1953) outlined the relationships of the most basal lineages within the order in a benchmark article, which foreshadowed subsequent work on this subject.

No reliable estimates of the Lepidoptera have been made. Several estimates have been made, ranging from 13,000 (Owen, 1971) to 20,000 (Vane-Wright, 1978). In a compilation by major faunal regions, Robbins (1982) estimated 15,900-18,225 species of Lepidoptera. Ackery (1984) attempted an evaluation of the present position of the scheme of classification of Lepidoptera and recognised four families and thirty subfamilies. More recently, Shields (1989) arrived at a total of 17,280 described taxa and he claimed that it is impossible to make a realistic estimate of different butterfly taxa except in Papilionidae. The numbers in other large groups may be over- estimated because many of the names had synonyms.

A provisional survey of the described world fauna of Lepidoptera, by family-group taxa and zoogeographical regions, was published by Heppner (1991) who made a compilation of the described Lepidoptera species and estimated the total number of species as 255,000.This survey was based partly on actual counts from the literature, partly on the card indexes in the Natural History Museum (London) and the National Museum of National History (Washington), and partly on estimates (the source is uncertain in many cases). Clearly, this task was a difficult one, but Heppner rightly underscored the uncertainties of the figures. Herbulot (1992) and Scoble *et al.,* (1995) highlighted these uncertainties by comparisons with (near) exact counts of Geometridae and he estimated a total for world Lepidoptera (146,565) was remarkably close to the estimates given about the same time by Holloway *et al.*, (1987) and Hammond (1992).

Kristensen (1998) had recognized about one hundred and twenty-four Lepidopteran families (52 of them with a subfamily classification) and these families were grouped into 47 diagnosed superfamilies, and a provisional phylogeny at the superfamily level was presented. At the same time an alternative classification was presented by Heppner (1998), who later expanded it at the tribal level. Heppner assigned numbers to all families from 1 to 124 and the use of family numbers facilitated the indexing and locating names in the catalogue. The two classifications are broadly similar, but some differences exist, partly because the superfamilies and higher-level entities in Heppner's work were not diagnosed.

2.2 Contributors from India

Consolidation of data on butterflies of Indian region may be said to have initiated with the advent of the British rule in India. The first account of Indian butterflies was published 1857 by Horsfield and Moore in the Catalogue of the Lepidoptera in the museum of the East India company. Later, Moore (1865) reported some new butterflies from India and published in the Proceedings of Zoological Society. In 1881, De Niceville began a series of papers on butterflies of Cachar and Andaman Islands as well as revisions on many genera in the Journal of Bombay Natural History Society. In 1882, along with Marshall, De Niceville published the first volume of the book on the

Butterflies of India, Burma and Ceylon. The second and third volumes appeared in 1886 and 1890. These three volumes are considered as a wealth and perhaps the most important contribution to the study of Indian butterflies that has yet been produced. It deals with mainly the Papilionidae, Pieridae and Hesperiidae.

Moore, in 1890, made descriptions of butterflies so far described with notes on their habits and distribution. These works, which ran into several volumes and was completed by Swinhoe in 1913. The first volume on butterflies in the Fauna of British India series was published by Bingham in 1905. The second volume was published in 1907. It contained the family Papilionidae. Bell (1909) reported on the common butterflies on the plains of India. In 1912, a list of Indian butterflies was published by Evans. Ormiston (1918) compiled his 'Notes on Ceylon Butterflies'. Antram (1924) studied the butterflies of India but the study did not cover the entire Indian area and many species of Lycaenid and Hesperiid species were not included. Later, Evans (1927, 1932) published the book entitled "Identification of Indian butterflies," in two volumes that provides a comprehensive account on the identification of the families and species of butterflies of Indian region along with some tips on the identification of Indian butterflies. Peile (1937) published a guide for collecting butterflies in India with a detailed description of over 600 forms. A more holistic account of the Papilionidae, Pieridae, Danidae, and Satyridae was given by Talbot (1939, 1947).

Wynter Blyth in 1957 reported about 75 species of Papilionidae, belonging to the genera *Troides, Polydorus, Chilasa, Papilio, Graphium, Lamproptera, Teinopalpus, Armandia* and *Parnassius* in his publication entitled "The butterflies of Indian Region". Larsen (1987a, 1987b, 1987c, 1988) made a survey of butterflies of the Nilgiri Biosphere Reserve discussing the population status of all species so far recorded from this area. Gay *et al.,* (1992) provided a detailed account of nearly 100 species of butterflies from seven different groups *viz.,* Swallowtails, Whites and Yellows, Blues, Milkweed butterflies, Browns, Brush footed butterflies and Skippers including some rare butterflies in his book Butterflies of India. The checklist of butterflies of Peninsular India published later by Khatri (1993) also includes all the Nilgiri species.

Gaonker (1996) made a detailed survey on the butterflies of Western Ghats. According to him, nearly 20% of the total butterfly species from the Western Ghats are endemics. Moreover, the highest degree of endemism among the butterflies was found in the family Papilionidae in which around 50% of the total species are endemic. It was the first study that took into account all the 330 species in 166 genera belonging to 5 families recorded from the mountain range and the adjacent areas. The butterfly species diversity in relation to plant diversity, resource richness across vegetation type was documented by Kunte (1999).

Kunte (2000) in his publication on "The Butterflies of the Peninsular India" made descriptions of 107 Papilionidae from India, of which 19 are from Kerala. He classified the Papilionidae into 3 subfamilies *viz.,* Baroniinae with a single species, Parnassiinae (Apollo butterflies) with approximately 50 species and Papilioninae with 650 species. Antram (2002) described about 77 species of Papilionidae coming under the genera *Armandia, Leptocircus, Teinopalpus, Papilio* and *Parnassius* in his book entitled "Butterflies of India".

Kehimkar (2008) documented about 735 species butterflies, including 71 Swallowtails, occurring in the Indian subcontinent. This book contained coloured illustrations for each described species, showing both upper and under surface of the wings along with notes on biology and nomenclatural changes. Gay *et al.,* (2008) in his book entitled "Butterflies of India" provided a detailed account of about 100 species of butterflies from seven different groups *viz.,* Swallowtails, Whites and Yellows, Blues, Milkweed butterflies, Browns, Brush footed butterflies and Skippers including some rare butterflies.

Singh (2011) in his publication on 'Butterflies of India' described about 255 species of butterflies found across different sub-regions of India. The book features the status, distribution, seasonality, identification characters and larval food plants of each species of butterflies. More recently, available information on 282 species of butterflies so far recorded from the Nilgiri Biosphere Reserve was consolidated by Mathew (2011) in his report entitled “A handbook on the butterflies of Nilgiri Biosphere Reserve.

2.3 Classification and nomenclature of Papilionidae

The generic name *Papilio* was coined by Linnaeus in 1758. Latreille (1802) was the first author who made an attempt to classify the Lepidoptera in the orthodox way by families and he mentioned ‘Papilionides’ as one of the families including the genus *Papilio* with 7 infra generic groups and *Hesperia*. Later, Leach (1815) quoted ‘Papilionidae’ in the Edinburgh Encyclopedia. Swainson (1840) described the subfamily Papilioninae, under which he recognized 4 Tribes - Troiidini, Papilionini, Graphiini (=Leptocercini) and Teinopalpini based on the studies of forewing venation and tarsal characteristics.

The Tribe Troiidini included 2 genera *viz., Troides* and *Polydorus*. The Genus name *Troides* was coined by Hubner (1819) and he mentioned 3 species belonging to the Genus *Triodes viz., helena, amphrysus ruficolli,* and *aecus*, based on wing venation. Of these*, Troides helena minos,* described as *Troides minos* by Rothschild (1895) in his revision of *Papilio*s of Eastern Hemisphere, is common in Kerala. The Genus name *Polydorus* was coined by Swainson (1833) in Zoological Illustrations. He classified the *Polydorus* into 4 groups - *nox* group, *coon* group, *hector* group and *latreillei* group. Among these groups, the *nox* group included 4 species - *aidoneus, varuna varuna, varuna zaleucus* and *sycorax.* The *coon* group contained 3 species - *coon, neptunes neptunes,* and *rhodifer*. The *hector* group included 3 species - *jophon pandiyana, hector* and *aristolochiae*. The *latreillei* group contained 8 species - *adamsoni, latreillei, polla, nevilli, philoxenus, dosarada, crassipes* and *plutonius. Polydorus* is the oldest name of this group and Reakirt (1865) coined the generic name *Atrophaneura*. The members of the *hector* group are present in Kerala.

The Tribe Papilionini was classified into 2 Genera *viz., Papilio* and *Chilasa* based on the pattern of oblique bands in the larva. The Genus name *Chilasa* was erected by Moore in his book on Lepidoptera Ceylon published in 1881a. In this work, he divided this genus into 2 groups based on hind wing venation *viz., agestor* and *clytia*. The former included the species *slateri*, *agestor* and *epycides*. The group *clytia* included *paradoxa* and *clytia.* Among these, *Chilasa clytia* described by Linnaeus (1758) is found in Kerala. Based on wing venation and genetalia studies, Hemming (1934) divided *Papilio* into 6 groups to include the 32 species. Of these, 9 species *viz., Papilio liomedon, P. polymnestor, P. helenus, P. polytes, P. dravidarum, P. demoleus, P. crino, P. buddha* and *P. paris* are found in Kerala.

The Tribe *Graphiini* (=Leptocercini) included 2 genera *viz., Graphium* and *Lamproptera.* The genus name *Graphium* was first coined by Scopoli in 1777 and Hemming (1934). It contained 4 groups and 19 species of which, 5 species *viz., G. doson, G. agamemnon, G. sarpedon, G. antiphates* and *G. nomius* are found in Kerala. The genus *Lamproptera* included 2 species *viz., curius* and *meges*. The Tribe Teinopalpini was described by Grote (1892) and it included a single Genus *Teinopalpus* by Hope. Stichel (1908) recognised a single species - *T. imperialis* and 2 subspecies under the genus *Teinopalpus*, although they are not found in Kerala.

The family Papilionidae was divided into 3 subfamilies - Papilioninae, Zerynthiinae, and Parnassiinae by Talbot (1939) in the Fauna of British India Series. Of these, the subfamily Zerynthiinae is essentially a palaearctic group, of which the Genus *Armandia* is the only representative found in the Indian region although this genus is not found in Kerala. The subfamily Parnassiinae was first mentioned by Elwes (1886) and Kirby (1896). The subfamily Parnassiinae included 2 Genera - *Hypermnestra* and *Parnassius* based on the characteristics of the antennal club and wing venation. Hemming (1934) also made a detailed description of the Genus *Parnassius* and concluded that 13 species were present in the Himalayas and these comprised of a number of subspecies and forms. The members of this subfamily are not found in Kerala.

The modern classification of the butterflies is based on the work of Ehrlich (1958), who divided the Lepidopteran group into Hesperioidea and the Papilionoidea, with the latter comprising five families and nineteen subfamilies. Munroe (1961) classified the family Papilionidae into different tribes and genera based on the characters like scaling and sensory structures of antennae, structure of palpi, scaling, spinning and pre-tarsal armature of the legs, wing venation, structure of inner margin of hind wing, wing pattern and pigmentation, food plant associations of larva, structure of pupa and geographic distribution. Munroe (1961) recognized two tribes [Parnassiini and Luehdorfiini (=Zerynthiini)] within Parnassiinae and four tribes (Leptocircini, Teinopalpini, Papilionini and Troiidini) within Papilioninae.

Hancock (1983) presented the first modern cladistic attempt to resolve the classification and phylogeny of Papilioninae. Within Papilioninae, Hancock recognized three tribes: Leptocercini, Papilionini and Troiidini. Igarashi (1984) presented a classification based on detailed studies of juvenile life stages. Miller (1987) presented the first computer-implemented cladistic analyses of Papilionidae with a focus on the subfamily Papilioninae. The study was based on analyses of three separate datasets comprising 170 morphological characters from both juvenile and adult stages. The first analysis focused on the intertribal relationships within Papilioninae, with Baroniinae and the two Parnassiine tribes Parnassiini and Luehdorfiini as outgroups. He concluded that the Leptocircini (=Graphiini) represented the sister group to the remaining Papilioninae. His second and third analyses focused on the Leptocircini and Troiidini, respectively. Tyler *et al.,* (1994) presented the next comprehensive computer-based analyses of Papilionidae, based on 155 characters from morphology, ecology and behaviour of adults and juveniles. When their 85 adult characters were analysed separately, the result was essentially similar to that of Miller (1987). In other analyses, Leptocircini and Papilionini were sister groups, with Troiidini being sister to the remaining Papilioninae.

Higher-level Papilionid phylogenetic research entered the molecular age with Yagi *et al.,* (1999). Caterino *et al.,* (2001) presented a more comprehensive molecular study of Papilionid phylogeny, based on 21 species representing all major tribes of the family. Nazari *et al.,* (2007) presented the first higher level of total evidence analysis of the Lepidoptera, especially the Papilionid group, based on morphology and 7 genes. This was mainly focused on the subfamily Parnassiinae and they noted that Parnassiinae and Baronia formed a monophyletic group. Kristensen *et al.,* (2007) reviewed the phylogeny of the principal lineages within the order Lepidoptera and the state of the taxonomic inventory of Lepidoptera was discussed separately for micro-moths, macro-moths and butterflies.

The taxonomy of the five species of Lime Swallowtails of the *Papilio demoleus* group (*P. demoleus*, *P. demodocus*, *P. erithonioides*, *P. grosesmithi*, and *P. morondavana*) were re-examined by Smith and Vane-Wright (2008), based on some sixty morphological characters drawn from the morphology of the wings, antennae, and male and female genitalia. Then the results of these cladistic analyses were further evaluated on the basis of DNA sequence data. The study had presented a dichotomous key to the species and subspecies based on adults, together with a synonymic checklist. Michel *et al.,* (2008) in molecular study focused on certain subfamilies of the order and found some sister groups of Parnassinae. Ming *et al.,* (2008) made an investigation of the insect species composition of Papilionidae in Gansu province, China and the study revealed that there were 36 species and subspecies of *Papilios*, belonging to Papilioninae and Zerynthiinae, recorded to date. There are 14 new records of species and subspecies of papilios reported in the province. Thomas *et al.,* (2010) studied the phylogenetic relationships of 18 genera of the subfamily Papilioninae, 4 genera of Parnassiinae and Baroniinae based on 94 morphological characters and 7 genes. They inferred that Baroniinae were the sister of the clade comprising Parnassiinae and Papilioninae. Four Papilioninae tribes were recognized *viz.,* Leptocercini, Teinopalpini, Papilionini and Troiidini, with Leptocercini being the sister of the remaining tribes.

Pathania and Kumari (2011) identified twenty eight species of nine genera belonging to three families of butterflies from fifteen localities of Japan. Among these, two of them belong to Papilionidae and thirteen each to Nymphalidae and Pieridae. The collected Papilionids included *Papilio demoleus demoleus* and *P. polytes nikobarus.* They provided some diagnostic features based on their head, antennae and wing venation. These features included smooth head vertex, three segmented labial palpi and absence of forewing chordate.

Revathy and Mathew (2014a) studied morphological details of the external genitalia of the Common Mormon, *Papilio polytes* L. The Common Mormon is a good example for sexual polymorphism and Batesian mimicry. It has four forms- three female forms and one male form; the female form *cyrus*, is similar to the male form both in colouration and form, *stichius* mimics the common Rose and *romulus* mimics the crimson rose. The study showed that morphological details of the external genitalia were useful in segregating three forms *viz*., *cyrus, stichius* and *romulus* of this species.

2.4 Biological studies

Because of their ecological and economical significance, several studies have been made on the biology and bionomics of butterflies. Among various groups of butterflies, the Swallowtails are the best studied group of Lepidoptera and several studies have been made on their life history, polymorphism, and host associations. Porter (1986) observed that females mate several times during their lifetime and develop eggs when necessary fat reserves or food are available. Most butterflies lay 100-500 eggs during their life span. The eggs of butterflies are usually spherical in shape. Singh (1991) made a survey of the natural enemies of four species of *Papilio*, *viz., P. demoleus, P.* polytes*, P. polymnestor and P. helenus* in Tamil Nadu, and reported several species of parasites such as *Apanteles papilionis, Holcojoppa coelopyga, Melalophacharops* sp.*, Brachymeria jambolana and Pteromalus puparum.*

Ramana *et al.,* (1996, 1997) studied the life history and morphology of *Papilio polytes* in Andhra Pradesh. The development was completed from egg to adult within 28-30. This butterfly which is multivoltine, produced 11-12 generations in a year and the peak population was during August-February. Although, normally the pupa was brown, a rare occurrence of green-coloured pupa was also reported. Cottin *et al.,* (1997) studied oviposition preferences of the protected species *Parnassius apollo* and the efficiency of larval food plants in France. The two species most frequently cited as food plants in literature, *Sedum album* and *S. maximum*, appeared to be the most efficient.

Bing *et al.,* (1998) reported on the rearing and breeding of white-band Swallowtail, *Papilio polytes* in China. Under natural illumination at 26.4°C and relative humidity of 66%, when *P. polytes* adults were fed honey solution. Adults copulated and oviposited normally and the larvae that hatched out were able to complete their development. Schmitz and Wasserthal (1999) studied the morphology and ultra structure of the adult belonging to three families of Lepidoptera *viz., Ornithoptera priamus* and *Pachliopta aristolochiae* (Papilionidae), *Attacus atlas* and *Acherontia atropos*.

Mathew (2001) studied the biology of 20 species of butterflies in order to assess their suitability for captive breeding programmes in Kerala. Atluri *et al.,* (2001, 2002a, 2002b) studied the life history of *Pachliopta aristolochiae, Papilio demoleus,* and *Graphium agamemnon* in Andhra Pradesh. The life cycle of *P. aristolochiae* was completed within 40-48 days and there were 5 instars over a period of 18-23 days. The short life cycle facilitates 6-7 broods yearly. In G. *agamemnon*, the eggs took 3-4 days to hatch. The larvae go through 5 instars over a period of 15-16 days and the pupal period was 13-14 days. The total period from egg to adult emergence spans over 33-36 days.

Kalita and Kakati (2002) discussed the adult, pupal and larval behaviour of *C. clytia* in Assam. They mentioned that the life cycle was completed within 28-30 days and larval duration was 12-13 days. Gravid females laid 2-3 eggs in 5 minutes on the plants. Ramana *et al.,* (2003, 2004) studied the life history of *G. doson* and the autecology *P. hector* in Andhra Pradesh. The features of adults, eggs, larvae, pupae of both species were described and *G. doson* have 4-7 broods yearly. *P. hector* is multivoltine with 6-7 broods yearly, with development from egg to the adult requiring 39–47 days. Butterflies serve as important plant pollinators in the local environment, and help to pollinate more than 50 economically important plant crops (Borges *et al.*, 2003).

Raju (2004) prepared a list of host plants of some papilionid butterflies (*Pachliopta hector, P. aristolochiae, Papilio polytes, P. demoleus, Graphium doson* and *G. agamemnon*) at Visakhapatnam. *Antigonon leptopus, Caesalpinia coriaria, Duranta repens, Jasminum angustifolium, Lantana camara, Sida cordifolia* and *Hamelia patens* were considered to be the most favourite nectar host plants for the Papilionids as they produce numerous flowers daily and provide ample nectar.

Susanth (2005) recorded the biology of *Papilio liomedon* Moore on the larval food plant *Evodia roxburghiana*. The Malabar Banded Swallowtail is a brownish-black butterfly with a prominent cream yellow band on its wings, is among the rarest papilionid butterflies in South India. It is endemic to the Western Ghats and an inhabitant of semi-evergreen and evergreen forests. It flies high in the dense forest, but is attracted to clearings and roadsides, where its adult food plant *Clerodendron paniculatum* and *C. infortunatum* grow. *Achromychia laurifolia* (family Rutaceae) is the recorded larval host plant of the butterfly. The Malabar banded Swallowtail laid their eggs in groups one over the other and the mean incubation period was five days. The lifecycle was completed within 37 days and the wingspan of male butterfly was 90-100 mm. The new food plant reported in this paper, *Evodia roxburghiana* also belongs to the family Rutaceae.

Kunte (2006) reported some specific larval host plants of 36 butterfly species from mainly three areas of the Western Ghats and it includes six Swallowtails *viz., Graphium sarpedon*, *G. agamemnon, Papilio helenus*, *P. dravidarum*, *P. polytes*, *P. polymnestor*.

Kumar and Hosetti (2007) Studied the autecology and morphometry of the Common Jay, *Graphium doson* (Lepidoptera: Papilionidae) on *Michelia champaka* in Karnataka. The study revealed that the average incubation period was 3-4 days, larval period was 16-21 days with five instars, pupal duration was 12-14 days and the total life cycle lasted for 32-40 days. The Common Jay was a multivoltine species with a minimum of 5-7 generations a year, with better breeding ability during October to February.

Barua and Slowik (2007) made some observations on the biology of *Pachliopta aristolochiae aristolochiae* on its host plant *Aristolochiae tagala* in Assam. The laboratory study revealed an incubation period of ±4 days, larval duration of ±20 days, pupation period of ±12 days, and total life cycle of ±30 days in the monsoon season. Field observations and laboratory study established that *Pachliopta aristolochiae aristolochiae* was multivoltine with 7-8 generations per year and the species displayed single egg-laying habit, which coupled with host-plant specialization with larvae feeding on *A. tagala* and *A. indica* allowed efficient utilization of the food resources. The occurrence of *Papilio demoleus* on *Psoralea corylifolia* was studied by Pandey *et al.,* (2007) in Allahabad.

Vu *et al.,* (2008) described the biology of *Graphium agamemnon* as a pest of soursop (*Annona muricata* L), in Vietnam. They documented the life history and ecology of *G. agamemnon* and investigated on the commonly used control measures in south-east Vietnam. Dahelmi *et al.,* (2008) examined the duration of the immature stages of 11 Swallowtail butterflies under laboratory conditions in Sumatra. An average egg incubation period of P. demoleus was 3.0 days, 4.4 days of *G. agamemnon,* while that of *P. aristolochiae* was 5.6 days. The average duration of the larval stages ranged from 13.5 days (*P. demoleus*) to 22.6 days (*G. agamemnon*) and that of *P. aristolochiae* was 34.9 days. Gaikwad and Bhawane (2008) were made some observations on emergence of *Papilio polytes polytes* in Maharashtra, India.

Zhou *et al.,* (2009) studied the morphology as well as behavioural characteristics of immature stages and adults of two papilionid butterflies, *Chilasa agestor* and *C. clytia* in China. He noted that *Chilasa clytia* was multivoltine, overwintering as diapaused pupae, with 5 generations in the experimental population in China. The females of both species laid eggs singly and larvae had 5 instars. *Litsea magnoliifolia* and *L. glutinosa* were the main host plants of *C. clytia*. Pal *et al.,* (2009) recorded the Common Rose butterfly, *Pachliopta aristolochiae* on medicinal plant, *Aristolochiae indica* L. in West Bengal.

Sehgal *et al.,* (2009) observed the gross morphology and duration of various stages of life history of three butterfly species: *Chilades lajus lajus*, *Papilio demoleus* and *Papilio polytes* infesting citrus species in Punjab. The larval and oviposition behaviour had also been studied along with nectar food plants of adults.

Suwarno *et al.,* (2010) studied the oviposition preference and oviposition site selection of *Papilio polytes* on four Rutaceous host plants, *viz., Citrus aurantofolia*, *Citrus hystrix, Citrus reticulata* and *Murraya koenigii* in Malaysia. The four host plants in descending order of preference were *C. reticulata* ≥ *C. aurantifolia* > *C. hystrix* > *M. koenigii.*

Prasannakumar *et al.,* (2012) studied the eco-biology of the *Tarucus nara* in Andhra Pradesh. The mean incubation was 3-4 days and the larvae had four instars and the total time for development from egg to adult was 22- 27 days.

Based on microarray analysis, Futahashi *et al.,* (2012) studied the specific genes associated with the larval camouflage pattern in the Swallowtail butterfly, *Papilio xuthus*, in Japan. They noted that the caterpillar of *P. xuthus* showed spectacular changes in the color pattern and the young larva mimics bird droppings and switches to a green camouflage coloration in the final instar. They also tried to prepare a catalogue of genes involved in larval mimetic and cryptic pattern formation and constructed the Expressed Sequence Tag (EST) libraries of larval epidermis for *P. xuthus*, and *P. polytes* that contained 20,736 and 5,376 clones, respectively, representing one of the largest collections available in butterflies.

Eilers *et al.,* (2013) studied the micro-climate factors that determine the oviposition sites and abundance in the butterfly *Pyrgus armoricanus* at its northern range margin in southern Sweden. Oviposition behaviour was observed and analysed using a two-step approach. First the characteristics of host plant ramets that female butterflies inspected for oviposition (including both ramets that were rejected and ramets used for oviposition) were compared with control ramets. Second, ramets on which female butterflies oviposited were compared with ramets that butterflies inspected but rejected. Among the inspected ramets, females chose to oviposit those situated in the warmest micro-climates and those surrounded by the largest percentage cover of bare ground. These results reveal the importance of a microclimate as a component of habitat quality for insect populations at the margins of their geographical range.

Revathy and Mathew (2014b) studied the role of niche breadth and resource availability on the life history of butterflies. The study is an analysis of relationship between three biological characteristics (mobility, body size, behaviour) with resource availability (abundance of host plants) and niche breadth (larval host plant specificity and adult habitat breadth). The adult habitat breadth has a positive correlation with mobility, resource availability and adult body size, although larval specificity showed very little correlation with any of the above factors. This indicates that species with narrow niche breadth in terms of larval feeding specificity or adult habitat breadth are less mobile than the species with wide niche breadth.

2.5 Ecological studies

Butterfly population size, vulnerability and structure together constitute perhaps the most urgent information required for any possible conservation target. Among the invertebrates, butterflies are sufficiently well studied since their populations respond more rapidly to adverse environmental changes than longer lived organisms. Transect counting is now used extensively in surveying and monitoring butterfly populations and communities. Frazer (1973) has emphasized that the transect survey is valuable as repeatable method which, while not giving an exact estimate of population abundance, can reflect numerical changes on a day to day or year to year basis. Butterflies show daily rhythms of flight activity. Therefore, it is recommended to make two census daily for optimum results (Yamamoto, 1975). Pollard (1977) derived an index of abundance from transect counts. The mean count per transect was calculated each week and these counts were summed over the season to arrive at an index which can be used to assess changes in abundance over many generations or years. Transects can be combined with MMR (Mark-Release-Recapture) techniques, so that the sampling for recaptures is based on transects and thus, on a standardized area of habitat. Douwes (1970) found a high correlation between the two kinds of estimates. Van Swaay (1992) has emphasized the role of the long term stability of some common species in assessing trends in the whole butterfly fauna. The ease of sampling butterflies has made them a focal group for characterizing tropical insect diversity, community structure and disturbance effects and as tools in conservation biology (De Vries and Walla, 2001). Information available on the pattern of butterfly diversity present in different landscapes is summarized below.

2. 5.1 Butterfly diversity in different landscapes

Work done in various countries

Feltwell (1986) cited that there is an intimate association between butterflies and plants and their lives are exceptionally interlinked, which leads to different patterns in their distribution depending on the availability of their food plants. Yen *et al.,* (1988) affirmed that only the long term monitoring can provide a clear picture of population trends of a particular species since short term fluctuations in population was common among invertebrates. Pollard (1988) showed a clear relationship between increased numbers and warm, dry summers. Butterflies have important ecosystem roles including pollination and they are useful in studies of population and community ecology as indicators of ecosystem health because they are very sensitive to changes in microclimate and habitat (Pollard, 1991; Kremen, 1992). Warren (1992) mentioned that butterflies fluctuate in abundance year to year. Habitats are dynamic, changing all the time and it may be able to support more individuals than at others.

Kitahara and Fujii (1994) studied the butterfly communities in several types of habitats (secondary forest, farmland, and city parks) in and around Tsukuba city, central Japan. They analyzed the community structure along a gradient of human disturbance by applying the generalist/specialist (r/K) concept. They clearly showed the systematic changes of the community structure along the gradient. It was found that the degree of human disturbance at each site was significantly correlated with species diversity, total species richness, and specialist species richness, but not with generalist species richness.

Tumuhimbise *et al.,* (2001) recorded 18 species of Swallowtail butterflies and their species richness of four habitats in North Maramagambo forest in Uganda. Hamer (2003) studied the ecology and the importance of habitant heterogeneity of butterflies in natural and selectively logged forests of northern Borneo. Changes in butterfly assemblages were associated with changes in vegetation structure following selective logging, which resulted in much lower habitat heterogeneity with less dense shade and fewer open gaps in logged forest. The results further indicate that selectively logged forests can make an important contribution to the conservation of tropical biodiversity, provided that they are managed in a way that maintains environmental heterogeneity.

Kitahara and Watanabe (2003) described diversity and rarity hotspots of butterfly communities in and around the Aokigahara woodland of Mount Fuji, central Japan. The results showed that butterfly species richness and species diversities $H'1/\lambda$ were significantly higher in forest-edge sites than in forest-interior and/or open-land sites. Variation in the total number of species among these three landscape types was well accounted for by ecologically specialist species, such as landscape specifics, oligovoltines, narrow diet feeders and low density species. Thus, the species regarded as vulnerable to extinction, including Red List species, were observed more often in forest-edge sites than in forest-interior and/or open-land sites. They concluded that it is very important to conserve and manage forest-edge habitats (considered to be semi-natural) as well as forest-interior habitats (considered to be the most natural) to maintain the diversity of butterfly communities and preserve the various types of threatened species in and around the Aokigahara woodland.

Dennis *et al.,* (2004) examined the associations between butterfly larval host-plant competitive, stress-tolerant, ruderal (C-S-R) strategies and butterfly biology. The results showed that butterfly biology is linked to host-plant strategies and the population attributes. Sawchik *et al.,* (2005) described the patterns of variation in butterfly assemblages on a diverse set of wet meadows in southern Belgium. They used multivariate techniques to identify the butterfly assemblages and the species that characterize these habitats. Three main assemblages were identified, based principally on the dominance of five butterfly species: *Brenthis ino, Clossiana selene, Lycaena helle, L. hippothoe* and *Proclossiana eunomia*. These are indicator species of different habitats structured along a vegetation gradient. The study assumed that focusing the conservation practices upon these species will promote the preservation of a wide range of organisms inhabiting the wet meadows.

Kitahara and Fujii (2005) analyzed butterfly community composition using multivariate analyses. The results showed that the butterfly community was composed of five species groups differing from each other in their ecological characteristics: a specialist group, two intermediate groups and two generalist groups. The comparison of their characteristics suggested that, in the butterfly community, the positions of the specialist group and one of the generalist groups are the endpoints on the generalist/specialist selection spectrum, and the three other groups are positioned between these two extremes. Davies *et al.,* (2006) observed the direct or indirect effects of temperature in the choice of oviposition sites, egg-laying rates, larval development and survival rates as well as range shifts and expansions.

Menendez *et al.,* (2007) examined the effects of climatic variables, host-plant richness and habitat diversity on butterfly diversity patterns in Britain. These factors were all important determinants of butterfly diversity, but their relative contributions differed between habitat generalists and specialists. The study showed that climatic variables had strong effects on habitat generalists, whereas host-plant richness and habitat diversity contributed relatively more for habitat specialists. Considering total effects (direct and indirect together), climate variables had the strongest link to butterfly species richness for all groups of species.

Ming *et al.,* (2008) studied faunistic distribution of Papilionidae in Gansu, China. The investigation of the insect species composition of Papilionidae in Gansu province showed that there were 36 species and subspecies of Papilios, belonging to Papilioninae and Zerynthiinae, including 14 new records of species and subspecies of Papilios.

Shan *et al.,* (2009), made a cluster analysis of geographical distribution of Papilionidae in China. Parsimony analysis of endemicity (PAE) was used to construct the cladogram of Papilionidae in China based on the statistics of diverse distribution. According to the cladogram, the eight biogeographic regions of Papilionidae in China were divided into six clustering groups. The diversity in South China and Southwest China region was the richest, which might be related to local ecological environment.

Savilaakso *et al.,* (2009) investigated the community of herbivorous Lepidopteran larvae and its temporal dynamics in a natural forest and three differently managed forest compartments after 40 years of regeneration in Uganda. Many of the protected forest areas in Uganda have been subject to logging in the past and the logging will change communities. The results showed that the herbivory, density of larvae, and species richness were significantly lower in logged compartments than in natural forest. Furthermore, the community composition differed significantly between the logged compartments and the natural forest.

Matteson and Roberts, (2010) studied the diversity and conservation of butterflies in the New York City. They compiled 12,732 reported sightings representing 106 butterfly species during 2001-2009. The five butterfly species with the most reported sightings were the Cabbage White, Orange Sulphur, Monarch, Spring Azure, and Eastern Tiger Swallowtail. The five species with the fewest reported sightings included three extra limital vagrants (Clouded Skipper, Eufala Skipper, and Sleepy Orange), one potential stray or escapee (Peacock Butterfly, from Europe), and one species that is rare within its range (Bronze Copper).

Vu and Vu (2011) reported the diversity of butterfly communities of a tropical rain forest of Bu Gia Map National Park in South Vietnam. The study was carried out in four different habitat types (the natural forest, the disturbed forest, the bamboo forest, and the stream sides in the forest) and a total of 112 species with 1703 individuals of Papilionoidae (except Lycaenidae) were recorded. The study revealed the tendency of rare species to decrease from the natural forest to the stream sides, while the proportion of common species tends to increase from the natural forest to the stream sides.

Munyuli (2012) reported the diversity of butterfly communities in the mixed coffee-banana mosaic (semi natural, agricultural) landscapes of rural central Uganda. A total of 56,315 individuals belonging to 331 species, 95 genera, and 6 families were sampled. The most abundant species was *Bicyclus safitza* (14.5%) followed by *Acraea acerata (*6.3%), *Catopsilia florella* (6.5%) and *Junonia sophia* (6.1%). The study showed highest diversity and abundance of butterflies in sites that contained forest remnants. Thus, forest reserves in the surrounding of fields increased the conservation values of coffee-banana agro forestry systems for butterflies.

Garcia Perez (2012) made a preliminary inventory on diversity of the butterflies present in different areas of cultivation of the Center Research Corpoica Nataima (Tolima-Colombia). Diversity of the diurnal butterflies was examined in four different crop areas and a total of 209 individuals represented in six families and 26 species were registered. *Anartia jatrophae* most abundant (15%) and the analysis of rarefaction curve indicates that the number of species registered is not approaching the real richness (X2 =8.62, Df =7 P<0.001). The values of richness and diversity were higher in the crops associated with vegetations and decreased in the less heterogeneous (crops cotton-rice).

Ferrer-Paris *et al.,* (2013) examined the congruence and diversity of butterfly-host plant associations at higher taxonomic levels. The compilation included 44,148 records from 5,152 butterfly species (28.6% of worldwide species of Papilionoidea) and 1,193 genera (66.3%). The study showed that majority of butterflies use angiosperms as host plants. Fabales is used by most species (1,007 spp.) from all seven butterfly families and most subfamilies, Poales is the second most frequently used order, but is mostly restricted to two species-rich subfamilies, Hesperiinae, and Satyrinae. There is a significant and strong correlation between host plant diversity and butterfly species richness.

Vlasanek *et al.,* (2013) studied the dispersal and diversity of butterflies in a New Guinea rainforest by using mark-recapture methods. This intensive Mark-Release-Recapture study of all butterfly species in a tropical rainforest understory showed 5903 individuals from 90 butterfly species and 1308 recaptured at least once. The study proved that mark-recapture methods are feasible in tropical rainforests, but also showed its limitations, that as after 232 person-days of sampling, it could only characterize dispersal for one-third of the species present. The mean dispersal distance was 184 ± 46.1 m per species, while for six of the 14 species studied >1% of individuals were estimated to disperse 1 km or more. These results, in combination with data from large permanent rainforest plots, suggested that most woody plant species in tropical forests are sufficiently abundant to serve as host plant species even to monophagous Lepidoptera species.

Work done in India

Information pertaining to the diversity, abundance, patterns of seasonality and habitat associations of butterflies have been studied at different places and reported by various workers. Earlier, records on the Swallowtail butterflies of the Himalayan region were compiled by Mani (1986) while Haribal (1992) reported on the diversity, status and habitat preferences of butterflies from the Sikkim Himalayas.

Mathew and Rahmathulla (1993), reported on the butterflies of the Silent Valley National Park. Sudheendrakumar *et al.,* (2000), reported 124 species of butterflies from Parambikulam Wildlife Sanctuary.

Sreekumar and Balakrishnan (2001) studied the habitat and altitude preferences of butterflies in Aralam wildlife sanctuary in Kerala and the study resulted that *Papilio helenus* and *P. buddha* are habitat specific, being restricted to evergreen forests and they prefer medium and high elevations.

Arun (2003) reported 75 species of butterflies from Siruvani Reserved Forests and his studies showed that Lepidoptera showed greater abundance in riverine habitat than hymenoptera, which were comparatively more abundant in teak plantations.

Rane and Ranade (2004) studied butterflies of Tamhini-Dongarwadi area, Maharashtra. 72 species were sighted in the Tamhini area, of which 33 species belonged to family Nymphalidae, 9 to Papilionidae, 13 to Pieridae, 11 to Lycaenidae and 6 to Hesperiidae. Species like *Danaus chrysippus, Danaus genuta, Euthalia garuda, Hypolimnas bolina, Kallima horsefieldi, Neptis hylas, Parantica aglea, Phalanta phalanta, Tirumala limniace* and *Papilio polymnestor* were very commonly found throughout the year, while species like *Charaxes solon* and *Appias indra* were sighted only once throughout the survey and thus appear to be very rare.

Barua *et al.,* (2004) analysed the status of Swallowtail butterflies in Garbhanga Reserve Forest, Assam. During the survey, 29 species and subspecies of Swallowtail butterflies belonging to 8 genera were identified in the study area, of which 10 were found to be very rare. They belonged to the genera *Pachliopta, Lamproptera, Atrophaneura* and *Princeps*. The dominant larval food-plants of the black-bodied Swallowtails belong to the families

Rutaceae, Annonaceae, Lauraceae and Magnoliaceae, while the larvae of red-bodied Swallowtails were found to prefer the plant family Aristolochiaceae that included *Aristolochiae tagala*, *A. indica* and *A. saccata*.

Ambrose and Raj (2005) reported 24 species of butterflies from Kalakkad-Mundanthurai Tiger reserve. Eswaran and Pramod (2005) reported 75 species from Anaikatty near Coimbatore. Because of their sensitivity to climatic variables, butterflies are often used to study the effects of climate change. Temperature strongly affects butterflies throughout their life histories and the precipitation influences larval development and survival by controlling host plant phenology.

Padhye *et al.,* (2006) studied season and landscape-wise distribution of butterflies in Tamhini, northern Western Ghats of India and he noted that butterflies and their caterpillars are dependent on specific host plants for food, thus the diversity of butterflies indirectly reflects overall plant diversity especially that of shrubs and herbs in the given area.

Tiple *et al.,* (2006) studied the butterfly species and their nectar host plant relationships from north central India. The study was carried out on Amravati University Campus and a total of 48 butterfly species was recorded belonging to five families and included five species previously unrecorded on the campus. Visits of butterflies were more frequent to flowers with tubular corollas than to non tubular ones, to flowers of herbs and shrubs rather than trees, to flowers coloured red, yellow, blue and purple than those coloured white and pink, and to flower sources available for longer periods in the year.

Tiple *et al.,* (2007) studied the pattern of butterfly abundance and species richness in wild and human-impacted areas in the 190-hectare campus of SGB Amravati University, Maharashtra. A total of 52 butterfly species belonging to Hesperiidae, Papilionidae, Pieridae, Lycaenidae and Nymphalidae families were recorded in five areas (biotopes). Species abundance rose from the beginning of the monsoon (June-July) and reached a peak in early winter (August-November). A decline in species abundance was observed from late winter (December-January) and continued up to the end of summer (May). On the basis of biotope occurrence, 67% of butterfly species were classified as disturbance-adaptable (occurring in all biotopes) and 33% as disturbance avoiders (restricted to wild areas such as forest, scrub and undisturbed areas elsewhere).

Zade and Gadhikar (2008) made a preliminary report on insect biodiversity in Amravati, Maharashtra. The study reported that a total number of 68 insect species were identified in a survey of insect fauna. Among butterflies belonging to 20 genera and 4 families, the family Nymphalidae dominated with 12 species exhibiting perennial occurrence, followed by Pieridae (6 species), Papilionidae (4 species) and Lycaenidae (3 species).

Thakur *et al.,* (2008) studied the biodiversity of the lepidopterous pests in different locations of Varanasi (Uttar Pradesh) through periodical surveys and collection of the insects. In total, 21 species belonging to 11 families (Plutellidae, Pyralidae, Pyraustidae, Danaidae, Nymphalidae, Lycaenidae, Pieridae, Papilionidae, Hesperiidae, Sphingidae and Noctuidae) were recorded from different locations.

Jayasooryan *et al.,* (2008) studied butterfly fauna of Aymanam gramapanchayath and a total of 62 species belonging to the families Papilionidae, Pieridae, Nymphalidae, Lycaenidae, and Hesperiidae were identified. A decrease in the number of individual species in the agricultural areas was also noticed. Krishnakumar *et al.,* (2008) studied the bio-ecology of ten selected species of Papilionidae in the Indira Gandhi Wildlife Sanctuary recorded the Papilionids *Troides minos*, *Pachliopta aristolochiae, P. hector, Graphium sarpedon, G. agamemnon, Papilio demoleus, P. helenus, P. polytes, P. polymnestor* and *P. crino* from the Sanctuary.

Prasad *et al.,* (2010) recorded 52 species from Kerala University campus, Thiruvananthapuram, while Toms *et al.,* (2010) reported 109 species from Mahatma Gandhi University campus, Kottayam. Shamsudheen and Mathew (2010) reported about 73 species of butterflies belonging to five families in

Shendurney Wildlife Sanctuary in Kerala and the species diversity and richness were highest in the Rosemala area compared to Thenmala.

Tiwari *et al.,* (2010) reported the butterflies of in Pench Tiger Reserve in Madyapradesh. Rich butterfly fauna was found in Pench Tiger Reserve which included a total of 126 butterfly species belonging to 74 genera and 5 families. Family Nymphalidae was dominant with 51 species belonging to 23 genera followed by Lycaenidae with 37 species in 25 genera, Hesperiidae and Pieridae with 16 and 14 species respectively and Papilionidae was represented by only 8 species.

Rajagopal *et al.,* (2011) studied diversity and community structure of butterfly of Arignar Anna Zoological Park, Chennai and a total of 56 species were recorded, among them Pieridae family were comparatively dominant than that of other families. The notable addition to the 25 more species listed during this observation was compared to previous field survey. It was suggested that butterfly species diversity generally increases with increase in vegetation and declines with the increase in disturbance.

Guptha *et al.,* (2012) conducted a preliminary survey on butterflies in Seshachalam Biosphere Reserve and the study concluded that the family Nymphalidae and Lycaenidae were dominant with 20 and 12 species respectively with six protected species.

Thakur and Bhardwaj (2012) surveyed the butterfly diversity and species richness in Himachal Pradesh. During studies a total of 40 butterfly species were collected from different study sites of lower Shiwalk hills which belonged to six families i.e. Nymphalidae, Pieridae, Papilionidae, Lycaenidae, Satyridae and Riodinidae and thirty genera. The Nymphalidae family was the most diverse family in the study area having ten genera followed by Lycaenidae with eight genera. But the abundance of Pierids was more in the study area. During sampling of specimens in the study areas, a total of 91 plants belonging to 44 families were reported. A total 40 species of butterflies were collected as flower visitors on 91 species of flowering plants (garden, cultivated, semi wild and wild) in Shiwalik hills.

Sebastian and Pachoni (2012) surveyed the butterfly diversity of Pakke tiger reserve in Arunachal Pradesh. Sixty five species in 43 genera representing 14 sub families and 5 families were recorded and Jaccard's similarity index showed greater dissimilarity of butterfly fauna between forest edge and forest habitats and also within families at two sites. This may be due to the difference in vegetation composition and disturbances at two sites.

Kasangaki *et al.,* (2012) discussed the butterfly species richness of 17 forests located in the western arm of Uganda using cluster analysis and PCA was conducted to assess similarities among forests. Result showed 7 ecological groupings with closed forest group having the most species and the swamp or wetland group with least number of species.

Kunte *et al.,* (2012) studied the diversity and conservation of butterflies of Garo Hills of Meghalaya. They reported 298 butterfly species for the Garo Hills, eight of which are legally protected under Schedule I and 33 under Schedule II of the Indian Wildlife (Protection) Act, 1972. Species accumulation curve suggested that many species remain to be discovered in the Garo Hills and they expect the total species richness to be closer to 600–650 species.

Aneesh *et al.,* (2013) recorded a total of 139 species of butterflies belonging to six families from the KAU campus, Thrissur and their observation were quite significant and it emphasizes the importance of University campuses in the conservation of biological diversity of a region. Tewari and Rawat (2013) studied the butterfly Fauna of Jhilmil Jheel Conservation Reserve, Haridwar, Uttarakhand. Based on the study, a checklist has been prepared and the list includes 134 species belonging to 81 genera and 8 families.

Narayanankutty *et al*., (2014) studied the diversity and distribution patterns of butterflies in the Shendurney Wildlife Sanctuary. They reported 265 butterfly species, of which maximum number of species recorded belonged to the family

Nymphalidae. Ghorai and Sengupta (2014) analysed the altitudinal distribution of Papilionidae butterflies across the East Himalayan Landscape of West Bengal. 26 butterfly species are known to occur across 11 altitudinal belts. Species richness (R) and species diversity (H') are said to be highest between 1200-1400 masl (meters above sea level). In contrast, lowest values of species richness and species diversity occur at the highest altitude of 3000 masl and above. Maximum number of individuals occurs between 900 - 1100 masl while the minimum number of individuals was present at the highest altitude of 3000 masl or above. 35 species of plants belonging to 6 families served as the larval food plant of these butterflies. Thus the presence of suitable larval host plants probably governs the altitudinal distribution of these Papilionid species of butterflies.

2.5.2 Seasonality of butterflies

Work done in various countries

Walker (2001) studied the seasonal patterns and long-term changes of butterfly migrations in Florida. Five species flew southward in the fall and northward in the spring: *Phoebis sennae, Agraulis vanillae, Junonia coenia, Urbanus proteus* and *Eurema lisa.* Five species had significant northward flights in spring but no significant migration in fall.

Stasek *et al.,* (2008) studied the butterfly abundance and movements among prairie patches. The study recorded butterfly movements, abundance and edge behaviors in two species of butterflies, the Great-spangled Fritillary and the Pearl Crescent, inhabiting remnant prairies surrounded by a forest matrix in south-central Ohio. The Great-spangled Fritillary exhibited a relatively high number of inter-patch movements and a propensity to cross the prairie-forest edges. The Pearl Crescent, in contrast, rarely crossed edge boundaries, moved infrequently among patches, and was more abundant within the patch interior and in patches with high host-plant and flower densities. Butterfly movement and edge behaviors mechanistically interact with patch quality, isolation, and the matrix permeability to determine the spatial structure of these populations in fragmented habitats.

Badenes-Pérez *et al.,* (2010) studied the diversity, ecology and herbivory of Hairstreak butterflies (Theclinae) associated with the velvet tree, *Miconia calvescens* in Costa Rica. Larvae of three species of hairstreak butterflies in the subfamily Theclinae were found feeding on developing inflorescences, flower buds, and immature fruits of the velvet tree, *Miconia calvescens*. Feeding damage by *E. opisena* was most abundant in pre-flowering season.

Kwon *et al.,* (2010) studied the changes in butterfly abundance in response to global warming and reforestation in the Republic of Korea. The results showed a different response to habitat change between northern and southern species. In northern butterfly species, butterflies inhabiting forests increased, whereas those inhabiting grasslands declined. However, the opposite was true when southern butterfly species were evaluated. Changes in the abundance indicate that habitat change may be one of the key factors related to the survival of populations that remain around the southern boundary of butterfly species.

Grotan *et al.,* (2012) studied the seasonal cycles of species diversity and similarity in a tropical butterfly community in the Amazonian Ecuador. Their 10 years of monthly sampling in the area yielded 20996 individuals of 137 fruit-feeding butterfly species. The study suggested that the seasonal cycles of rainfall drive annual cycles in species diversity and community similarity. Monitoring and analysis of changes in community composition over a range of time-scales can be used to refine models of community dynamics by incorporating environmental factors.

Morehouse *et al.,* (2013) studied seasonal variation in resource availability, uptake and allocation in *Araschnia levana*, a butterfly species that exhibits a striking seasonal colour polyphenism consisting of predominantly orange ‘spring form’ adults and black-and-white ‘summer form’ adults. ‘Spring form’ individuals develop as larvae in the late summer, enter a pupal diapause in the fall and emerge in the spring, whereas ‘summer form’ individuals develop directly during the summer months. The study evidenced for seasonal declines in host plant quality and similar reductions in resource uptake in late summer, 'spring form' larvae. Further, they reported the shifts in the body composition of diapausing 'spring form' pupae consistent with a physiological cost to overwintering. The results indicated that resource dynamics in *A. levana* are shaped by seasonal fluctuations in host plant nutrition, climatic conditions and intraspecific interactions.

Chandra *et al.,* (2014) carried out the field observations on habitat and the seasonal activity patterns of *P. schmeltzi* in Sigatoka, Fiji. Fiji's Swallowtail butterfly, *Papilio schmeltzi*, is a Rutaceae feeding, tropical Papilionid butterfly that is endemic to the Fiji islands and generally occurs in low density. *P. schmeltzi* adults were found throughout the year and showed seasonal variations in abundance. High abundance was recorded for all the *P. schmeltzi* stages during the dry season (May to September). Adults and larvae were the most abundant when compared to eggs and pupae and showed the greatest variation with respect to distribution of life stages throughout the year.

Work done in India

Kunte (1997) studied the seasonal patterns in butterfly abundance and species diversity in four tropical habitats in the northern Western Ghats. In northern Western Ghats (India), four tropical habitats with different disturbance levels were monitored for diversity and seasonal patterns in butterfly communities. Species richness was highest in late monsoon and early winter and the study had proved that many of butterfly species are seasonal and prefer a particular habitat.

Seasonality of Swallowtails of the Siruvani forest was studied by Arun (2008) and out of the 19 species of Swallowtails found in Western Ghats, 13 were represented in the mixed deciduous forest patch of Siruvani.

Tiple and Khurad (2009) reported the butterfly species diversity, habitats and seasonal distribution in and around Nagpur city. Totally 145 species of butterflies were recorded at the eight study sites, of which 62 species were new records for the city. The highest number of butterflies recorded belonged to Nymphalidae (51 species) with 17 new records, followed by Lycaenidae (46 species) with 29 new records, Hesperiidae (22 species) with 14 new records, Pieridae (17 species) with 4 new records and Papilionidae (9 species). This study revealed that Nymphalidae was the most dominating family with a highest number of species in 6 out of 8 sites. Most butterfly species were observed from the monsoon to early winter but thereafter declined in early summer.

Talukdar and Sharma (2010) surveyed the butterfly diversity in selected districts in the western part of Arunachal Pradesh. Five Lepidopteran families were recorded which included Papilionidae (15 spp.), Pieridae (19 spp.), Nymphalidae (56 spp.), Lycaenidae (10 spp.) and Hesperiidae (8 spp.). Among the collected data, 60% of the species were observed as common butterflies, while 34% uncommon and 6% rare species. Lower Subansiri district exhibited the maximum number of species, while the district of Kameng valley showed the least number.

Saikia *et al.,* (2010) studied the seasonality of Nymphalid butterflies in Rani Garbhanga Reserve forest. Altogether 1627 individuals belonging to 109 species were sampled in Rani-Garbhanga Reserve Forest. The most abundant species comprised 22.38% of the total individual count and 19 species were represented by 1-2 individuals.

Gowda *et al.,* (2011) studied the butterfly diversity, seasonality and status in Lakkavalli range of Bhadra Wildlife Sanctuary, Karnataka. A total of 54 species of butterflies belonging to the families *viz.,* Papilionidae, Lycaenidae, Nymphalidae, Danaidae, Satyridae, Pieridae, Hesperiidae were recorded, Out of which 16 species were abundant, 20 species common and 18 species rare. The study of seasonal variation revealed that 44 species present in the monsoon season increased to 49 in winter and dropped to 26 species in summer and 20 species were recorded all-round the year.

Hussain *et al.,* (2011) studied seasonal dynamics of butterfly population in DAE campus, Kalpakkam, Tamil Nadu. The survey yielded 2177 individuals of

56 butterfly species, belonging to the families Nymphalidae, Pieridae, Lycaenidae, Papilionidae and Hesperiidae. Nymphalidae were found to be the dominant family during all seasons. Species richness and abundance were highest during the northeast monsoon and winter periods, indicating that in the southern plains of India, butterflies prefer cool seasons for breeding and emergence.

Nimbalkar *et al.,* (2011) examined the butterfly diversity in relation to nectar food plants from Bhor Tahsil, Maharashtra. A total of 64 butterfly species were recorded. Family Nymphalidae dominates in the study area, followed by Lycaenidae, Pieridae, Hesperiidae and Papilionidae. Nineteen nectar food plants were identified belonging to 10 plant families. Plants of the Asteraceae family are more used by butterflies as nectar food plants. Species abundance reached the peak in the months during August to November. A decline in species abundance was observed from the months December to January and continued up to the end of May.

Choudhury *et al.,* (2012) studied the seasonal patterns in butterfly abundance and species diversity of Trishna Wildlife Sanctuary of North-East India. The study revealed that on a spatial scale of 1 KM, 29 species belonging to 23 genera occurred. Species like Common Emigrant, Common Grass Yellow and Psyche showed higher species ranking and those like Brown Awl and Common Wanderer which showed much lower ranking. Butterflies were less abundant in winter and most abundant in the late monsoon months indicating that the butterflies of north-east India prefer the monsoon period for breeding and emergence.

Tiple (2012) reported the butterfly species diversity, relative abundance and status in Tropical Forest Research Institute, Jabalpur. A total of 66 species of butterflies belonging to 47 genera and five families *viz.,* Papilionidae (5 species), Pieridae (9 species), Nymphalidae (25 species), Lycaenidae (18 species) and Hesperiidae (9 species) were recorded. Among these 65 species, 24 (37%) were commonly occurring, 16 (24%) were very common, 2 (3%) were fairly common, 18

(27%) were rare and 6 (9%) were very rare. They were also reported an increasing trend in species abundance from the beginning of the monsoons till early winter and decline in species abundance from late winter to the end of summer.

Manzoor *et al.,* (2013) discussed about the significance and role of butterflies as bioindicators. He mentioned that butterflies depend on three types of vegetations for their survival and distribution. The three types of plant population categories were larval food plants, nectar plants, and shade plants. The habitats of butterflies were easily defined and delineated because the larval stage is highly dependent upon host plants. As adults, most butterflies are generalists and can find food in the form of nectar, rotting fruit, and sap, however, larvae are usually specialist feeders and some require a specific host plant. Since larvae were closely tied to their host as their food source, the plant's distribution defines the potential distribution of the butterfly. Therefore impact of climate change on these plants can cause serious threat to butterflies.

Sengupta *et al.,* (2014) studied the butterfly diversity in the adjacent areas of the upper Neora Valley National Park, a part of the Himalayan landscape. A total of 4163 butterflies representing 161 species belonging to five families were recorded during the study. One-hundred and forty three species of plants belonging to 44 families served as the larval food plants of butterflies. The maximum number of butterfly species and maximum number of individuals were sampled during the monsoons. The monsoons with least skewed rank abundance curve of species distribution, was also marked by maximum species diversity and maximum species evenness. This was probably due to the abundant distribution of luxurious vegetation that served as food plants for the larval stages of butterflies. Nymphalidae was the most dominant family with 43.48% of the total number of species. Autumn followed by the monsoon was associated with high species richness probably due to the abundance of vegetation that provides foliage to its larval stages.

2.5.3 Behavioural studies

Pinheiro (1990) studied differences in the territorial hilltopping behavior of *Papilio thoas, Battus polydamas* and *Eurytides orthosilaus.* Seven behavioral activities of hilltopping males are described and measured, including inter and intra-specific aggression, territory establishment, and choice of preferred sites for territories. *P. thoas* and *B. polydamas* shared many behavioral characteristics and preferred the same territorial site, near the highest point of the hill. *P. thoas,* the dominant species, won aggressive encounters and established its territories first. Marked behavioral differences were found between *E. orthosilaus* and the other species. Its territories were established several meters above the largest trees in the area and did not overlap with those of *P. thoas* and *B. polydamas.*

Watanabe and Imoto (2003) observed the flying habits of the Japanese Sulfur Butterfly, *Colias erate* in an open habitat. This study evaluated the impact of the thermal environment on the flying behavior of male Japanese Sulfur Butterflies searching for females in an open habitat. Mean thoracic temperature of butterflies immediately after landing was consistently higher, but independent of ambient temperature. Although ground speed of flying butterflies was different between flight types, air speed against the butterfly was similar across flight types. The excess of thoracic over ambient temperature was lower in flying butterflies than in basking ones, as predicted by a model. This difference appeared to be due to air current, which enhanced heat loss.

Takeuchi (2010) studied the mate-locating behavior of the butterfly *Lethe diana.* The mate-locating behavior of male butterflies has been classified into two major types, territorial and patrolling. Territorial males defend a specific site, whereas patrolling males fly around a wider area without having to defend a site. The study investigated the use of these tactics by males of the Satyrine butterfly, *Lethe diana.* From the study, it was found that males often flew around in the morning and competed for territories in the afternoon and closer observations revealed that copulations found in male territories were achieved by the owner of the territory. Males tended to feed in the morning, suggesting that the males flying in the morning searched for food rather than females. The study concluded that territory holding is the primary male mate locating tactic in *L. diana*.

Pohl *et al.,* (2011) examined the flower colour preferences of butterflies. The flower colour of four Asteraceae species was phenotypically manipulated to decouple the influence of that trait from others on visitation by *Lycaena heteronea, Speyeria mormonia, Cercyonis oetus,*and *Phyciodes campestris*. Over three field seasons, 3558 individual flower visits in 1386 foraging bouts were observed for free-flying butterflies. All four butterfly species responded to the phenotypic manipulations of flower colour, although in different ways. *Speyeria mormonia* and *L. heteronea* also exhibited preferences based on other flower traits. *Lycaena heteronea* responded to combinations of traits such that the other traits it preferred depended upon the context of flower colour. None of the butterfly species exhibited flower constancy in any of the arrays employed. The observed preferences show that butterflies, like some other pollinators, are potentially capable of exerting selection on colour and other floral traits. Moreover, these flower preferences can depend on the context of other flower traits.

2.5.4 Butterfly conservation

Protection of locations with a relatively large number of native species is thought to be an efficient way to maintain overall biodiversity. Butterfly gardens are the 'gate-ways' to protect the butterfly population and promoting *in-situ* conservation. Recently, butterfly gardens and butterfly houses have become popular in several Asian, European and American countries. Birdwings (*Ornithoptera* spp.) in Papua New Guinea have been a major focus since seven taxa were declared National Butterflies in 1967. A government-backed Insect Farming and Trading Agency was established to centralize insect trade (Parsons, 1984). The promotion of ranching Birdwings and other butterflies to satisfy collector demand has established a cottage industry involving about 500 people throughout the country. This advance has great implications for conservation management and has stimulated similar operations elsewhere. Papilionidae have received the most attention in the tropics, largely because they are prized by collectors (Collins and Morris, 1985). The largest New World Papilionid, the commercially desirable Jamaican endemic *Papilio homerus*, now occurs in only two small areas of Jamaica (Emmel and Garraway, 1990). Elements of this conservation strategy are intensive study of status and environmental needs and critical features of the butterfly's lifecycle, negotiations to preserve native forests in the susceptible eastern range, analysis for the establishment of a cottage industry based on ranching the butterfly for commercial sale and population enhancement and consideration of cross breeding of the two wild populations to counter genetic deterioration.

Long term studies on population dynamics are the ideal background for understanding the parameters of successful management. Moreover, the adults of many species of butterflies may have particular needs with regard to topography for mating, nectar sources for food, and larval food plants for oviposition. Caterpillars may need certain food plants, sometimes in specific growth stages (Duffey, 1977). These various complementary resource suites determine the suitability of a habitat. Hence, management to conserve a particular species involves determining and sustaining these resources, in conjunction with assuring that microclimatic needs are met.

In the early 1970's, the first true butterfly house was established at the Isle of Guernsey. However, in most tropical areas, the description of the faunas and determination of their status is preliminary at best (Pyle, 1976). As most tropical countries have few resident lepidopterists, opportunities to improve databases in many places subject to massive habitat destruction are few. In these countries, practical conservation management necessitates active local involvement and can benefit from appropriate development for economic gain. The eastern Palaearctic, southern temperate and tropical regions generally lag far behind Europe and North America in development of butterfly conservation management. Priority taxa are being defined in Australia (Hill and Michaelis, 1988), Japan (Hama *et al.,* 1989) and South Africa (Henning and Henning, 1989) and many countries list butterflies under various protective legislation.

Butterfly gardening has been defined as an art of growing plants to attract butterflies (Booth and Allen, 1990). The first butterfly exhibit was opened in the year 1960 in England (Hughes and Bennett, 1991). Butterfly conservation has made considerable progress since the 1990's (New, 1997) and the significance of butterfly gardens in promoting environmental education and biodiversity conservation has been recognized by various authors. Management of domestic gardens and urban and suburban gardens to encourage butterflies has become more frequent and in the UK a national garden butterfly survey was launched in 1990 with the objective of discovering how butterflies may be fostered in gardens and as the start of a survey of year to year changes in butterflies in gardens (Vickery, 1995). Vickery also emphasized the great value of gardens sources of nectar for butterflies, especially in spring and autumn when wild nectar sources may be scarce.

Kunte (2008) published a paper on the Wildlife Protection Act and conservation prioritization of butterflies of the Western Ghats. The most important legal system for protection of endangered animals in India is the Wildlife (Protection) Act, 1972. The analysis presented in the paper offers a rationale, *viz.*, conservation values of species based on multiple species attributes, for including species in the WPA schedules and providing them legal protection. As conservation biologists assess the status of various species and organismal groups, rank species by their conservation values and make the information available in peer-reviewed, publicly available research journals, government bodies can use this information for designing and implementing conservation strategies, including placement of species in appropriate WPA schedules according to their conservation values. This is crucial since conservation concerns are not unchanging even for apparently unthreatened species, as the alarming decline in vulture populations recently demonstrated. Thus, periodic assessments of the WPA listings, particularly of those taxa on which new information is continuously being generated, will better equip us in dealing with the changing conservation scene. This is more likely to succeed in protecting India's biodiversity wealth in the long term.

In India, our knowledge of butterfly gardening and their importance in promoting the *in-situ* conservation of butterflies through has been greatly enhanced through the studies carried out at KFRI during 1993-1996 (Mathew, 1998 and 2001). Mathew and Anto (2007) studied the *in situ* propagation of butterflies through establishment of a butterfly garden in Kerala and continuous monitoring and field observations showed a steady increase in sightings with 69 species of butterflies being recorded in the butterfly garden at KFRI campus, Peechi. Participation of the public is essential for the success of any conservation program, so we have to generate interest among the public for conserving biodiversity. Students form the most important target group in conservation programmes and the formation of Bio-parks in schools through students' participation is a very effective method to achieve biodiversity conservation (Mathew and Yesodharan, 2010).

Mohandas and Remadevi (2012) studied the role of butterfly gardens as tools for development of ecotourism infrastructure in protected areas of central Western Ghats in Karnataka and to examine the suitability of various butterflies for captive breeding in *ex situ* conservation and for butterfly exhibitory programmes. They studied the biology of 14 species of butterflies and methods for captive breeding were standardized. Based on the data generated in this study, 39 species of butterflies were selected as candidate species suitable for butterfly parks and gardens. Prominent among them are: *Pachliopta aristolochiae, Papilio demoleus, P. hector, P. polytes, Troides minos* (Papilionidae); *Anapheis aurota* (Pieridae); *Talicada nyseus (L*ycaenidae); *Danaus chrysippus, Danaus genutia, Tirumala limniace, Cynthia cardui* (Nymphalidae); *Gangara thyrsis* (Hesperiidae).

MATERIALS AND METHODS

Revathy V. S "Systematics of swallowtail butterflies (Lepidoptera: Papilionidae) of Kerala, India " Thesis. Kerala Forest Research Institute, University of Calicut, 2014

MATERIALS AND METHODS

Chapter 3: Materials and Methods

3.1 Study area and source of materials

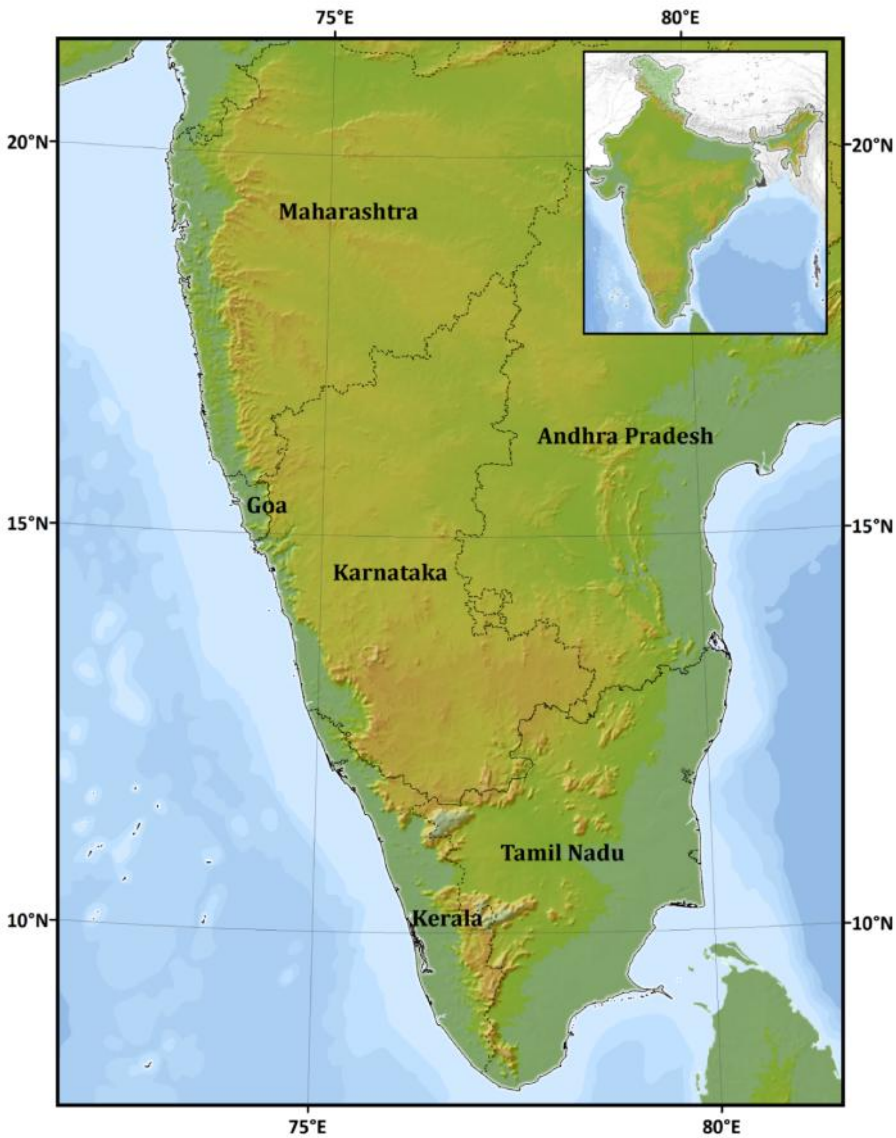
India, with its rich biological diversity and immense range of ecosystems, is considered to be one of the 12 mega diverse countries in the world, commanding 7-8% of the world's biodiversity and supporting 16% of the major forest types, varying from alpine pastures in the Himalayas to temperate, sub-tropical and tropical forests as well as mangroves in the coastal areas. With only 2.4% of land area, India accounts for 7-8% of the recorded species of the world. After surveying almost 70% of the country’s land area, about 45,000 species of plants and 89,000 species of animals have been described. It has been estimated that another 4, 00,000 species may still exist in India which so far remain as undescribed (Gokhale, 2010). Out of the 34 biodiversity hot spots identified, India has two hotspots- the Himalayas and the Western Ghats.

Kerala, situated between North latitudes 8° 17' 30" N and 12° 47' 40" N and East longitudes 74° 27'47" E and 77° 37' 12" E, is well-known for its lush greenery, dense forests, diversified ecological habitats, topography and the unabated biodiversity. It is bounded by thickly wooded and forested hills of the Western Ghats in the east and Arabian sea in the west. Kerala occupying 38,863 km^2 and comprising approximately 1.18% of India’s landmass, the joint gift of sea and mountains, is blessed with heavy rainfall, altitudinal diversity and fertile soils. Out of the total length of the Western Ghats, Kerala covers around 600 km. Nearly 56% of total geographical area of the state receives an annual average rainfall of 2800mm mainly due to its windward location of the Ghats (Padmakumar, 2007). Due to the integration/combination of different climatic conditions like warmer climate, altitudinal variations, two different rainfall patterns and seasons (South west monsoon and North East monsoon), several soil types and agro-ecological zones results in a variety of macro environments varying from tropical rain forests to hot dry deciduous forests through a number of unique ecological habitats. These diversified habitats and local ecological niches decked with dense canopies and plantations and the physiographic endowments had contributed to a variety of macro and micro environments conducive for a variety of flora and fauna requiring contrasting environments. Therefore, there is no surprise that this land that occupies 1.1% of the total geographic area of the country and sustains over 24 percent of the plant species, 30% of animal species and 35% of freshwater fish species reported from India (Padmakumar, 2007), is rightly known as 'The God's own country'.

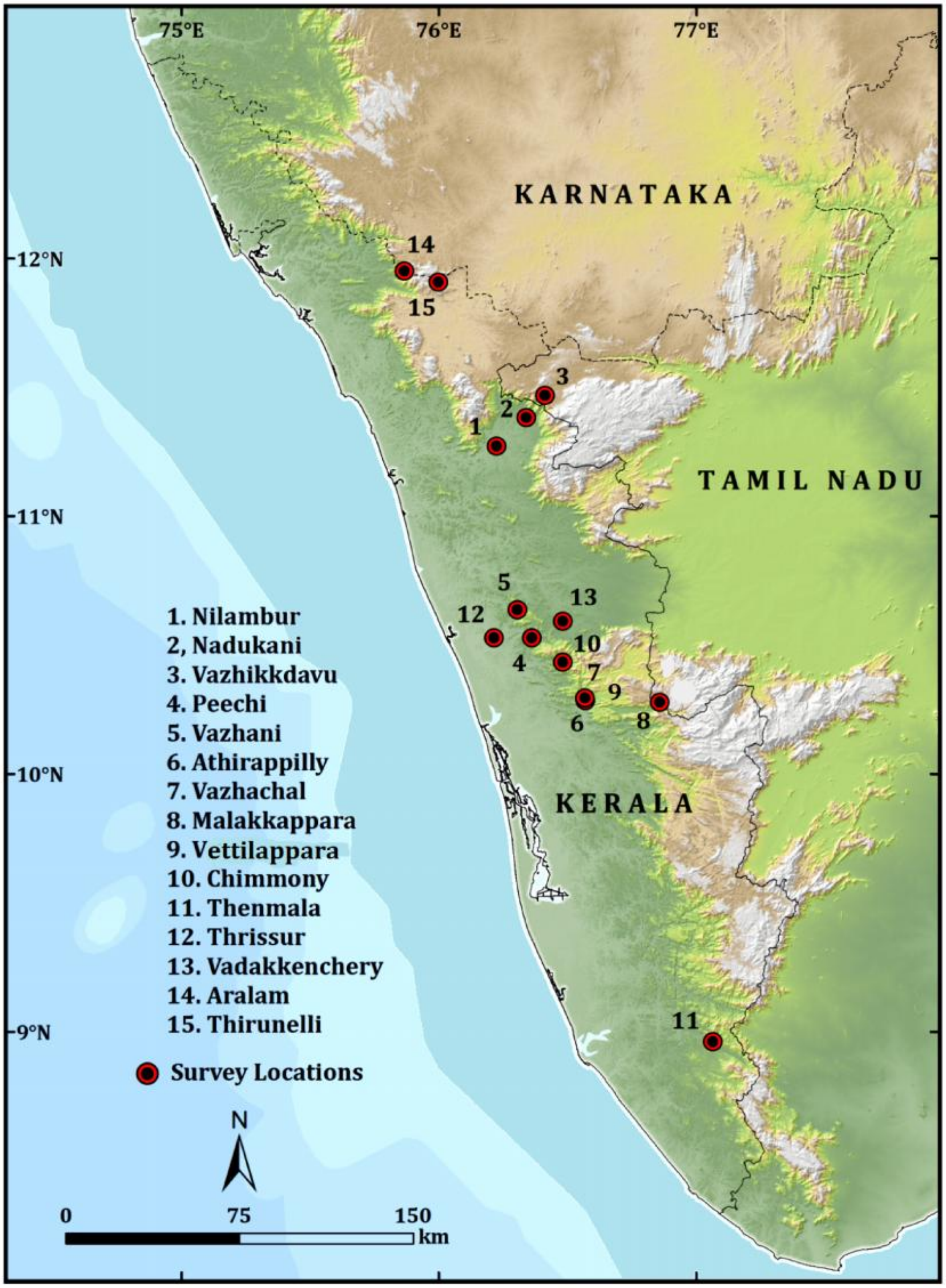
The Western Ghats, also known as "Sahyadri", constitutes a mountain range along the western side of India. It is acclaimed as World Heritage Site by UNESCO and is one of the world's eight "hottest hotspots" of biological diversity. The Western Ghats is a classic example of great escarpment of the world (Kale, 2010). It is an area of spectacular scenery, rugged terrain, deep valleys, impressive waterfalls and dense forest teeming with wildlife. The range originates from the south of Tapti river, near the border of Gujarat and Maharashtra, and runs approximately 1,600 km (990 miles) through the states of Maharashtra, Goa, Karnataka, Tamil Nadu, and Kerala ending at Kanyakumari, at the southernmost tip of Peninsular India. The Southern Western Ghats extending from the Agasthamalai to Palghat Gap has highest butterfly diversity with maximum endemics. Thirty six species of butterflies are reported to be endemic to the Ghats and among the butterfly genera, the genus *Parantirrhoea* is exclusively endemic to this region (Radhakrishnan and Rajmohana, 2012).

Sampling of butterflies was done by conducting field surveys in the representative habitats of northern, central and southern Kerala part of Western Ghats. The areas covered included Nilambur (11°17′58″N 76°15′03″E), Nadugani reserve forest (11° 24.547′ N 76° 23.206′ E), Vazhikkdavu (11° 23.343′ N 76° 20.775′ E), Aralam (11° 57.008′ N 75° 51.901′ E), Thirunelli (11° 54.519′ N 75° 59.830′ E), Thrissur (10° 31.702′ N 76° 12.864′ E), Palakkad

(10º 47.277′ N 76º 39.279′ E), Peechi (10º 28.928′ N 76º 25.957′ E), Vazhani (10º 38.207′ N 76º 18.334′ E), Athirappilly (10º 17.450′ N 76º 30.935′ E), Vettilappara (10º 17.543′ N 76º 30.889′ E), Vazhachal (10º 18.166′ N 76º 35.531′ E), Malakkappara (10º 16.684′ N 76º 51.504′ E), Chinmoni (10º 25.863′ N 76º 29.461′ E) and Thenmala (8º 57.829′ N 77º 3.854′ E). At each of these locations, sampling sites were selected based on previous faunal records.



Map 1. Study area - Kerala



Map 2. Kerala, showing the locations covered in the survey

3.2 Taxonomic studies

3.2.1 Collection and preservation of material

Most of the Papilionids are fairly big in size and they fly swiftly and brilliantly through dense canopies. So, the time when the butterflies rests on vegetation or bask in the sun is the best time to sweep the net and to catch them. For collecting, the net can be either brought down upon it or swept in from side. Once the butterfly is caught in the net, it shows a tendency to fly upwards, and therefore, the rim should be rapidly turned around to seal the net. The most important thing to be kept in mind for collecting the butterfly is prudence while approaching the resting butterfly and the speed at which the net is swept. Generally, six males and 6 females were used for genitalia studies. However, when enough samples could not be collected especially in the case of some rare and endemic butterflies, material available in the samples was utilized. In such cases, the abdomen of the specimen was clipped off and used for dissection. Immediately after collection, the butterflies were transferred to a killing bottle containing a killing agent like benzene or they may be immobilized through freezing. As a rule, subsequent to killing, the specimens need to be kept with proper pinning and labeling. For that, they have to be spread before the muscles become rigid. The spreading was done with help of a spreading board. Spreading board is a long, flat board with central groove and the width of the central groove is adjustable. The specimen was thoroughly relaxed and pinned using an entomological pin of appropriate thickness. An insect pin, long and rust-proof pin, was inserted through the middle of mesothorax. It was then adjusted to the desired height on the pin and was then carefully pinned into the groove of the spreading board, pushing the pin right through so that the body of the specimen is correctly settled into the groove. In butterflies, where the wings are of paramount importance, the legs are tucked into the side of the body, in the groove and the specimen made to rest with the wings on the board so that they can be set flat. It is important that the bases of the wings should be just level with the side boards. Paper strips can be used to keep the wings in position. After one or two weeks, the paper strips were removed and the specimen along with the central insect pin was shifted to an insect storage box. The insect storage boxes were properly fumigated with naphthalene powder. Then these specimens were properly labelled and identified to the species level by comparing with available data. All specimens are deposited in Kerala Forest Research Institute, Peechi.

3.2.2 Processing and preparation of slide mounts

For preparing the slide mounts of body parts, the method proposed by Robinson (1976) for the microlepidoptera has been adopted. To begin with, the abdomen of each specimen was removed using micro-needles and then placed in a test tube containing 10% KOH solution. The test tube was placed in a beaker containing boiling water for ten to fifteen minutes. After appropriate maceration in KOH, the abdomen was washed two to three times in distilled water for removal of any trace of KOH. The abdomen was gently squeezed using a blunt needle to squeeze out dissolved tissue. The external genitalia were then gently removed from the abdomen by tearing the inter-segmental membranes from and around the organ using fine forceps and micro needles.

For examining the structural details of aedeagus, it was pulled out from the male genitalial armature. After clearing, the dissected material was stained with acid fuschin in acetic acid and cleared using carbol-xylol (carbolic acid and xylene in 2:3 ratio) and directly mounted in canada balsam. Regarding the preparation of slide mounts of female genitalia, after gently brushing the abdomen, a cut was given between the 7th and 8th inter-segmental membranes, anterior to the ostium bursa. Due care was taken to avoid any damage to the soft structures inside, especially the ductus seminalis and apophyses. The superfluous matter in terms of muscles, fat and fungal hyphae was removed by using a pair fine forceps. The rest of the procedure followed was similar to that adopted for the male genitalia.

3.2.3 Illustrations

All illustrations male and female genitalia were drawn by using a camera lucida fitted in a zoom stereo-binocular microscope.

3.2.4 Cladistic analysis

The method that groups of organisms sharing derived characters is called Cladistics or Phylogenetic Systematics. Taxa that share many derived characters are grouped more closely together than those that do not. The relationships are shown in a branching hierarchical tree called Cladogram. Seventeen species of Swallowtail butterflies collected from Kerala were used as samples for cladistic analysis. Morphological features of external genitalia, the features of immature forms and adults were selected as characters for the phenetic and phylogenetic analysis (Appendix I; Appendix II). For the character selection, guidelines given by Hennig (1966) were adopted and the family Pieridae was selected as outgroup taxa (Ehrlich and Ehrlich, 1967; Scott, 1985). A total of forty two characters were selected and the characters which showed significant variations between the species were selected.

3.2.4.1 Phenetic analysis

Principal Coordinates Analysis (PCoA) and cluster analysis were conducted using NTSYS pc (Rohlf, 2000). Principal coordinates analysis (PCoA) is a method to explore and to visualize similarities or dissimilarities of data. It starts with a similarity matrix or dissimilarity matrix (= distance matrix) and assigns for each item a location in a low-dimensional space. Cluster analysis was used to assess the grouping found in principal co-ordinates analysis. Cluster analysis is a statistical method of partitioning a sample into homogeneous classes to produce an operational classification. For this, the standardised data were used to compute a distance matrix based on average taxonomic distance and this was subjected to unweighted pair group method with arithmetic mean (UPGMA). Unweighted pair group method yielded the co-phenetic correlation, which was computed by means of the Mantel T- test (Rohlf, 2000).

3.2.4.2 Phylogenetic analysis

Phylogenetic analysis was carried out using the 42 morphological characters used for the phenetic analysis. The characters were scored as binary; *ie.,* '0' for absence and '1' for presence: in some cases multi-states were also used. The polarity of the characters were assessed according to Tyler *et al.,* (1994); Parsons (1996); Sibatani *et al.,* (1994); Freitas and Brown, (2004). The data matrix was constructed and edited with Winclada (Nixon, 1999) and the parsimony analysis was conducted in NONA version (Goloboff, 1999). The multi* max* search strategy was used with the following settings: hold= 1000, multi X N=100 and hold/ =10. Tree support was calculated with the boot-strap (NONA: 1000 replications, option "multi* 100; hold/100").

3.3 Biological studies

The Swallowtails are perhaps the largest and the most magnificent of Indian butterflies. They range widely in their choice of habitats. Butterflies found in different habitats tend to show marked differences in their general appearance and biology as evidenced by the "ecological races" reported in several species of butterflies. Thorough understanding of the life history and their behavioural patterns of immature stages is essential for recognizing the geographical and ecological races, cryptic species etc. In the present study, the biology of various species was studied in the laboratory. Samples for the biological studies were collected from representative habitats. The areas covered included Nilambur, Nadukani Ghat, Vazhikkdavu, Aralam, Thirunelli, Thrissur, Palakkad, Peechi, Vazhani, Athirappilly, Vazhachal, Malakkappara, Chinmoni and Thenmala.

3.3.1 Methodology

Biology of butterflies was studied by rearing field collected eggs. For each species, 5-10 eggs were collected based on availability. Rearing was carried out in the laboratory at room temperature (28-32^{o}C) and humidity ranging (80-90%). Eggs collected from the field were placed in small sterilized glass jars, 2 cm diameter and 10 cm height, covered with a clean, dry cloth and securely fastened with a rubber band. Containers were kept moist by keeping a small piece of absorbent tissue holding as much water as will evaporate in 24 hours. On hatching, the larvae were transferred to sterilized glass containers of 6 cm diameter and 15 cm height. The mouth of the container was closed with sterilized clean dry cloth fastened with rubber band. The larvae were provided with fresh leaves of the preferred host plant and all frass and excreta accumulated in the container were removed daily. Towards the final instar, the larvae were transferred to larger containers of 12 cm diameter and 25 cm height. The container was provided with a dry twig so as to serve as a substratum for pupation. Duration of the larval instars was recorded based on the moulted shell of the head capsule of the caterpillar that remains in the container after moulting. Larval measurements were recorded within twenty four hours after moulting. For this, the length of the larva from the anterior to the posterior and as well as its width across the mesothorax were recorded. Data generated on the dimensions of larval instars of each species were subjected to one-way analysis of variance, followed by Duncan's multiple range test (Gomez and Gomez, 1984). Based on the number of host plants consumed, butterflies were categorized into different groups such as monophagous specialist (feeding on a particular plant species that belong to one plant genus), oligophagous generalist (feeding on several plant species within the same family) and polyphagous generalist (feeding on a number of plant species from different families). Descriptions of the larva, pupa and the adult were made after close examination under a stereoscopic binocular microscope.

3.4 Ecology

Ecology of Papilionid butterflies was studied by making regular observations in the field. It is well known that various environmental, climatic, topographical and vegetational parameters play an important role in the distribution as well as habitat associations of different butterflies. In this study, specific observations were made at three locations representing northern, central and southern parts of Kerala. At each of these locations, observations were confined to an area of 0.5 ha. Brief accounts of the study areas are given below.

3.4.1 Northern region

An area of 0.5 ha of degraded moist deciduous forest patch in the Kerala Forest Research Institute (KFRI) sub-centre campus at Nilambur (11° 17.958′ N 76° 15.054′ E) was selected. This study plot included both landscaped areas containing streams, waterfalls, rock gardens, bushes, lianas, hedges and creepers as well as natural forest patch which offer appropriate conditions for a variety of Papilionid butterflies. The area also contained various nectar plants such as *Ixora* spp., *Cassia* spp., *Allamanda cathartica, Hibiscus rosa-sinensis, Cuphea* spp., *Zinnia* spp., Marigold, *Clerodendrum capitatum* as well as larval host plants such as *Wattakaka volubilis, Thottea siliquosa, Tylophora* spp., *Calotropis gigantea, Carissa carandas, Ruta graveolens, Aegle marmelos, Albizia lebbeck, Cassia* spp., *Citrus* spp., *Murraya koenigii, Mussaenda* spp., *Ixora spp., Kalanchoe blossfeldiana* and *K. pinnata.*

3.4.2 Central region

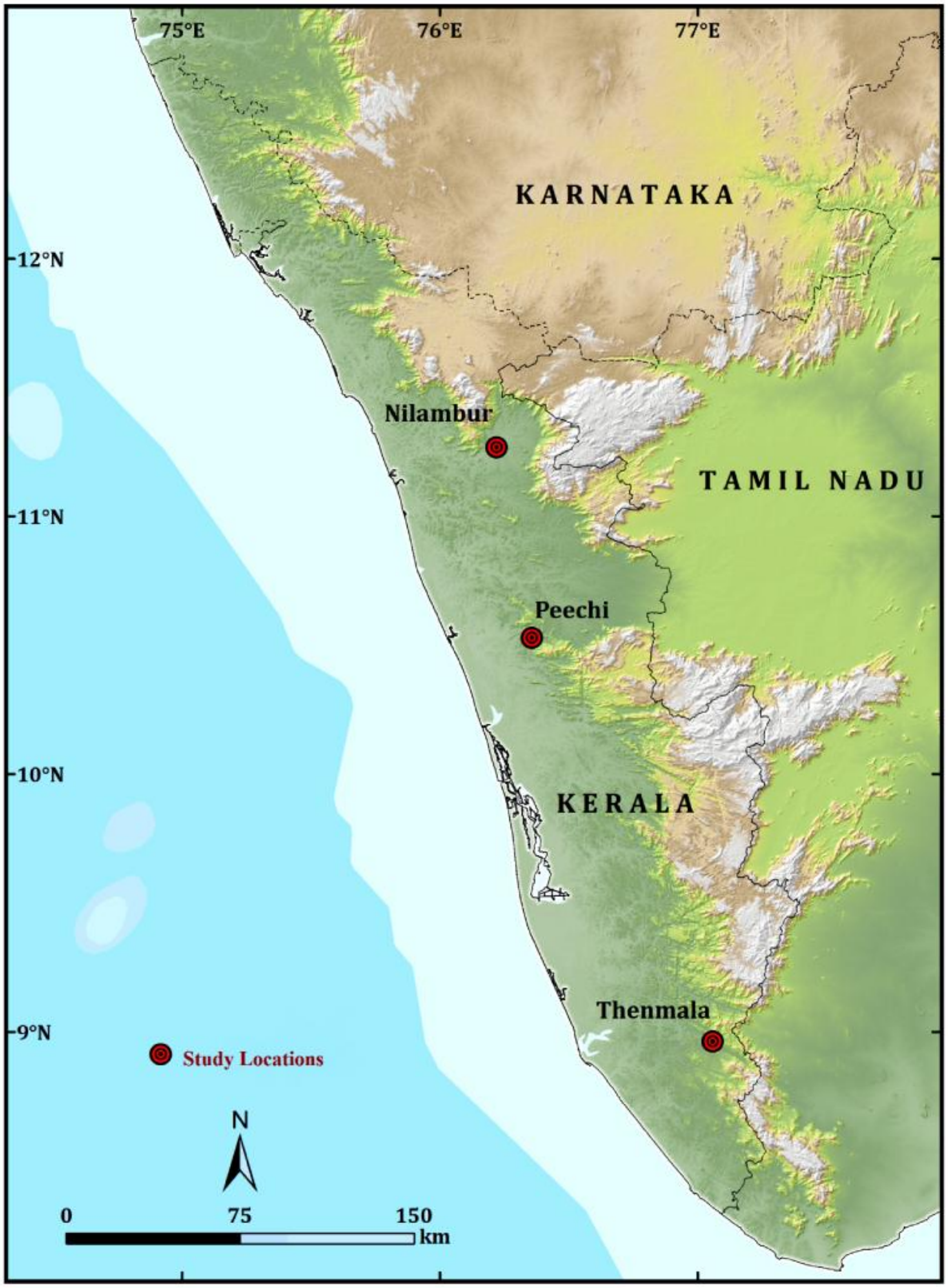
An area of 0.5 ha of moist deciduous forest patch within the Kerala Forest Research Institute (KFRI) campus at Peechi (10° 31.601′ N 76° 21.057′ E) was selected for ecological monitoring. This area which was hilly in nature with steep slopes and with more or less plain ridges was close to the Peechi-Vazhani Wildlife Sanctuary. The area contained tall trees such as *Zanthoxylum* *rhetsa, Tectona grandis, Bombax* spp., *Ailanthus triphysa, Grewia* spp. and *Terminalia* spp. The area also contained various nectar plants such as *Ixora* spp., *Cassia* spp., *Allamanda cathartica, Hibiscus rosa-sinensis, Cuphea* spp., *Clerodendrum capitatum,* as well as larval host plants such as *Wattakaka volubilis, Thottea siliquosa, Tylophora indica, Asclepias* sp., *Calotropis gigantea, Carissa carandas, Ruta graveolens* and *Aegle marmelos, Albizia lebbeck, Cassia* spp., *Citrus* spp., *Murraya koenigii, Mussaenda luteola, M. laxa, Ixora* spp., *Kalanchoe blossfeldiana* and *K. pinnata.*

3.4.3 Southern region

Approximately 0.5 ha of moist deciduous forest patch at Thenmala, located at (8° 57.829′ N 77° 3.854′ E), under the Shendurney Wildlife Sanctuary was selected. The area was pervaded by the Shendurney River with the banks supporting dense forests on either side. The area also contained landscaping gardens. A number of adult and larval host plants were present in the area. Some of larval host plants present in the study area included *Citrus* spp., *Albizia* spp., *Cassia* spp., *Cinnamomum* spp., *Aristolochiae indica*, Milk weeds, *Tylophora* spp., *Wattakaka volubilis* and *Mussaenda* spp. and nectar plants *Ixora,* Marigold, *Cuphea* spp., *Zinnia* spp. and *Clerodendrum paniculatum.*

3.4.4 Methodology

At each location, data pertaining to butterfly population, seasonal patterns and habitat associations was generated by making regular observations in the field along a transect. The transect was laid out as per the method suggested by Ishii (1993) and Pollard (1977). Transects of 175 m long and 1.2 m wide traversing differing habitats such as landscaped area, natural vegetation, and forest areas was monitored regularly at 15 days interval during the two year period. Observations were made for a period of 28 months from September 2010 to December 2012.



Map 3. Kerala, showing the locations selected for ecological studies

For generating ecological data, butterflies encountered at an approximate distance of five meters on either side of transect were recorded. A thirty minute visual survey was done during each transect walk and the walking pace was slow but constant. The sampling period covered the flying periods of most species. The identity of butterflies, date of observation, the number of species and individuals encountered were recorded. All observations were made during the forenoon hours between 10:00 and 11:30 hrs during which the butterfly has maximum activity. All the transect walks were taken on days with favourable weather conditions. Although sampling was done on separate days for the study sites of three different locations, the sampling duration for each of the 3 transects were the same. Whenever visual identification on the wing was not possible, specimens were collected for subsequent identification. Initially, the unfamiliar species were collected for identification and released later. Identification of butterflies was done using available literature (D' Abrera, 1982, 1985, 1986; Larsen, 1987a, 1987b, 1987c, 1988; Wynter Blyth, 1957; Kehimkar, 2008 and Singh, 2011) or by reference to the insect collection at KFRI. While monitoring the population diversity and seasonality, behavioral aspects patrolling, foraging, oviposition, courtship and mating were also recorded.

Weather data from weather stations in the study areas was collected for correlating the seasonal abundances of butterflies to the weather parameters particularly temperature, rainfall and humidity. In the case of the central zone (Peechi), weather data was taken from the Automatic Weather Station maintained by Kerala Forest Research Institute, Peechi; for Thenmala, data from the Automatic Weather Station in Thenmala maintained by the Ground Water Department, Kollam and for Nilambur, weather data from the Kerala Forest Research Institute sub centre, Nilambur were used.

3.4.5 Data analysis

3.4.5.1 Abundance of Swallowtails

Data generated from the 3 fixed transects of the three study sites were pooled species-wise and year-wise. The total abundance of Swallowtail butterflies observed in different seasons in each study site over the study period were computed and graphically plotted. The differences in the mean abundances of butterflies sampled between seasons in 3 different locations were compared using One-way ANOVA (SPSS for MS windows statistical package version 16).

3.4.5.2 Seasonal index of Swallowtails

The seasonal index for each species in the three different regions was computed separately in the following manner. The number of butterflies sighted during each month was recorded separately for each location. The total number of butterflies sighted during the period of study was calculated. For comparing the butterfly population trends, the seasonal index for each month was calculated using the following formula:

Seasonal Index = Month-wise mean/ Overall mean x 100

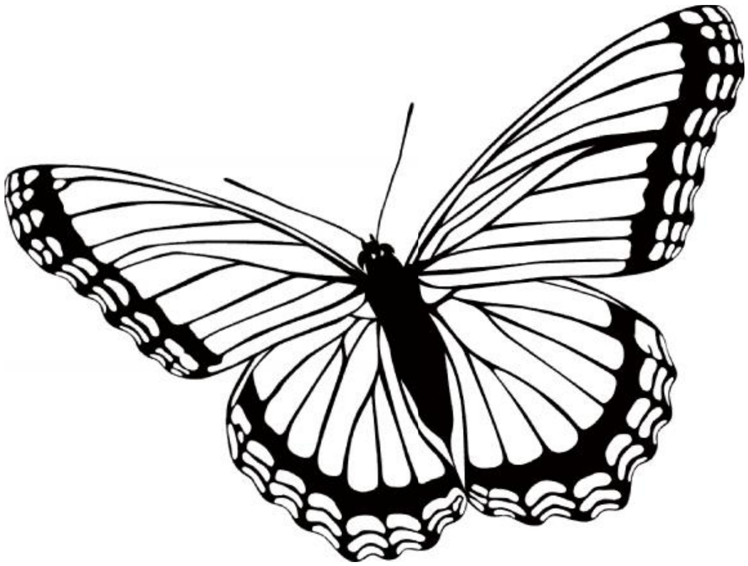
Where, the month-wise mean is the number of butterflies for a given species sighted during the study period and the overall mean is the mean of all month-wise means. The mean percentage occurrence of butterflies in a given month in relation to the overall mean monthly sightings was calculated based on the seasonal index.

3.4.3.3 Correlation between sightings of Swallowtails and weather parameters

The total number of butterflies sighted per month belonging to each species was recorded. The mean monthly temperature, humidity and rainfall for a period of twenty eight months from September 2010 to December 2012 were calculated from daily weather recordings. The correlation co-efficient between number of sightings per month and each of the above weather parameters were computed for each species by using SPSS (SPSS for MS windows statistical package).

EXTERNAL MORPHOLOGY AND HIGHER CLASSIFICATION OF PAPILIONIDAE

Revathy V. S "Systematics of swallowtail butterflies (Lepidoptera: Papilionidae) of Kerala, India " Thesis. Kerala Forest Research Institute, University of Calicut, 2014



A

EXTERNAL MORPHOLOGY AND HIGHER CLASSIFICATION OF PAPILIONIDAE

Chapter 4: External morphology and higher classification of Papilionidae

In Lepidoptera, segregation of various taxa is based on the morphological features of head, thorax, wing venation, abdomen, male and female external genitalia. A general account of the morphological features of various body parts is presented here.

4.1 General morphology

The body of a butterfly is divided into three segments *viz.,* the head, thorax and abdomen (Plate 1). The structural details of various body parts are given below.

4.1.1 Head

Head is small, hairy or scaled. On the head are the antennae, the eyes and the proboscis. Antennae are primarily the olfactory organs which are very useful in detecting the opposite sex for mating. These are segmented, movable appendages placed in sockets situated more or less between or in front of the eyes. Other than the olfactory use, antennae are also useful in navigation while in flight. The eyes of butterflies are complex structures composed of thousands of hexagonal units termed 'ommatidia' which are directed to all sides. As a result, butterflies can virtually see in all directions. It has been stated that there are over 6000 ommatidia in a single compound eye. The image formed by the ommatidia provides only a blurred, mosaic vision which is sensitive to movements and colour. The colour spectrum perceived by butterflies is also quite different from that of the human beings. While man can perceive colours ranging from red to indigo, butterflies can see further into the violet and ultra-violet range of the light spectrum. Plants can absorb as well as reflect the ultra violet rays. In some flowers, the petals reflect ultra violet rays which attract and guide butterflies to the nectaries.

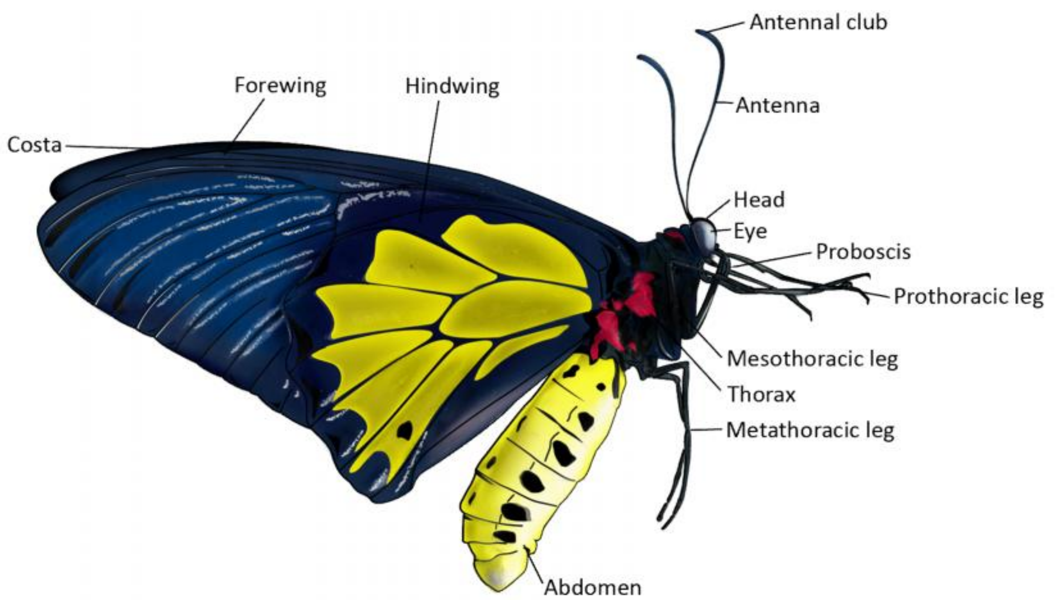


Plate I. Figure 1. Generalized structure of the Swallowtail butterfly

The main dorsal part of the head is called the *epicranium,* the posterior portion of which is called the *occiput*, the upper portion the *vertex* and the anterior portion above the clypeus, the *frons*. The *clypeus* which is a fixed sclerite above the labrum or upper lip, is well developed in Lepidoptera. The latter is very minute and concealed by the clypeus. The *labium* or the lower lip has well developed *labial palpi* consisting of three joints, their shape being of great use in generic distinction. Lepidopterans feed by sucking nectar/plant juice with the help of a long sucking tube, called *haustellum* (proboscis), which in fact is a modification of *galea* of the maxilla. While not feeding, the proboscis is held rolled up beneath the head. The length of the haustellum is related to the length of the corolla tube. Usually, nectar feeding butterflies have longer haustellum compared to the saprophytic forms in which the haustellum is short.

4.1.2 Thorax

The thorax is composed of three segments, *viz., prothorax*, *mesothorax* and *metathorax.* Each of these bears a pair of segmented legs. Each leg consists of five segments; the coxa, trochanter, femur, tibia and the 5-jointed tarsus bearing claws. The tarsus consists of specialized sensory cells which help in the detection of the chemical nature of the substratum. The claws are helpful to hold on to the substratum. The legs furnish characters of considerable taxonomic importance. The thorax also bears two pairs of wings dorso-laterally on the meso and meta thoracic segments. The wings are covered with scales, some of which are modified in the males into sex brands (androconia) which emit a characteristic odour to arouse sexual attraction in female for courtship. The wings are flattened, membraneous expansions, strengthened by a system of thickened hollow ribs called veins or nervures, which are of great help in the taxonomy of this group of insects. The forewing is attached to the mesothorax and hindwing is attached to the metathorax.

4.1.2.1 Wings

The Lepidopteran wings being generally covered densely with pigmented scales which provide the colour patterns characteristic of the species. These scales are minute specialized hairs, and each is inserted in a very minute socket. They are varied in form and arranged in regular rows. The colour being usually due to the interference of light at the surfaces of extremely delicate laminae. The shape of the wing is very variable. The upper or anterior margin is Costa (outermost margin) which runs along the coastal margin from base to the top; the posterior edge or inner margin is dorsum; distal extremity of costa is apex and similar extremity of inner margin is Tornus; the margin posterior to the apex is called termen and its limits are clear in a rectangular wing (Plate 2). Wings consist of a large cell called basal or discal cell, usually closed with a number of veins radiating from it.

Typical Papilionid forewing consists of 12 veins with a large cell called discal cell, usually closed with a number veins radiating from it. Among the 12 veins, the first and last are arising from the base and others from the discal cell. On the forewing, vein 12 is known is subcosta (Sc); veins 11-7 are the radial veins which have five branches (R1-R5); Veins 6-4 are the median veins which have three branches M1-M3; veins 3-2 are the cubital veins, Cu1a and Cu1b and the last vein is the anal vein, which has two branches *viz.,* 1A and 2A (Plate 3). The second anal vein is short and third anal vein is totally absent. In most Papilionidae, there is a short transverse vein near to the base between the cell and vein 1, termed median spur.

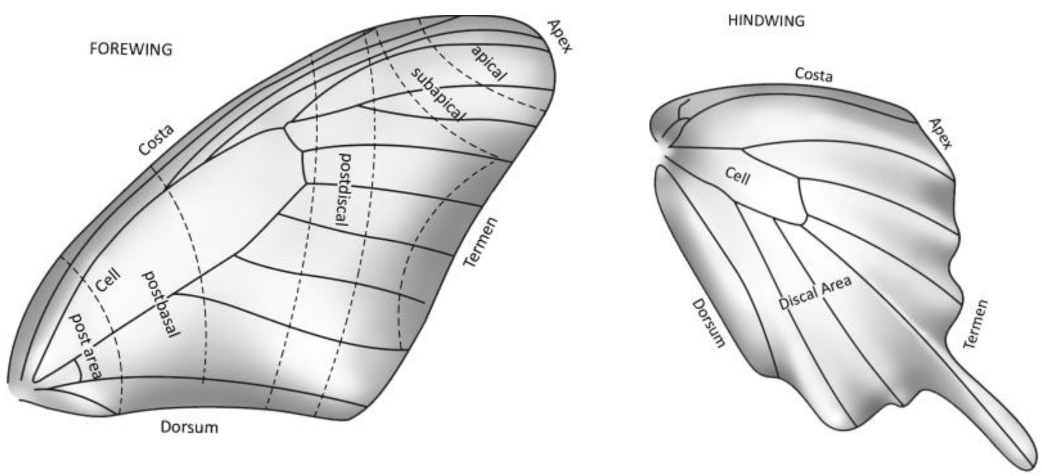


Plate II. Figures 1 -2. Butterfly wings showing venation and structure. Figure 1. Forewing; Figure 2. Hindwing.

In the hind wing, the first radial vein is fused with subcosta (Sc and R1 are fused), thus vein 8 is Sc+R1; The radius is not divided further and the remaining one is termed radial sector (7th vein, Rs). Veins 6-4 are the median veins, they have three branches (M1-M3). Veins 3-2 are the cubital veins- Cu1a and Cu1b. Only one anal vein is present *viz.,* 1A. There is a small spur near the base of 8th vein, projecting towards the costa, is called humeral vein. In most of the species, the hind wing is provided with conspicuous tail-like prolongations which are marginal extensions from the 4th vein (M3). These tail like projections are absent in *Troides minos, Chilasa clytia, Papilio polymnestor, P. demoleus, P. dravidarum, Graphium sarpedon* and *G. doson* (Plate 4-7).

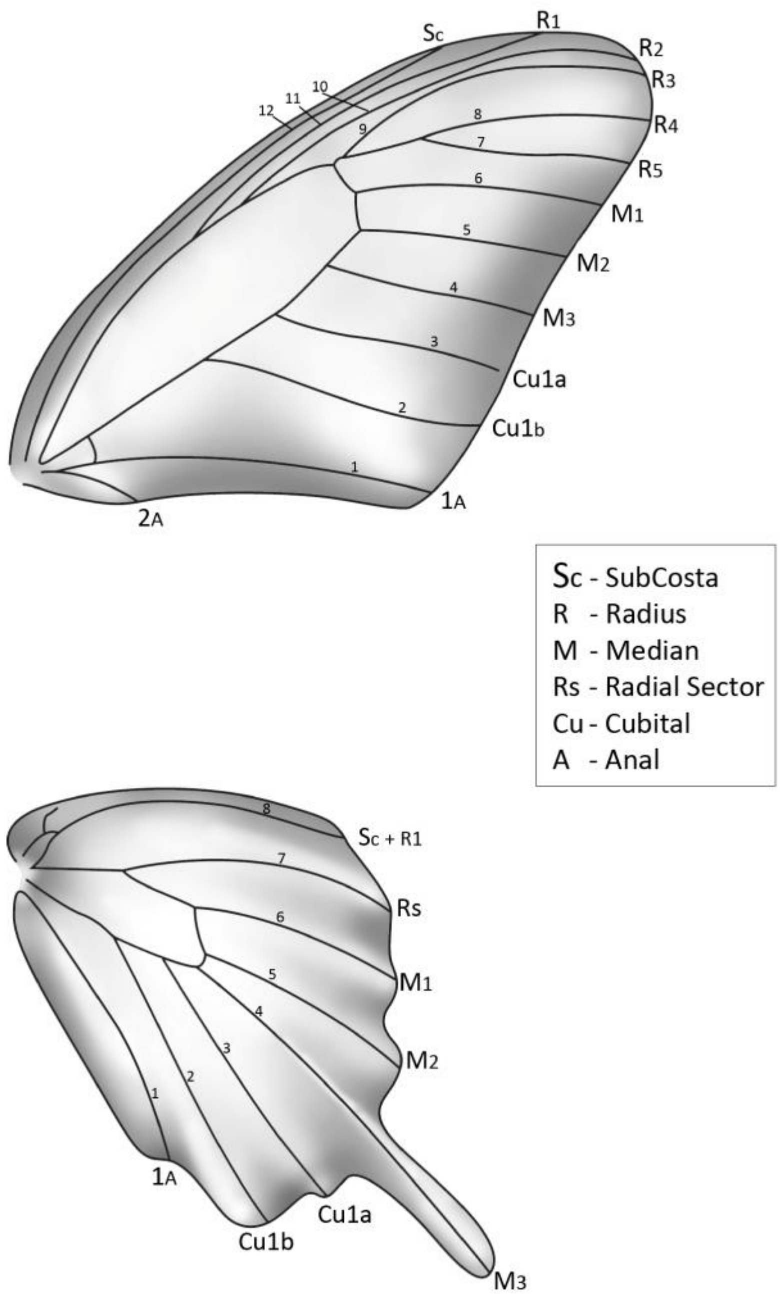


Plate III. Figures 1-2. Typical venation of wings in Papilionidae
Figure 1. Forewing; Figure 2. Hindwing.

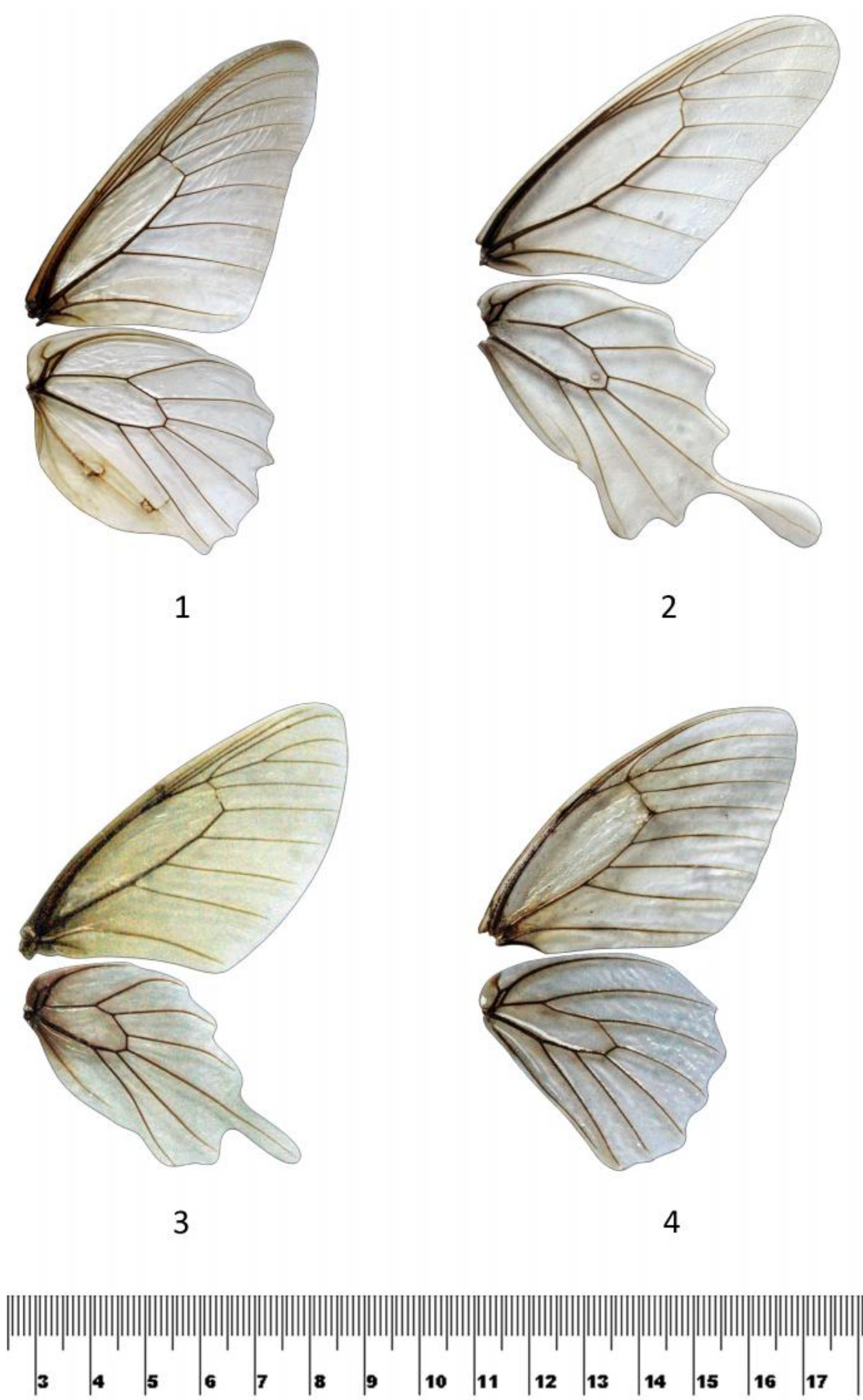


Plate IV. Figures 1-4. Wing venation in Papilionidae. Figure 1. *Troides minos;* Figure 2. *Atrophaneura pandiyana;* Figure 3. *A. aristolochiae;* Figure 4. *Chilasa clytia clytia*

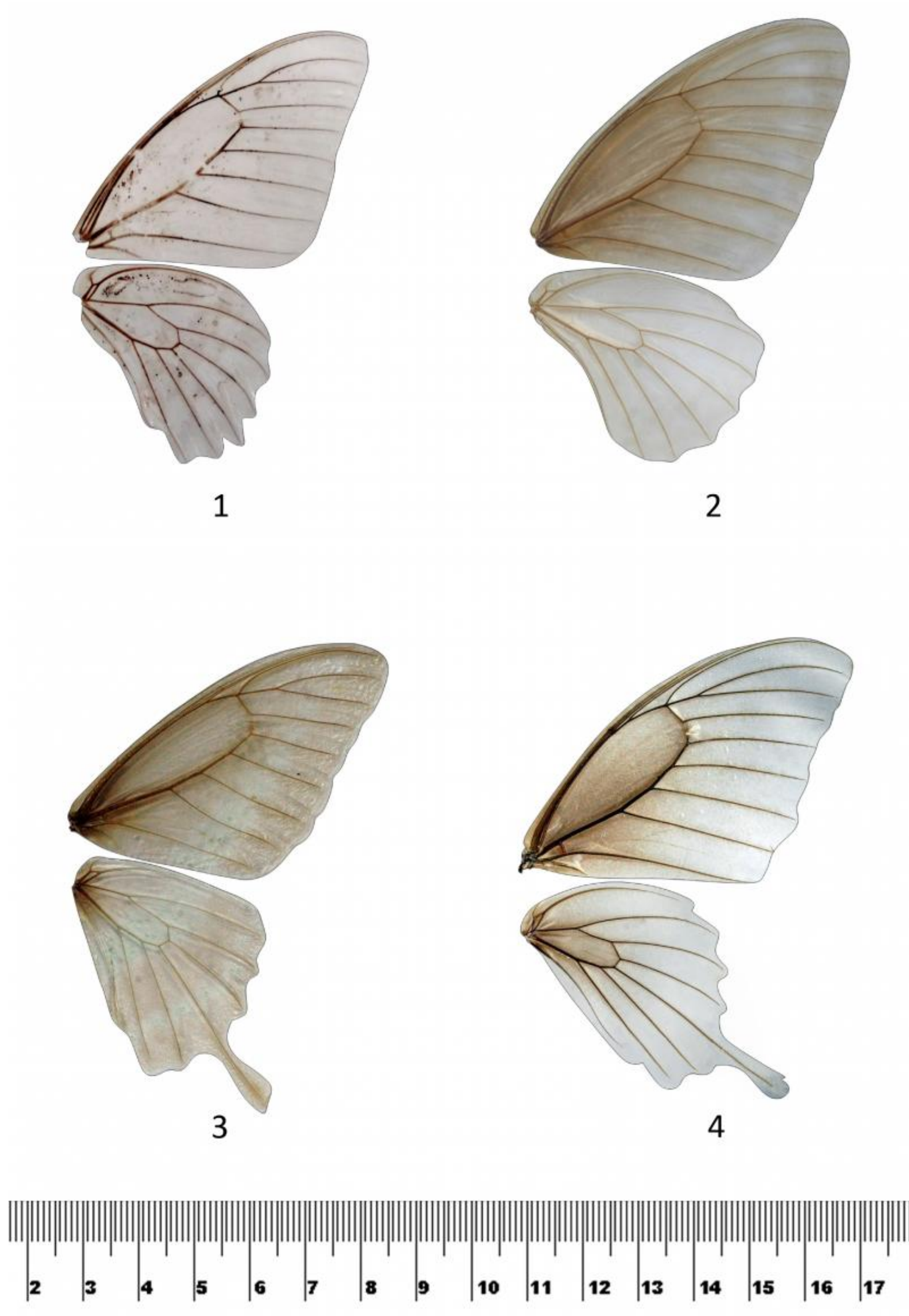


Plate V. Figures 1-4. Wing venation in Papilionidae. Figure 1. *Papilio demoleus;* Figure 2. *P. dravidarum;* Figure 3. *P. liomedon;* Figure 4. *P. paris*

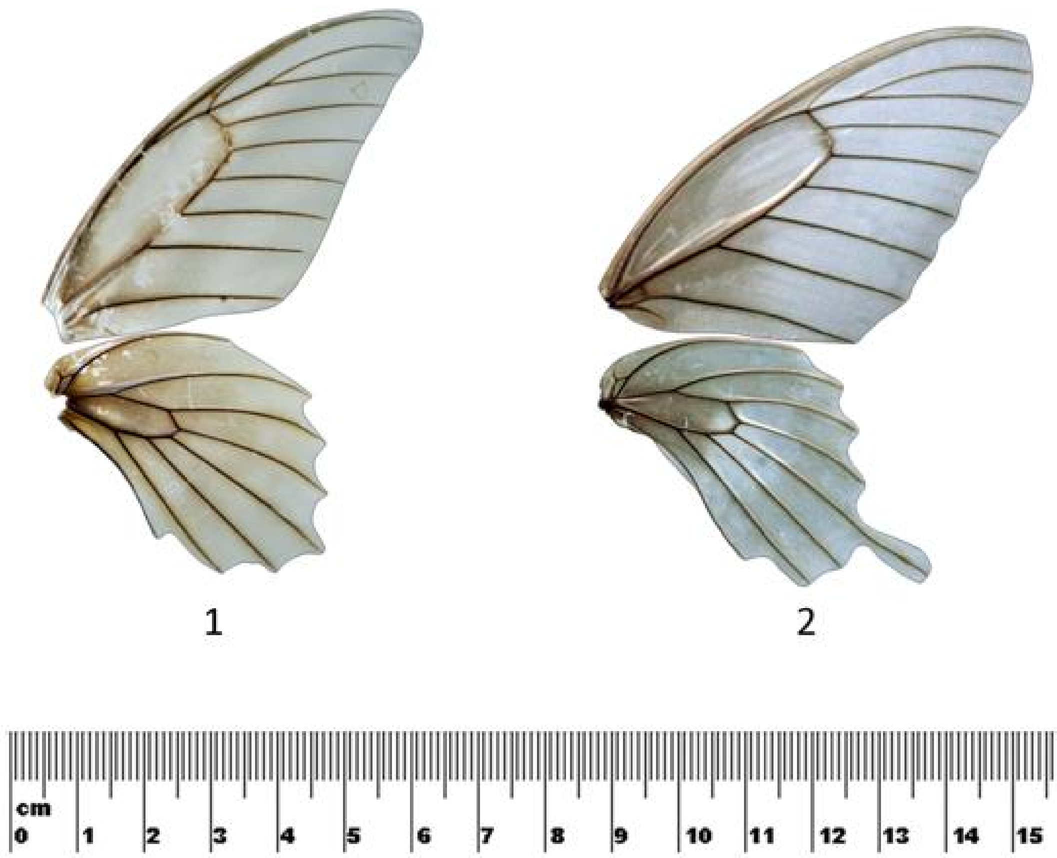


Plate VI. Figures 1-2. Wing venation in Papilionidae. Figure 1. *Papilio polymnestor;* Figure 2. *P. polytes cyrus*

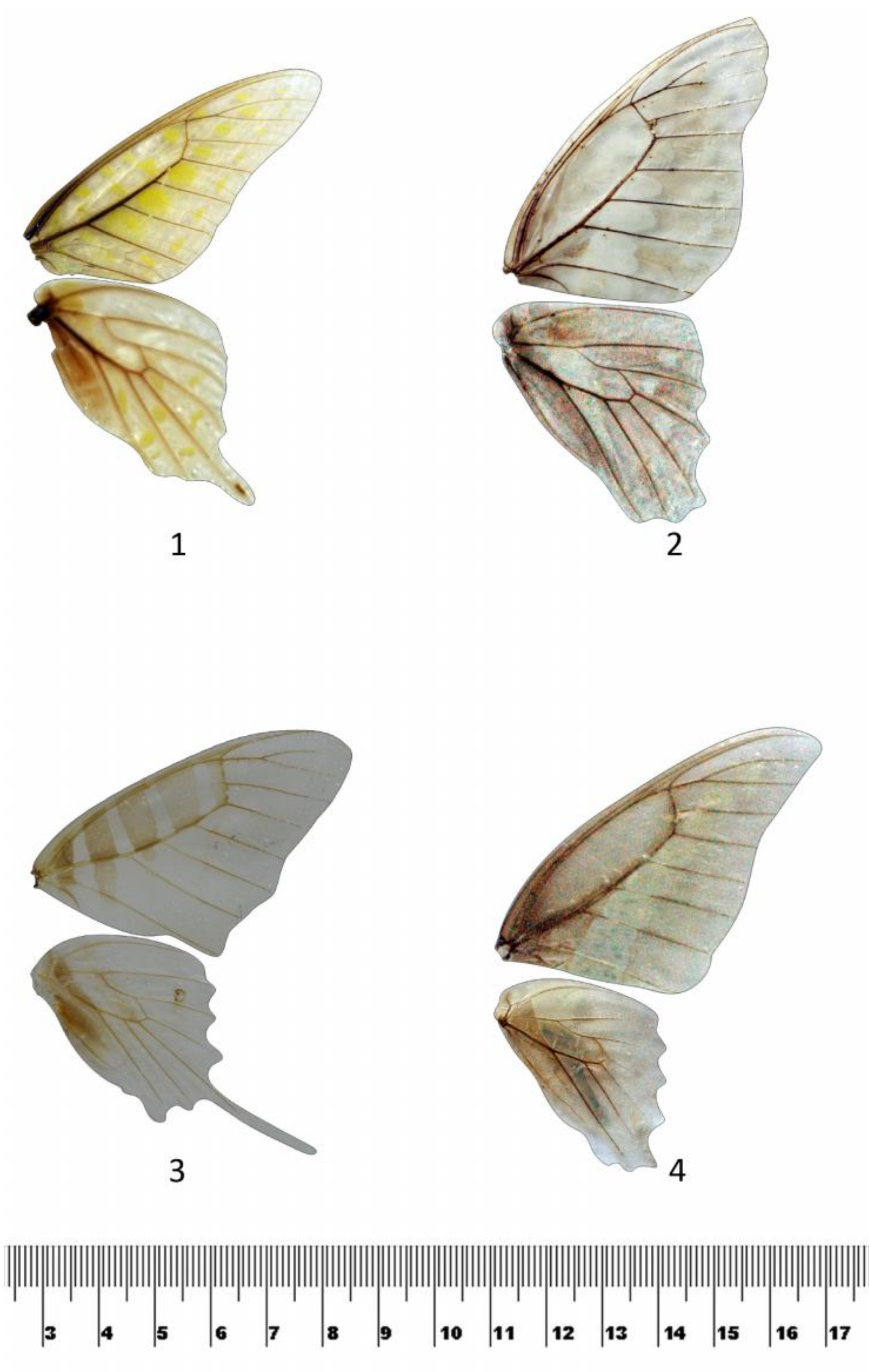


Plate VII. Figures 1-4. Wing venation in Papilionidae. Figure 1. *Graphium agamemnon;* Figure 2. *G. doson;* Figure 3. *G. nomius;* Figure 4. *G. sarpedon.*

4.1.3 Abdomen

The abdomen is composed of ten segments opening posteriorly into the anus. It is cylindrical or fusiform and completely covered with scales. It contains important organs related to respiration, circulation, digestion, excretion and reproduction. Respiration is through a series of spiracles situated on the sides of the abdomen. There are seven pairs of spiracles on segments 1 to 7 leading to a network of tunnels (tracheae) opening in to the tissues. The 7^{th} and 8^{th} segments are sometimes slightly modified in relation to the genitalia and the 9^{th} and 10^{th} segments are greatly modified in the latter respect. In the male, this modification presents a vast variety of forms. Such variations are of great value in distinguishing species, and in some case even groups. The morphological details of the genitalia are given below.

4.1.3.1 Genitalia

The genitalia consist of both external and internal parts. Morphological details of the external genitalia have been recently considered as a dependable tool for species identification (Tuxen, 1970). The general structure of male and female external genitalia is discussed below.

Male

The important parts of the male genitalia are 1. uncus, 2. socii, 3. gnathos, 4. tegumen, 5. vinculum, 6. saccus, 7. valvae, 8. juxta and 9. aedeagus or phallus (Plate 8). Morphological details of each of these parts are given below:

Uncus (Gosse, 1883)

This forms the dorsal process of the 10th segment and is in close contact with the caudal end of the 9th tergite. It is used for grasping the female, dorsally fitting between the lobes of the female ovipositor during coitus. In all Papilionidae, the uncus is formed of hardened chitin and occupies the central upper part of the tegumen (Talbot, 1939). It is long, varying considerably in shape and size. It may be tongue-shaped, tapering, straight, curved or cygnate. The supra-anal process is called scaphium, which is not prominent in Papilionidae.

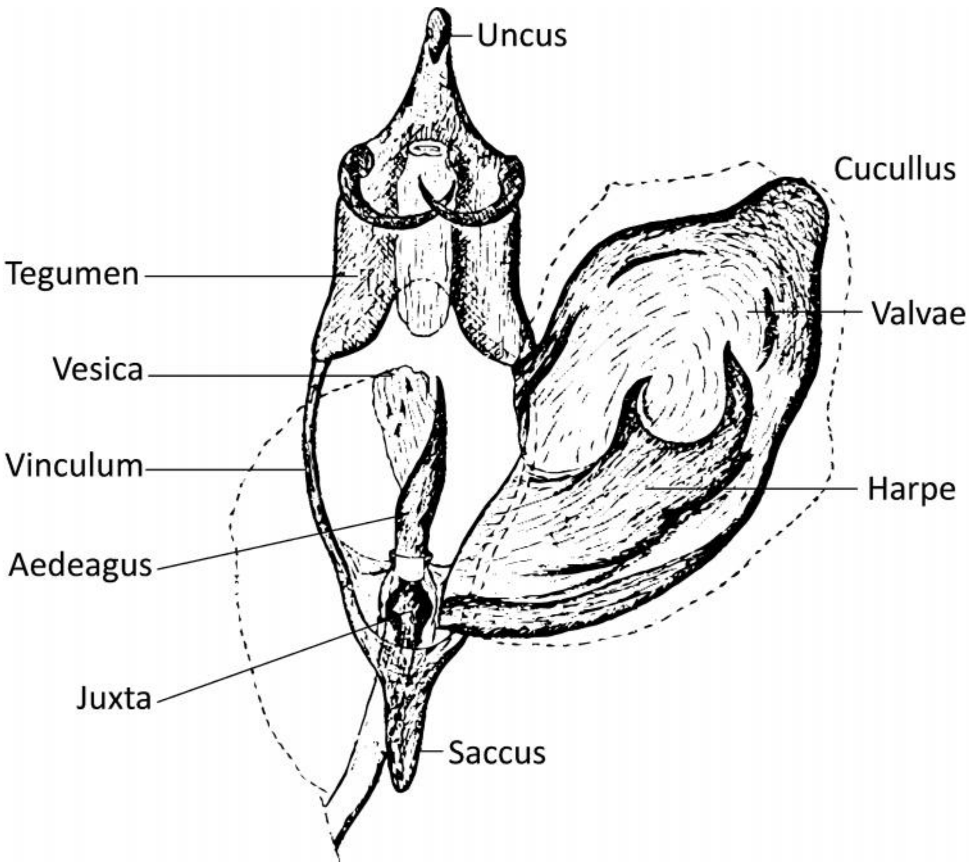


Plate VIII. Figure 1. Morphological details of the male external genitalia

Socii (Pierce, 1914a)

The socii which is sometimes petiolate, are paired organs, weakly sclerotised, or mernbraneous, situated ventrally on either side of the base of the uncus, on the caudal margin of tegumen.

Gnathos (Pierce, 1914a)

It is derived from the 10th sternite and is a structure similar to the uncus on the ventral side of the anal tube. It is typically in the form of a pair of arms which is articulated to lateral edges of the base of the uncus and the caudal margin of tegumen which extend around the anal tube to meet in the mid ventral line, where they expand as a plate.

Tegumen (White, 1876)

Tegumen, which is the dorsal part of the 9th tergite, is usually very large and heavily sclerotised serves for the attachment of other parts of the genitalia. Usually it forms a complete transverse ring by joining with vinculum. Tegumen may vary in size and shape being very small or large, usually broad. It may sometimes develop certain latero-basal hairy pads called peniculus, which is a paired hairy, lobate process of lateral margin of tegumen near the articulation of dorso-proximal angle of valvae, easily confused with socii.

Vinculum (Pierce, 1909)

Vinculum is a ventral chitinised band formed by the 9th sternite attached at its dorsal extremities with the tegumen. Typically, it appears as a thin 'U' or 'V'-shaped structure, continuous across the ventral side of the abdomen.

Saccus (Zander, 1903)

It is a blind, tubular, or trough-shaped process located mid-ventrally to the Vinculum extending anteriorly inside the body. Usually it is cylindrical but sometimes flat. Saccus may be very short or very long or even absent.

Valvae (Burmeister, 1832)

These are paired clasping organs, which basally articulate with the vinculum and lie in a latero-ventral position. The front margin is often termed costal margin with its apex at the extremity. They are typically in the form of a pair of large, flattened, double-walled lobes, usually more or less tapering and bluntly pointed apically. They are always adorned with hairs and scales and articulate with the ring formed by the tegumen and vinculum. In Papilionids, valvae are simple, short or long, broad or narrow, often with marginal spines. Valvae vary greatly in shape and armature. They may be peaked, bifurcate, trigonate, rhomboid, oval, divided into lobes or emarginate, spined or hairy. Different portions of the valvae are known by different names as given below:

Costa (Pierce, 1914a): Upper or dorso-proximal sclerotised margin of the valvae.

Sacculus (Pierce, 1909): The area along the lower margin of valvae is differentiated into an expansion or sac-like portion is the sacculus. It appears to be formed of the outer wall of the valvae which has been expanded and folded inwards so as to form part of the inner surface. It may be sometimes emarginate and produced into lateral arms.

Cucullus (Pierce, 1909): This is the dorso-distal part of the valvae and is usually hairy or setosed. A series of incurved spines, called corona, may be present on its outer margin.

Harpe (Gosse, 1881): This is a strongly sclerotised arm usually in the form of a curved spine provided with independent musculature and arising from the inner surface of the valvae, usually near the base or towards the middle and always quite distinct from the sacculus and extending outwards and upwards as a free arm. Harpe may be small and rudimentary or well developed. It may be curved and terminate on the cucullus into hook - shaped process or may be bifurcate.

Ampulla (Pierce, 1909): It is a major division of valvae occupying the central part of the inner surface of the valvae, it forms a major terminal part of valvae.

Juxta (Pierce, 1914a)

This is often a shield-shaped sclerotised plate, located ventral to the aedeagus. In most cases, the base of the sacculus is attached to juxta, which is a median rod-like process, often forked dorsally so as to surround the aedeagus.

Aedeagus /Phallus (Pierce, 1909)

It is the intromittent organ and passes through a funnel-like membraneous sheath called anellus. It is in the form of a stout tube, with an opening on the side near the base, which receives the seminal duct and contains the eversible, balloon-like membrane, the vesica. The vesica is the most delicate structure and often bears sclerotised spines or scobinate patches, termed 'cornuti' which penetrates into the *bursa copulatrix* of the female during copulation, sometimes leaving its armature behind after copulation. Inside the vesica, is a narrow tube called the *ductus ejaculatorius* through which the seminal fluid passes into the bursa, after being received from the testicula through the seminal duct. Penis may be short or long, thick, or slender, basally broad, straight or curved. The cornuti may be variable.

Female

In the female, the important parts are 1. ovipositor, 2. apophyses, 3. ductus bursa, 4. ostium, 5. corpus bursae and 6. ductus seminalis (Plate 9).

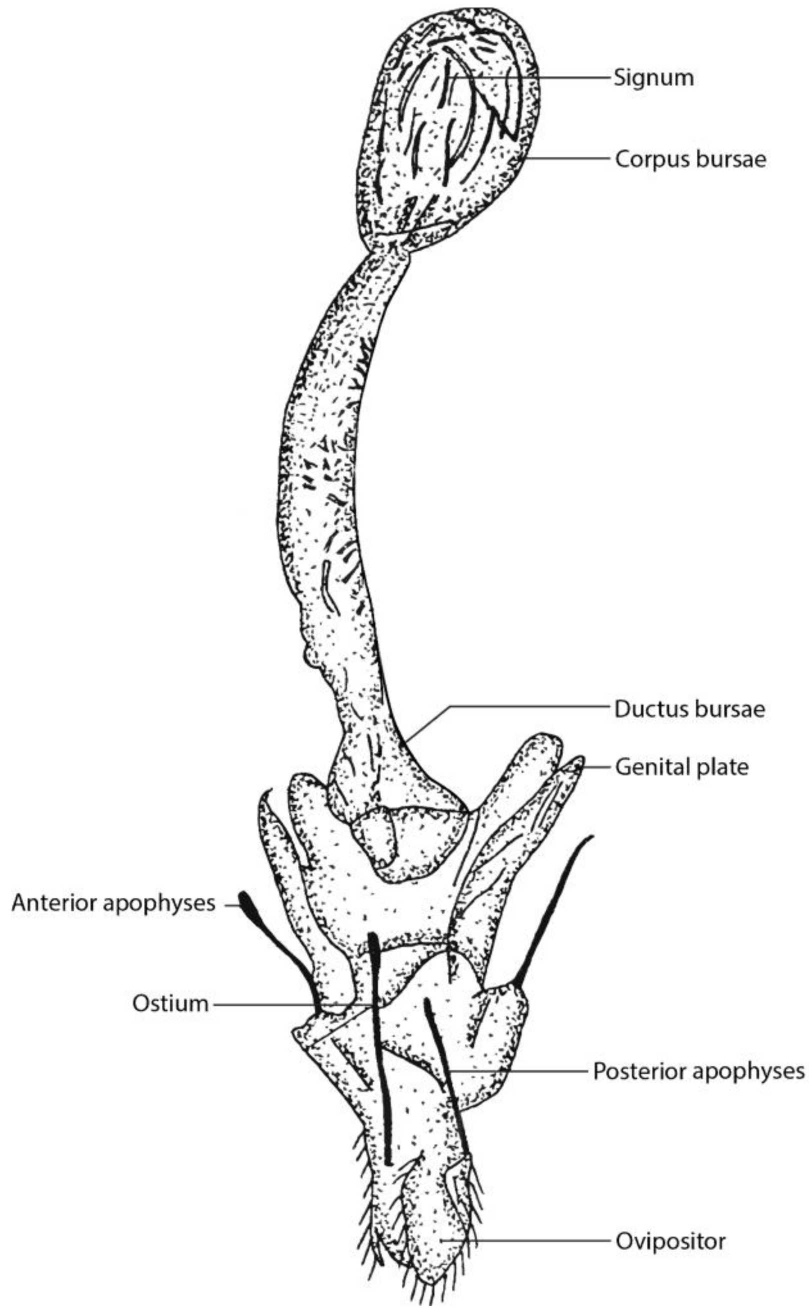


Plate IX. Figure 1. Morphological details of the female external genitalia

Ovipositor (Pierce, 1914b)

The segments 8th to 10th may become comparatively long, narrow and telescopic as to function as an egg inserting apparatus. Distally it bears two bean-shaped or elongate lobes, fringed with hairs called 'ovipositor lobes'.

Apophyses

From the cephalo-dorsal or lateral edges of the 8th and 9th tergites arise long, slender apodemes directed anteriorly. Those of the 8th segment are referred to as the anterior apophyses and those of the 9-10th segments form the posterior pair.

Ductus bursae

This is usually developed in the form of a tube of varying length leading from the ostium to the bursa. Its walls are lightly sclerotised and may possess sclerotised patches, corrugation etc.

Ostium

Ostium is the external opening of the ductus bursae. It is directly attached to the segmental ridges, which are sometimes dorsally united by a hard chitinous band.

Corpus bursae

Typically this is a globular or ovoid structure lying in the abdominal cavity. Its walls are lightly sclerotised and may bear sclerotised patches, spines etc., called the signum which has great significance in taxonomy.

Receptaculum seminis

From somewhere along the bursae or from the ductus bursae springs a narrow duct, the ductus seminalis which opens into a sac-like structure, the receptaculum seminis.

4.2 Higher classification of the family Papilionidae

The Papilionids are characteristically large sized butterflies, usually with well developed proboscis and small palpi, which is appressed to large, projecting frons. Antennae are comparatively short and clubbed. The mesothorax is very powerful and the sternum completely fused with the episternum.

Generally, the wings are more thickly scaled and the venation is well developed. The forewing has twelve veins, with a short, second anal vein. The hind wing has tail, which may be slender or spatulate, but always an extension of the termen at vein M3. One anal vein often with a prominent angle or tail to the centre of the margin. The inner margin of the hindwing is frequently folded over and in males, within the fold bears a patch of special scales called androconia. Legs are fully developed. Fore tibia with spur on the underside and hind tibia with middle spurs. Claws simple, rarely with a tooth. Abdomen is densely clothed with scales and hairs.

The family is divided into three subfamilies *viz.,* Parnassiinae, Zerynthiinae and Papilioninae. In Parnassiinae, the basal cell of the hindwing is almost obsolete and the precostal vein is short and straight. In the forewing, the vein 9 is absent. In Zerynthiinae, the hindwing has large, elongated and broad basal cell and the precostal vein is curved. In Papilioninae, the hindwing has small basal cell and the precostal vein is directed distally. The median spur of the forewing is strong (Plate 10). Among the subfamilies, Zerynthiinae and Parnassiinae are not so far recorded from Peninsular India.

The subfamily Papilioninae is divided into four tribes *viz.,* Troiidini, Papilionini, Leptocercini and Teinopalpini.

Tribe Troiidini

The butterflies of the tribe Troiidini are popularly known as the *Aristolochia* Papilios because their larva feeds almost entirely upon the plants of the family Aristolochiaceae. In the forewing, vein 11 is not anastomosed with vein 12 and the outer ventral row of spines of the tarsi is not separated from the dorsal spines by a spineless longitudinal depression. Hind wing with an anal fold bearing a scent organ. The Troiidini comprise two genera viz., Troides and Atrophaneura.

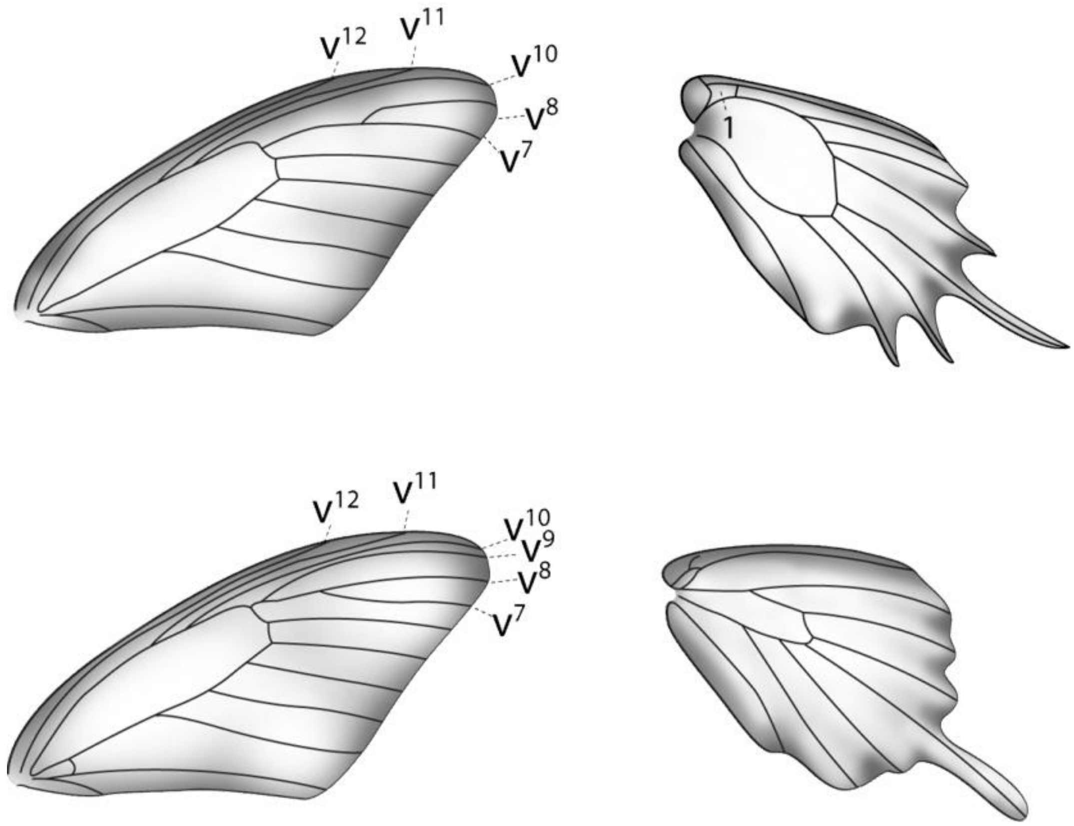


Plate X. Figures 1-4. Venation of anterior portions of forewing and hindwing of different subfamilies of Papilionidae. Figure 1. Forewing in Parnassiinae; Figure 2. Hindwing in Zerynthiinae; Figure 3. Forewing of Papilioninae; Figure 4. Hindwing of Papilioninae.

Genus *Troides:* In the genus *Troides*, both wings are large and ample. Hind wing with well developed scent brushes. In the forewing, vein 11 arises from the point opposite to vein 2. Claspers are well developed in males. In India, the genus *Troides* consists of three species, of which, one species is found in Kerala.

Genus *Atrophaneura:* The oldest name of this genus is *Polydorus* coined by Swainson (1833) and *Tros* by Kirby (1896). They classified *Polydorus* into 4 groups - *nox* group, *coon* group, *hector* group and *latreillei* group. Among these, members of the *hector* group *viz., pandiyana, hector* and *aristolochiae* are found in Peninsular India. Eventhough butterflies of the genus *Atrophaneura* resembles *Troides* in many ways, they are always smaller than *Troides*.

Tribe Papilionini

In Papilionini, the hind wing has the abdominal margin curved downwards, forming a groove beneath. The frons are not projecting and palpi are not long. The tarsi are without scales and the dorsal spines are separated from the rows of the under surface by a lateral, impressed, spineless longitudinal stripe. The hind wing of the male butterfly has no scent organs. The Papilionini comprises of two genera - *Chilasa* and *Papilio.*

Genus *Chilasa*: This genus is entirely mimetic resembling Danaidae. Their body is spotted with white and there is a white dot or spot at the base of the hindwing. It comprises of four groups, of which, only two are found in Indian area. They are *agestor* group and *clytia* group. In *agestor* group, the hindwing with the upper disco-cellular not reaching half the length of vein 7; vein 7 at its point of origin placed farther distal than vein 2. In *clytia* group, the hindwing with the upper discocellular is nearly as long as vein 7; vein 7 at its point of origin is placed nearer the base than vein 2. The *clytia* group consists of two species *viz., paradoxa* and *clytia*, of which the species *clytia* is found in Kerala.

Genus *Papilio*: The genus *Papilio* consists of a number of groups, of which 6 are represented in the Indian area, comprising of 32 species. The classification of the genus *Papilio* is based on general body characters and wing venation. Among these, 9 species *viz., Papilio polymnestor* (*memnon* group); *P. dravidarum* (*castor* group); *P. helenus, P. polytes, P. liomedon* (*helenus* group); *P. demoleus* (*demoleus* group); *P. crino, P. buddha and P. paris* (*paris* group) are found in Kerala.

Tribe Leptocercini

The members of the Tribe Leptocercini are known as Kite-Swallowtails. The wings are thinly scaled, semitransparent, especially in the costal part of the forewing. In most species, vein 11 of the fore wing is running into 12 and in some species, vein 10 is also united with 12. Inner margin of the hindwing bent over upwards with the edge fringed with long hairs. Antennae short and clubbed. Tarsi with the dorsal spines separated from the ventral ones by a spineless impressed interspace. The tribe Leptocercini comprises of two genera - *Graphium* and *Lamproptera.*

Genus *Graphium*: Butterflies belonging to this genus are good fliers and occur in woody areas. This genus consists of six groups, of which four groups, *viz., payeni* group, *antiphates* group, *eurypylus* group and *macereus* group are found in the Indian region. In peninsular India, five species *viz.*, *sarpedon, agamemnon, doson* (*eurypylus* group); *antiphates* and *nomius* (*antiphates* group) are reported.

Tribe Teinopalpini

In Teinopalpini, the frons projects conically and the palpi are very long and pointed. Antennae are short with strong clubs. The median spur of fore wing is only indicated and the upper transverse vein is short. Apex of the fore wing is pointed and the hindwing possess one or two long tails. The members of the tribe Teinopalpini are not so far reported from Kerala.

Based on the characters of wings and larval features, Talbot (1939) in his publication entitled, "Fauna of British India, Butterflies," has prepared a classificatory scheme for various families of the suborder Rhopalocera, which covers the subfamilies of Papilionidae and different tribes in Papilioninae. A key adapted from the above publication is presented here.

Key to the families

1	Fore wing with vein 7 forked. Antennae approximate at the base..	2
-	Fore wing with all veins arising from the cell. Antennae wide apart at the base, and often with a hooked club...	Hesperiidae
2	Hind wing with a precostal vein (except in a few Pieridae)	3
-	Hind wing without a pre-costal vein	Lycaenidae
3	Fore legs fully developed in both sexes	4
-	Fore legs not perfect in one or both sexes	5
4	Hind wing with vein 1b absent................................	Papilionidae
-	Hind wing with vein 1b present	Pieridae
5	Forelegs imperfect in both sexes	6
-	Forelegs imperfect and brush like in the male; developed for walking in the female.........................	Riodinidae
6	Both wings with the cell closed; cross veins present ..	7
-	Hindwing with the cell open; cross veins absent	9
7	Forewing with vein 1a forked with 1b.......................	Danaidae
-	Forewing with vein 1a free	8
8	Fore wing one or more veins inflated or swollen at base. Wings normally scaled, not spotted	Satyridae
-	Fore wing without any vein inflated at base. Wings thinly scaled and spotted..	Acraeidae
9	Palpi small, narrow and sharp in front.....................	Amathusiidae
-	Palpi large, broad, rounded in front. Cell of wing usually open	Nymphalidae

Key to the subfamilies of the Papilionidae

1	Hind wing with a precostal vein and a basal cell........	2
-	Hind wing with basal cell almost obsolete. Precostal vein short and straight. Fore wing with vein 9 absent	Parnassiinae
2	Basal cell large, elongate, longer than broad. Precostal vein curved basad.....................................	Zerynthiinae
-	Basal small. Precostal vein directed distad. Median spur of forewing strong..	Papilioninae

Key to the tribes of Papilioninae

1	Forewing with vein 11 not anastomosed with vein 12. Tarsal claws without a tooth....................................	2
-	Forewing with vein 11 anastomosed with vein 12. Tarsal claws without a tooth (except in *G. payeni* and *G. gyas* and in *Lamproptera*, all of which have a tooth on the tarsal claw)..	Leptocercini
2	Larvae feeding on Aristolochiae. Thorax or abdomen red below. Hindwing with an anal fold bearing a scent organ (weak in some cases, eg., *hector*)	Troiidini
-	Larvae not feeding on Aristolochiae. Hindwing without a scent organ. Thorax or abdomen not red below..	3
3	Hindwing with abdominal margin curved downwards, forming a groove beneath. Frons not projecting. Palpus not long	Papilionini
-	Hindwing without an abdominal fold. Frons projecting. Palpus very long.....................................	Teinopalpini

RESULTS

Revathy V. S "Systematics of swallowtail butterflies (Lepidoptera: Papilionidae) of Kerala, India " Thesis. Kerala Forest Research Institute, University of Calicut, 2014

RESULTS

Chapter 5: Results

5.1. Taxonomic studies: butterfly survey

An exhaustive survey of Swallowtail butterflies has been made in different parts of Kerala and the areas covered in this study included Nilambur, Nadugani Ghat, Vazhikkdavu, Aralam, Thirunelli, Thrissur, Palakkad, Peechi, Vazhani, Athirappilly, Vazhachal, Vettilappara, Malakkappara, Chinmoni and Thenmala. Sampling of butterflies was done by using line transect method. Altogether, 17 species of Papilionids belonging to 5 genera under the subfamily Papilioninae were recorded in the survey (Plate 46, 47). Maximum number of species collected belonged to the genus *Papilio* (8 spp.) followed by *Graphium* (4 spp.), *Atrophaneura* (3 spp.) *Troides* and *Chilasa* (1 sp.). A list of species recorded in this study is provided below.

5.1.1 List of Swallowtail butterflies collected from Kerala

Family: Papilionidae

Sub family: Papilioninae

Tribe: Troiidini

Genus: *Troides* Hübner

Hübner, 1819. *Verzeichniss bekannter schmetterlinge (sic),* 17-176 pp.

1. *Troides minos* Cramer (Southern Birdwing)

(=*Troides helena*) Cramer, 1779. *Papillons exotique des trois parties du monde I'Asia, I'Afrique et I'Amerique,* 176 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 372.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 26.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 144.

Material in collection: 1♂2♀., 8.xi.11, Palakkad; 1♂1♀., 13.x.12, Thenmala.

Wing span: 138 (± 18.26) mm.

Distribution: India: In India, Western Ghats (southern Maharashtra).

Host plants: *Aristolochia indica, A. tagala* and *Thottea siliquosa* (Aristolochiaceae).

Status: Not rare. It is endemic to southern India and the Western Ghats.

Remarks: From Kerala, it has been recorded from Athirappilly, Peechi, Vazhani, Nilambur, Vazhachal and Thenmala. The male and female external genitalic structures have been described in detail here for the first time.

Genus: *Atrophaneura* Reakirt

(=Pachliopta) Reakirt, 1865. *Proc. Ent. Soc. Philad.*, 3: 443 - 504.

***2. Atrophaneura pandiyana* Moore (Malabar Rose)**

(=*Pachliopta pandiyana*) Moore, 1881a. *Transactions of Entomological Society of London*, 305-313 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 374.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 28.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 141.

Material in collection: 2♂2♀., 6.x.11, Thenmala; 1♀., 7.vi.12, Peechi.

Wing span: 108.7 (± 11.16) mm.

Distribution: India: The Western Ghats (South of Maharashtra).

Host plants: *Thottea siliquosa* (Aristolochiaceae).

Status: It is endemic to the Western Ghats.

Remarks: Recorded from the Nadugani Ghat, Nilambur, Thenmala and Peechi.

***3. Atrophaneura aristolochiae* Fabricius (Common Rose)**

(=*Pachliopta aristolochiae*) Fabricius, 1775. *Systema entomologiae*, 832 pp.

Wynter-Blyth, 1957, *Butterflies of the Indian Region*, Bombay Natural History Society, p. 375.

D'Abrera, 1982, *Butterflies of the Oriental Region,* Part 1: 30.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 141.

Material in collection: 5♂5♀., 22.xi.11. Peechi; 1♂1♀., 15.viii.12, Nilambur.

Wing span: 86.6 (± 7.65) mm.

Distribution: Sri Lanka, Myanmar, Pakistan, Nepal, Bhutan, Bangladesh and India.

Host plants: *Aristolochia indica, A. bracteolata, A. tagala*, *A. elegans* and *Thottea siliquosa* (Aristolochiaceae)

Status: Common.

Remarks: From Kerala, it has been recorded from several places including Peechi, Nilambur, Chinmoni, Thenmala.

***4. Atrophaneura hector* Linnaeus (Crimson Rose)**

(=*Pachliopta hector*) Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 375.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 28.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 142.

Material in collection: 2♂2♀., 5.i.12, Peechi; 1♂2♀., 9.ii.12, Vazhani.

Wing span: 99.8 (± 4.28) mm.

Distribution: Sri Lanka, Myanmar, Bangladesh and India: In India, Orissa, Jharkhand, West Bengal, Andaman Islands and South India.

Host plants: *Aristolochia indica, A. bracteolata, A. tagala* and *Thottea siliquosa* (Aristolochiaceae).

Status: Shared endemic to Peninsular India and Sri Lanka. Protected under Schedule I of the Indian Wildlife Protection Act (GOI, 1972).

Remarks: It has been recorded from Peechi, Vazhani, Chinmoni and Thenmala.

Tribe: Papilionini

Genus: *Chilasa* Moore

Moore, 1881b. *Lepidoptera Ceylon*. 1: 190 pp.

***5. Chilasa clytia* Linnaeus (Common Mime)**

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 381.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 92.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 126.

Material in collection: 4♂4♀., 13.ix.10, Peechi; 1♂2♀., 16.viii.11, Thrissur.

Wing span: 79.3 (± 11.16) mm.

Distribution: Nepal, Bhutan, Sri Lanka, Myanmar, Bangladesh, Thailand, Southern China, Hongkong, Vietnam, Loas, Kampuchea, Malaysia, Philippines, Indonesia and India. In India it has been reported from Himachal Pradesh to Arunachal Pradesh, Sikkim, Assam, Bombay, Madhya Pradesh and S. India. It is well distributed all over the Western Ghats and has been recorded from many places in Kerala.

Host plants: *Cinnamomum zeylanicum, C. camphora, C. macrocarpum, Litsea chinensis, L. deccanensis, Persea macrantha* and *Alseodaphne semecarpifolia* (Lauraceae).

Status: Not rare. Common in localities having the larval Host plants. Its form *commixtus* is Protected under Schedule I of the Indian Wildlife Protection Act, (GOI, 1972).

Remarks: It is well distributed all over the Western Ghats and has been recorded from Trivandrum, Thenmala, Nilambur, Peechi, Vazhani and Athirappilly.

Genus: *Papilio* Linnaeus

Linnaeus, 1758, *Systema Naturae*, 10: 534 pp.

***6. Papilio demoleus* Linnaeus (Lime Butterfly)**

Linnaeus, 1758, *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 395.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 60.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 133.

Material in collection: 3♂4♀., 30.xii.10, Athirappilly; 2♂1♀., 7.iv.11, Vazhachal.

Wing span: 81.5 (± 12.08) mm.

Distribution: Sri Lanka, China, Vietnam, Arabia, Pakistan, Afghanistan, Nepal, Bhutan, Bangladesh, Myanmar and India. From India, it has been recorded from the Nadugani Ghat, Silent Valley, Thenmala, Peechi and Nilambur.

Host plants: *Aegle marmelos, Glycosmis arborea, Murraya koenigii,* and *Citrus medica, Limonia crenulata,* limes, lemons and other Rutaceae (Rutaceae).

Status: Very common. Commonest among Swallowtails.

Remarks: It has been recorded from the Athirappilly, Peechi, Vazhani, Nilambur, Vazhachal and Thenmala and Nadugani Ghat. It is generally found in the low land deciduous forests and rarely in dense wet evergreen forests.

7. *Papilio liomedon* Moore (Malabar Banded Swallowtail)

Moore, 1874. *Proceedings of Zoological Society of London,* 565-577 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 394.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1:60.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 133.

Material in collection: 1♂., 17.xii.12, Thenmala.

Wing span: 95 (± 3.6) mm.

Distribution: The Western Ghats (South of Goa) specifically Coorg and Kanara. It is a rather scarce butterfly which is somewhat localized. In Kerala, it has been reported from Thenmala and Nilambur.

Host plants: *Evodia roxburghiana, Acronychia pedunculata* and *A. laurifolia* (Rutaceae).

Status: Rare, endemic to the Western Ghats. Protected under Schedule I of the Indian Wildlife Protection Act (GOI, 1972).

Remarks: Recorded from Nilambur and Thenmala.

8. *Papilio dravidarum* Wood-Mason (Malabar Raven)

Wood-Mason, 1880. *Journal of Asiatic Society Bengal,* 134 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 390.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 88.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 128.

Material in collection: 2♂2♀., 21.xii.12, Thenmala; 1♂., 14.xi.11, Chinmoni.

Wing span: 88.5 (± 4.45) mm.

Distribution: The Western Ghats. This species is reported to be fairly common along the western slopes of the Nilgiris.

Host plants: *Glycosmis arborea* (Rutaceae).

Status: Rare, endemic to the Western Ghats.

Remarks: Recorded from Nilambur and Thenmala.

9. *Papilio helenus* Linnaeus (Red Helen)

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Regio*n, Bombay Natural History Society, p. 392.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 64.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 129.

Material in collection: 4♂4♀, 25.ix.12, Peechi; 2♂2♀., 20.x.12, Thenmala; 1♂1♀., 18.x.12, Nilambur.

Wing span: 117.3 (± 4.50) mm.

Distribution: Nepal, Bhutan, Myanmar, Bangladesh, Sri Lanka and India: In India, it is reported from Mussoorie, Assam, and the Western Ghats (Peechi, Thenmala, Nadugani Ghats, Coorg and Bangalore).

Host plants: *Zanthoxylum rhetsa, Z. acanthopodium, Toddalia asiatica, Evodia* sp. and *Glycosmis arborea* (Rutaceae).

Status: Common

Remarks: It has been recorded from Peechi, Nilambur, Chinmoni and Thenmala.

10. *Papilio polytes* Linnaeus (Common Mormon)

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 392.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 72.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 127.

Material in collection: 6♂6♀., 23.ix.10, Peechi; 1♂1♀., 17.xi.11, Athirappilly.

Wing span: 85.3 (± 5.25) mm.

Distribution: Myanmar, Sri Lanka, Nepal, Bhutan, Bangladesh, Pakistan and India.

Host plants: *Glycosmis arborea, Murraya koenigii, Atalantia racemosa, Aegle marmelos, Zanthoxylum rhetsa, Citrus medica* and *Citrus* sp. (Rutaceae).

Status: Very Common.

Remarks: It has been recorded from Peechi, Nilambur, Chinmoni, Vazhani, Athirappilly, Vazhachal and Thenmala.

11. *Papilio polymnestor* Cramer (Blue Mormon)

Cramer, 1775. *Papillons exotique des trois parties du monde I'Asia, I'Afrique et I'Amerique*, 132 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 383.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 74.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 130.

Material in collection: 4♂4♀., 25.xi.10, Peechi; 2♂2♀., 20.x.11, Thenmala.

Wing span: 120.30 (± 13.15) mm.

Distribution: Sri Lanka, Myanmar and India (Peninsular and Central India): In India, specifically recorded from Jharkhand, Madhya Pradesh, S. Gujarat, W. Bengal, Kerala and rare and straggler in Sikkim

Host plants: *Atalantia racemosa, Atalantia wightii, Glycosmis arborea, G. pentaphylla, Paramigyna monophylla, Citrus grandis, C. limona, C, documana, C. maxima,* cultivated limes (Rutaceae) and *Garcinia xanthochymus* (Clusiaceae).

Status: Shared endemic to Peninsular India and Sri Lanka.

Remarks: Recorded from Nilambur, Nadugani Ghat, Aralam, Thirunelli, Thrissur, Palakkad, Peechi, Vazhani, Athirappilly, Vazhachal, Chinmoni and Thenmala.

12. *Papilio paris* Linnaeus (Paris Peacock)

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 388.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 52

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 134.

Material in collection: 1♂., 23.xii.12, Thirunelli, Wayanad.

Wing span: 103.75 (± 2.63) mm.

Distribution: Bangladesh, Myanmar, India: South India up to Southern Maharashtra and Andhra Pradesh, Chhttisgarh, Uttaranchal, Orissa, Kumaon, Sikkim, Assam. It has been reported from the moist-deciduous forests of the Wayanad, Nilambur and Thenmala.

Host plants: *Toddalia asiatica, Zanthoxylum ovalifolium* and *Evodia roxburghiana* (Rutaceae).

Status: Rare.

Remarks: Recorded from Nilambur, Thirunelli and Thenmala.

13. *Papilio buddha* Westwood (Malabar Banded Peacock)

Westwood, 1872. *Transactions of Entomological Society London,* 85 -110 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 390.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 58.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 137.

Material in collection: 1♂., 19.viii.12, Peechi.

Wing span: 88.5 (± 4.45) mm.

Distribution: Sri Lanka, India: In India, it has been recorded from south India upto southern Maharashtra, Madhya Pradesh, Orissa and West Bengal.

Host plants: *Zanthoxylum rhetsa.*

Status: Endemic to the Western Ghats and protected under Schedule II of the Indian Wildlife Protection Act 1972. It is stated that this species is unable to survive in severely disturbed forests (Larsen, 1987a), although, this butterfly has been observed even in urban areas.

Remarks: In Kerala, it has been recorded from Nadugani Ghats, Peechi.

Tribe: Leptocercini

Genus: *Graphium* Scopoli

Scopoli, 1777. *Introduction to the History of Nature,* 433 pp.

14. *Graphium sarpedon* Linnaeus (Common Bluebottle)

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 401.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 98.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 118.

Material in collection: 6♂6♀., 21.x.11, Nadugani Ghat; 2♂2♀., 16.ix.12, Nilambur.

Wing span: 73.8 (± 2.10) mm.

Distribution: Sri Lanka, Myanmar, Nepal, Singapore, Bhutan, Bangladesh and India: From India, specifically recorded from Kashmir, Assam and south India (Vazhachal, Nadugani, Peechi, Thenmala and Parambikulam).

Host plants: *Alseodaphne semecarpifolia*, *Cinnamomum camphora*, *C. malabathrum, C. macrocarpum, Persea macrantha, P. odoratissima, Litsea chinensis* (Lauraceae); *Miliusa tomentosa* and *Polyalthia longifolia* (Annonaceae).

Status: It is a common butterfly occurring at all elevations both in forests and in agricultural lands.

Remarks: Recorded from Nilambur, Nadugani Ghat, Peechi.

15. *Graphium doson* Felder & Felder (Common Jay)

Felder & Felder, 1864. *Verh. Zool. Bot. Ges. Wein*, xiv: 289-378 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 402.

D'Abrera, 1982, *Butterflies of the Oriental Region*, Part 1: 100.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 120.

Material in collection: 6♂6♀., 9.ii.11, Peechi.

Wing span: 75.3 (± 2.45) mm.

Distribution: Sri Lanka, Myanmar, Nepal, Bhutan and India. From India, specifically recorded from Bengal, Kumaon to Assam and S. India to Maharashtra.

Host plants: *Annona lawii, Polyalthia longifolia, Miliusa tomentosa (Annonaceae), Magnolia grandiflora, M. pumila, Michelia champaca* (Magnoliaceae), *Cinnamomum macrocarpum* (Lauraceae), *Hunteria zeylanica, Trachelospermum asiatica* (Apocynaceae).

Status: Locally Common.

Remarks: Recorded from Peechi and Nilambur.

16. *Graphium agamemnon* Linnaeus (Tailed Jay)

Linnaeus, 1758. *Systema Naturae*, 10: 534 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 404.

D'Abrera, 1982. *Butterflies of the Oriental Region*, Part 1: 102.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 120.

Material in collection: 6♂6♀., 17.xii.10, Peechi; 1♂., 16.i.11, Nilambur.

Wing span: 76.5 (± 5.23) mm.

Distribution: Oriental Region, Myanmar, Sri Lanka and India. From India, specifically recorded from S. India to Gujarat (Kutch), Uttaranchal to Arunachal Pradesh as well as in Andaman and Nicobar Islands.

Host plants: *Michelia champaca, M. doltsopa* (Magnoliaceae), *Annona reticulata, A. squamosa, A. muricata, A. discolor, Artabotrys hexapetalus, Polyalthia longifolia, P. cerasoides, Miliusa tomentosa (Annonaceae)* and *Cinnamomum* spp. (Lauraceae).

Status: Common.

Remarks: Recorded from Nilambur, Nadugani Ghat, Peechi and Thenmala.

17. *Graphium nomius* Esper (Spot Swordtail)

(=*Pathysa nomius*) Esper, 1785-98. *Die Schmetterlinge* (=the butterflies) Suppliment, 210 pp.

Wynter-Blyth, 1957. *Butterflies of the Indian Region*, Bombay Natural History Society, p. 398.

D'Abrera, 1982. *Butterflies of the Oriental Region*, Part 1: 110.

Kehimkar, I. 2008. *The Book of Indian Butterflies*. Bombay Natural History Society and Oxford University Press, Mumbai, India, p. 121.

Material in collection: 4♂4♀., 6.ii.13, Peechi; 1♂1♀., 1.iii.13, Peechi.

Wing span: 74.2 (± 9.71) mm.

Distribution: Sri Lanka, Myanmar, Nepal, Bangladesh, Bhutan and India: Peninsular India to Gujarat, Madhya Pradesh, Chhttisgarh, Uttar Pradesh, Uttaranchal to Arunachal Pradesh.

Host plants: *Miliusa tomentosa, M. velutina, Polyalthia longifolia* and *P. cerasoides* (Annonaceae).

Status: Rare.

Remarks: In Kerala it has been recorded from moist deciduous forests of Peechi and Vazhani during the summer season.

5.1.2 External genitalial morphology of Swallowtails

Descriptions of external genitalia of 17 species Papilionid butterflies have been made in this study as detailed below.

Family: Papilionidae

Sub family: Papilioninae

Tribe: Troiidini

***Troides minos* Cramer (Southern Birdwing)** (Plate XI. Figure 1; Plate XX. Figure 1)

Male genitalia: Uncus well developed, broad, conical and narrow apically with a median notch, fringed laterally and apically with sparse hairs, the apical fringe being relatively longer. Gnathos with slender lateral arms. Tegumen short and broad. Vinculum long, highly sclerotised, cylindrical and moderately emarginated in the middle portion. Valvae broad, ovate, densely setosed with long stiff hairs on inner surface. Harpe stout apically curved at about the valvula. Apical boarder dentate. Sacculus oval in shape. Juxta small and fused with sacculus. Saccus prominent, broad and U-shaped. Phallus short, stout, apically conical and blunt with a wavy margin on one side.

Female genitalia: Ovipositor with flattened conical lobes fringed with short hairs. Anterior and posterior apophyses apically clubbed and almost of uniform length. Ostium circular with two lateral lobes and a median narrow sclerotisation for separating the lateral arms. Ductus bursae small and narrow. Corpus bursae large, elongate, roughly oval with parallel rows of scobinations in concentric rings covering half of the bursa.

***Atrophaneura pandiyana* Moore (Malabar Rose)** (Plate XI, Figure 2; Plate XX, Figure 2)

Male genitalia: Uncus short, sharply pointed and basally broad. Gnathos and socii are absent. Tegumen expanded and elongated, broader in the middle and having thick sclerotisation in the apical ends. Vinculum broad, U-shaped and anteriorly produced into conical knobs. Juxta small and covered with the sclerotised portions of sacculus. Valvae flap-like, apically conical. Harpe stout, apically curved and with a narrowed pointed hook-shaped process. Costa straight and is continuous with the apical portions of tegumen which is sclerotised. Sacculus broad and semi-membraneous. Saccus broad and U-shaped. Phallus long, sclerotised, pointed at the apex and broad at the base.

Female genitalia: Ovipositor lobes oval, soft, broad, moderate in size and more or less separate and strongly setosed. Posterior apophyses narrow and shorter than the anterior. A distinct genital chamber, sinus vaginalis present. Ostium bursae almost round in outline with two highly sclerotised lobes. Ostium bursae lead to the ductus bursae, which is moderately long and of varying width. Corpus bursae elongate and tubular with a distinct spindle-shaped signum bearing pectinations.

***Atrophaneura aristolochiae* Fabricius (Common Rose)** (Plate XII, Figure 1; Plate XXI, Figure 1)

Male genitalia: Uncus short, bilobed with a constriction at the base. Socii and gnathos lacking. Tegumen broad. Vinculum with broad basal portion and narrow apex with thick sclerotisation. Valvae broad and distinguishable into a sclerotised sickle-shaped ventral half and a flat, oval dorsal half. Harpe stout, L-shaped and apically bent. Sacculus globular in outline and well emarginated medially on the apex. Juxta membraneous. Saccus stout, elongate and U-shaped. Phallus very long and slender, with a sharply pointed apex and membraneous vesica. Posterior portion broad.

Female genitalia: Ovipositor lobes soft, elongated, medium sized and strongly setosed. Apophyses of more or less the same size. Sinus vaginalis broad and of varying width. Ostium bursae with two highly sclerotised lateral flaps. Ostium bursae continued as ductus bursae. Ductus bursae short and narrow distally. Corpus bursae elongated, swollen, striated, narrowed and oval proximally. Signum elongated sclerotised and spindle-shaped.

Atrophaneura hector **Linnaeus (Crimson Rose)** (Plate XII, Figure 2; Plate XXI, Figure 2)

Male genitalia: Uncus bud-shaped, swollen, notched terminally and sparsely hairy. Socii absent. Gnathos small, broad and rounded. Tegumen slender, basally broad and pointed towards the apex, laterally fringed with rows of short, stiff hairs. Vinculum dome-shaped, much broader, well sclerotised on the apex, and highly setosed with tapering ends in the posterior part. Valvae broad, elongated and sclerotised with a sickle-shaped ventral half and a flat, oval, dorsal half. Harpe stout, L-shaped, apically bent. Costa narrow and diagonal. Sacculus oval in shape, semi membraneous and strongly scleritised. Ampulla well separated from harpe and highly scleritised. Juxta present. Saccus massive, long, and U-shaped. Phallus very long, apex narrowed with a prominent pointed tip on one side and with the membraneous vesica on the other side. There is a broad lobe attached to the proximal end.

Female genitalia: Ovipositor with broad, elongated oval lobes and highly setosed. Anterior apophyses longer than posterior one. Sinus vaginalis moderately long and of varying width. Ostium circular. Ductus bursae curved, broad at the base and highly sclerotised, distally narrowed. Corpus bursae elongated, swollen and oval in shape with a distinct signum which is elongated and spindle-shaped.

Tribe: Papilionini

***Chilasa clytia* Linnaeus (Common Mime)** (Plate XIII, Figs. 1, 2; Plate XXII, Figs. 1, 2)

Male genitalia: Form *clytia:* Uncus is short, narrow, tubular, ending bluntly. Socii absent. Gnathos relatively small and lobed. Tegumen and vinculum elongate with narrow arms. Valvae conical, flap-shaped. Cucullus pointed, costal margin almost straight, with short dense setae along the distal margin. Harpe flat with a dentate ventral margin and bearing two lobes. Saccular margin slightly wavy on the sides and slightly curved in the middle into which fits the juxta. Saccus is low and U-shaped. Phallus medium sized, tubular, curved in the middle and moderately thickened and apically blunt.

Form *dissimilis:* Uncus short, swollen and ending bluntly. Socii absent. Gnathos lobed. Tegumen and vinculum with narrow arms. Valvae ovate, flap-shaped and fringed with short, stiff setae. Cucullus blunt, costal margin almost straight, with a fringe of short setae. Harpe short and indistinct with two conical lobes. Saccular margin curved and rounded. Saccus low and broadly U-shaped. Phallus medium sized, curved in the middle, apically broadened with uneven tip.

Female genitalia: Form *clytia:* Ovipositor bean-shaped, sclerotised and fringed with thin hairs. Posterior apophyses long and curved. Anterior apophyses short and apically swollen. Ostium wide, W-shaped, having lobular, leaf- like lobes at the base. Ductus bursae short. Corpus bursae large, swollen and basally narrowed. Signum long and spindle shaped.

Form *dissimilis:* Ovipositor lobes round in outline, finely setosed and sclerotised. Anterior apophyses about ½ the length of the posterior apophyses. Ducuts bursae small, short and of uniform width. Corpus bursae more or less globular with a spindle-shaped signum.

***6. Papilio demoleus* Linnaeus (Lime Butterfly)** (Plate XIV, Figure 1; Plate XXIII, Figure 1)

Male genitalia: Uncus conical. socii and gnathos elongated and slender. Gnathos oval uniting in the middle into a pointed process. Tegumen and vinculum with narrow arms. Valvae broad basally, conical apically and ventrally setosed. Harpe appearing as a ring-shaped structure. Cucullus pointed and blunt. Costal margin straight with thick sclerotisation. Sacculus prominent. Juxta broad, conical with a small cleft in the middle. Saccus low and U-shaped. Phallus short and slender with a blunt end. Vesica narrow.

Female genitalia: Ovipositor lobes broad and fringed with short hairs. Posterior apophyses short. Sinus vaginalis striated dorsally forming a deep intersegmental membraneous pouch. Ostium bursae small. Ductus bursae narrow, short and of uniform width. Corpus bursae elongated, incurved in the middle. Signum leaf-like with a median vertical line and with numerous horizontal striations.

Papilio liomedon **Moore (Malabar Banded Swallowtail)** (Plate XIV, Figure 2)

Male genitalia: Uncus short, narrow and tubular. Socii elongated, bean-shaped. Tegumen broad, with narrow sclerotised lateral arms. Vinculum longer than the tegumen. Posterior 2/3rd part of the former narrow and the anterior 1/3rd part broadened and curved at the apex. Valvae short, broad, ear-shaped, setosed, with a band fringed with hairs surrounding all around the outer margin. Another submarginal band just below the outer band. Cucullus fringed with short hairs. Sacculus small. Juxta well developed with a broad apical part and a narrow basal part. Saccus low and U-shaped. Phallus short, stout, cylindrical, slightly bulged out subapically and slightly bent at the proximal end.

Papilio dravidarum **Wood-Mason (Malabar Raven)** (Plate XV, Figure 1; Plate XXIII, Figure 2)

Male genitalia: Uncus short, tubular and blunt. Gnathos with curved narrow lateral arms and with a well developed cylindrical median part. Tegumen broad and elongated. Vinculum with elongate narrow arms. Sacculus short, straight and sclerotised. Harpe thumb-shaped with a small projection towards the cucullus. Valvae oval in outline, outer margin fringed with small hairs and highly setosed in the distal inner part. Cucullus round. Costal margin straight. Harpe broad, blunt, finger- like lobe bearing a short conical lobe. Juxta indistinct. Saccus V-shaped. Phallus short, arched and apically pointed. Vesica membraneous, triangular and pointed at the distal end. Proximal end broad.

Female genitalia: Ovipositor with prominent bean-shaped lobes. Posterior apophyses small and narrow compared to the anterior apophyses. Sinus vaginalis triangular and sclerotised. Ostium bursae round. Ductus short and broad. Corpus bursae elongate, large, basal half tubular and distal half globular with truncated apex. Signum very long and lamellate, extending the entire length of the bursae and having narrow striations with tapering ends.

***Papilio helenus* Linnaeus (Red Helen)** (Plate XV, Figure 2; Plate XXIV, Figure 1)

Male genitalia: Uncus short, sclerotised and finger-shaped. Tegumen with broad arms, inwardly produced into two lobes, which are distinct. Vinculum V-shaped and sclerotised. Valvae with the outer margin round, setosed and sclerotised but in costa, sclerotisation is not distinct. Harpe distinct and apically flag-shaped with thick sclerotisation but proximal region is widened. Sacculus slightly convex, of uniform width and with a small cleft in the middle. Saccus more or less U-shaped. Phallus stout, curved and slender. Distal end pointed on one side. Proximal end round with a sub proximal bulging.

Female genitalia: Ovipositor lobes elongate, oval, sclerotised and fringed with hairs. Apophyses, more or less of the same size. Genital chamber globular with three central, short, broad, ribbon-like flaps that partially cover the ostium bursae. These flaps are thickly sclerotised with curved apical margins. Laterally, a thick sclerotised patch present in the sinus vaginalis. Corpus bursae, very large and balloon-shaped.

10. *Papilio polytes* Linnaeus (Common Mormon) (Plate XVI, Figure 1; Plate XXIV, Figure 2; Plate XXV, Figures 1, 2)

Male genitalia: Uncus short, of uniform width, blunt and finger-shaped. Tegumen and vinculum with narrow, slender arms. Valvae broad, oval with a broad, sclerotised band bearing a fringe of short setae. Costa distinct with broad sclerotised patches extending upto the margin. Harpe appears as a mouse- shaped structure with the proximal end drawn out into a tail-like structure. Sacculus triangular in shape, with an expanded lobe-like portion reaching the base of the valvae. Saccus U-shaped. Phallus long and tubular with a pointed tip bearing the membraneous vesica. Basal part handle-shaped having a round tip.

Female genitalia: Form s*tichius*: Ovipositor lobes broad, strongly sclerotised, fringed with short hairs and almost round in outline. Posterior apophyses slightly shorter than the anterior. Sinus vaginalis well developed. Ductus bursae short. Corpus bursae large and balloon-shaped. Signum long, narrow and lamellate, with well developed sclerotisation on the dorsal surface.

Form *romulus*: Ovipositor lobes broad with sclerotised sides and thickly fringed with short hairs. Posterior shorter than the anterior. Sinus vaginalis well developed with lateral thickly sclerotised triangular membraneous flaps. Ductus bursae wide and of medium length. Corpus bursae elongated, with the basal half narrower than the apical half. Signum very long, broad in the middle and tapering at the ends.

Form *cyrus*: Ovipositor lobes oval in outline, slightly sclerotised. Posterior apophyses very short compared to the anterior. Sinus vaginalis well developed. Small, round ostium very much concealed by proximal margins of the sinus. Ductus bursae very short. Corpus bursae oval in shape. Signum spindle-shaped and lamellate, with well developed sclerotisation on the dorsal surface.

***Papilio polymnestor* Cramer (Blue Mormon)** (Plate XVI, Figure 2; Plate XXVI, Figure 1)

Male genitalia: Uncus short, blunt. Socii present. Gnathos composed of two spiral processes, joined apically. Tegumen and vinculum slender and bar-like. Valvae broad in the apical half. Apical and outer margins boardered by a setose, sclerotised band. Cucullus slightly curved and sclerotised. Costal margin slightly concave. Harpe spatulate, having a broad apex with a tapering proximal part. Juxta with acute lateral lobes. Sacculus straight. Saccus short, U-shaped. Phallus long, stout bow-shaped and curved in the middle. Apex broadened with flat edge. Vesica prominent, extending the entire apex.

Female genitalia: Ovipositor lobes oval, short and fringed with short hairs. Apophyses more or less similar in size. Sinus vaginalis, broad. Ductus short and narrow. Corpus bursae elongate oval, proximally narrowed. Signum prominent, sickle-shaped and swollen in the middle.

***Papilio paris* Moore (Paris Peacock)** (Plate XVII, Figure 1)

Male genitalia: Uncus tubular, apically blunt. Gnathos with two lateral projections. Tegumen and vinculum with elongate slender arms. Valvae basally broad, more or less conical apically and strongly sclerotised. Harpe spatulate, highly sclerotised. Cucullus pointed, setosed. Costa curved. Saccular margins straight. Juxta triangular in shape. Saccus U-shaped. Phallus short, stout, of uniform width and almost cylindrical in shape. Apex pointed, triangular, with conspicuous vesica, proximal end bent outwards and enlarged.

***Papilio buddha* Westwood (Malabar Banded Peacock)** (Plate XVII, Figure 2)

Male genitalia: Uncus short, tubular, broadened at the base, apex blunt. Socii and gnathos present. The latter produced into two lobes. Tegumen and vinculum with long narrow arms. Valvae elongate, oval, flap-shaped and well setosed at the outer margin. Harpe apically hooked with well sclerotised margins. Cucullus slightly pointed, setosed. Costa curved. Saccular margins straight. Juxta with an apical notch. Saccus U-shaped. Phallus short, stout, sides uneven, apical end round. Proximal end narrowed.

Tribe: Leptocercini

***Graphium sarpedon* Felder & Felder (Common Bluebottle)** (Plate XVIII, Figure 1; Plate XXVI, Figure 2)

Male genitalia: Uncus short, more or less finger-shaped with a broad proximal part and a narrow, slightly curved and blunt apical part. Socii long, cylindrical and apically blunt situated below the uncus. Tegumen and vinculum with elongated, narrow arms. Valvae ovate, having a deep invagination at the apex near the cucullus. The edges of invaginated portion of valvae are sharply pointed. A pair of pointed processes near cucullus. Costa strongly arched in outline. Harpe comprising of a flat plate bearing a narrow lobe-like appendage at the distal end, towards the costal margin. Sacculus straight and not sclerotised. Saccus U-shaped. Phallus very long and narrow with the apex having a notch leaving a small spine. Proximal end swollen with uneven margin.

Female genitalia: Ovipositor lobes long, narrow and fringed with hairs. Posterior apophyses approximately double the length of anterior. Sinus vaginalis broad. Ostium, small with sclerotised walls. Ductus bursae short, broad and almost of uniform width. Corpus bursae more or less balloon-shaped. A short, tubular signum present.

Graphium doson **Felder (Common Jay)** (Plate XVIII, Figure 2; Plate XXVII, Figure 1)

Male genitalia: Uncus broad, rectangular, bearing two lobes on either side. Tegumen and vinculum with long narrow arms. Valvae ovate, lobe-shaped. Costa little raised, slightly convex in outline, cucullus straight and sclerotised. Harpe flattened lobe bearing four prominent spines. One pair pointing towards the ventral margin, the second pair towards cucullus and the third pair towards the costal margin. Saccular margin slightly curved. Saccus U-shaped. Phallus long with sharply pointed apex. Vesica pouch-like occurring subapically. Proximal end with a broad segment.

Female genitalia: Ovipositor short with broad lobes. Anterior apophyses longer than the posterior. Sinus vaginalis broad. Ostium wide. Ductus bursae short and wide. Corpus bursae globular and striated. Signum composed of a long, basally broad, blunt, tubular process.

Graphium agamemnon **Linnaeus (Tailed Jay)** (Plate XIX, Figure1; Plate XXVII, Figure 2)

Male genitalia: Uncus broad, ligulate, deeply invaginated in the middle forming two lateral lobes each bearing a tuft of hairs either side. Socii and

Gnathos not distinct. Tegumen and Vinculum long, almost straight with lateral sclerotisation. Juxta roughly rectangular and indented laterally. Valvae broad, more or less round. Costa straight and cucullus curved bearing numerous denticles. Harpe expanded, sclerotised and distally bearing a short blunt lobe. Sacculus broad at the distal end and tapering proximally. Saccus well developed, with a long U-shaped blunt process. Phallus very long slightly curved in the middle with a sharply pointed apex. Vesica pouch-like occurring subapically. Proximal end with a broad segment.

Female genitalia: Ovipositor lobes elongated, swollen and fringed with small hairs. Apophyses of equal size. Sinus vaginalis laterally expanded, narrow and boat-shaped. Ostium wide. Ductus bursae medium sized and of uniform width. Corpus bursae more or less globular with concentric rings. Signum composed of a pouch-like sclerotised body and another triangular process.

***Graphium nomius* Esper (Spot Swordtail)** (Plate XIX, Figure 2; Plate XXVIII, Figure 1)

Male genitalia: Uncus broad, ligulate, with a shallow invagination in the middle to form two slightly pointed lateral lobes. Socii and Gnathos not distinct. Tegumen and Vinculum with long narrow arms. Valvae short, oval with the apex slightly drawn out, costa straight with setose and bearing sclerotised patches at cucullus. Harpe composed of two basally expanded and distally pointed sclerotised spine-like processes. Sacculus broadly globular in outline. Juxta prominent. Saccus U-shaped and well developed. Phallus very long with a blunt tip, highly setosed and strongly sclerotised.

Female genitalia: Ovipositor broad and triangular. Anterior apophyses slightly longer than the posterior which has lobed endings. Sinus vaginalis narrow and short. Ductus bursae of medium length, basally swollen. Corpus bursae roughly globular and with a marginal sclerotised patch. Signum composed of a small spine-like process.

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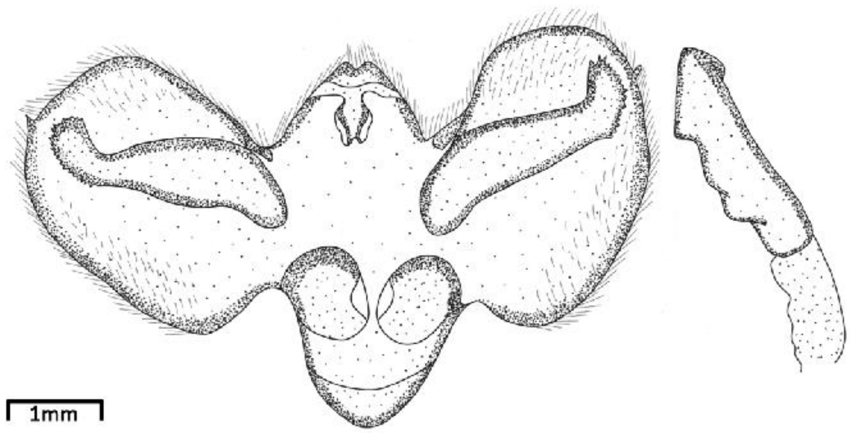

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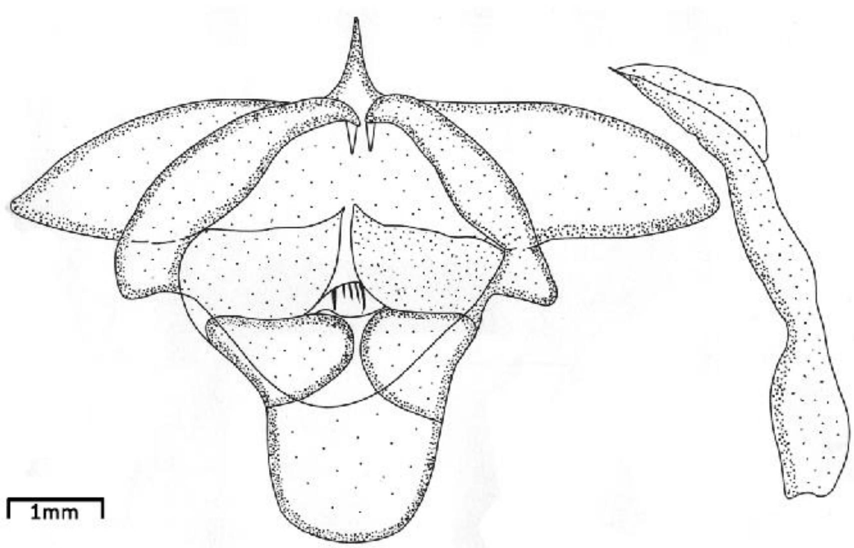

Plate XI. Figures 1-2. Male external genitalia. Figure 1. *Troides minos* Cramer; Figure 2. *Atrophaneura pandiyana* Moore

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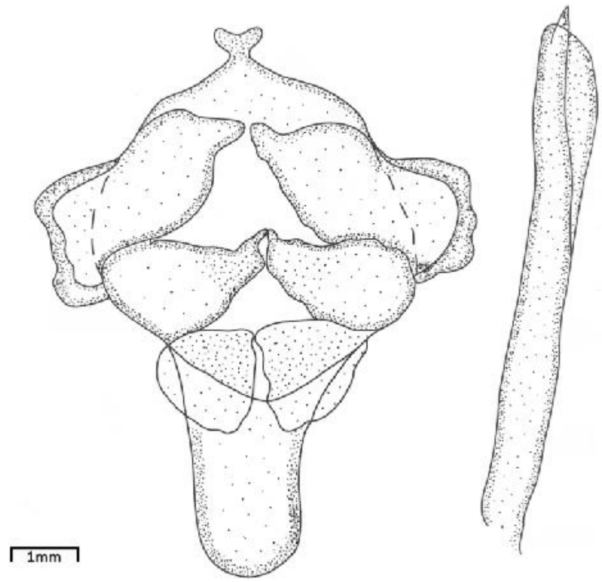

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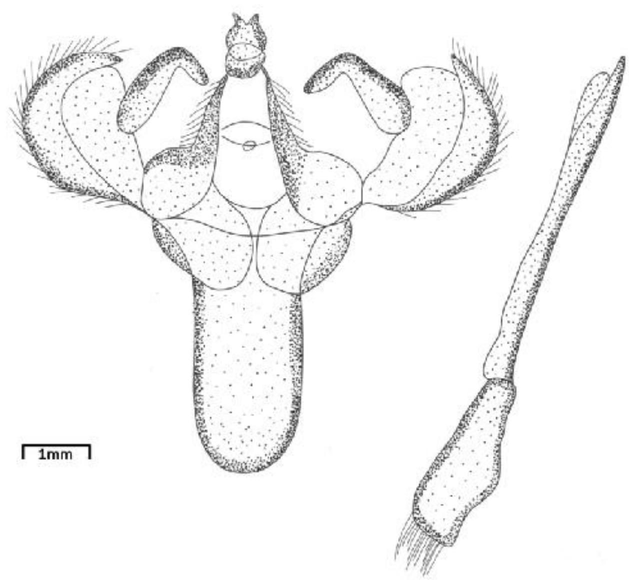

Plate XII. Figures 1-2. Male external genitalia. Figure 1. *Atrophaneura aristolochiae* Fabricius; Figure 2. *Atrophaneura hector* Linnaeus

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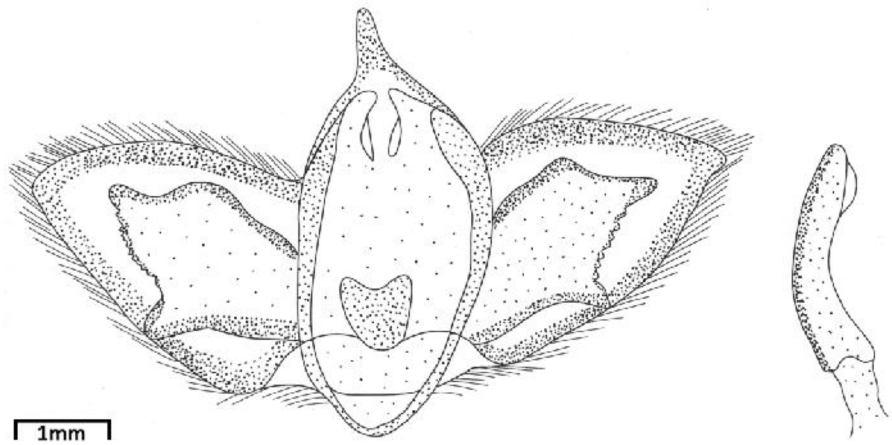

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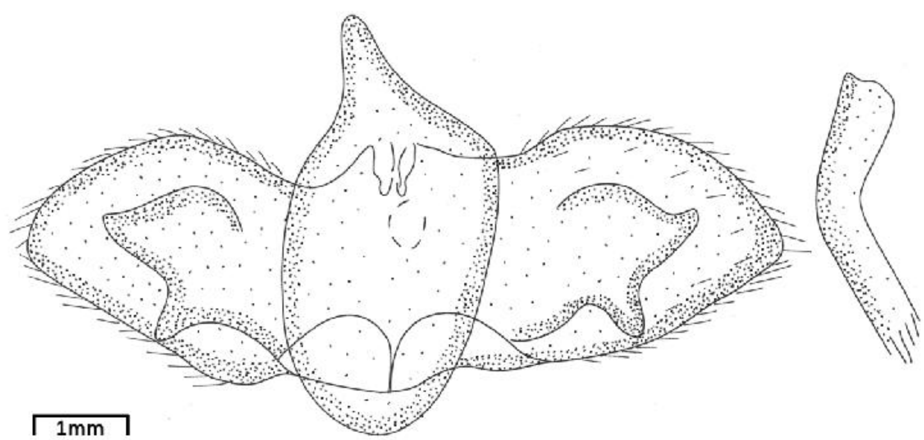

Plate XIII. Figures 1-2. Male external genitalia. Figure 1. *Chilasa clytia clytia* Linnaeus; Figure 2. *Chilasa clytia dissimilis* Linnaeus

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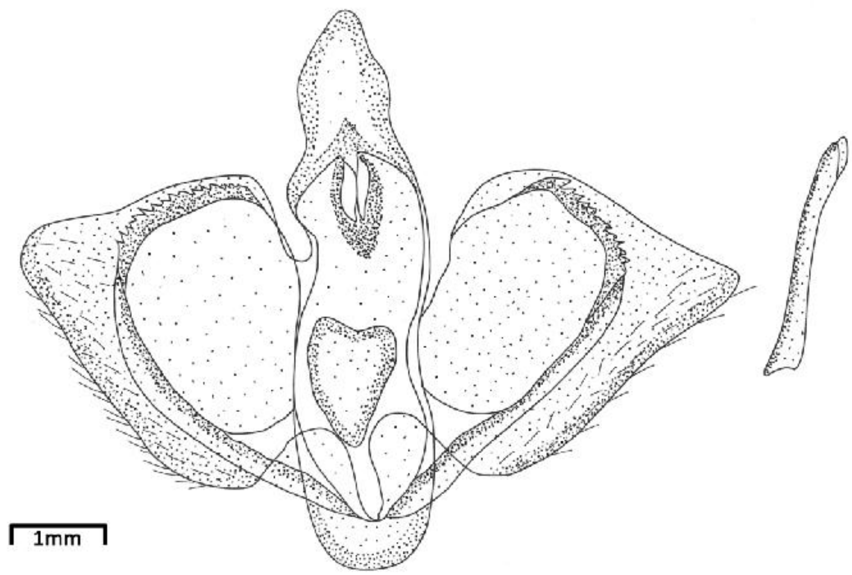

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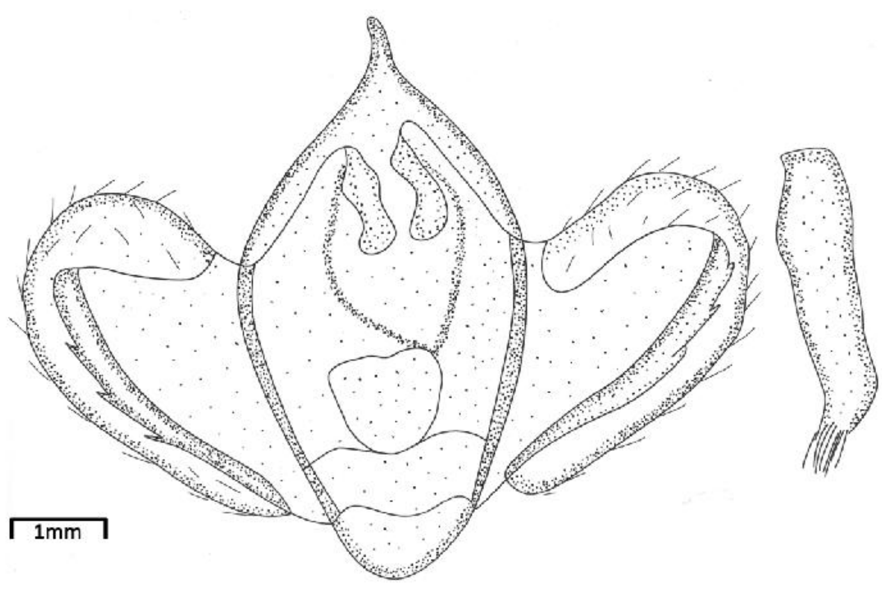

Plate XIV. Figures 1-2. Male external genitalia. Figure 1. *Papilio demoleus* Linnaeus; Figure 2. *Papilio liomedon* Moore

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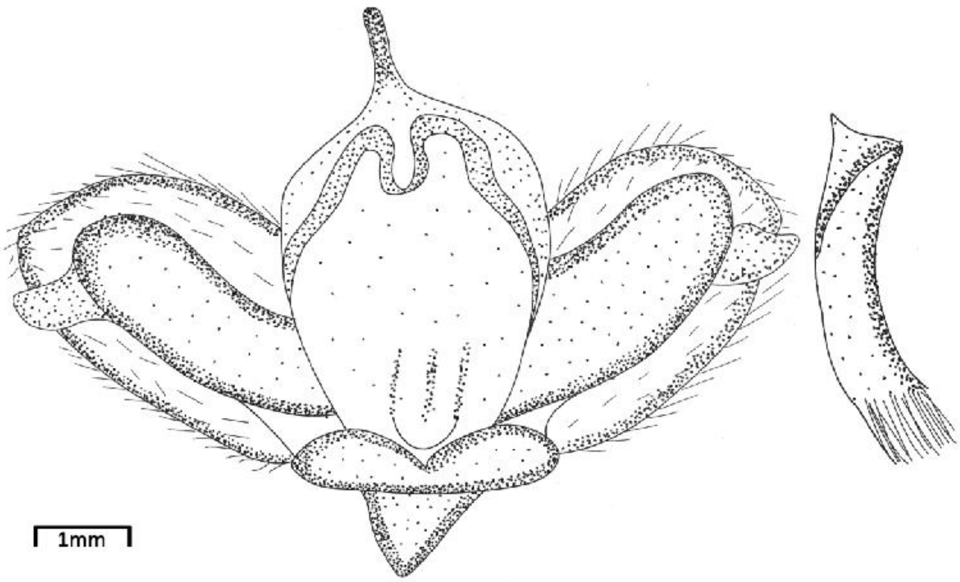

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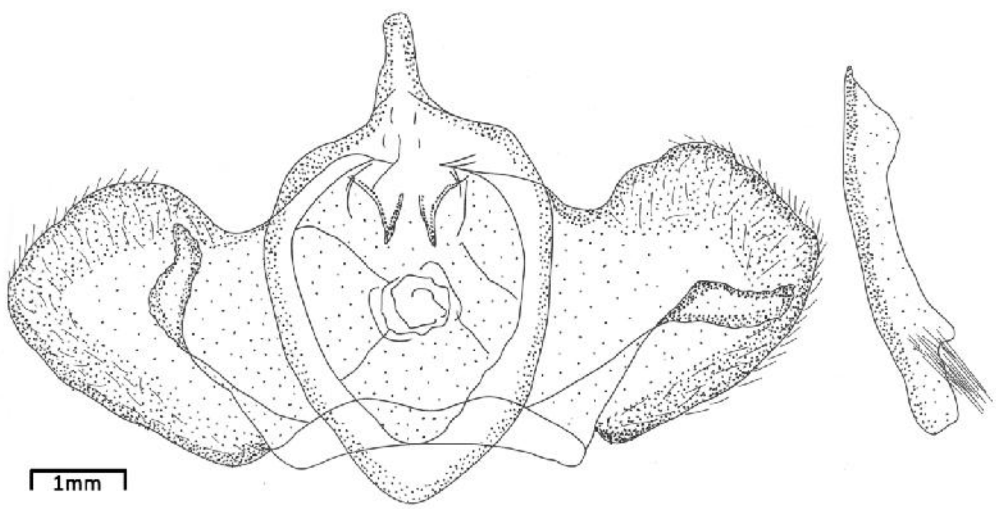

Plate XV. Figures 1-2. Male external genitalia. Figure 1. *Papilio dravidarum* Wood-Mason; Figure 2. *Papilio helenus* Linnaeus

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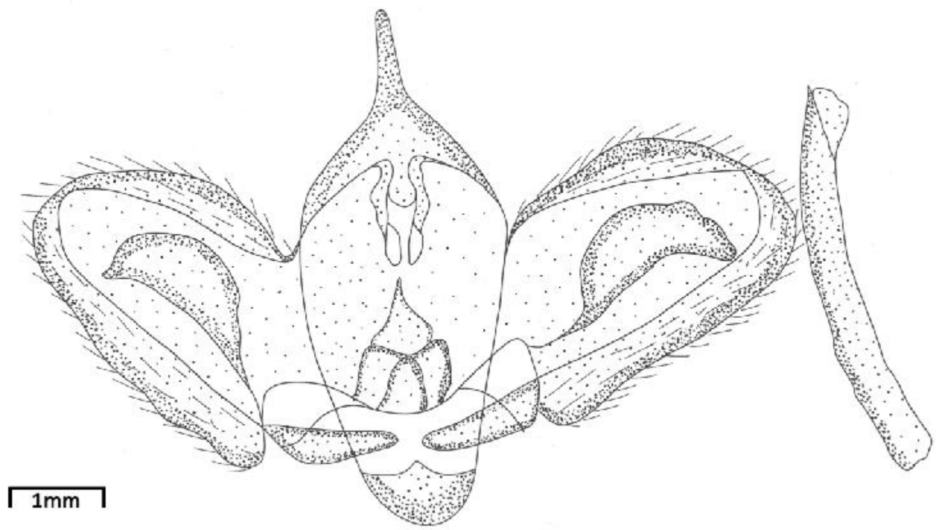

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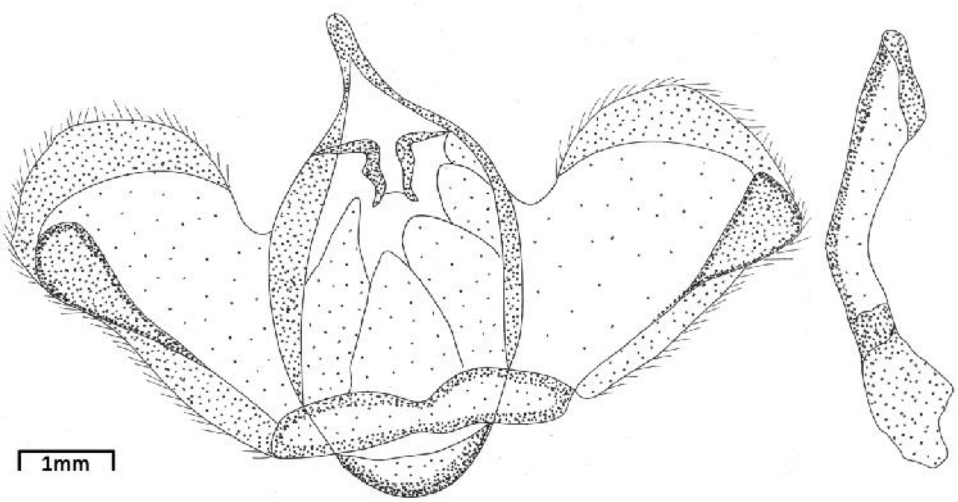

Plate XVI. Figures 1-2. Male external genitalia. Figure 1. *Papilio polytes* Linnaeus; Figure 2. *Papilio polymnestor* Cramer

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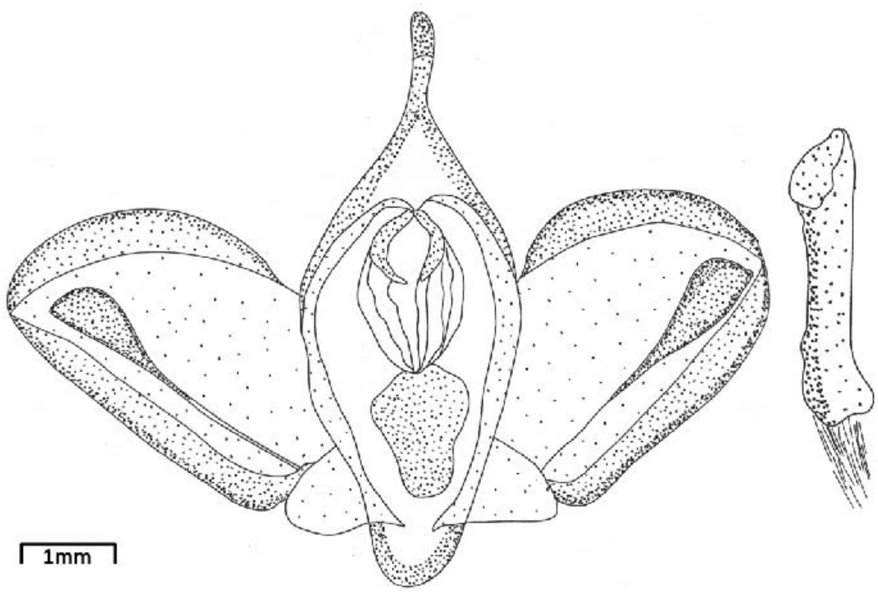

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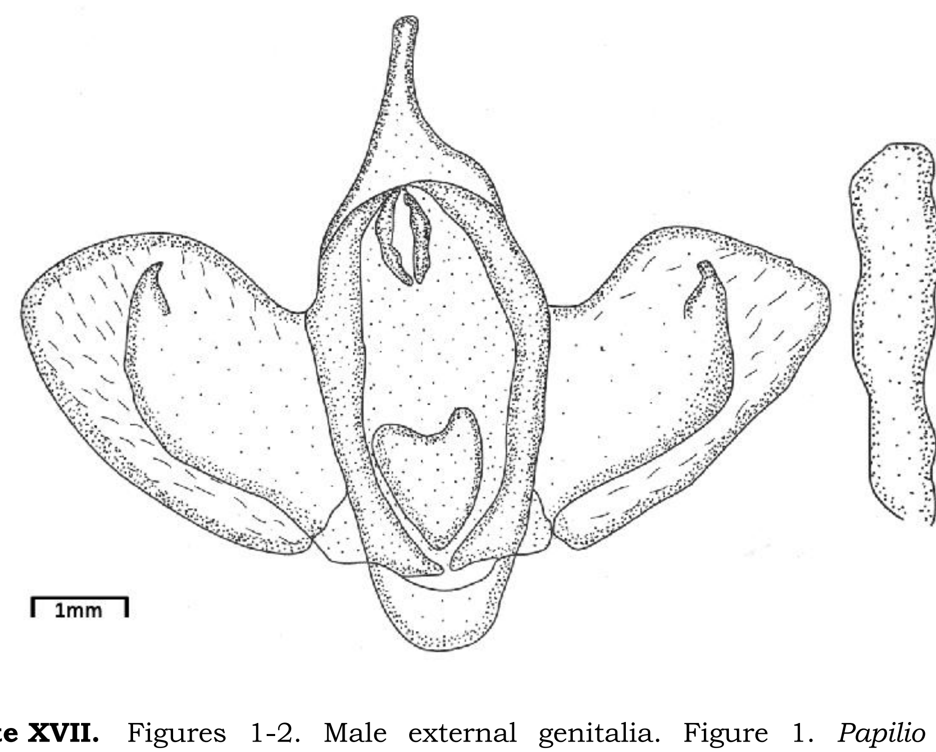

Plate XVII. Figures 1-2. Male external genitalia. Figure 1. *Papilio paris* Moore; Figure 2. *Papilio buddha* Westwood

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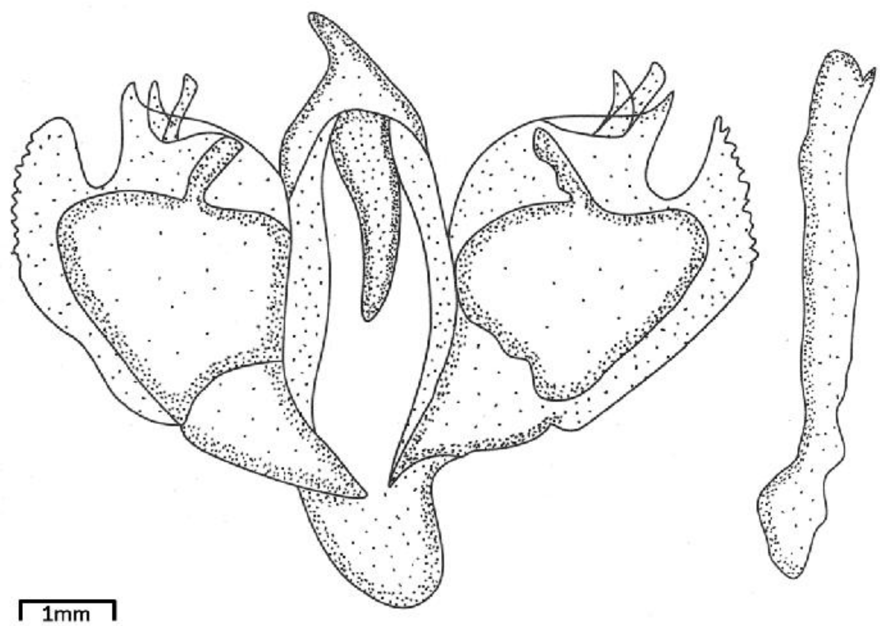

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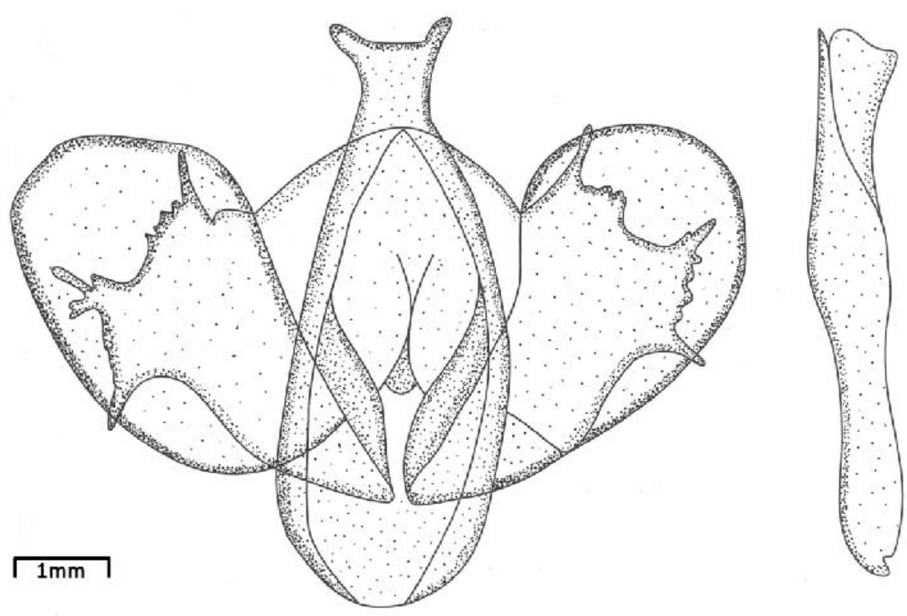

Plate XVIII. Figures 1-2. Male external genitalia. Figure 1. *Graphium sarpedon Felder*& Felder; Figure 2. *Graphium doson* Felder

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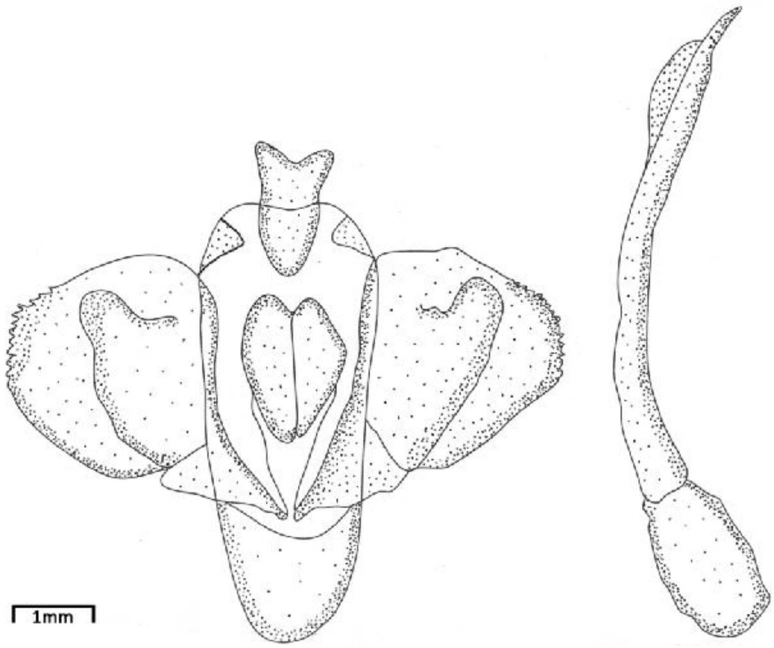

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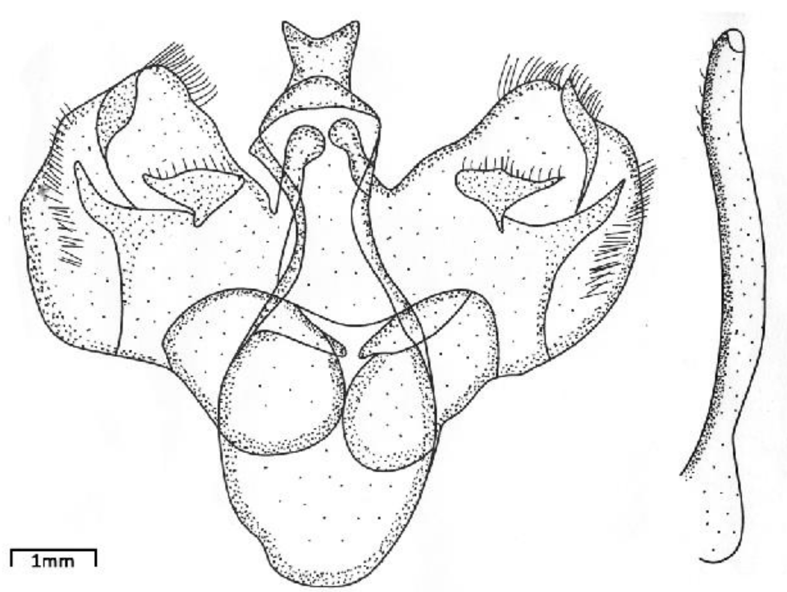

Plate XIX. Figures 1-2. Male external genitalia. Figure 1. *Graphium agamemnon* Linnaeus; Figure 2. *Graphium nomius* Esper

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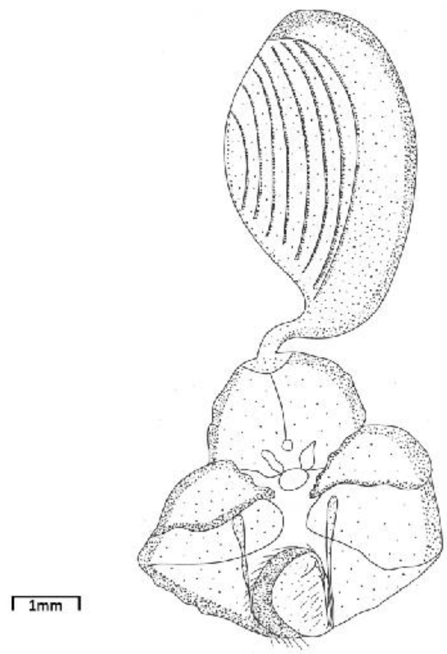

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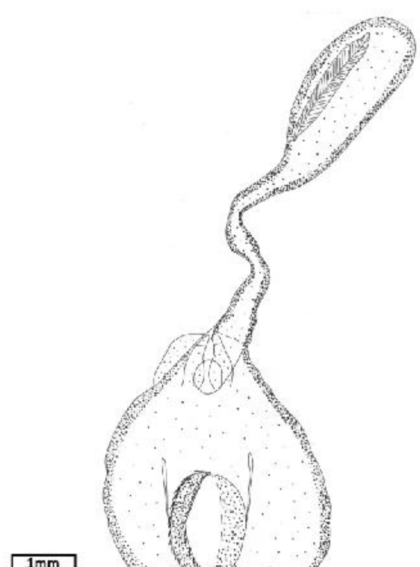

Plate XX. Figures 1-2. Female external genitalia. Figure 1. *Troides minos* Cramer; Figure 2. *Atrophaneura pandiyana* Moore

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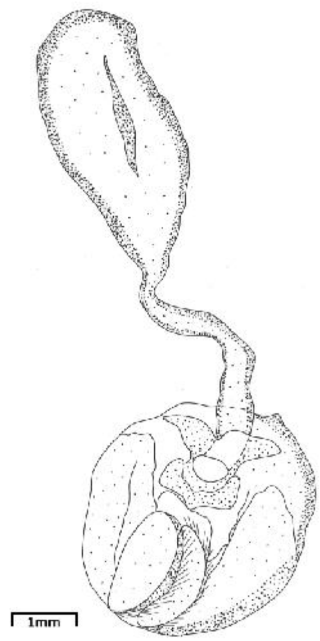

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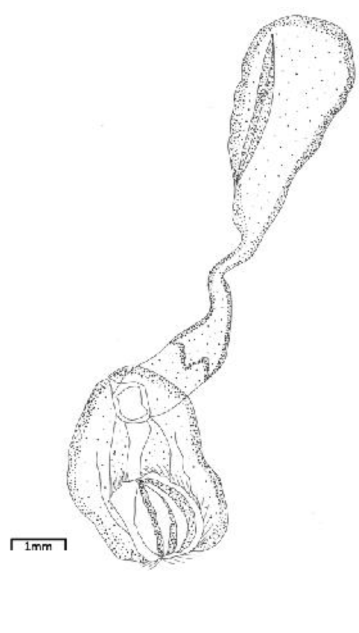

Plate XXI. Figures 1-2. Female external genitalia. Figure 1. *Atrophaneura aristolochiae* Fabricius; Figure 2. *Atrophaneura hector* Linnaeus

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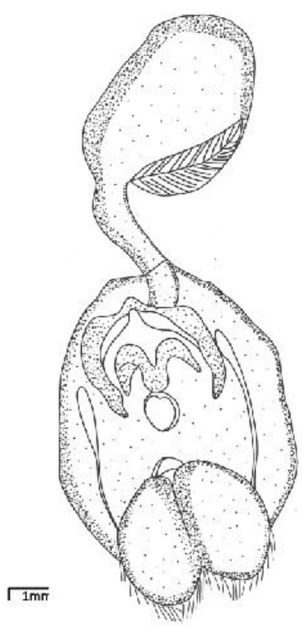

Plate XXII. Figures 1-2. Female external genitalia. Figure 1. *Chilasa clytia clytia* Linnaeus; Figure 2. *Chilasa clytia dissimilis* Linnaeus

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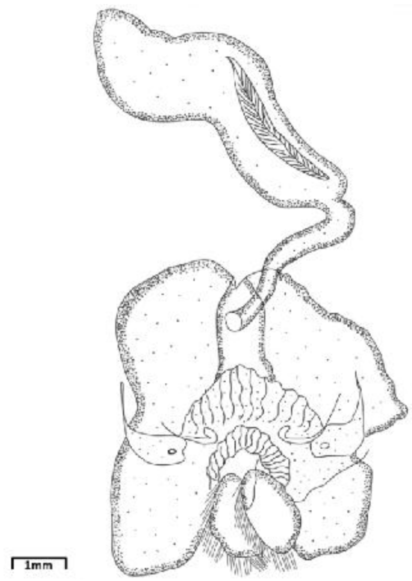

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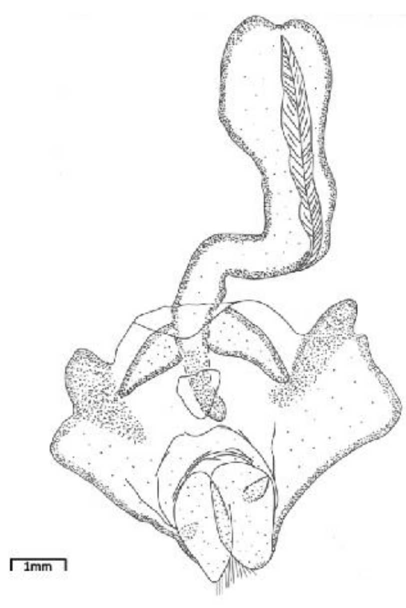

Plate XXIII. Figures 1-2. Female external genitalia. Figure 1. *Papilio demoleus* Linnaeus; Figure 2. *Papilio dravidarum* Wood-Mason

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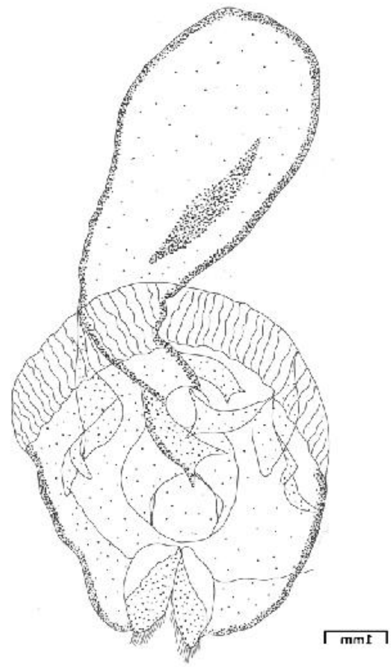

2.

Plate XXIV. Figures 1-2. Female external genitalia. Figure 1. *Papilio helenus* Linnaeus; Figure 2. *Papilio polytes stichius* Linnaeus

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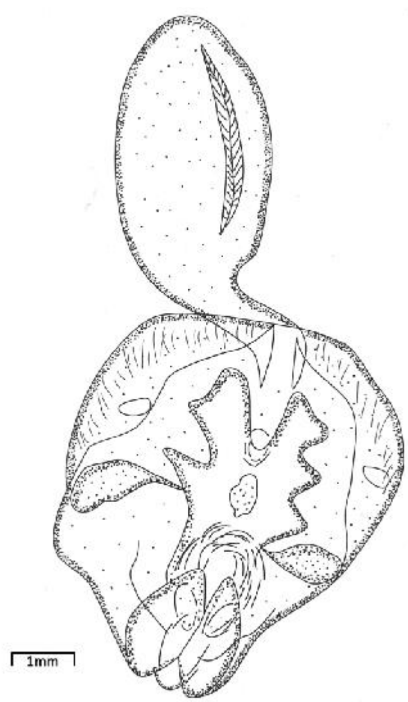

Plate XXV. Figures 1-2. Female external genitalia. Figure 1. *Papilio polytes romulus* Linnaeus; Figure 2. *Papilio polytes cyrus* Linnaeus

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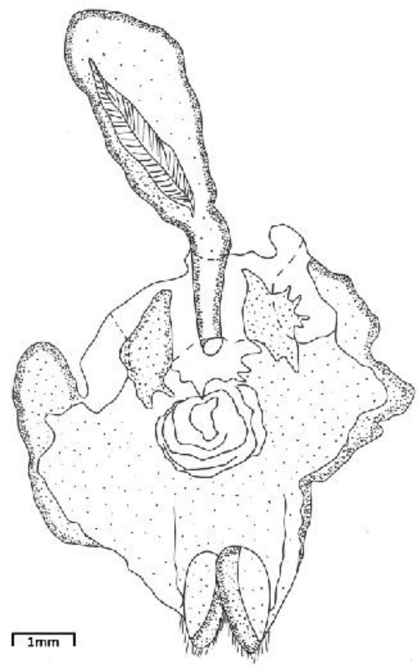

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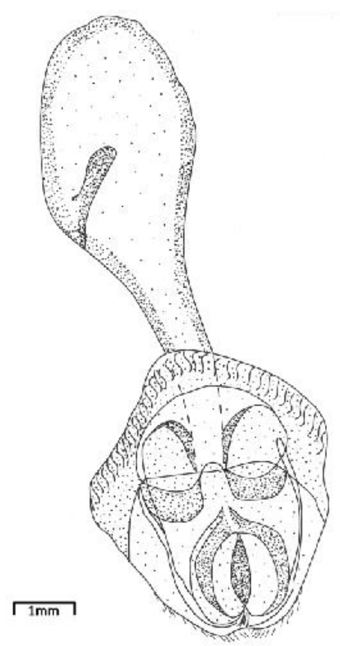
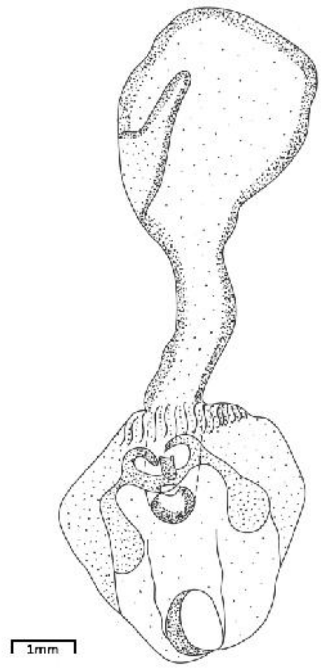


Plate XXVI. Figures 1-2. Female external genitalia. Figure 1. *Papilio polymnestor* Cramer; Figure 2. *Graphium sarpedon Felder*& Felder

1.



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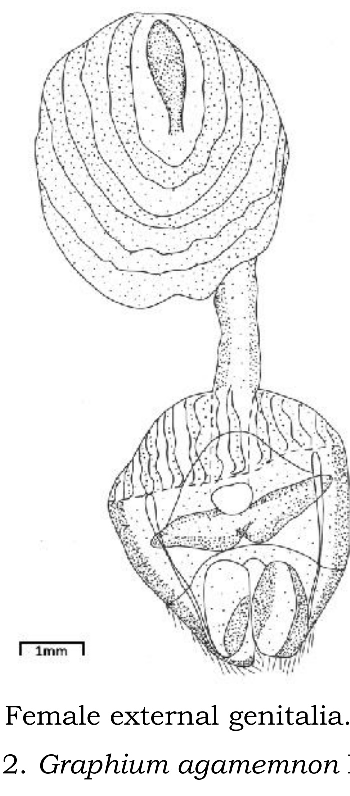

Plate XXVII. Figures 1-2. Female external genitalia. Figure 1. *Graphium doson* Felder; Figure 2. *Graphium agamemnon* Linnaeus

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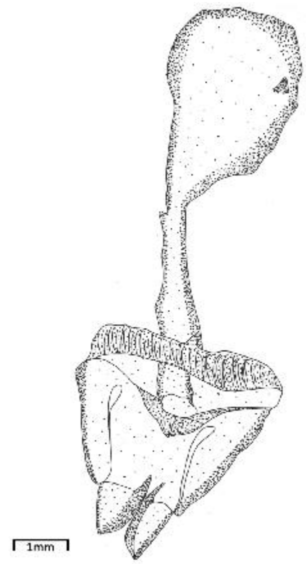


Plate XXVIII. Figure 1. Female external genitalia. Figure 1. *Graphium nomius* Linnaeus

5.1.3 Taxonomic segregation of Papilionidae using characters of the external genitalia

Current identification of butterflies belonging to this family is possible only from the original species description which is based on the colour pattern of the wings as well as the venation. In order to supplement this classification and also to find the interrelationships of various taxa, an identification key based on the morphological characters of the external genitalia was prepared and presented herein.

5.1.3.1 Key for the identification of species

Family: Papilionidae

Sub family: Papilionini

1	Uncus low with a median notch...............................	*T. minos*
-	Uncus elongate and projecting................................	2
2	Uncus conical and apically pointed..........................	*A. pandiyana*
-	Uncus not apically pointed	3

3	Uncus slender and tubular......................................	4
-	Uncus not slender and tubular; apically broad with lobes	13
4	Harpe spatulate	5
-	Harpe not spatulate	8
5	Phallus short and stout..	6
-	Phallus not short and stout	7
6	Phallus with a blunt end , lateral margins sinuous....	*P. buddha*
-	Phallus without a blunt end , lateral margins even	*P. paris*
7	Phallus bow-shaped, sub-apically broadened, apex narrow and blunt	*P. polymnestor*
-	Phallus sharply pointed at the apex	*P. polytes*
8	Harpe broad, flattened and lobate	9
-	Harpe not broad and lobate, but variously produced .	10
9	Valvae ovate; phallus curved in the middle...............	*C. clytia*
-	Valvae notched and dentate; phallus elongated	*G. sarpedon*
10	Valvae dome-shaped; phallus slender	*P. demoleus*
-	Valvae not dome-shaped; phallus not slender...........	11
11	Harpe finger-shaped...	*P. helenus*
-	Harpe not finger-shaped..	12
12	Harpe swollen, thumb-shaped with an apical lobe.....	*P. dravidarum*
-	Harpe elongated and dentate on one side	*P. liomedon*
13	Saccus long, blunt finger-shaped.............................	14
	Saccus not long, not blunt and finger-shaped	15
14	Uncus short and bilobed	*A. aristolochiae*
-	Uncus bulbous, notched and with two small lateral lobes	*A. hector*
15	Harpe with an expanded lobe having irregularly dentate margins...	*G. doson*
-	Harpe without irregularly dentate lobes	16
16	Harpe with a blunt apical process............................	*G. agamemnon*
-	Harpe with a conical lobe and another triangular two pronged, spinuous process	*G. nomius*

5.1.4 Phenetic analysis

UPGMA clustering based on average taxonomic distances and the total species clustering is shown in Plate 29. Despite the absence of strict rules to determine the number of clusters, the cluster pattern itself is informative and the cluster analysis showed a good clustering pattern among species with a co-phenetic correlation (r) of 0.94. The dendrogram consisted of two primary clusters at a dissimilarity coefficient of 1.49 and the outgroup (Pieridae) differs from all other groups.

The first primary cluster (A) was subdivided into two sub- clusters (A1, A2) and second primary cluster (B) consisted of four sub-clusters (B1, B2, B3, B4). In Cluster A, the first sub cluster (A1) consisted of *G. sarpedon, G. agamemnon, G. doson* and *G. nomius* at a taxonomic distance of 1.24. In this cluster, *G. sarpedon* was closely related to *G. agamemnon* which was allied to *G. doson* and then to *G. nomius.* The second sub cluster (A2) included *Atrophaneura* group at a dissimilarity coefficient of 0.79 and the species consisted of *A. pandiyana, A. aristolochiae* and *A. hector*. Among these, *A. aristolochiae* and *A. hector* were closely related than *A. pandiyana.* The second primary cluster (B) included four sub clusters. The first sub cluster (B1) consisted of most of the members of the *Papilio* group at a dissimilarity level of 1.08. It included *P. liomedon, P. paris, P. buddha, P. helenus, P. polytes* and *P. polymnestor*. *P. paris* and *P. buddha* showing 100 % similarity in this cluster. The second sub cluster (B2) consisted of *P. demoleus* and *P. dravidarum* at a dissimilarity coefficient of 0.98. The third (B3) and fourth (B4) sub clusters consisted of single individuals *viz., C. clytia* and *T. minos*, respectively.

Principal Coordinate Analysis (PCoA) summarised the phenetic relationships between the taxa (Plate 30). The Pieridae group were scattered in the right and upper part of the phenetic space. *Atrophaneura* group lie in the lower and left part of the phenetic space. *A. hector* and *A. aristolochiae* were closer than *A. pandiyana* reflecting morphological similarities of uncus, harpe and phallus. *G. agamemnon, G. doson, G. sarpedon* and *G. nomius* were seen on the left upper part of the phenetic space. *G. nomius* was sharply separated from the other members of the *Graphium* group reflecting the contrast between the shape of phallus and presence of prominent signum. The right and middle part of the phenetic space consisted of *P. demoleus, P. dravidarum, P. buddha, P. paris, T. minos, C. clytia, P. polymnestor, P. polytes, P. helenus, P. liomedon. T. minos* and *C. clytia* which were seen in intermediate positions closer to *Papilio* group. Although *T. minos* and *C. clytia* do not overlap, there was very little separation between them reflecting the differences in overall size. The clusters of *P. buddha* and *P. paris* as well as *P. demoleus* and *P. dravidarum* were found to be closely overlapped. Orientation allowed almost the same pattern of relationships corresponding to cluster analysis.

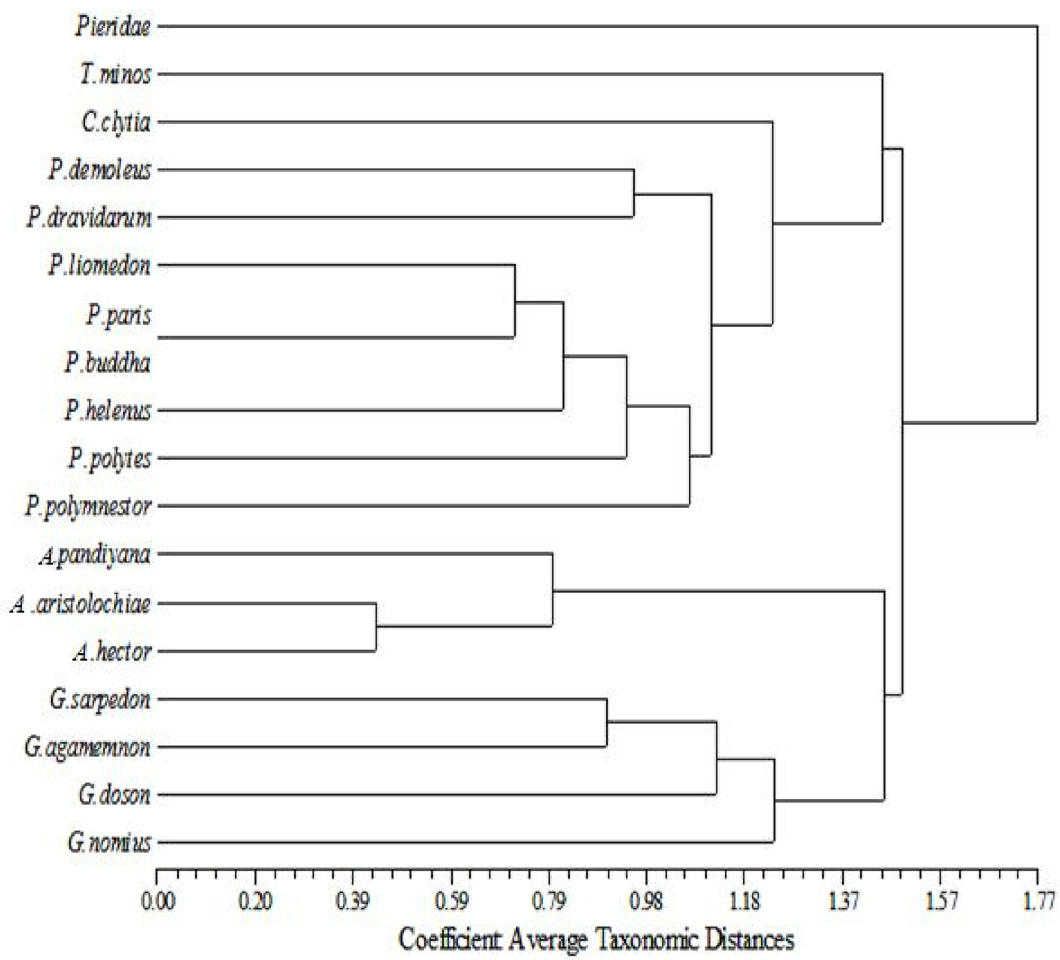


Plate XXIX. Figure 1. UPGMA dendrogram based on the features of male and female external genitalia of 17 species of Papilionid butterflies (Cophenetic correlation coefficient (r) = 0.94.

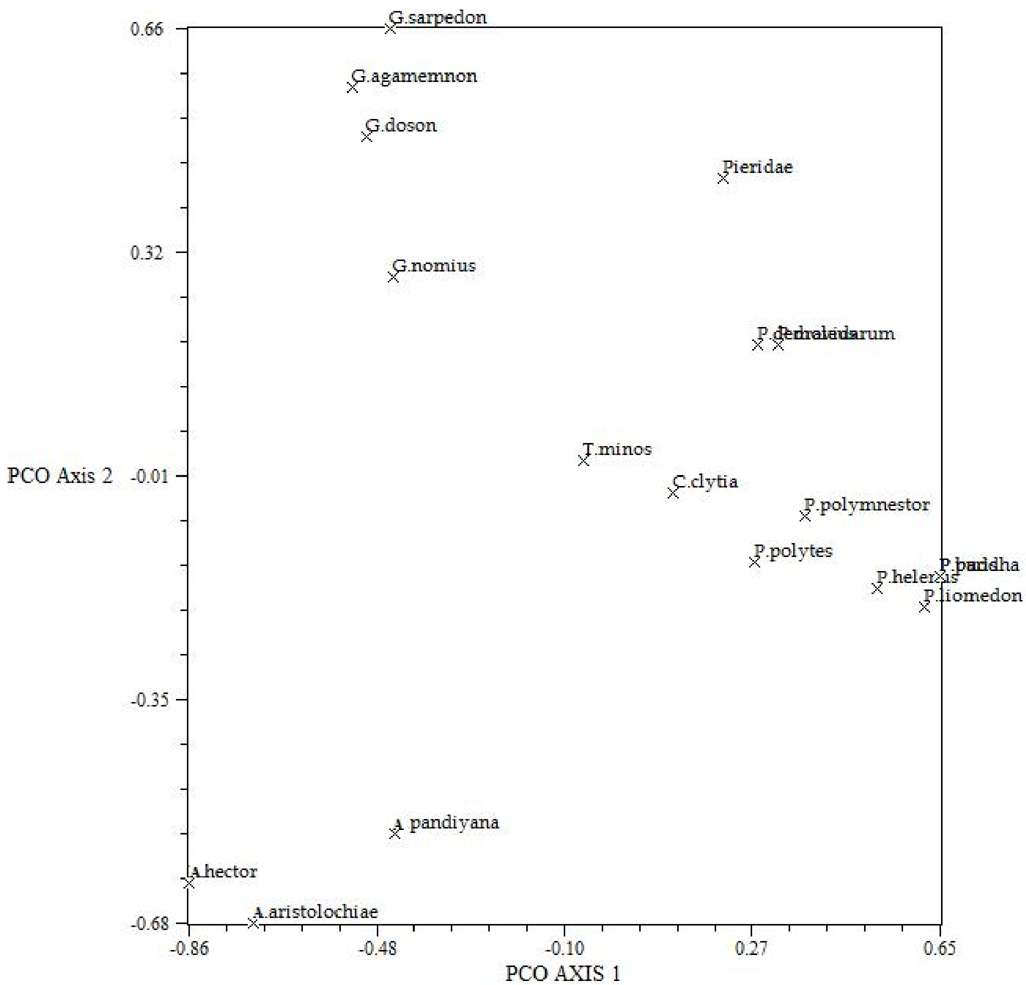


Plate XXX. Figure 1. Two-dimensional scattergram of 17 species of Papilionid butterflies from the Principal co-ordinate analysis (PCoA) showing species groupings.

5.1.5 Phylogenetic analysis

Analysis using forty three characters have yielded six equally parsimonius trees of 150 steps, with Consistency Index of 0.52 and Retention Index of 0.61. One of the most parsimonious tree is shown in Plate 31. Percentage of bootstrap support of the clades have been reported when ≥ 50 %. This was almost consistent with phenetic dendrogram. In the strict consensus (Plate 32), Papilionidae formed a well supported group, monophyletic with respect to Pieridae clade and received 100 % bootstrap support.

In strict consensus tree, *T. minos* which formed the basal clade, was supported by eight genitalic characters including one synapomorphic character *ie.,* shape of uncus. Other characters were the shape of sacculus, features of corpus bursae, ductus bursae, signum and one larval feature, including the oviposition nature. *C. clytia,* which has branched off from the basal lineage was characterised by two unique synapomorphies, *ie.,* the presence of clubbed posterior apophyses and the colour of pupa and other features including the shape of phallus, harpe, gnathos, longitudinal ridges on eggs and adult wingspan. The basal clade of the genus *Papilio* was formed by *P. demoleus*. *P. dravidarum* was distinguished by the shape of phallus, the presence of juxta and the shape of anal papillae. The *P. demoleus* clade was a sister clade of other *Papilios* which was characterised by one synapomorphy, *ie.,* the position of signum. In addition, the group was supported by the shape of harpe and sacculus. The clade of other *Papilios viz., P. polymnestor, P. helenus, P. polytes, P. liomedon, P. buddha* and *P. pari*s shared one unique synapomorphy- the length of posterior apophyses. The other apomorphic characters included the shape of harpe, length of ductus bursae, and shape of anal papillae. Within this group, *polymnestor* branched off in the basal position based on the features of uncus and phallus. The clade then splitted into two sister groups based on the characters of gnathos and the presence of a tail on the hindwing. One sister group included *helenus* and *polytes* and the other clade included *liomedon, paris* and *buddha*. *P. helenus* was distinguished by the shape of phallus, juxta, corpus bursae and signum. *P. paris* and *P. buddha* were sharing two common characters, presence of thoracic tubercles and body rings with similar polarity, formed the sister clades.

Another clade splitted into *Atrophaneura* group and *Graphium* group with 59% of bootstrap support. They shared six characters including one synapomorphic character *ie.,* the size of the saccus. The *Atrophaneura* group was again splitted into *pandiyana* and *hector-aristolochiae* sister clades with 86% of bootstrap support. They were characterised by two genitalic characters and two larval features. *A. pandiyana* has diverged on the basis of a unique character, the pointed uncus. *A. aristolochiae* and *A. hector* were sister clades with 94 % bootstrap value. The *Graphium* group was characterised by one genitalic character and three larval features. The three species (*G. sarpedon, G. doson, G. nomius*) shared one synapomorphy, *ie.*, the presence of hairs on the anal papillae. *G. agamemnon* has branched off from the other three members of *Graphium* on the basis of the presence of distinct juxta and characteristic shape of corpus bursae.

Thus, the phenetic and phylogenetic analysis of various species has shown that all the Papilionids studied herein formed a well differentiated clade indicating the monophyletic nature of Papilionidae. In strict consensus, *T. minos* formed the basal clade, *A. aristolochiae - A. hector* and *P. paris - P. buddha* formed the sister clades and *A. pandiyana* diverged from rest of the *Atrophaneura*.

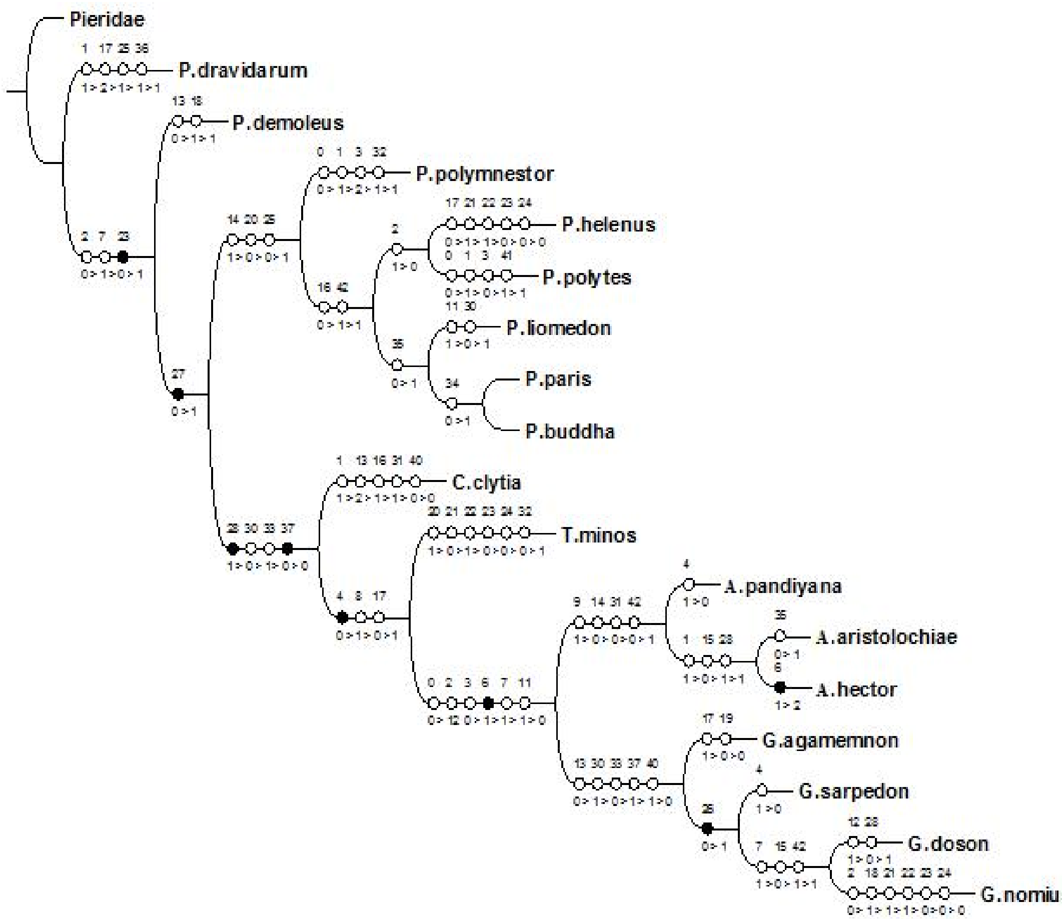


Plate XXXI. Figure 1. One of the six equally parsimonious trees (Length 150, CI 0.52, RI 0.61) chosen at random; Apomorphic characters are black and Plesiomorphic characters are white. Numbers above the branches refer to characters, numbers below branches to character states.

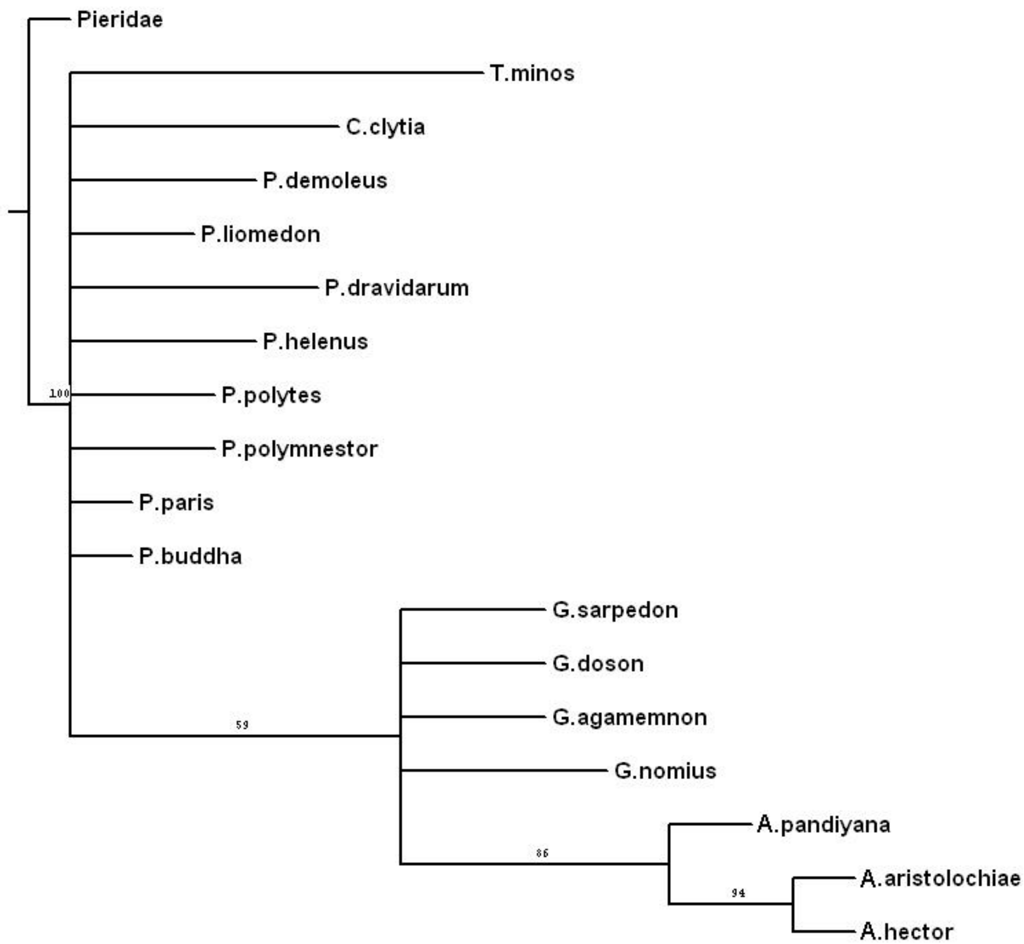


Plate XXXII. Figure 1. Strict consensus tree of the six equally most parsimonious tress derived from the analysis of the 17 species of Papilionidae butterflies. Bootstrap support are shown above the nodes.

5.2. Biological studies

Butterflies have complete metamorphosis and the life history strategy of each species tends to represent an optimum use of resources in climate which are seasonally variable and which may restrict periods of activity. Information on the biology of butterflies is essential in conservation programmes. Biology of

13 species of Swallowtails *viz., Troides minos, Atrophaneura aristolochiae, A. hector, A. pandiyana, Papilio helenus, P. dravidarum, P. polymnestor, P. demoleus, P. polytes, Chilasa clytia, Graphium agamemnon, G. doson* and *G. sarpedon* has been worked out. Data pertaining to the duration of various instars, mean incubation period, larval features, pupal characters and adult features, coloration and behaviour was recorded. The results of one-way analysis of variance and Duncan's Multiple Range Test are given in Appendix III, IV, V. In all species, there was significant difference in length and breadth between the species at 1% level.

5.2.1 Descriptions of each instar of different species

Descriptions of the immature stages are presented below and the adult descriptions are given in the previous chapters.

***Troides minos* Cramer.** (Tables 1, 2; Plate XXXIII)

Eggs: Eggs are bright orange in colour. They were collected from host plants *Aristolochia indica, A. tagala* and *Thottea siliquosa.* The colour gradually fades and become brownish orange prior to hatching. They are spherical, smooth and are laid singly. The size size varies from 1.5 to 2.0 mm in diameter. The mean incubation period is 7.88 (± 9.64) days.

Larva: There are five larval instars. The duration of various instars are presented in Table 1. Detailed description of each instar is given below.

First instar larva: It measures about 7.7 (± 0.48) mm in length and 3.4 (± 0.84) mm in width. Body is brownish black in colour which changes to deep brown in colour as the growth progresses. Abdominal and thoracic segments bear pale orange in coloured tubercles. The newly emerged larva feeds on the egg shell and in most cases it is completely eaten. Initially, larva feed exclusively on young tender foliage leaving small circles. At the end of the instar, the larva become less active and when alarmed due to any movement in the leaves, the larva raised their heads and osmetarium and moved sideways.

Second instar larva: It measures about 16.8 (± 0.78) mm in length and 5.3 (± 0.48) mm in width. Body is deep blackish brown with more prominent tubercles and the dorsal tubercles of the fourth abdominal segment are reddish orange with tips darker. Towards the end of the instar, the larva attaches itself to a leaf or to the sides of the container and spins a moulting mat and undergo moulting.

Third instar larva: It measures about 23.10 (± 1.1) mm in length and 7.2 (± 0.79) mm in width. Body colour change to dark maroonish with darker tubercles bearing orange tips. The dorsal tubercles of the fourth abdominal segment and the lateral tubercles of the third abdominal segments are reddish orange with their tips darker. Upto the third instar, larva requires young leaves while later instars utilize mature leaves.

Fourth instar larva: There is an increase in length of 38.70 (± 1.34) mm in length and 11 (± 0.82) mm in width. Body colour is black with the tip of the tubercles orange in colour. The duration of this instar is 8 days. Late fourth instar larva show a preference for the bark of the host plant.

Fifth instar larva: Reaches a maximum of 59.80 (± 1.81) mm in lengths and 17 (± 0.82) mm in widths. The larva turns dull black in colour and the black coloured patterns on the body become more prominent.

Table 1. A comparison of larval instars of *Troides minos*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	7-8	7.7	0.48	2-4	3.4	0.84
Second instar	16-18	16.80	0.78	5-6	5.3	0.48
Third instar	22-25	23.10	1.1	6-8	7.2	0.79
Fourth instar	37-41	38.70.	1.34	10-12	11	0.82
Fifth instar	57-62	59.80	1.81	16-18	17	0.82

* *SD: Standard deviation*

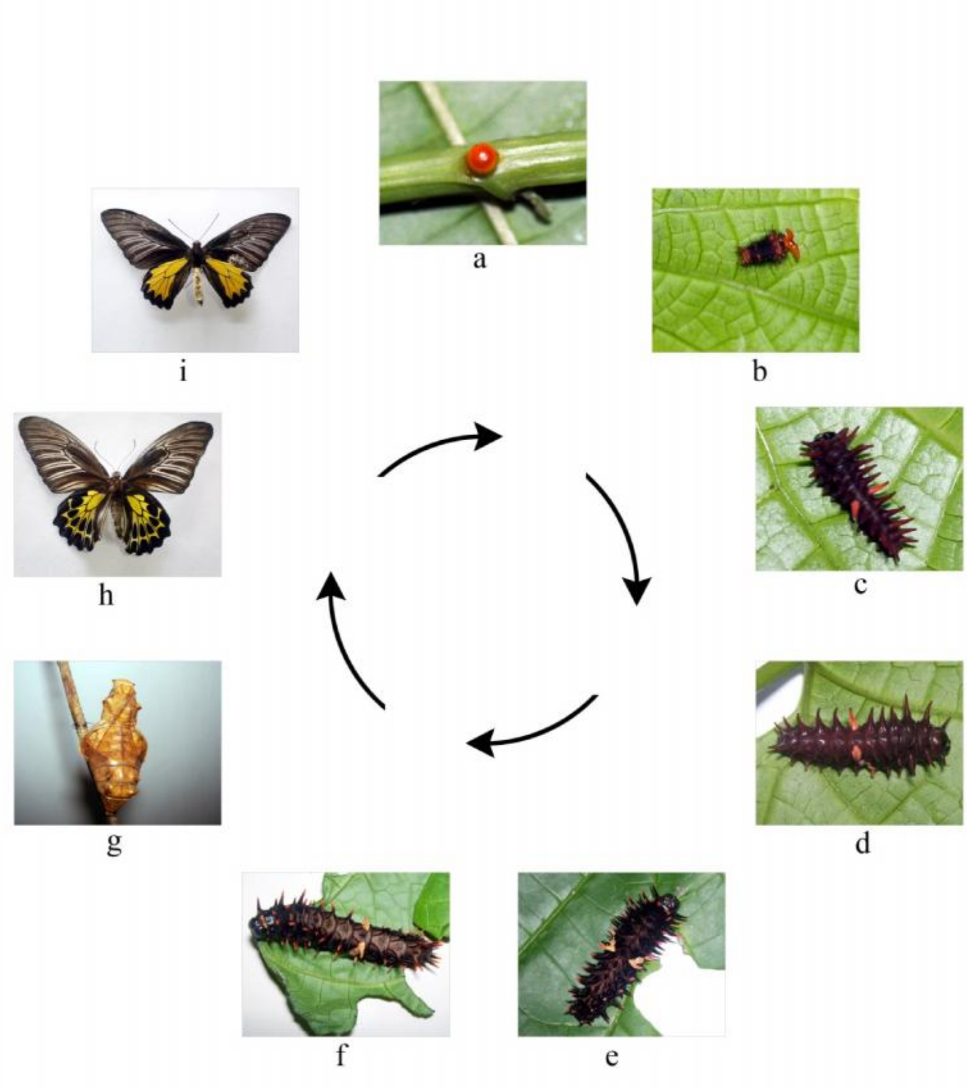


Plate XXXIII. Figures a-i. Life cycle of *Troides minos* Cramer. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h-i. adult

Pupa: The approximate length of the pupa is 20-24 mm and the pupal duration extend upto 24(± 0.76) days. The pupa is yellowish brown in colour and the whole body is reticulated with brown markings. The thoracic and abdominal segments have numerous pointed teeth-like projections and it produces a distinct sound when disturbed.

Life cycle: The life cycle of *T. minos* takes about two months for completion. The duration of various stages is given in Table 2.

Table 2. Duration of various life history stages in *Troides minos*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	7-9	7.88	0.64
Larva	10	30-34	32.13	1.25
Pupa	10	23-25	24	0.76
Duration (egg – adult)	10	55-58	56.38	1.19

*N: No. of individuals reared; ^*SD: Standard deviation*

***Atrophaneura aristolochiae* Fabricius** (Tables 3, 4; Plate XXXIV)

Eggs: Eggs are spherical, brick red in colour, measuring 1-2 mm in diameter. They are round in shape and flattened at the base. The eggs are laid singly on the underside of tender leaves as well as on the tender shoot. In field conditions a gravid female may lay 8-10 eggs at a time on different leaves of the host plant within a time span of 5 minutes. In the absence of suitable tender leaves, the females prefer to oviposit on tender shoots. Eggs are collected from *Aristolochia indica, A. tagala* and *Thottea siliquosa.*The mean incubation period is 4.43 (± 0.53) days.

Larva: There are five larval instars. The duration of various instars are presented in Table 3. Detailed description of each instar is given below.

First instar larva: The first instar larva grows up to a maximum length of 4 (± 0.67) mm with 0.5 mm in width. The freshly emerged larva is pale brownish red in colour with faint blackish markings and with minute pale orange coloured fleshy spines on the body.

Second instar larva: The larva grows up to a maximum length of 8 (± 1.24) mm and the body width measures 2.3 (± 0.48) mm. The body is brownish black bearing 12 pairs of fleshy spines on the dorsal and lateral sides. The spines are brownish red in colour with the dorsal spines longer than the lateral ones. In the 6th segment, the paired dorsal and lateral spines are joined on either side by a white line. As the growth progresses, the larva grows bigger and bigger with the fleshy spines becoming more prominent.

Table 3. A comparison of the larval instars of *A. aristolochiae*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	3-5	4	0.67	0.5-0.5	0.5	0
Second instar	6-10	8	1.24	2-3	2.3	0.48
Third instar	12-14	13.20	0.79	4-6	4.9	0.74
Fourth instar	26-29	27.20	1.03	6-8	7.2	0.63
Fifth instar	34-39	35.80	1.55	8-10	8.9	0.74

**SD: Standard deviation*

Table 4. Duration of various life history stages in *A. aristolochiae*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.43	0.53
Larva	10	22-24	23.25	0.71
Pupa	10	14-15	14.38	0.52
Duration (egg – adult)	10	36-38	37.2	0.79

*N: No. of individuals reared; ^*SD: Standard deviation*

Third instar larva: The larva grows to a maximum of 13.20 (± 0.79) mm in length and 4.9 (± 0.74) mm in width. Body is velvety red and covered with 12 pairs of spines. The dorsal spine measures 2 mm and lateral spine 1 mm in length. On the 6th segment, white line has 1mm in thickness.

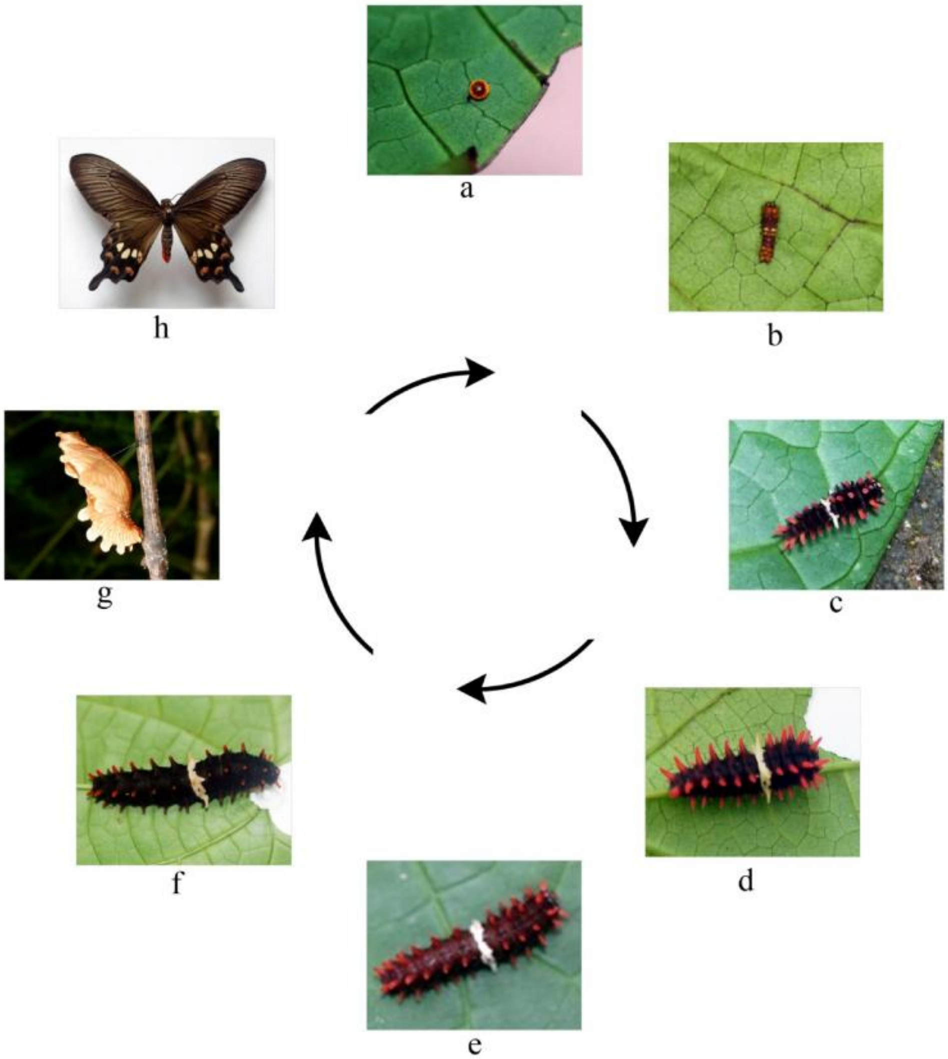


Plate XXXIV. Figures a-h. Life cycle of *Atrophaneura aristolochiae* Fabricius. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h. adult

Fourth instar larva: The larva attains a maximum length of 27.20 (± 1.03) mm and 7.2 (± 0.63) mm in width. The larva has a dark velvety black body with fleshy spines, crimson red at the upper portion and black at the basal half. The dorsal and lateral spines of the 6th segment are creamy white in colour and are joined both dorsally and laterally by thick white lines. All the spines become more prominent and increase in thickness during this instar.

Fifth instar larva: The larva attains a maximum of 35 .80 (± 1.55) mm in length and 8.9 (± 0.74) mm in width. The larval body is dark velvety black with fleshy spines which are bright reddish in colour.

Pupa: It is light brown in colour with a mixture of white, orange and dark brown markings on the dorsal side. The ventral side is light brown with faint white stripes. The anterior end of the pupa is produced into a frontally flattened broad projection, which further had a pair of flattened flaps on either lateral side. The pupa measures 22 mm in size and the pupal duration lasts for 14.38 (± 0.52) days.

Life cycle: The life cycle is completed within 37.2 (± 0.69) days under laboratory conditions. The duration of various stages is given in Table 4.

Atrophaneura hector **Linnaeus** (Tables 5, 6; Plate XXXV)

Eggs: The eggs are laid singly on the lower surfaces of tender leaves of *A. indica, A. tagala* and *Thottea siliquosa.* Six to eight eggs are laid in a sequence, preferably on different leaves. Eggs are round, with longitudinal ridges extending from base to apex. They are orange red in colour and 1-2 mm in diameter. The eggs hatch in about 4.43 (± 0.53) days and the larva has five instars.

Larva: The duration of various instars is presented in Table 5. Detailed description of each instar is given below.

First instar larva: The larva measures as 5 (± 0.82) mm in length and 1mm in width. It is reddish brown in colour and has several spines of orange red colour. The first instar lasts for 2–3 days.

Second instar larva: Larva grows upto 12.6 (± 0.84) mm in length and 3.6 (± 0.52) mm in width. The spines of the body is orange in the middle segments and spines also begin to appear on other segments of the body.

Third instar larva: Larva grows upto 22.70 (± 0.82) mm in length and 5 (± 0.53) mm in width. A pair of red stripes is present on the ventral side of the body between the last thoracic and first abdominal segment. During this stage, the colours of the spines on the body turn dark orange. This stage lasts for 3-4 days.

Table 5. A comparison of the larval instars of *A. hector*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-6	5	0.82	1-1	1	0
Second instar	12-14	12.60	0.84	3-4	3.6	0.52
Third instar	22-24	22.70	0.82	5-6	5.5	0.53
Fourth instar	27-28	27.40	0.52	6-7	6.7	0.48
Fifth instar	40-43	41.60	1.08	10-11	10.4	0.52

**SD: Standard deviation*

Table 6. Duration of various life history stages in *A. hector*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.43	0.53
Larva	10	21-23	21.83	0.75
Pupa	10	13-15	14.17	0.75
Duration (egg – adult)	10	35-37	36	0.63

*N: No. of individuals reared; ^*SD: Standard deviation*

Fourth instar larva: The larva grows to 27.50 (± 0.52) mm in length and 6.7 (± 0.48) mm in width. There is no change in physical appearance of the larva except that the body is dark brownish black in colour with bright crimson spots. This stage lasts for about lasts 4–5 days.

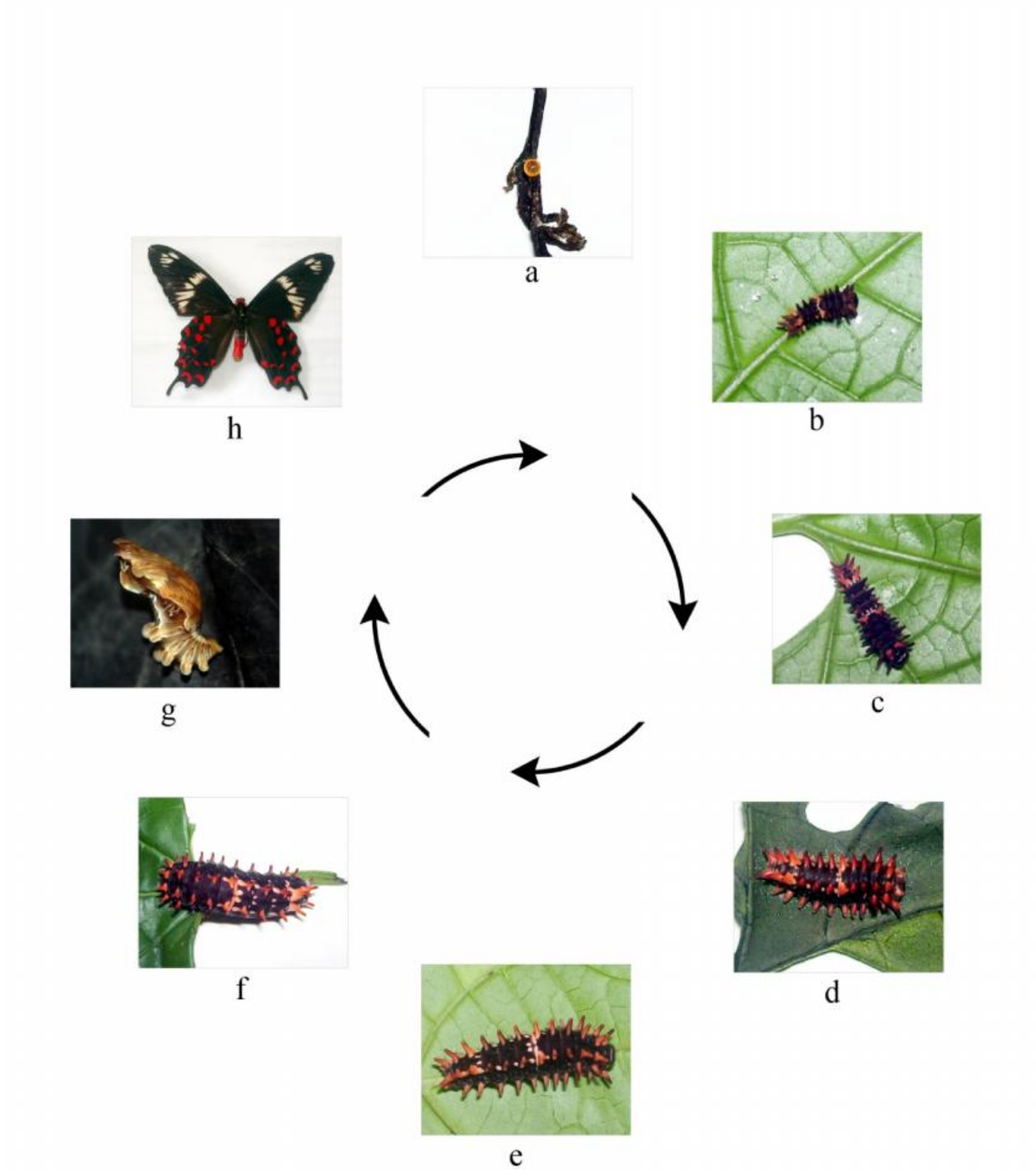


Plate XXXV. Figures a-h. Life cycle of *Atrophaneura hector* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h. adult

Fifth instar larva: The larva attains a maximum of 41.60 (± 1.08) mm in length and 10.4 (± 0.52) mm in width and this stage lasts for 6–7 days. At the end of this instar the larva shrinks its body in preparation for pupation. It attaches itself to the substratum using silken threads.

Pupa: It is flattened dorso-ventrally and has two lateral projections in the thoracic region and abdominal regions. Pupal stage lasts for 13–15 days. The entire life cycle is completed within 36 (± 0.63) days in laboratory conditions.

Life cycle: The life cycle completed in 36 (± 0.63) days in laboratory conditions. The duration of various stages is given in Table 6.

Atrophaneura pandiyana **Moore** (Tables 7, 8; Plate XXXIV)

Eggs: Eggs are spherical in shape and brick red in colour, measuring 1-2 mm in diameter. The basal part is slightly flattened at which it is attached to the leaf or stem. The eggs are laid singly on the underside of tender leaves. A gravid female may lay 8-10 eggs at a time on different leaves of the host plant and within a time span of 5 minutes. In the absence of suitable tender leaves, the female preferred to oviposit on tender shoots. The host plant is *Thottea siliquosa* and the mean incubation period was 4 days.

Larva: The duration of various instars is presented in Table 7. Detailed description of each instar is given below.

First instar larva: The first instar larva grows up to a maximum length of 4.9 (± 0.57) mm and the body width of 1mm. The freshly emerged larva is brown in colour with minute pale orange coloured fleshy spines.

Second instar larva: The larva grows up to a maximum length of 14 (± 0.67) mm and the body width measures 3.4 (± 0.52) mm. Body is brownish black bearing 12 pairs of fleshy spines on both dorsal and lateral sides and the dorsal spines are longer than the lateral ones. The thoracic spines are pale orange in colour while the 3, 4, 7 abdominal spines are white in colour and in the 3rd segment of abdomen, the paired dorsal and lateral spines were joined by a thin white line. The last 2 pairs of spines are pale orange in colour. With the growth of the larva, the fleshy spines become more prominent.

Table 7. A comparison of the larval instars *A. pandiyana*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-6	4.90	0.57	-	1	0
Second instar	13-15	14	0.67	3-4	3.4	0.52
Third instar	25-27	25.90	0.74	5-6	5.6	0.52
Fourth instar	34-37	35.40	1.08	7-8	7.4	0.52
Fifth instar	44-47	45.50	1.08	9-10	9.4	0.52

**SD: Standard deviation*

Third instar larva: The larva grows upto a maximum of 25.90 (± 0.74) mm in length and 5.6 (± 0.52) mm in width. There is no change in body characteristics except that the body is dark maroonish brown in colour.

Table 8. Duration of various life history stages in *A. pandiyana*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.29	0.49
Larva	10	20-22	21.33	0.71
Pupa	10	13-16	14.67	1
Duration (egg – adult)	10	35-37	35.89	0.78

*N: No. of individuals reared; ^*SD: Standard deviation*

Fourth instar larva: The larva attains a maximum length of 35.40 (± 1.08) mm and breadth of 7.4 (± 0.52) mm. The larva has a dark velvety brown body with the fleshy spines turning dark brown in colour. In the 3rd and 7th segments, dorsal and lateral spines are creamy white in colour. All the spines are become more prominent with the progression of growth.

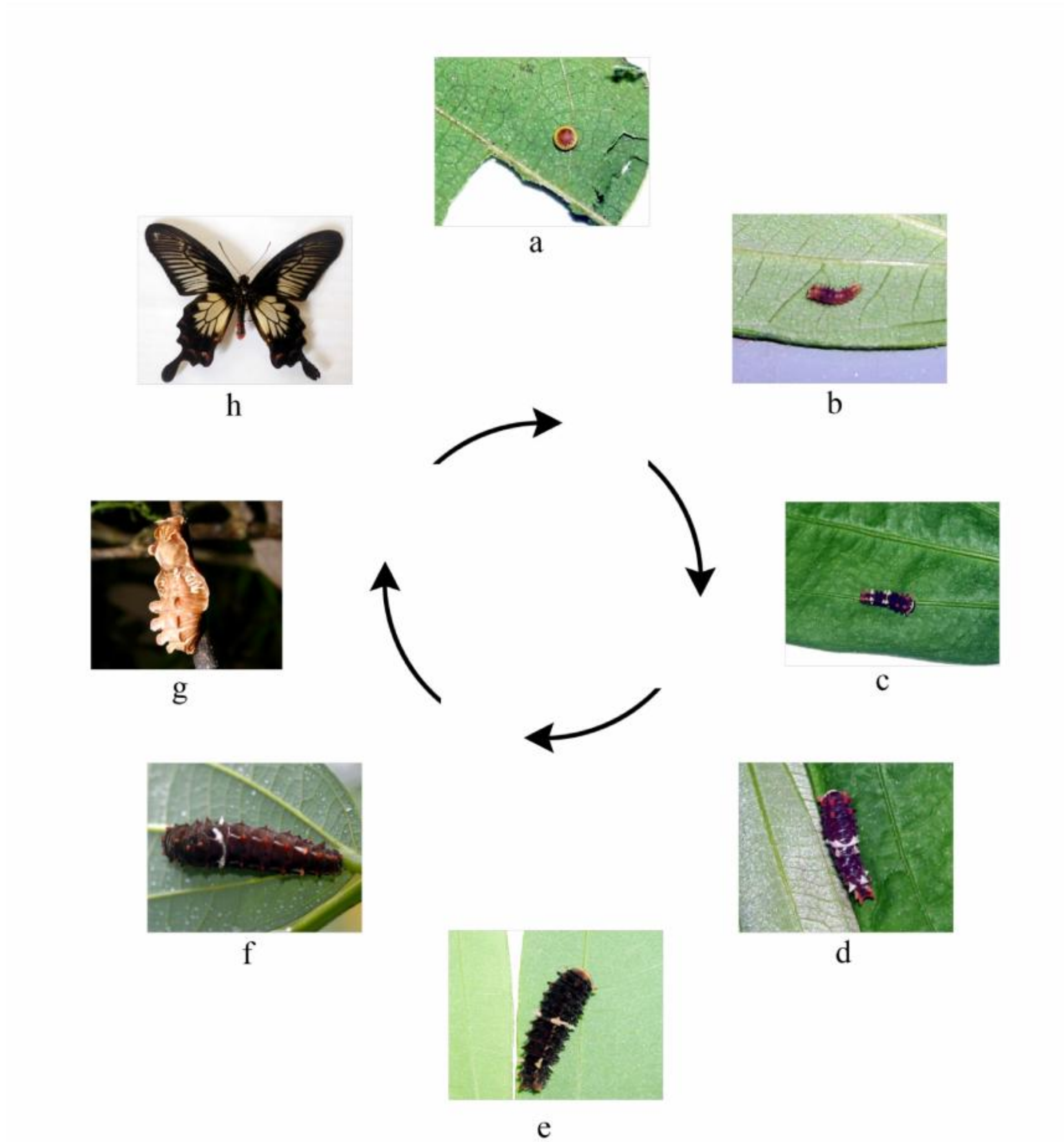


Plate XXXVI. Figures a-h. Life cycle of *Atrophaneura pandiyana* Moore. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h. adult

Fifth instar larva: The larva attains a maximum of 45.50 (± 1.08) mm in length and 9.4 (± 0.52) mm in width. The larva has dark velvety brown body with fleshy spines having bright orange tips. There is a thin white band present in the third segment.

Pupa: Light brown in colour with a mixture of white, orange and dark brown markings on the dorsal side. The ventral side is light brown with faint white stripes. The anterior end of the pupa is produced into a frontally flattened broad projection with a pair of flattened flaps on either side.

Life cycle: The life cycle is completed within 35.89 (± 0.78) days under laboratory conditions. The duration of various stages is given in Table 8.

Papilio helenus **Linnaeus** (Tables 9, 10; Plate XXXVII)

Eggs: The eggs are laid singly on the underside of tender leaves of the host plant. The egg is pale creamy yellow with a finely roughened surface. It is nearly spherical with a diameter of about 1.8 mm. Mean incubation period is 4.43 (± 0.53) days. The host plants are *Zanthoxylum rhetsa, Z. acanthopodium, Toddalia asiatica, Evodia* sp. and *Citrus* sp.

Larva: The duration of various instars are presented in Table 9. Detailed description of each instar is given below.

First instar larva: The larva grows into a maximum of 45 (± 0.71) mm in length and 0.5 mm in width. The young caterpillar eats its way out of the mature egg, and then proceeds to finish up the rest of the egg shell. The newly hatched larva has a rather spiky appearance and is greyish green dorsally and dark brown laterally. As the first instar caterpillar grows to a maximum length, the dorsal whitish patches become more prominent and the body colour changes to dark green with white markings on the posterior abdominal segments. The duration of first instar lasts for 3 days.

Second instar larva: The larva grows to about 15 (± 1.41) mm in length and 5.5 (± 0.71) mm in width. The second instar caterpillar has a similar appearance to the late first instar caterpillar except for the more distinctly white markings in the posterior abdominal segments. This instar lasts for 3 days.

Third instar larva: The larva grows upto 25 (± 0.71) mm in length and 8 mm in width and there is no drastic change in physical appearance except that the body develop a dark brownish green appearance. This instar lasts for about 3 days.

Fourth instar larva: The larva grows upto 34 (± 1) mm in length and10 mm in width. The 4th instar caterpillar looks almost the same as the 3rd instar but with a more slimy appearance. This instar lasts for 4 days.

Fifth instar larva: The larva attains a maximum of 44.50 (± 0.71) mm in length and 14.5 (± 0.71) mm in width. There is drastic change in appearance in this instar. Just after the moult, the body is pale green in colour and gradually it changes to a bright green color after one day. The shield-like thorax is very prominent and there are two eye spots on the third thoracic segment connected by a transverse green dorsal band.Towards the end of this instar, the body gradually shrinks and eventually begins to pupate.

Table 9. A comparison of the larval instars of *P. helenus*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-5	4.5	0.71	-	0.5	0
Second instar	14-16	15	1.41	5-6	5.5	0.71
Third instar	25-26	25.50	0.71	-	8	0
Fourth instar	33-35	34	1041	-	10	0
Fifth instar	44-45	44.50	0.71	14-15	14.5	0.71

**SD: Standard deviation*

Table 10. Duration of various life history stages in *P. helenus*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	2	4-5	4.43	0.53
Larva	2	22-24	23.3	0.67
Pupa	2	15-19	16.9	1.20
Duration (egg – adult)	2	39-43	40.33	1.58

*N: No. of individuals reared; ^*SD: Standard deviation*

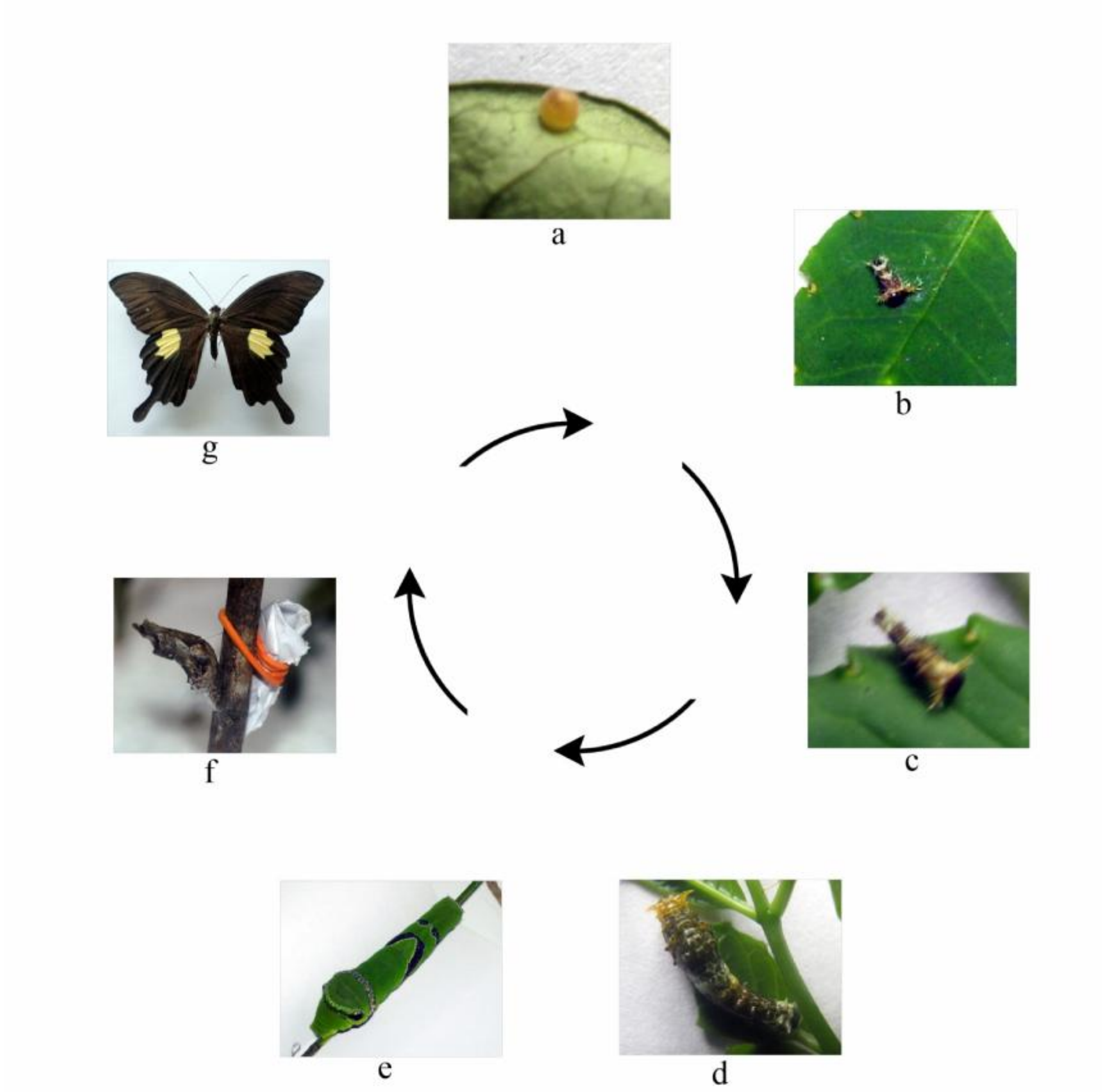


Plate XXXVII. Figures a-g. Life cycle of *Papilio helenus* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. V instar larva; f. pupa; g. adult

Pupa: The pupa suspends itself with a silken girdle attached to the stem. The pupa is brownish with green and white tinge. The pupa has cephalic horns and a dorsal thoracic hump. The pupa measures 36-37 mm in length.

Life cycle: The life cycle is completed within 40.33 (± 1.58) days in laboratory conditions. The duration of various stages is given in Table 10.

***Papilio dravidarum* Wood-Mason** (Tables 11, 12; Plate XXXVIII)

Eggs: The egg is small, spherical, smooth, pale yellow to creamy in colour and lay singly. The mean incubation period is 4.43 (± 0.53) days. *Glycosmis arborea* is the host plant of Malabar Raven.

Larva: The duration of various instars are presented in Table 11. Detailed description of each instar is given below.

First instar larva: It measures about 4.75 (± 0.5) mm in length and 1mm in width. Generally, hatching of the egg takes place in the morning. The larva is light brownish black with dirty white bands on the last and first abdominal segments. Primary setae are present on the head. The thoracic region is slightly projecting. The last two abdominal segments have a row of tubercles on each side. The newly hatched larva feeds on the egg shell. The first instar larva feeds exclusively on tender leaves. The instar lasts for about 2-3 days. Towards the end of the first instar, the larva attaches itself to a leaf and spins a moulting mat.

Second instar larva: The larva measures 13.25 (± 0.9) mm in length and 3.25 (± 0.5) mm in width. On the third day, the larva sheds its old skin and head capsule. There is no apparent change in colour and behaviour except the difference in size. The whitish band becomes more prominent. This stage lasts for 2-3 days.

Third instar larva: Third instar larva measures about 25.25 (± 0.96) mm in length and 5.25 (± 0.5) mm in width. After the second moult, no drastic change takes place except for an additional dirty whitish band or thin streak that appear on the lateral side of the body and three pairs of spots on the abdominal segments. The body colour changes to greyish green.

Fourth instar larva: Fourth instar larva is 36.25 (± 0.5) mm in length and 8.75 (± 0.5) mm in width. The larva feed voraciously on mature leaves.

Fifth instar larva: Length of the body is 46 (± 0.82) mm in length and 13.5 (± 0.58) mm in width. There is a drastic change in colour, appearance and behavior of the caterpillar. The body becomes greenish in colour with two bands on the head. There is also a band in between the eyes and another on the first thoracic segment. Two arch-shaped wide bands are present in the middle of the abdominal segments. There are whitish stripes present on the legs and prologs and throughout the body.

Table 11. A comparison of the larval instars of *P. dravidarum*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-5	4.75	0.5	-	1	0
Second instar	12-14	13.25	0.96	3-4	3.25	0.5
Third instar	24-26	25.25	0.96	5-6	5.25	0.5
Fourth instar	36-37	36.25	0.5	8-9	8.75	0.5
Fifth instar	45-47	46	0.82	13-14	13.5	0.58

**SD: Standard deviation*

Pupae: Pupa measures 22.2 (± 0.92) mm in length. It is smooth, arch-shaped, curved inwards mid- ventrally and green in colour. Two light green patches are present on the mid-dorsal side. Before eclosion, the pupa turns black in colour. Pupal stage lasts for 16-18 days after which the adult hatches out.

Life cycle: The life cycle is completed within 38.89 (± 1.67) days in laboratory conditions. The duration of various stages is given in Table 12.

Table 12. Duration of various life history stages in *P. dravidarum*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	4	4-5	4.43	0.53
Larva	4	20-23	21.9	0.99
Pupa	4	16-18	17	0.82
Duration (egg – adult)	4	36-40	38.89	1.67

*N: No. of individuals reared; ^*SD: Standard deviation*

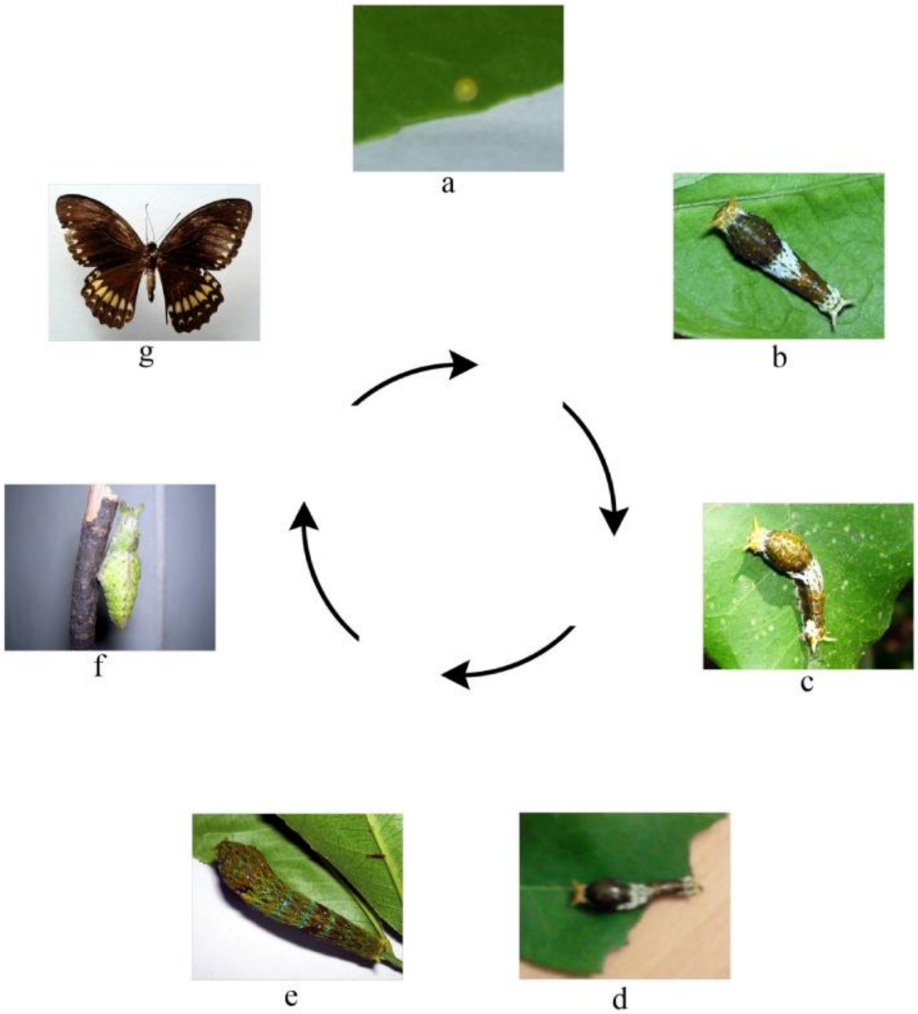


Plate XXXVIII. Figures a-h. Life cycle of *Papilio dravidarum* Wood-Mason. Figure a. egg; b. II instar larva; c. III instar larva; d. IV instar larva; e. V instar larva; f. pupa; g. adult

***Papilio polymnestor* Cramer** (Tables 13, 14; Plate XXXIX)

Egg: Eggs are collected from the host plants *viz.*, *Atalantia racemosa, A. wightii, Glycosmis arborea, Citrus* sp. (Rutaceae). Besides the host plants already recorded, *Euodia ridleyi* (family Rutaceae) was recorded as a new larval host plant of this butterfly.

The eggs are laid singly on the underside of leaves of the host plant. The egg is pale creamy yellow with a finely roughened surface. It is nearly spherical having a diameter of about 1.8 mm. Mean incubation period is 4.43 (± 0.53) days.

Larva: The duration of various instars are presented in Table 13. Detailed description of each instar is given below.

First instar larva: Larva measures about 5.7 (± 0.48) mm in length and 0.5 mm in width. The freshly emerged larva is transparent, greyish white dorsally and dark brown laterally in colour with faint whitish markings on the body. Gradually the whitish dorsal patches changes to greenish brown with clear white markings on the prothorax and posterior abdominal segments. After about 3 days, the caterpillar moults to the next instar.

Second instar larva: The larva measures 18 (± 0.67) mm in length and 6.1 (± 0.57) mm in width and the larval duration lasts for 3 days. Body is bright greenish yellow with distinct white markings on the anterior, middle and posterior body segments.

Third instar larva: The larva grows upto a maximum of 24.7 (± 0.68) mm in length and 8.2 (± 0.42) mm in width. There is no drastic change in physical appearance except that the larva is more greenish in colour.

Fourth instar larva: The larva measures 27 mm in length and 9.5 (± 0.53) mm in width. As the growth proceeds, light to dark green coloured cryptic markings mixed with white streaks become prominent.

Fifth instar larva: The larva attains a maximum of 44 (± 0.94) mm in length and 12.2 (± 0.42) mm in width. The larva is bright green in colour with two eye spots on the third thoracic segment, a transverse band at the abdominal segments 1 and 2 and oblique bars on the mid-abdominal segments. The eye spots on the 3rd thoracic segment are connected by a transverse green dorsal band. A similar band occurs between the abdominal segments 1 and 2, with pale bluish gaps between the markings. There are oblique bars extending from the base of abdominal segment 3 to segment 4 one on either side. The second oblique bar which is wide at the base and tapering to the dorsum appears on either side of the 5th abdominal segment. Both sets of oblique bars are mainly whitish, dotted with tiny greenish and bluish spots. Osmetarium is also present in the prothoracic segment.

Pupa: Pupa is greenish in colour with large yellowish markings. The pupa bears cephalic horns and humped in the thoracic area. The pupa measures 37-38 mm in length.

Life cycle: The life cycle is completed within 43 (± 1.80) days under laboratory conditions. The duration of various stages is given in Table 14.

Table 13. A comparison of the larval instars of *P. polymnestor*

Stage	Length (mm)			Width (mm)		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	5-6	5.7	0.48	-	0.50	-
Second instar	17-19	18	0.67	5-7	6.1	0.57
Third instar	24-26	24.7	0.68	8-9	8.2	0.42
Fourth instar	32-35	33	1.05	9-10	9.5	0.53
Fifth instar	43-45	44	0.94	12-13	12.2	0.42

**SD: Standard deviation*

Table 14. Duration of various life history stages in *P. polymnestor*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.43	0.53
Larva	10	21-24	22.22	0.97
Pupa	10	18-23	20.78	1.56
Duration (egg – adult)	10	40-46	43	1.80

*N: No. of individuals reared; ^*SD: Standard deviation*

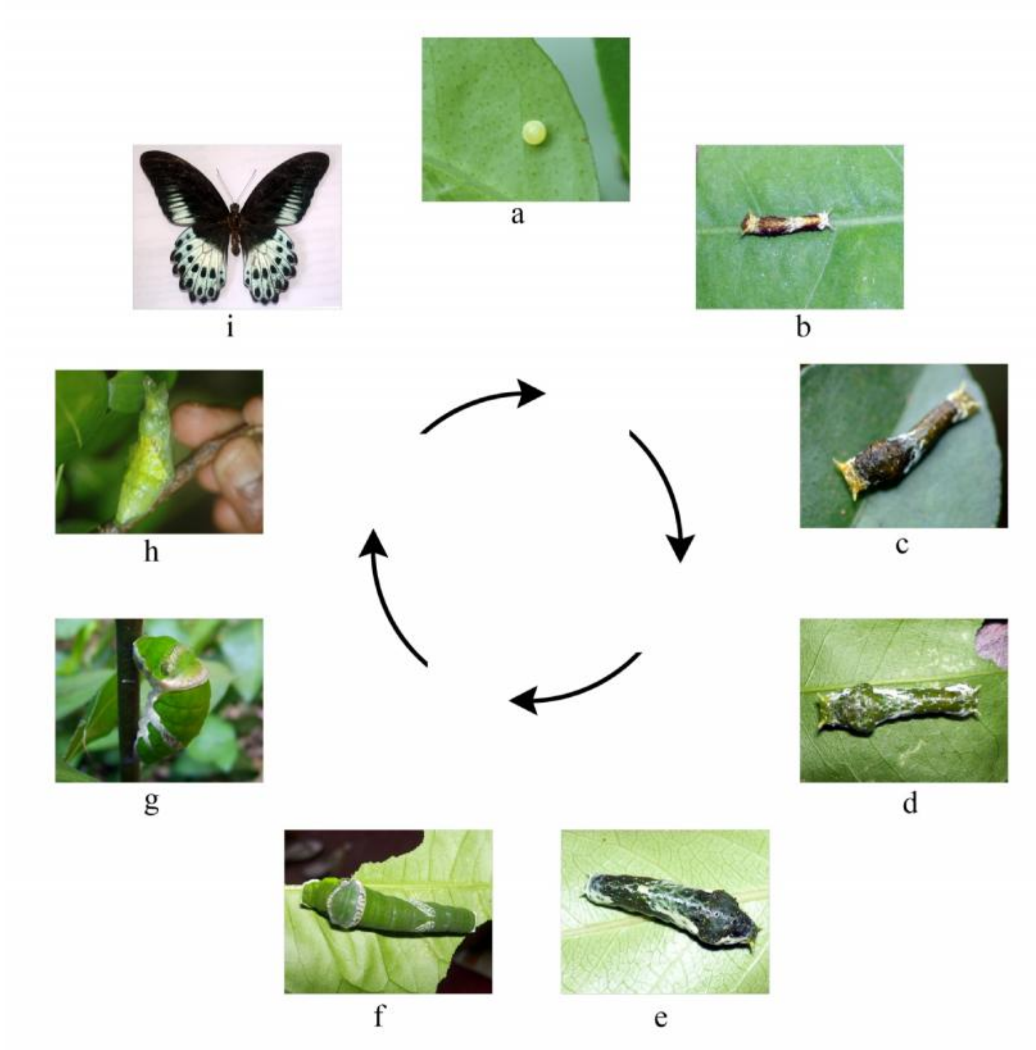


Plate XXXIX. Figures a-i. Life cycle of *Papilio polymnestor* Cramer. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pre-pupa; h. pupa; i. adult

***Papilio demoleus* Linnaeus** (Tables 15, 16; Plate XL)

Eggs: The eggs are laid singly on the tender shoots, on the petiole or on the underside of leaves. The egg is pale creamy yellow with a finely roughened surface. It is nearly spherical with a diameter of about 1.1-1.2 mm. The egg takes about 2.5-3 days to hatch. The caterpillars of the Lime Butterfly reared on host plant *Aegle marmelos, Glycosmis arborea, Murraya koenigii* and *Citrus* spp.

Larva: The duration of various instars are presented in Table 15. Detailed description of each instar is given below.

First instar larva: The newly hatched larva has a body length of about 3.6 (± 0.83) mm in length and 0.5 mm in width. The young caterpillar eats its way out of the mature egg, and then proceeds to finish up the rest of the egg shell. It has a rather spiny appearance. The body is yellowish brown dorsally and dark brown laterally. The head is dark brown. This stage lasts for 3 days

Second instar larva: Body measures upto 12.2 (± 0.92) mm in length and 2.3 (± 0.48) mm in width. The 2nd instar caterpillar has a similar appearance to the late first instar caterpillar except for the more prominent whitish markings. As the caterpillar grows, small whitish patches appear laterally on the first two thoracic segments. This instar lasts for about 2 days

Third instar larva: This instar takes about 2 days to complete with a body length of 23.9 (± 0.74) mm and width of 5.4 (± 0.52) mm. The 3rd instar caterpillar has whitish lateral patches on the anterior and posterior body segments.

Fourth instar larva: The larva attains a maximum of 29.7 (± 3.60) mm in length and 6.6 (± 0.70) mm in width and this instar lasts for about 2-3 days. The fourth instar caterpillar resembles the late third instar caterpillar initially but with a more slimy appearance and with a dark brown colour.

Fifth instar larva: The larva has a length of 37.6 (± 1.27) mm and 8 (± .67) mm width and this instar lasts for 3-4 days. There are two lateral eye spots near the third thoracic segment with a milky brown transverse band linking these and another transverse band at the posterior margin. A long, dark brown oblique bar extends from the base of the 4^{th} abdominal segment to the dorsum of the 5^{th} abdominal segment and a short one in the 6^{th} abdominal segment. During this instar, the body color is initially mottled yellowish green, but which gradually changes to green or yellowish green after a day or so. Towards the end of this instar, the body gradually shrinks in size and eventually adheres itself to the underside of a leaf or stem.

Table 15. A comparison of the larval instars of *P. demoleus*

Stage	Length (mm)			Width (mm)		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	3-5	3.6	0.83	-	0.5	0
Second instar	11-14	12.2	0.92	2-3	2.3	0.48
Third instar	23-25	23.9	0.74	5-6	5.4	0.52
Fourth instar	20-32	29.7	3.60	5-7	6.6	0.70
Fifth instar	36-39	37.6	1.27	7-9	8	0.67

**SD: Standard deviation*

Table 16. Duration of various life history stages in *P. demoleus*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	3-4	3.63	0.52
Larva	10	14-16	15	0.93
Pupa	10	9-12	10.98	1.06
Duration (egg – adult)	10	24-27	25.38	0.92

*N: No. of individuals reared; *^SD: Standard deviation*

Pupa: The pupa measures 30-32 mm in length and the pupal period lasts for 10.38 (± 1.06) days. The pupa is found to suspend itself from silken girdle on the substrate. There are two color forms. In the green form, the pupa is greenish with a large yellowish diamond-shaped patch on the dorsum of the abdominal segments. In the brown form, the pupa is greyish brown with dark patches. Each pupa has a pair of cephalic horns, a dorsal thoracic hump and is angled in side view.

Life cycle: The life cycle was completed within 37.2 (± 0.63) days in laboratory conditions. The duration of various stages is given in Table 16.

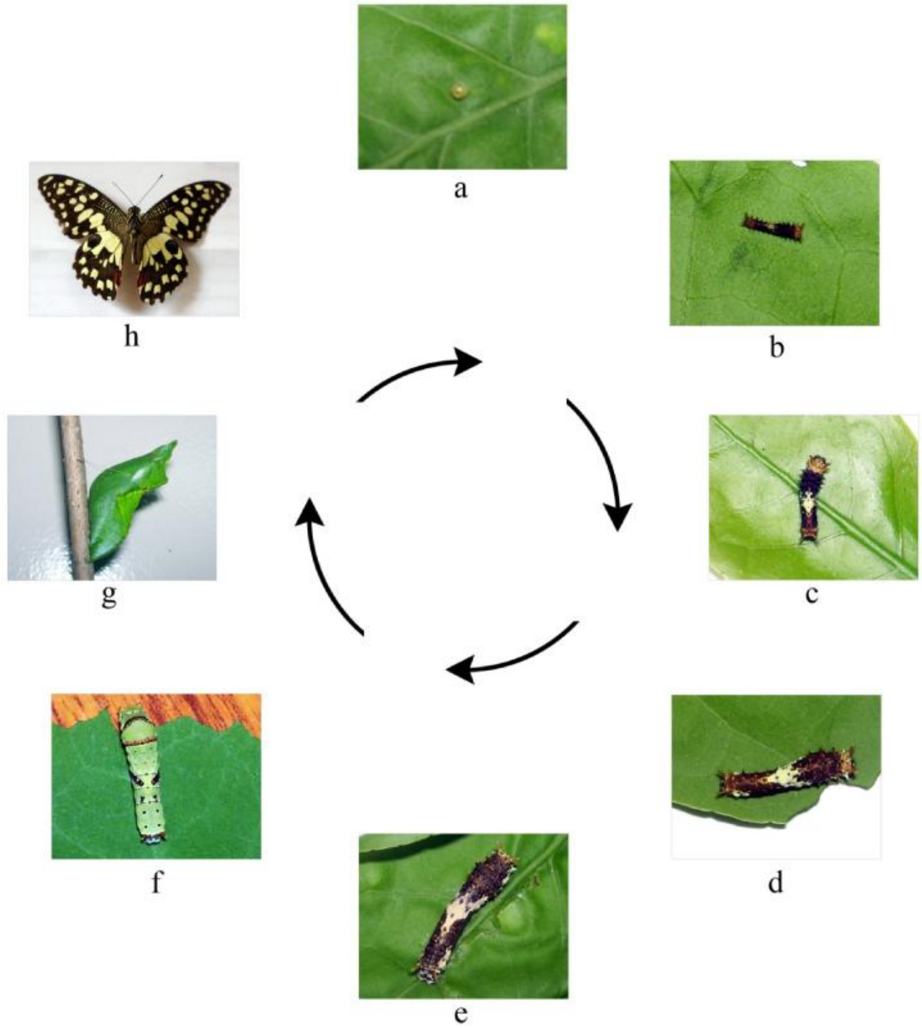


Plate XL. Figures a-h. Life cycle of *Papilio demoleus* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h. adult

***Chilasa clytia* Linnaeus** (Tables 17, 18; Plate XLI)

The early stages feed on the foliage of plants such as *Cinnamomum zeylanicum, C. camphora, C. macrocarpum, Litsea chinensis,* and *Alseodaphne semecarpifolia*. Besides the host plants already recorded, *Litsea coriacea* (Lauraceae family) was recorded as a new larval host plant of this butterfly.

Adults: It measures about 79.3 (± 11.16) mm in expanse.

Eggs: The eggs are small, smooth, spherical, pale yellow in colour and measures 1.2-1.3 mm in diameter. They are laid singly on the petioles of a sapling of the host plant. There is no visible change for the egg during the first three days, after which the colour gradually fades to creamy white. A pale black marking appears on the upper side and closer observations revealed that this spot represented the head of the caterpillar. The incubation period is 3-4 days.

Larva: The duration of various instars is presented in Table 17. Detailed description of each instar is given below.

First instar larva: Hatching usually takes place in the morning. After eating the egg shell, the larva settles under the tender leaves of the host plant. The newly hatched larva is black in colour with yellow and white patches. From the second day onwards, the larva feeds exclusively on tender leaves of the actively growing branch. It feeds along the edges of the leaves and makes small circles. The larva attains a length of 3.9 (± 0.7) mm and 1 mm width. This instar lasts for about 2-3 days. As it grows, the body colors become more prominent with darkened black lateral markings and yellowish brown and whitish dorsal patches. The head capsule also turns black. Towards the end of this instar, the larva attaches itself to a leaf or to the side of the bottle and spins a moulting mat. Under laboratory conditions, this stage was found to be susceptible to dehydration and fresh, tender foliage is essential to sustaining the culture. In the field, it is highly susceptible to predators.

Second instar larva: The larva grows to a maximum of 10.60 (± 0.84) mm in length and 1.5 (± 0.53) mm in width. The larva sheds its old skin and head capsule and the caterpillar has similar appearance except for the longer and stubby processes and brighter shades of orange and white markings on the posterior abdominal segments. It feeds mostly on mature leaves unlike the first instar larva. Gradually, body length increases and segments and tubercles become clearer. When alarmed, the larva raises its head and exerts its pale brown coloured osmetarium. This stage lasts for 2-3 days.

Third instar larva: The third instar larva measures 18 (± 1.41) mm length and 4.2 (± 0.42) mm in width. There is no much change in appearance except for the deepening of the black and orange shade. Larva feeds voraciously and this instar lasts for 3-4 days.

Fourth instar larva: The larva attains a length of 29.80 (± 2.57) mm in and width of 8.8 (± 0.79) mm. After the third moult, the caterpillars possess extensive white markings on the body. The seventh abdominal segment becomes fully extended with a white patch and lateral white patches appear on the thoracic segments. The white patch on the posterior abdominal segments gets extended to the whole of abdominal segment 7 and white lateral patches appear on the thoracic segments. The duration of this instar lasts for 4-5 days.

Fifth instar larva: Larva feeds voraciously and attains a size of 39.5 (± 3.09) mm in length and 10.7 (± 0.95) mm in widths. The body becomes dark grayish black with numerous inconspicuous black spots. On each side of the body, there are two rows of tubercles on 1^{st} to 4^{th} segments and a single row on the remaining segments. A crimson red spot is present at the base of the tubercles. The body also had creamy yellow patches on the lateral and dorsal side. The 5th instar lasts for 4 days. Towards the end of this instar, the body gradually shrinks in size. Eventually, the caterpillar comes to rest on the lower surface of a stem and transform into a pre-pupa.

Table 17. A comparison of the larval instars of *C. clytia*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	3-5	3.9	0.7	-	1	0
Second instar	9-12	10.60	0.84	1-2	1.5	0.53
Third instar	15-20	18	1.41	4-5	4.2	0.42
Fourth instar	27-35	29.80	2.57	8-10	8.8	0.79
Fifth instar	35-43	39.5	3.09	9-12	10.7	0.95

**SD: Standard deviation*

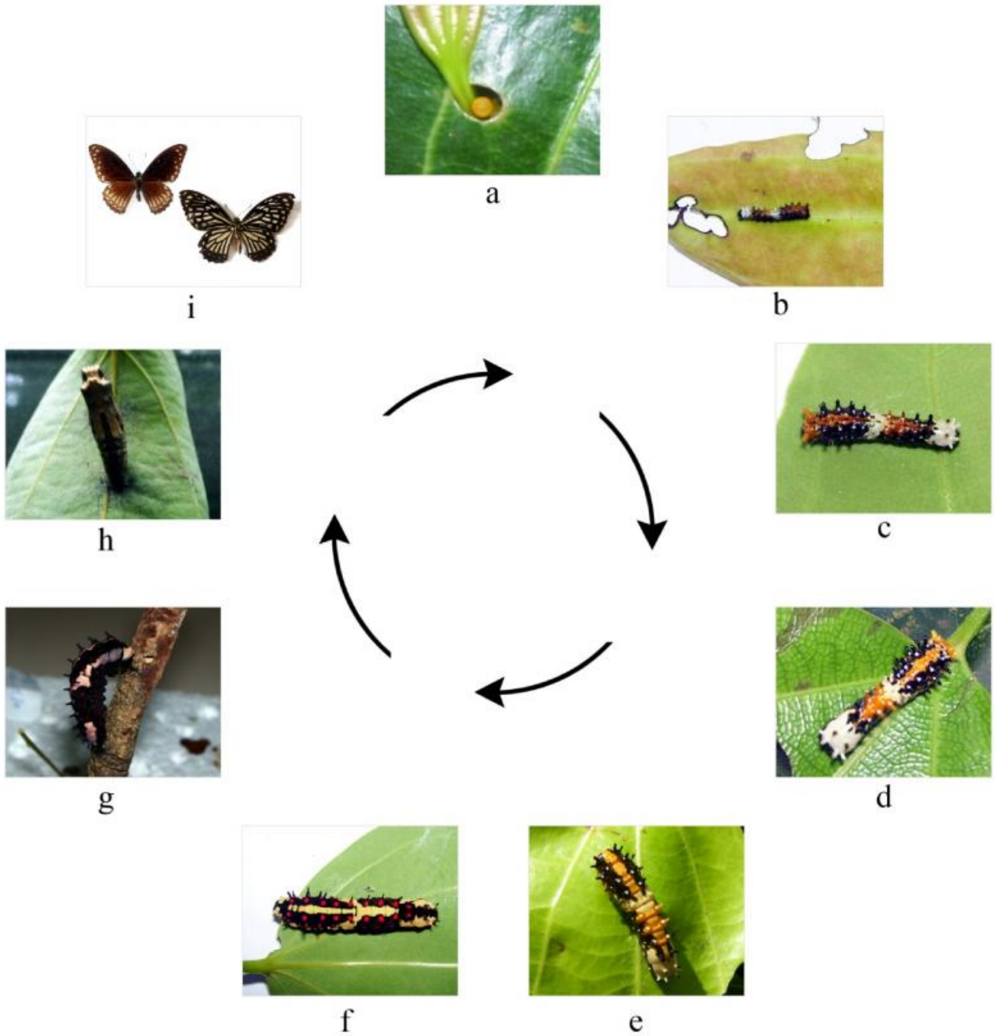


Plate XLI. Figures a-i. Life cycle of *Chilasa clytia* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pre pupa; h. pupa; i. adult

Pupa: The pupa measures 3.42 (± 0.12) mm in length. It is dark brown in colour, smooth, cylindrical in shape and resembles to twig. Pupal stage lasts for 15-16 days.

Life cycle: The length of the life cycle of *C. clytia* is 32 – 36 days from larva to adult. The duration of various stages is given in Table 18.

Table 18. Duration of various life history stages in *C. clytia*

Developmental stages	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.6	0.52
Larva	10	15-18	16.43	1.13
Pupa	10	13-17	15.6	0.84
Duration (egg – adult)	10	32-36	33.2	1.32

*N: No. of individuals reared; ^*SD: Standard deviation*

***Papilio polytes* Linnaeus** (Tables 19, 20; Plate XLII)

Eggs: The early stages are collected from *Glycosmis arborea, Murraya koenigii, Atalantia racemosa, Aegle marmelos, Zanthoxylum rhetsa,* and *Citrus* sp. The egg is small, spherical, smooth, pale yellow to creamy in colour and are laid singly. Gradually, the egg fades in colour and the mean incubation period is 3-5 days.

Larva: The duration of various instars is presented in Table 19. Detailed description of each instar is given below.

First instar larva: It measures about 5.9 (± 0.88) mm in length and 0.76 (± 0.39) mm in width. The body colour is light brownish black with dirty white bands on the last and first abdominal segments. Primary setae are present on the head. The last two abdominal segments have a row of tubercles on each side. Osmetarium present, usually hidden, brown in colour. The larva is sluggish and rests on the upper side of the leaf. The newly hatched larva feeds on the egg shell. The first instar larva feeds exclusively on tender leaves near the apex of the actively growing branch. This instar lasts for about 2-3 days. Towards the end of the instar, the larva attaches itself to a leaf and spins the moulting mat.

Second instar larva: The larva measures 10 (± 0.94) mm in length and 2.3 (± 0.88) mm in width. On the third day, the larva sheds its old skin and head capsule. There is no apparent change in colour and behaviour except in size. Dirty whitish band gets more widened. This stage lasts for 2-3 days.

Third instar larva: Third instar larva measures about 19.1 (± 0.88) mm in length and 4.4 (± 0.52) mm in width. After the second moult, an additional dirty whitish band appears on the lateral side of the body and three pairs of spots on the abdominal segments. The body colour changes to greyish green.

Fourth instar larva: Fourth instar larva measures 23.5 (± 1.27) mm in length and 6.6 (± 0.70) mm in width. The larva feeds voraciously on mature leaves.

Fifth instar larva: It measures 32.7 (± 1.25) mm in length and 9.7 (± 0.67) mm in width. There is drastic change in colour, appearance and behavior of the caterpillar. The body becomes green in colour with two bands on the head region on which one band is present in between the eyes and the other on the first thoracic segment. Two arch-shaped wide bands are present on the middle of the abdominal segment. A broad whitish stripe is present on the legs and prologs and extend throughout the body.

Table 19. A comparison of the larval instars of *P. polytes*.

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-7	5.9	0.88	0.2-1	0.76	0.39
Second instar	8-11	10	0.94	2-3	2.3	0.88
Third instar	18-20	19.1	0.88	4-5	4.4	0.52
Fourth instar	22-25	23.5	1..27	6-8	6.6	0.70
Fifth instar	31-35	32.7	1.25	9-11	9.7	0.67

**SD: Standard deviation*

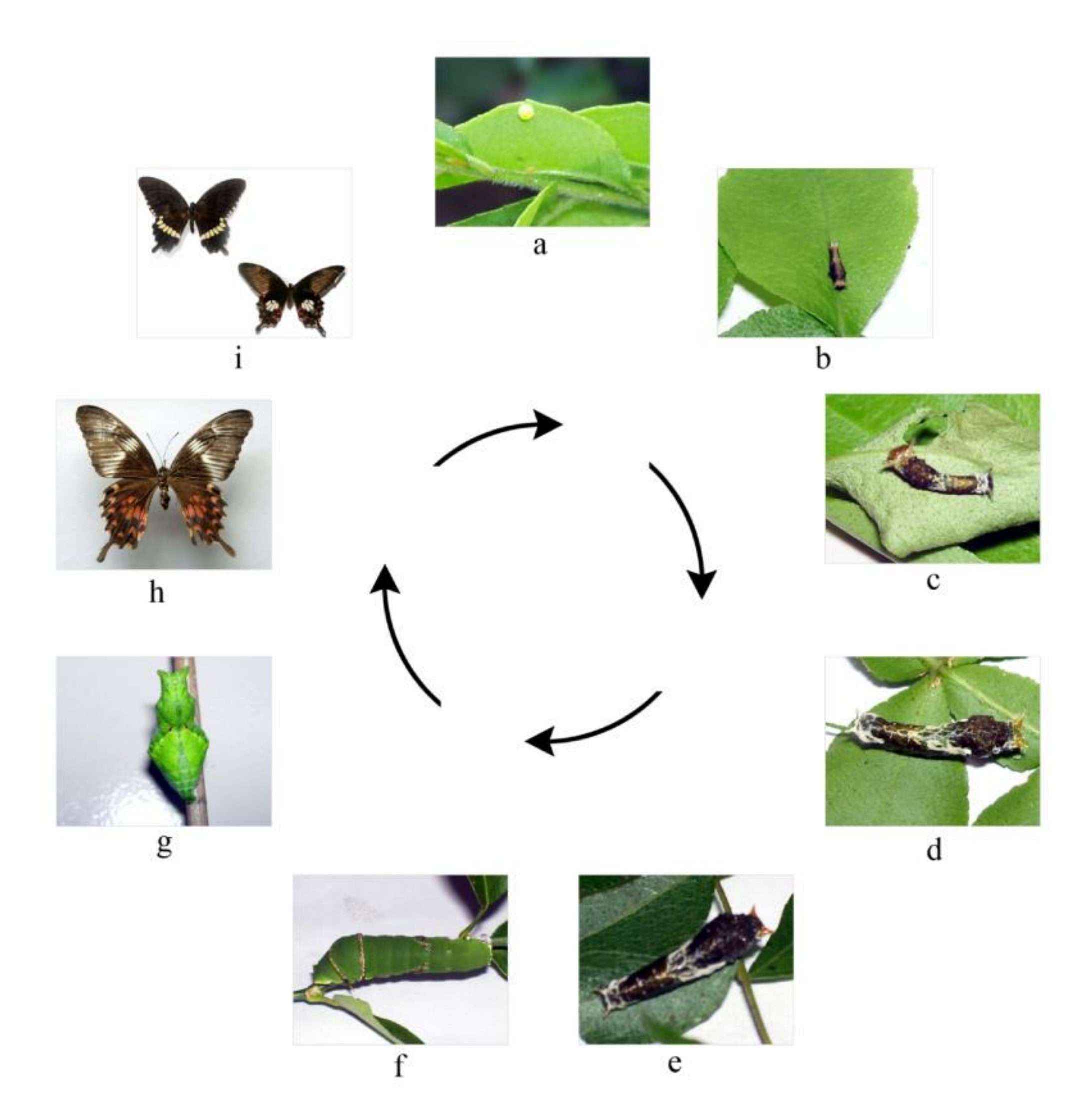


Plate XLII. Figures a-i. Life cycle of *Papilio polytes* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h-i. adult

Pupa: Pupa is smooth, green in colour, arch-shaped and bent inwards mid-ventrally. Two light green patches are present on the mid-dorsal side. Pupa measures 22.2 (± 0.92) mm in length. Before eclosion, the pupa turns black in colour. Pupal stage lasts for 13-15 days after which the adult hatches out.

Life cycle: The life cycle is completed within 35.45 (± 0.83) days. The duration of various stages is given in Table 20.

Table 20. Duration of various life history stages in *P. polytes*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	3-4	3.63	0.52
Larva	10	20-23	21.64	0.81
Pupa	10	12-15	13.82	0.75
Duration (egg – adult)	10	34-38	35.45	1.29

*N: No. of individuals reared; ^*SD: Standard deviation*

***Graphium agamemnon* Linnaeus** (Tables 21, 22; Plate XLIII).

Eggs: Eggs are laid on the tender leaves of saplings. The egg is spherical, creamy white with a diameter of about 1.1mm. The egg takes 3 - 4 days to hatch. The host plants includes *Polyalthia longifolia, Michelia champaca, Annona reticulata, A. squamosa, A. muricata* and *Cinnamomum* sp. Besides the host plants already recorded, *Kingiodendron pinnatum* (Leguminosae) is recorded as a new larval host plant of this butterfly.

Larva: There are five larval instars. The duration of various instars are presented in Table 21. Detailed description of each instar is given below.

First instar larva: The newly hatched larva has a body length of about 4.8 (± 0.63) mm and 0.65 (± 0.24) mm in width. The body is dark green in colour. There are rather broad and white dorsal patches on the posterior abdominal segments. A pair of yellowish brown lateral spines are present on each of the three thoracic segments and another pair on the anal segment. Rows of short, dorso-lateral tubercles with long setae are present on the body.

Second instar larva: The body grows to a length of 8.2 (± 0.79) mm and 4.6 (± 0.52) mm in width. The body colour becomes pale green. The thoracic segments get much enlarged.

Third instar larva: The larva measures 14.2 (± 0.79) mm in length and 6.7 (± 0.48) mm in width. The colour of the thoracic spines are black and the anal spines are white. As growth proceeds, the white dorsal patch on the posterior abdominal segments gradually changes to yellow.

Fourth instar larva: The larva measures about 18.6 (± 0.97) mm and 8.3 (± 0.48) mm in width. The body is yellowish green and speckled with small dark green markings. The yellow dorsal patches on the posterior abdominal segments become less well defined. Each thoracic spine on the 3rd thoracic segment has an orange circular base. This instar lasts for 3-4 days.

Fifth instar larva: The larva attains 33 (± 1.56) mm in length and 9.9 (± 0.74) mm in width. The body color turns yellowish green. The fifth instar lasts for 5-6 days.

Table 21. A comparison of the larval instars of *G. agamemnon*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-6	4.8	0.63	0.5-1	0.65	0.24
Second instar	7-9	8.2	0.79	4-5	4.6	0.52
Third instar	13-15	14.2	0.79	6-7	6.7	0.48
Fourth instar	17-20	18.6	0.97	8-9	8.3	0.48
Fifth instar	31-35	33	1.56	9-11	9.9	0.74

**SD: Standard deviation*

Pupa: Towards the end of the 5th instar, the body gradually shrinks in size. The pupa is yellowish green measuring about 33 mm in length with a slender and obtusely pointed thoracic process.

Life cycle: The life cycle is completed within 35.45 (± 0.83) days. The duration of various stages is given in Table 22.

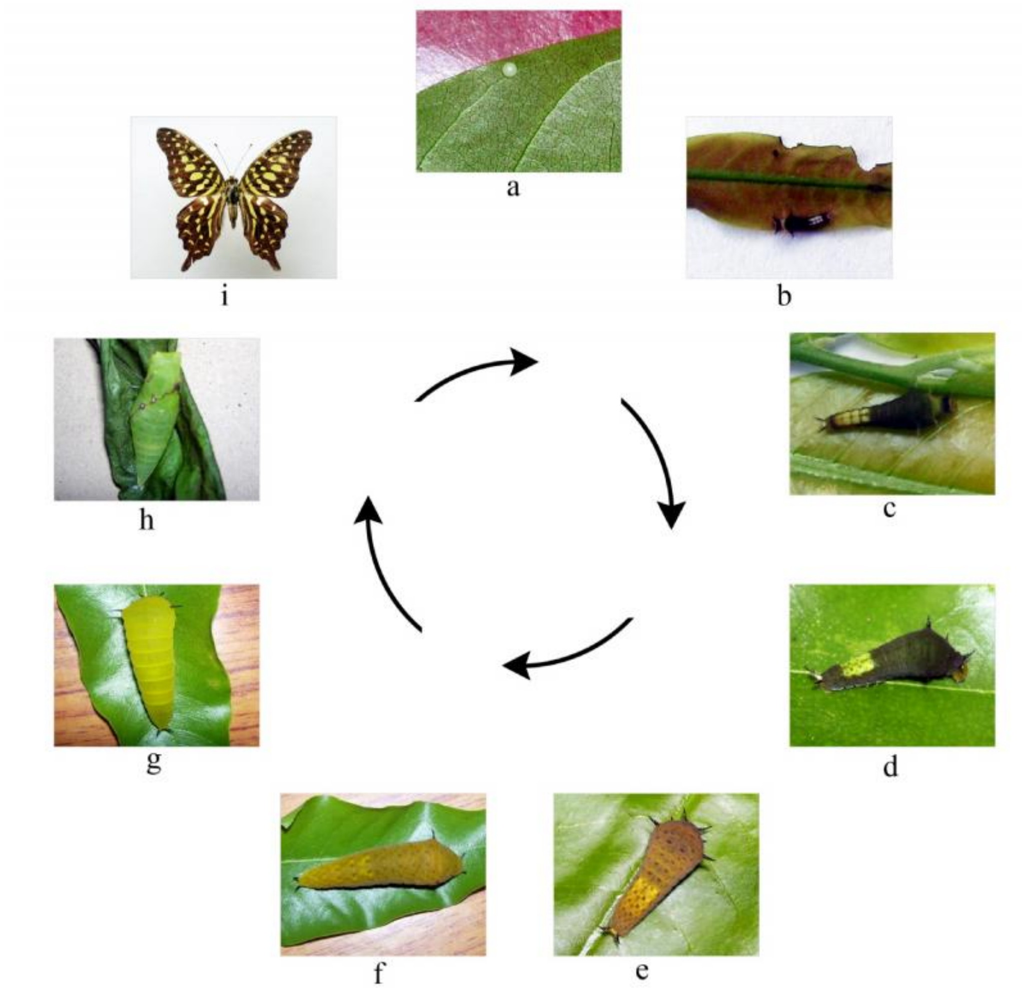


Plate XLIII. Figures a-i. Life cycle of *Graphium agamemnon* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pre pupa; h. pupa; i. adult

Table 22. Duration of various life history stages in *G. agamemnon*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.38	0.52
Larva	10	20-22	20.67	0.71
Pupa	10	10-12	11.22	0.97
Duration (egg – adult)	10	31-33	32.22	0.83

*N: No. of individuals reared; ^*SD: Standard deviation*

***Graphium doson* Felder** (Tables 23, 24; Plate XLIV)

Eggs: The eggs are laid singly on tender leaves of saplings. The egg is spherical and creamy white having a diameter of about 1.1 mm. It takes 3-4 days to hatch and the newly hatched larva has a body length of about 4.2 (± 0.42) mm and 1 mm in width. *Polyalthia longifolia*, *Michelia champaca, Annona lawii* and *Cinnamomum macrocarpum* are the most preferred host plants of Common Jay.

Larva: The duration of various instars is presented in Table 23. Detailed description of each instar is given below.

First instar larva: The larva measures about 4.2 mm in length and 1mm in width. It is brownish black in colour with swollen thorax. A white spot is present on the posterior end of the body. A pair of black lateral spines are found on each of the thoracic segments and another pair on the anal segment.

Second instar larva: The larva grows to a size of 12.1 (± 0.88) mm in length and 4.3 (± 0.48) mm in width. There is no change in body colour.

Third instar larva: The larva measures 16.1 (± 0.88) mm in length and 5.7 (± 0.48) mm in width. The body is black in colour with four black coloured spines.

Table 23. A comparison of the larval instars of *G. doson*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-5	4.2	0.42	-	1	0
Second instar	11-13	12.1	0.88	4-5	4.3	0.48
Third instar	15-17	16.1	0.88	5-6	5.7	0.48
Fourth instar	21-24	22.5	1.08	7-8	7.4	0.52
Fifth instar	31-34	32.4	1.35	8-10	9.1	0.57

**SD: Standard deviation*

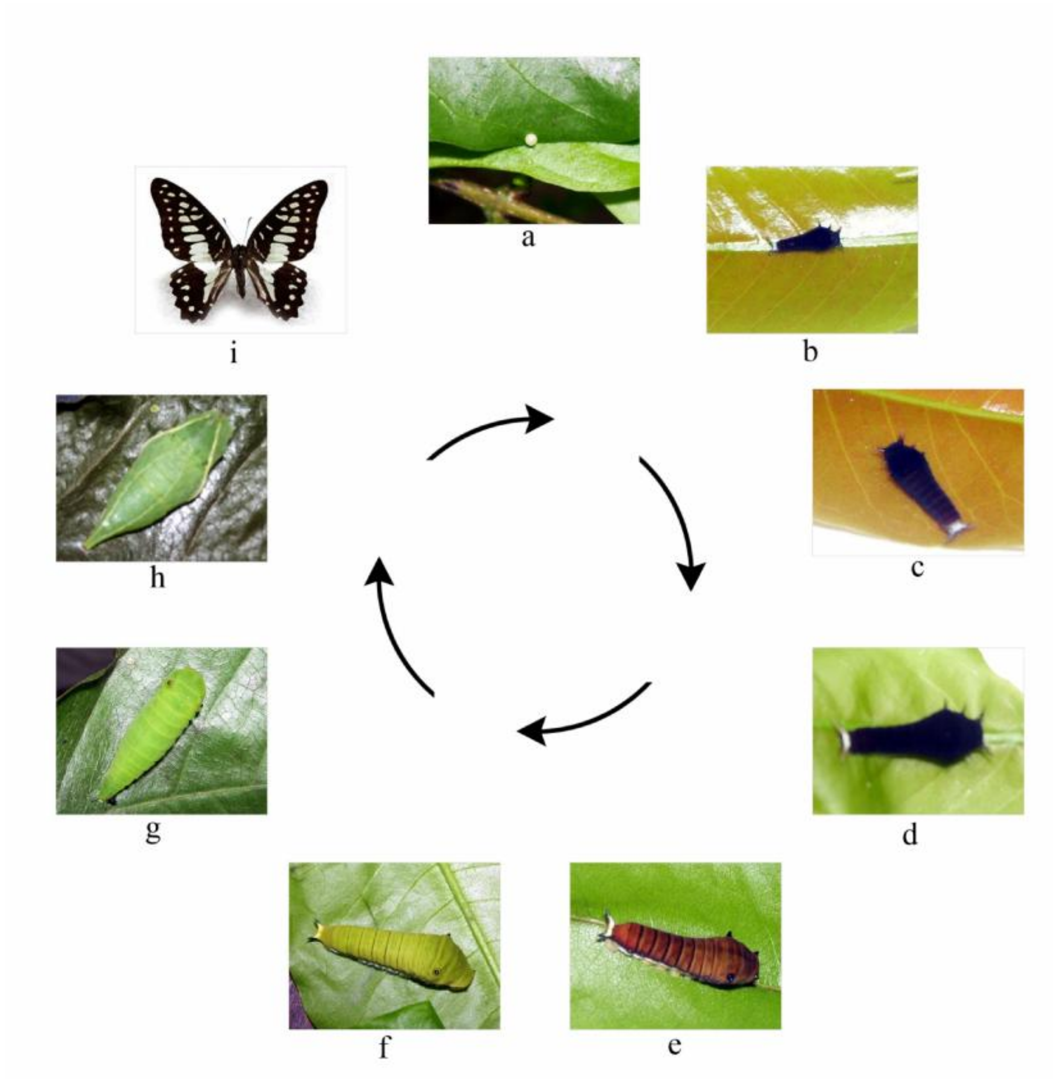


Plate XLIV. Figures a-i. Life cycle of *Graphium doson* Felder. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pre pupa; h. pupa; i. adult

Fourth instar larva: The larva measures 22.5 (± 1.08) mm in length and 7.4 (± 0.52) mm in width. It becomes yellowish brown in colour with four spines. The anal spine becomes white in colour.

Fifth instar larva: The larva measures 32.4 (± 1.35) mm in length and 9.1 (± 0.57) mm in width. The larva is bright green in colour with four spines.

Table 24. Duration of various life history stages in *G. doson*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	10	4-5	4.33	0.5
Larva	10	16-18	16.44	0.73
Pupa	10	9-12	9.89	0.93
Duration (egg – adult)	10	26-28	26.56	0.88

*N: No. of individuals reared; ^*SD: Standard deviation*

Pupa: The pupa is greenish with a slender and obtusely pointed thoracic process. The pupa suspends itself with a silken girdle from the leaf surface secured with its posterior end.

Life cycle: The life cycle is completed within 26.56 (± 0.88) days. The duration of various stages is given in Table 24.

***Graphium sarpedon* Linnaeus** (Tables 25, 26; Plate XLV)

Eggs: The eggs are laid on very young leaves or petioles of the host plant. The spherical egg is creamy white with a diameter of about 1.2 mm. The egg takes 43 (± 0.82) days to hatch. The early stages of the Common Bluebottle feed on leaves of the plants *Cinnamomum camphora*, *C. malabathrum, C. macrocarpum,* and *Polyalthia longifolia*

Larva: The duration of various instars is presented in Table 25. Detailed description of each instar is given below.

First instar larva: The larva measures 4.8 (± 0.84) mm in length and 1 mm in width. The larva is initially pale yellowish brown in colour and it has a pair of lateral spines on each of the thoracic segments and another white pair at the anal segment. Short, dorsal-lateral tubercles with long setae are present on the body.

Second instar larva: The larva grows to a size of 10.70 (± 1.67) mm in length and 4.4 (± 0.55) mm in width. The body color is dark yellowish green with the abdominal segments in alternating shades of yellow to dark green. The thoracic segments are much enlarged and the basal ends of the thoracic spines turns black while the distal ends remain yellowish brown.

Third instar larva: The larva measures 15.20 (± 1.1) mm in length and 5.8 (± 0.45) mm in width. The thoracic spines change to black in colour with a bluish tinge and with greater contrast between the yellow and dark green rings on the abdominal segments.

Fourth instar larva: The larva measures 20.6 (± 2.7) mm in length and 7.4 (± 0.55) mm in width. The body of the caterpillar is yellowish green, speckled with small yellow markings and with a prominent yellow transverse band connecting the two spines on the 3rd thoracic segment. This instar lasts for two days.

Table 25. A comparison of the larval instars of G. *sarpedon*

Stage	Length			Width		
	Range (mm)	Mean (mm)	SD*	Range (mm)	Mean (mm)	SD*
First instar	4-6	4.8	0.84	-	1	0
Second instar	9-13	10.6	1.67	4-5	4.4	0.55
Third instar	14-17	15.2	1.1	5-6	5.8	0.45
Fourth instar	17-24	20.6	2.70	7-8	7.4	0.55
Fifth instar	31-34	33	1.41	8-10	9	0.71

**SD: Standard deviation*

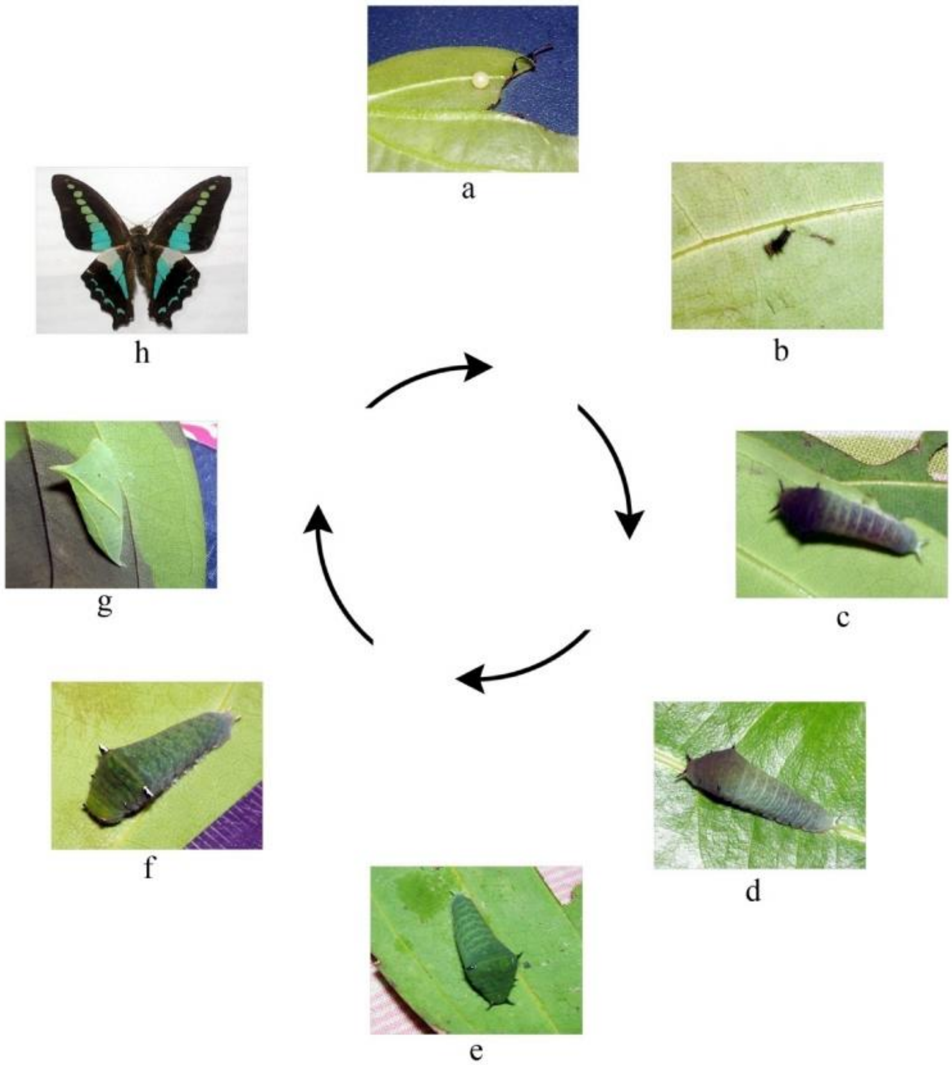


Plate XLV. Figures a-i. Life cycle of *Graphium sarpedon* Linnaeus. Figure a. egg; b. I instar larva; c. II instar larva; d. III instar larva; e. IV instar larva; f. V instar larva; g. pupa; h. adult

Table 26. Duration of various life history stages in *G. sarpedon*

Developmental stage	N*	Range (days)	Mean (days)	SD^
Egg	5	3-5	4.3	0.82
Larva	5	17-20	18.2	1.03
Pupa	5	10-12	11.2	0.92
Duration (egg – adult)	5	27-31	29.4	1.43

*N: No. of individuals reared; ^*SD: Standard deviation*

Fifth instar larva: The larva measures 33 (± 1.41) mm in length and 9 (± 0.71) mm in width. The caterpillar closely resembles the 4th instar larva, the only noticeable change being the prominent yellow, transverse band connecting the 3rd pair of thoracic spines, and the first two pair of thoracic spines.

Pupa: The pupa is greenish with a slender and obtusely pointed thoracic process. The pupa suspends itself with a silken girdle from the leaf surface, secured with a firm anchor at the posterior end.

Life cycle: The life cycle is completed within 29.4 (± 1.43) days. The duration of various stages is given in Table 26.

5.2.2 Behavioural aspects of Swallowtails

Observations on the behavioural aspects are summarized below.

5.2.2.1 Patrolling: The Swallowtail butterflies were found to be territorial only to the extent that males patrol constantly for females and they try to locate other butterflies entering into their territories. The patrolling behaviour of the Papilionid butterfly, *Troides minos* has been observed at Peechi. Patrolling was mainly by the males in order to protect the foraging area to prevent the entry of other male butterflies and also other species of butterflies and honey eating birds that may be its possible competitors.

5.2.2.2 Territorial behavior: In territorial behaviour, the male stayed in a particular area referred as the inspection area and occasionally flew around it. When other males intruded into this area, the territorial male rushed to him and engaged in a circling flight. During this flight, the two males sometimes strayed far away from the territory. After the circling flight, the resident returned to his territory in almost all cases. It usually exhibited the territorial behavior during late morning and afternoon, during which they involved in mating. *Troides minos* has exhibited territorial behavior and was found to chase away other butterflies (Common Rose and Crimson Rose) and even humming birds that entered its territory for foraging.

5.2.2.3 Oviposition behaviour: The oviposition behaviour of *Troides minos, Atrophaneura pandiyana, A. aristolochiae, A. hector, C. clytia, Papilio helenus, P. buddha, P. polymnestor* and *P. polytes* have been observed in all the locations. The females were observed to repeatedly visit the host plants and tried to probe the leaves for ascertaining their suitability for egg laying such as the tenderness of the leaves, availability of shade etc. After repeatedly flying around the host-plant for about 5-8 minutes, the female laid its eggs singly on the tender leaves. During egg laying, the forewings were observed to be continuously fluttering and it took about 5 seconds to lay an egg. The female under observation laid only 2 eggs within a time span of 30 seconds. The female repeatedly tested similar-shaped leaves before finally selecting the underside of suitable tender leaves in a shady damp place for egg laying. All the species studied herein were found to lay their eggs singly.

5.2.2.4 Foraging: The Swallowtail butterflies are strictly diurnal. Adults have been observed taking nectar from the blossoms of *Pentas* spp., *Ixora* spp., *Clerodendrum paniculatum* L., *Marigold, Cuphea* spp., *Zinnia* spp., and *Mussaenda* spp. Most species preferred red colored *Pentas*, *Ixora* and *Clerodendrum paniculatum* for nectaring. None of the species exhibited flower constancy in any of the sampling period except for *Papilio buddha* which showed high preference to the flowers of *Pentas* spp. The observed preferences show that butterflies, like some other pollinators, are potentially capable of exerting selection based on colour and other floral traits.

5.2.2.5 Courtship and mating: Courtship and mating of Papilionid butterflies *viz., Troides minos, Atrophaneura pandiyana, Papilio helenus, P. buddha, P. polymnestor* and *P. polytes* have also been observed. The Swallowtails rest with its wings spread open and after mating, the pair rests facing away from each other with the wings open. If disturbed, the female flies away while the male holds on with his claspers and press the wings together ventrally. In the case of *Troides minos*, the female sits motionlessly on leaves or branches of trees while the male keeps on fluttering its wings which may continue for half an hour or more. Sometimes, the male may proceed for nectaring or chase away other males entering its territory.

5.3 Ecology

Monitoring of butterflies has been done at three locations *viz.,* Nilambur, Peechi and Thenmala representing northern, central and southern zones of Kerala. Data generated from each of these zones is presented below.

5.3.2 Northern region

5.3.2.1 Faunal elements and population abundance

A list of Papilionidae recorded together with the details of sightings is given in table 28. Of the various species recorded, 6 species belonged to the genus *Papilio;* 3 species to *Atrophaneura;* 2 species to *Graphium* and 1 species each to *Troides* and *Chilasa.* Of these, *Papilio* had the highest number of species, with *Papilio polytes* and *P. polymnestor* being the most abundant species. There were 3 species belonging to *Atrophaneura* and one species to *Troides* which together formed the Troidine group. It is interesting to note that 6 species recorded from the garden *viz.*, *Troides minos, Atrophaneura pandiyana*, *A. hector, Papilio dravidarum, P. liomedon* and *P. polymnestor* were endemic to the Western Ghats; two species *viz., P. liomedon and Atrophaneura hector* were having protected status, while another species, *viz., Papilio paris* has been ranked as Rare. The total number of species recorded from the present study represented 68.8% of the total Papilionid species documented from the Kerala part of the Western Ghats.

A total of 2,466 sightings of 13 species of Papilionid butterflies were recorded during the study period. Of these, sightings of 1,185 individuals were recorded during the first half of the study and 1,281 individuals in the second half. Of the various species recorded, six species, *viz., Troides minos, Atrophaneura aristolochiae, Papilio polytes, P. polymnestor*, *Chilasa clytia and G. agamemnon* were commonly observed in the area during most of the seasons while species such as *Atrophaneura hector, A. pandiyana, P. paris, P. dravidarum, P. demoleus*, *P. liomedon* and *Graphium sarpedon* were present in the garden only during certain seasons. With regard to species abundance, except for *Atrophaneura aristolochiae* and *Papilio polymnestor* which enjoyed relatively higher abundance and wider distribution within the study area.

Table 27- Sightings of butterflies at Nilambur (Sep. 2010 – Dec. 2012)

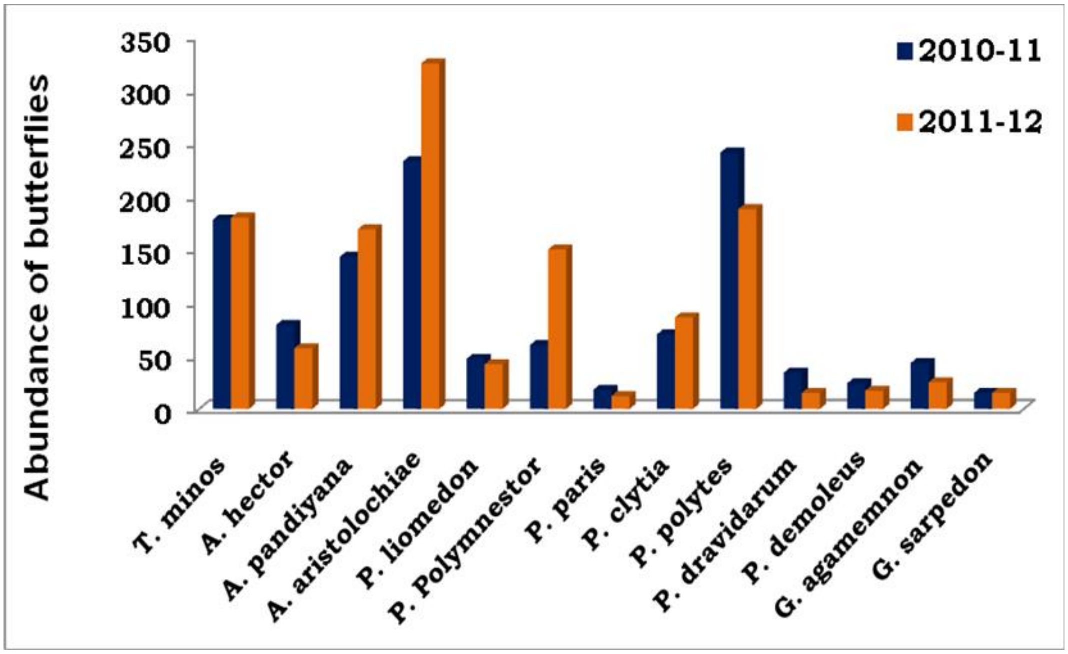
Sl. No	Species	Sightings		Total sightings
		Ist Half	II nd Half	
1	*Troides minos* (Southern Birdwing)	178	180	358
2	*Atrophaneura hector* (Crimson Rose)	79	57	136
3	*A. aristolochiae* (Common Rose)	233	325	558
4	*A. pandiyana* (Malabar Rose)	143	169	312
5	*Chilasa clytia* (Common Mime)	70	86	156
6	*Papilio paris* (Paris Peacock)	18	12	30
7	*P. polytes* (Common Mormon)	241	188	429
8	*P. polymnestor* (Blue Mormon)	60	150	210
9	*P. demoleus* (Lime Butterfly)	24	17	41
10	*P. dravidarum* (Malabar Raven)	34	15	49
11	*P. liomedon* (Malabar Banded Swallowtail)	47	42	89
12	*Graphium sarpedon* (Common Bluebottle)	15	15	30
13	*G. agamemnon* (Tailed Jay)	43	25	68
	Total sightings	1,185	1,281	2,466

A comparison of the mean abundance of each species covered in the study is presented in Graph 1. Compared to the first year, species richness of *A. pandiyana*, *P. polymnestor* and *C. clytia* was higher during the second year. However, sightings of *A. hector, P. dravidarum, P. liomedon*, *P. paris*, *P. demoleus* and *G. agamemnon* were less during the second year. This may be due to the unfavourable climatic conditions or due to the scarcity of water, nectar or fresh foliage.

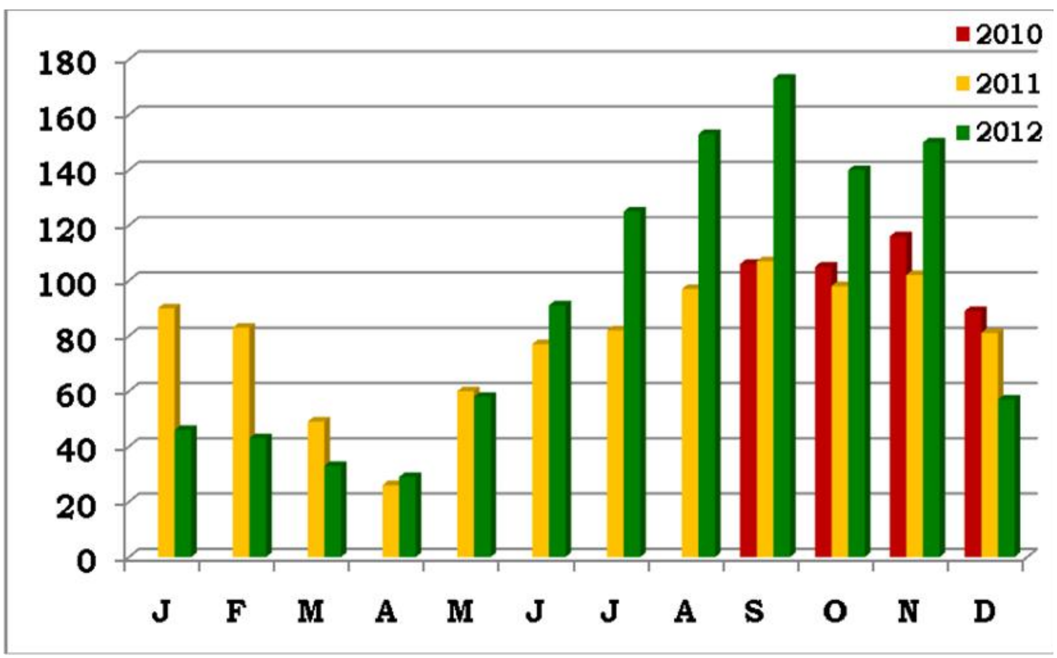
The pooled data from two years' transect count showed a remarkable difference in the proportional abundance of different species of Papilionids during different seasons. The population was present throughout the year, with maximum number of sightings in September 2012. The population had lowest sightings during the summer months (March- April) probably due to high temperature characteristic of these months. From June onwards, the population registered an increase and reached its peak in September 2012. The population showed a sharp decline during April. The total number of sightings of butterflies of the family Papilionidae obtained in different months from September 2010 to December 2012 is presented in graph 2. The number of total sightings was considerably high during the second year compared to the first year, which may be due to the better performance of larval and nectar plants inroduced in the Safari.

5.3.2.2 Overall population trends

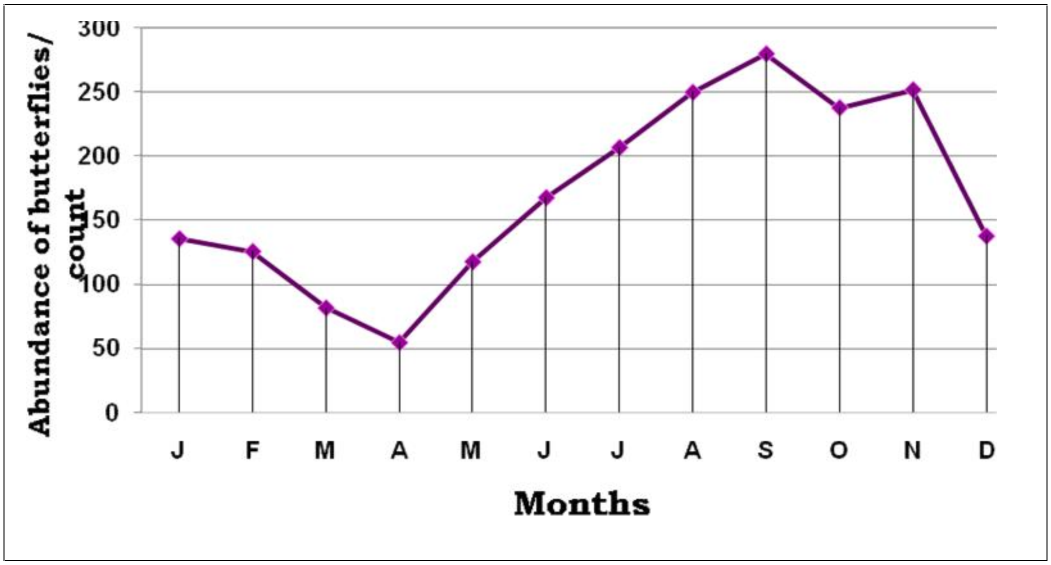
The overall population trends of butterflies in the study area are given in graph 3. Highest number of sightings was observed in September and least number of sightings in April. The butterfly abundance was moderate during the months January and February. The population showed a gradual decline from March onwards reaching its minimum in April. From May onwards the population registered gradual increase and with the commencement of monsoon, butterfly abundance increased and reached its peak during August to November. During this season, there was very good plant growth with flowering and the enhancement in butterfly population may be related to the availability of flowering plants and also to the appropriate climatic conditions. Among the post-monsoon months, compared to other months, October month had lowest sightings. The butterfly population showed a gradual decline in numbers from December onwards with the onset of dry condition and reached its peak during March-April. This dry period was least favourable to many butterflies, probably due to the scarcity of water, nectar and fresh foliage.



Graph 1. Species-wise population trends of Papilionids in the northern region



Graph 2. Seasonal abundance pattern of Papilionids in the northern region.



Graph 3. Overall population trends of Papilionids in the northern region

5.3.1 Central region

5.3.1.1 Faunal elements and population abundance

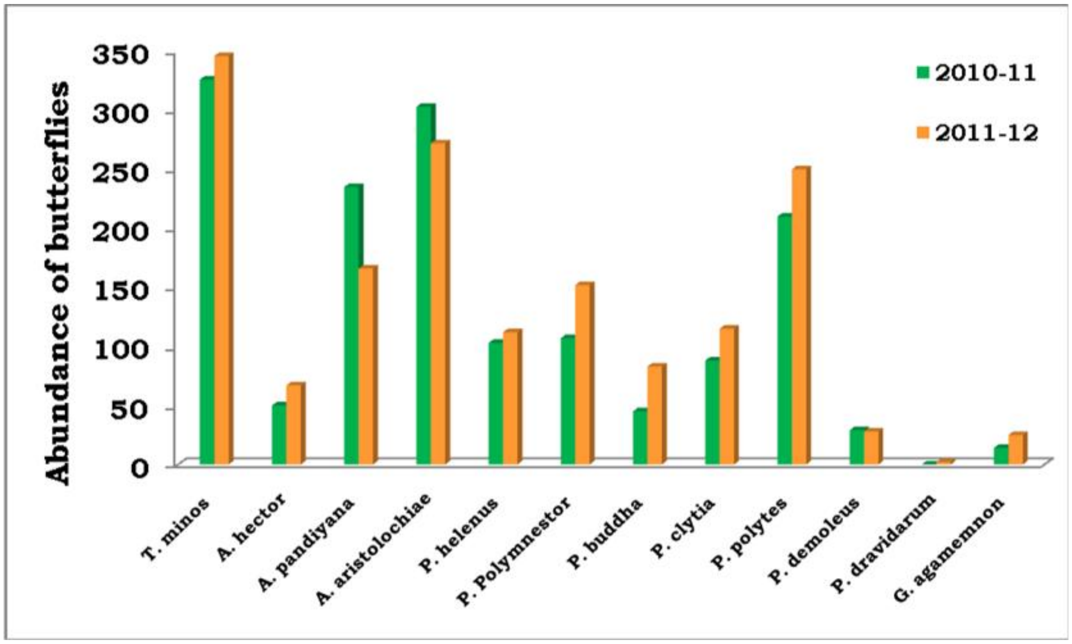
A total of 3,128 individuals belonging to 12 species of Swallowtail butterflies under five genera were recorded from the location during the study period. A list of Papilionidae recorded together with the details of total sightings is given in table 29. Out of these, the genus *Papilio* contained maximum number of species (7) followed by *Atrophaneura* (3 species). The genera *Troides, Graphium* and *Chilasa* were represented by 1 species each. The butterflies recorded in the study included six species that are endemic to the Western Ghats, two species having protected status under the Indian Wildlife Act (GOI, 1972) and one species that was rare species. *Troides minos, Atrophaneura pandiyana, A. hector, Papilio polymnestor, P. buddha* and *P. dravidarum* were the Western Ghats endemics recorded from this area. Similarly*, Atrophaneura hector* and *P. buddha* having protected status and *P. helenus* that is ranked as Rare from this area.

Altogether, sightings of 1,510 individuals were recorded during the first half of the study and 1,618 individuals in the second half. Of the butterflies recorded, five species were commonly seen in this area while the remaining species were found only in specific seasons. *Troides minos, Atrophaneura aristolochiae, Papilio polytes, P. polymnestor* and *Chilasa clytia* were the most common species in the area. Species such as *Atrophaneura hector, A. pandiyana, P. buddha, P. dravidarum, P. demoleus*, *P. helenus* and *Graphium agamemnon* were present during certain seasons.

Table 28- Sightings of butterflies at Peechi (Sep 2010 - Dec 2012)

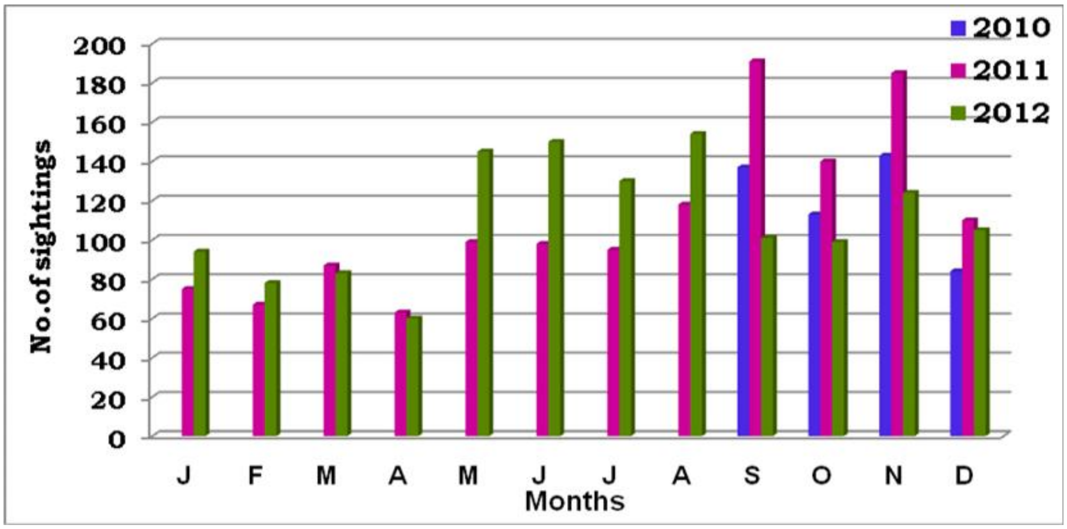
Sl. No	Species	Sightings		Total sightings
		Ist Half	IInd Half	
1	*Troides minos*	326	346	672
2	*Atrophaneura hector*	50	67	117
3	*A. aristolochiae*	303	272	575
4	*A. pandiyana*	235	166	401
5	*Graphium agamemnon*	14	25	39
6	*Chilasa clytia*	88	115	203
7	*Papilio buddha*	45	83	128
8	*P. polytes*	210	250	460
9	*P. polymnestor*	107	152	259
10	*P. helenus*	103	112	215
11	*P. demoleus*	29	28	57
12	*P. dravidarum*	0	2	2
	Total sightings	1,510	1,618	3,128

An examination of the data on butterfly sightings shows that the species abundance was relatively higher in the second year than in the first year except for Malabar Rose and Common Rose. The latter two species showed much lower population density during the second year and the sudden decline in number was attributed to parasitism of larval and pupal stages. *Troides minos* with 326 sightings during the first half of the study and 346 sightings during second half of the study formed the maximum sighted species. *Atrophaneura* *hector, Papilio polytes, P. demoleus, P. helenus, P. polymnestor* and *Chilasa clytia* showed relatively higher population density and better sightings in the second year than in the first year. It is interesting to note that both adult and immature stages of *Papilio buddha*, an endemic, protected species, was sighted in the study area during the monsoon season on *Evodia roxburghiana*. Comparison of mean abundance of each species surveyed is presented in graph 4.



Graph 4. Species-wise population trends of Papilionids in the central region

With regard to seasonality of various butterflies, maximum abundance was noticed during the post monsoon season and least sightings during the pre monsoon period. Although, a resident population was present throughout the study period, maximum build up was observed during September to November 2011 with a sharp decline from December onwards, probably due to the heavy wind characteristic of this month and mostly it continued till May. The lowest population was observed during April. From June onwards, there was an enhancement in population reaching its peak during September to November. The population remained moderate during the remaining months. Seasonal abundance pattern of Swallowtail butterflies on different months in Peechi during 2010-2012 is plotted in graph 5. The number of sightings was considerably high during the first year compared to the second year, which could be due to the effect of predatory organisms or due to parasitism.

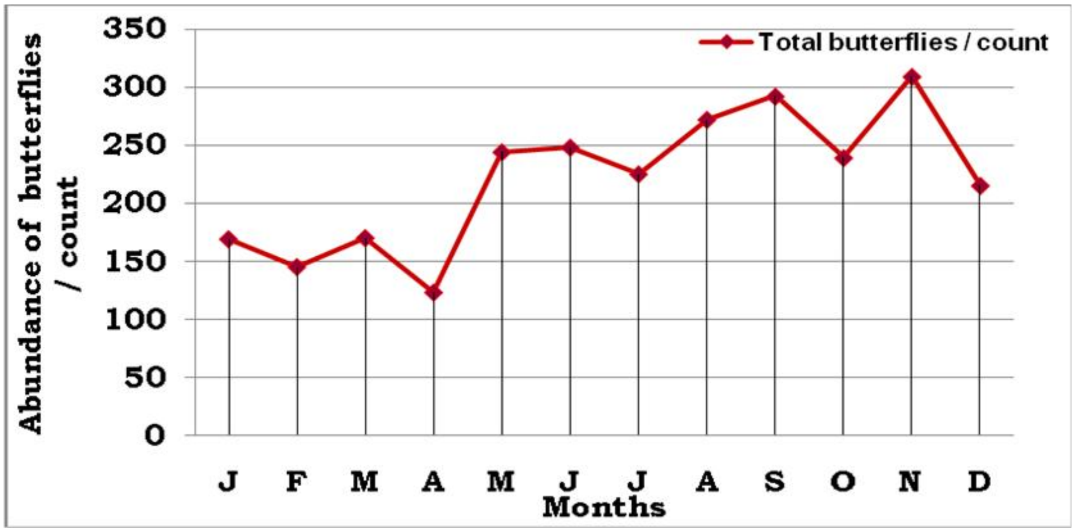


Graph 5. Seasonal abundance patterns of Papilionids in the central region

Butterflies are already known to be highly vulnerable to the climatic extremes (Van Swaay, 1990). Availability of host plants is an important factor affecting abundance and species richness of butterflies. Similarly, availability of diverse habitats is essential to ensure the survival of various butterfly groups. The study area at Peechi which comprised of different habitats such as open areas, damp areas, shades etc. was highly suitable for many groups of butterflies as shown by the abundance of butterflies.

5.3.1.2 Overall population trends

The overall population trend of butterflies is shown in graph 6. The population showed variations in different months. During the months December to May, butterfly populations showed only average sightings in the study area. From May onwards, there was an increasing trend and reached its maximum in November. The monsoon and post monsoon seasons from June to November had conducive weather conditions and hence the butterfly population was high during these seasons. On the other hand, the pre monsoon and summer seasons have dry conditions which are not preferred by several species of butterflies and hence the population was fairly low during these seasons. Thus, low population of butterflies was noticed in the garden during the months December to May with the minimum records in April.



Graph 6. Overall population trends of Papilionids in the central region

Highest number of sightings was observed in November and least number of sightings in April. This is attributed to the conducive weather conditions and greater nectar availability during these months. The months August to October have optimum weather conditions for butterflies and hence their population is very high during this period.

5.3.3 Southern region

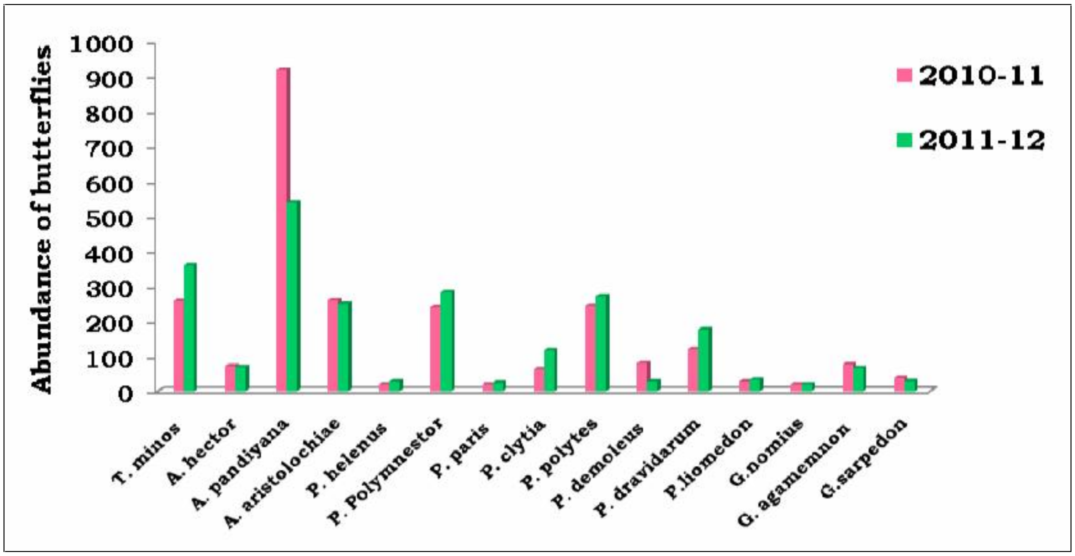
5.3.3.1 Faunal elements and population abundance

A total of 4,601 individuals comprising 15 Papilionid species from five different genera were recorded. Continuous monitoring of the garden showed 2,304 individuals during the first half of the study and 2,297 individuals in the second half, of which 9 species are common in this area and the remaining ones found only in specific seasons. Of the various species recorded, *Troides* *minos, Atrophaneura pandiyana*, *A. aristolochiae, Chilasa clytia, Graphium agamemnon, G. sarpedon, Papilio polytes, P. demoleus, P. polymnestor* formed resident populations while species such as *A. hector, P. helenus, P. dravidarum, P. paris, P. liomedon* and *G. nomius* were present only in certain seasons. Mud puddling by the Common Bluebottle, *G. sarpedon* was observed during February. Among the species recorded, two were having protected status under different schedules of the Indian Wildlife Protection Act 1972 (GOI, 1972) and six species were endemic to the Western Ghats and two species were extremely rare (Table 30). Two species *viz., A. hector* and *P. liomedon* were having protected status while *P. helenus* and *G. nomius* are ranked as Rare. *T. minos, A. pandiyana, A. hector, P. polymnestor, P. liomedon* and *P. dravidarum* recorded in the study are endemic to the Western Ghats. Of the various species recorded, eight species, *viz., T. minos, A. aristolochiae, A. pandiyana, P. polytes, P. polymnestor*, *P. dravidarum, Chilasa clytia and G. agamemnon* were having continuous generations throughout the year in Thenmala while the remaining were recorded only during certain seasons. Species such as *A. hector, P. paris, P. demoleus*, *P. liomedon*, *Graphium nomius* and *G. sarpedon* were present in the garden only during certain seasons.

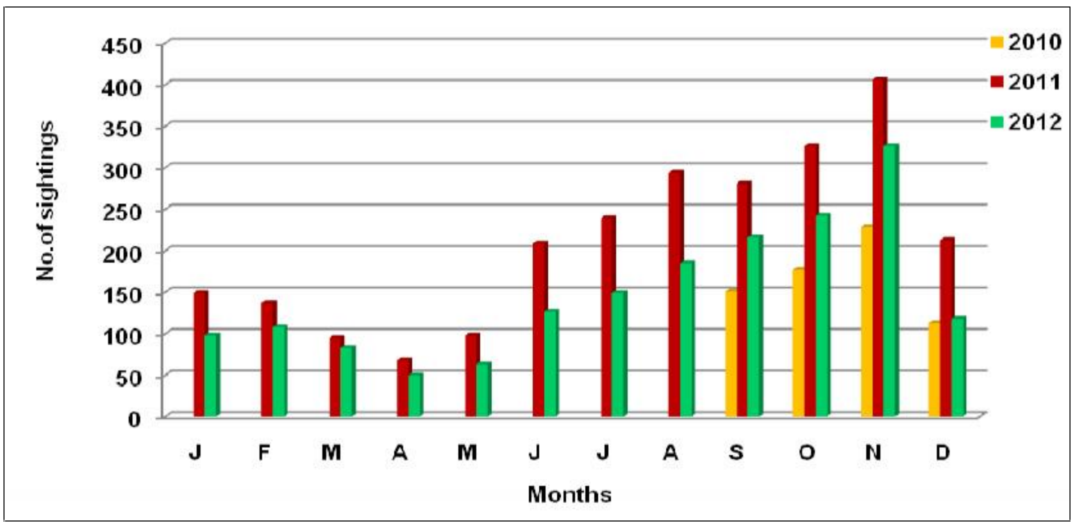
The species-wise population trends of various Swallowtails in Thenmala are presented in graph 7. *Troides minos*, *Atrophaneura aristolochiae*, *Papilio polymnestor*, *P. polytes*, *P. dravidarum* and *Chilasa clytia* showed good population build up for the second year. However, the species *Atrophaneura pandiyana* and *A. hector* had relatively high species abundance in the first year compared to the second year. This may be due to the incidence of predatory or parasitic organisms. Data generated by pooling the total number of sighting of Swallowtail butterflies during the period September 2010 to December 2012, showed that most members of the family were able to efficiently exploit the available resources of the forest habitats at Thenmala since very good population was present throughout the year. Maximum number of sightings was in November 2011 and moderate population was observed during December, January and February after which, there was a sharp decline from March to May in both the years (graph 8). The number of sightings was highest during 2011-12 than in the previous years, which might be due to the establishment of host plants that have been introduced as part of eco-restoration. The population registered an upward trend from June and reached its peak during November which then showed a gradual decrease until May. The population density was maximum during the monsoon and post monsoon seasons and minimum during the pre monsoon period. It may be noted here that due to habitat improvement and conservation, more and more rare species such as *G. nomius, P. paris, P. dravidarum* and *P. liomedon* have colonised in the study area.

Table 29 - Sightings of butterflies at Thenmala (Sep. 2010 - Dec. 2012)

Sl. No	Species	Sightings		Total sightings
		Ist Half	IInd Half	
1	*Troides minos* (Southern Birdwing)	258	360	618
2	*Atrophaneura hector* (Crimson Rose)	72	69	141
3	*A. aristolochiae* (Common Rose)	260	250	510
4	*A. pandiyana* (Malabar Rose)	920	540	1460
5	*Chilasa clytia* (Common Mime)	63	118	181
6	*Papilio paris*(Paris Peacock)	20	24	44
7	*P. polytes* (Common Mormon)	245	272	517
8	*P. polymnestor* (Blue Mormon)	241	283	524
9	*P. helenus*(Red Helen)	20	28	48
10	*P. demoleus*(Lime Butterfly)	80	28	108
11	*P. dravidarum*(Malabar Raven)	121	177	298
12	*P. liomedon* (Malabar Banded Swallowtail)	28	33	61
13	*Graphium sarpedon* (Common Bluebottle)	38	29	67
14	*G. agamemnon* (Tailed Jay)	77	66	143
15	*G. nomius* (spot sword tail)	20	20	40
	Total sightings	2,463	2,297	4,760



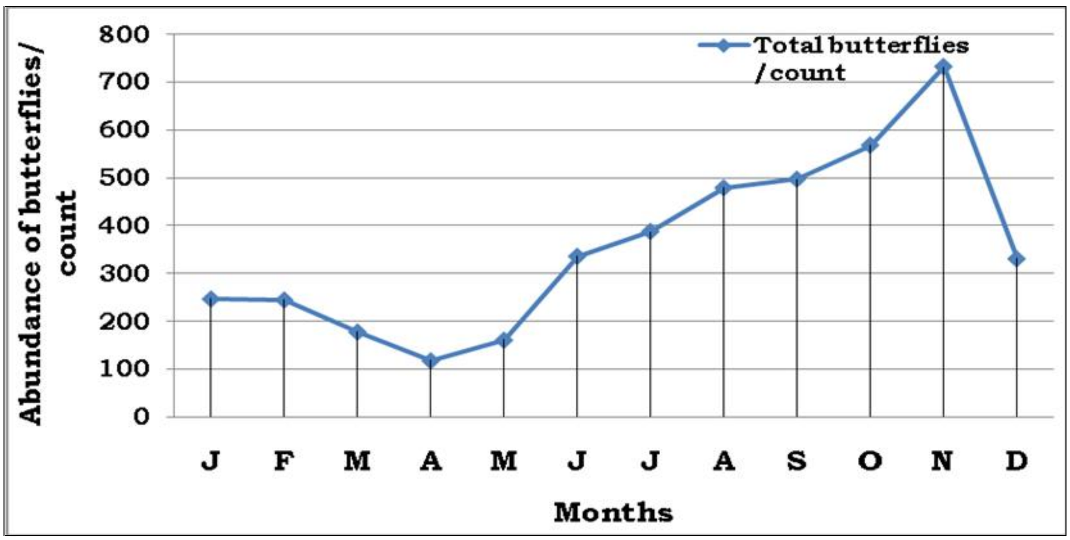
Graph 7. Species-wise population trends of Papilionids in the southern region



Graph 8. Seasonal abundance patterns of Papilionids in the southern region

5.3.3.2 Overall population trends

The overall population trends of butterflies in the study area are given in graph 9. The overall butterfly population showed an increasing trend from January to December. Highest number of sightings was observed in November and lowest in April. Most of the butterfly population had average sightings in January and gradually there was a decrease in its number reaching the minimum in April. These dry periods were least favourable due to the scarcity of water, poor nectar availability and scarcity of tender foliage leading to a sharp decline in butterfly population. From May onwards, the population showed an increasing trend and reached the maximum in November due to onset of appropriate climatic conditions in the safari. Thus, the overall population trend in Thenmala showed marked increase in butterfly abundance from the beginning of monsoon reaching its maximum during September – November and with a sharp decline in summer.



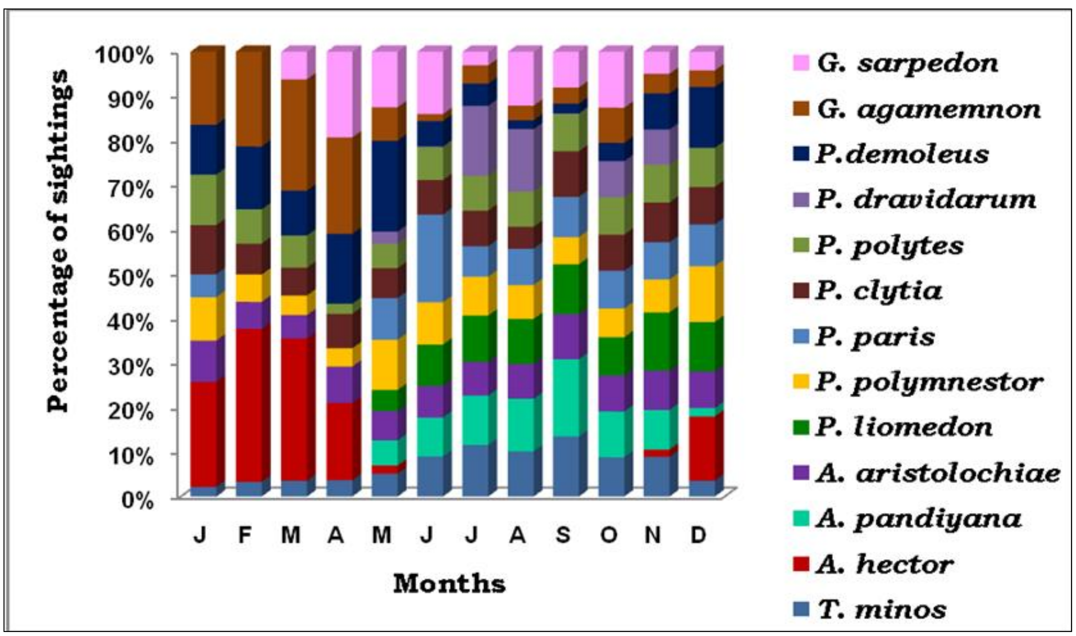
Graph 9. Overall population trends of Papilionids in the southern region

5.3.4 Comparison of seasonal trends of Papilionids in the three zones

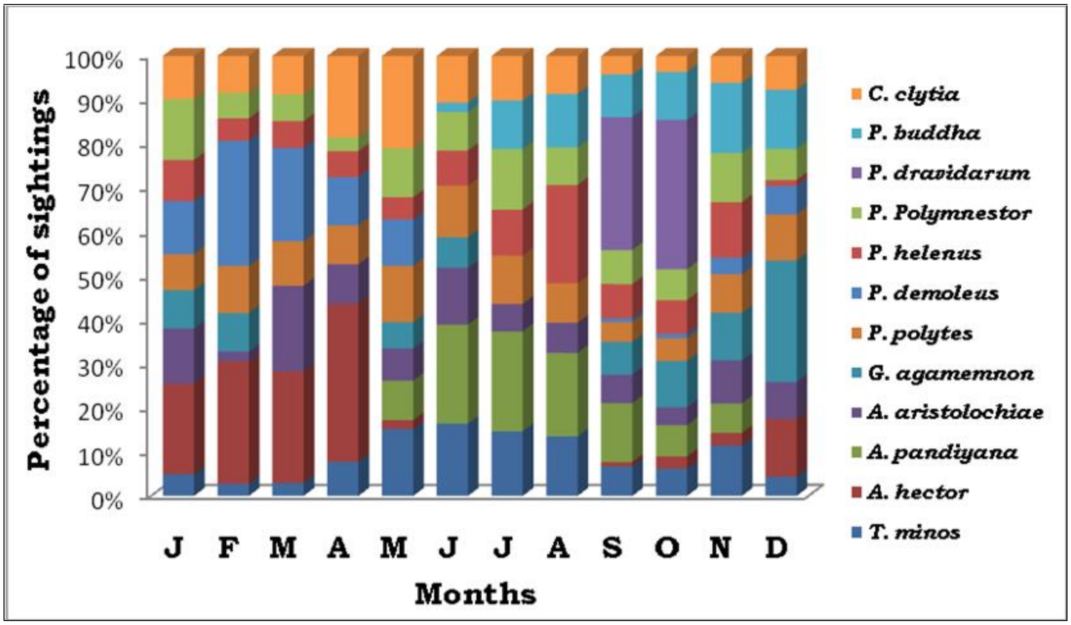
The seasonality of Papilionids in the three different geographical zones showed interesting trends. The percentage of occurrence of each Papilionid species in three different locations during different months is presented in graphs 10, 11 and 12 and the seasonal indices of Swallowtails in three locations are given in appendix VI, VII and VIII. Among the Troidines, *T. minos* showed some similarity in seasonal trends in all the three locations. Their population showed high dominance from June to November followed by a gradual decline in numbers during December to April. The highest abundance of this endemic species was sighted at Peechi during May and June. In the case of

Atrophaneura hector, the population was more dominant from December to April. The populations of *A. pandiyana* showed peak abundance in June and July after which the population remained more or less uniform until November. Thereafter a decreasing trend was seen until May. They were more or less common and present throughout the year at Thenmala although they were quite seasonal and observed from June to November months at Peechi and Nilambur. In the case of *A. aristolochiae,* population were observed during all months of the year, with highest population during monsoon and lowest in March and April at Nilambur and Thenmala while at Peechi, population decline was noticed in February.

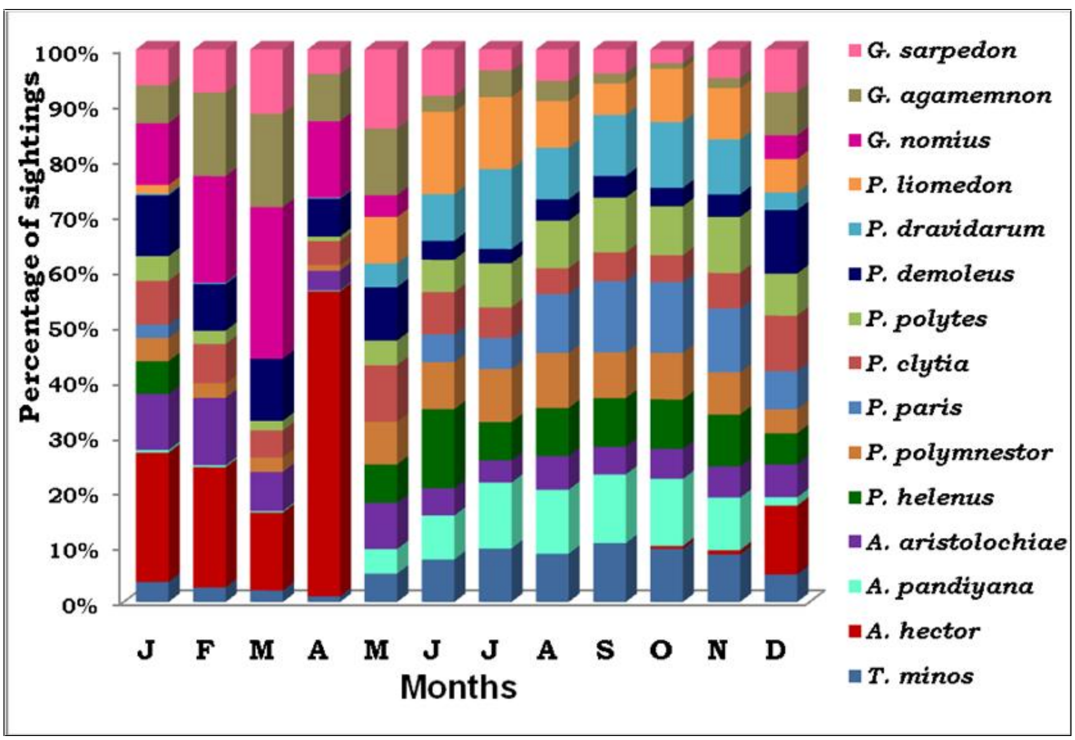
In the case of *C. clytia*, population build-up was observed from September to January at Nilambur and Thenmala. But in Peechi, highest numbers recorded in April and May and lowest in September to December. The sudden decline in number was attributed to parasitism of larval and pupal stages. The juvenile forms of *C. clytia* were found to be susceptible to parasitism by tachinid flies (Diptera: Tachinidae).



Graph 10. Seasonal index of Papilionids in the northern region



Graph 11. Seasonal index of Papilionids in the central region



Graph 12. Seasonal index of Papilionids in the southern region

Among the *Papilio*s, *P. polytes* and *P. polymnestor* showed more or less moderate sightings in all seasons and they were predominant during the monsoon season from June to November. In the case of *P. buddha*, an endemic, protected species, the population was sighted only at Peechi. They were observed from June to December, with highest numbers recorded in October and November. Other rare species recorded from the locations included *P. paris, P. liomedon* and *P. dravidarum* which were sighted only from Thenmala and Nilambur during the months May to December. At Nilambur, highest abundance of *P. paris* was recorded in June, highest abundance of *P. liomedon* in November and *P. dravidarum*, in July and August. At Thenmala, highest number of *P. paris* was recorded in June, July and *P. liomedon* and *P. dravidarum,* in September and October. With regard to *P. helenus,* the population was present throughout the year with the highest count during the monsoon season. Even though *P. helenus* are sighted at Nadugani Ghat situated close to Nilambur, they were not recorded from the study area. Similarly, *P. demoleus* was observed from December to April in all the three locations although their sightings were negligible during the rest of the year.

Regarding the seasonality of Leptocercini, *G. sarpedon* showed continuous population throughout the year at Thenmala. However, from Nilambur, it was reported during March to December. Its peak population was during the months April, May and June. They were quite common in mud-puddling associations at Thenmala. Sightings of *G. nomius* were noticed only at Thenmala and they were strictly seasonal in the dry summer months. The population was highest in March and April. Similarly, *G. agamemnon* was sighted from all the three locations during the months December to April.

5.3.5 Relationship between butterfly abundance and weather conditions

With regard to the influence of weather parameters on the Papilionids, the occurrence of the Papilionid butterflies in three locations was found to be correlated with temperature, humidity and rainfall. Of the three locations, high degree of correlation of butterfly abundance and weather parameters was noted at Thenmala.

At Nilambur, *Troides minos, Papilio dravidarum, P. paris, P. liomedon* and *Graphium sarpedon* were found to be positively correlated with average monthly rainfall. They had high seasonal index during the monsoon periods. *Atrophaneura hector* showed a negative correlation with rainfall (Appendix IX).

At Peechi, *Troides minos, Atrophaneura pandiyana* and *Papilio helenus* showed a significant positive correlation with humidity and rainfall. Correspondingly, the number of sightings of these species increases with increase in humidity and rainfall. Population abundance and seasonal indices of these species were high during the monsoon seasons and the adults were sighted in low numbers during the summer seasons. *Atrophaneura hector* and *Papilio demoleus* showed a significant negative correlation with humidity and rainfall (Appendix X).

In Thenmala, *T. minos, A. pandiyana, P. polymnestor, P. paris, P. dravidarum, P. helenus, P. polytes* and *P. liomedon* showed a significant negative correlation between population abundance and monthly average temperature. These Papilionids had high seasonal indices in months of low temperature. While species *viz., Graphium nomius* and *G. agamemnon* showed a significant positive correlation with average temperature (Appendix XI). With regard to humidity, a significant positive correlation was obtained in *T. minos, A. pandiyana, P. polymnestor, P. paris, P. dravidarum, P. helenus, P. polytes* and *P. liomedon.* The seasonal indices of these species showed correspondingly higher values during the months of high humidity. *A. hector, A. aristolochiae, G. nomius* and *G. agamemnon* showed a significant negative correlation with average humidity. In the case of rainfall, a significant positive correlation was obtained in four species *viz., T. minos, P. paris, P. polytes* and *P. dravidarum* and of these species had high seasonal indices during rainy months while a significant negative correlation found for *G. nomius* and *G. agamemnon* which were more predominant during summer months (March-April).

DISCUSSION

Revathy V. S "Systematics of swallowtail butterflies (Lepidoptera: Papilionidae) of Kerala, India " Thesis. Kerala Forest Research Institute, University of Calicut, 2014

DISCUSSION

Chapter 6: Discussion

6.1 Taxonomic studies: Morphology of external genitalia

Morphology of external genitalia has been shown to be useful in the taxonomic segregation of insects especially of Lepidoptera. In this work, attempts have been made to study the morphology of the external genitalia of Papilionids with a view to use them for their segregation. Modifications of various parts of the external genitalia in the different taxa are discussed below.

6.1.1 Comparative morphology of male external genitalia

Uncus

Uncus was prominent and well developed in all the species studied. It may be broad, conical and narrow apically with a median notch as in *Troides minos*; short, sharply pointed and basally broad in *Atrophaneura pandiyana;* short, bilobed with a constriction at the base as in *A. aristolochiae* or bud-shaped, swollen and notched in *A. hector.* It was short, tubular and narrow in *Chilasa clytia clytia, Papilio paris, P. buddha, P. liomedon* and *P. dravidarum;* very broad and conical in *Papilio demoleus*; short, swollen, ending bluntly in *Chilasa clytia dissimilis*; short and finger-shaped in *P. polytes, P. helenus* and *G. sarpedon* or short and blunt in *P. polymnestor*; broad and ligulate with two lobes in *Graphium nomius* and *G. agamemnon* and broad and rectangular with two lobes in *G. doson.*

Tegumen

Generally, tegumen was elongated, narrow with slender arms. It was well developed in all the species studied and exhibited considerable variations among different genera. In *Troides minos, A. pandiyana, Chilasa clytia dissimilis, Chilasa clytia clytia, Papilio polymnestor, P. polytes, P. paris, P. buddha, P. helenus, P. liomedon* and *P. dravidarum,* tegumen had two inwardly produced distinct lobes, which may be small (*A. pandiyana*) or fused (*T. minos, P. demoleus, P. dravidarum, P. polytes*). In *Atrophaneura aristolochiae*, tegumen is broad. Tegumen is long with narrow arms in *Graphium agamemnon, G. sarpedon, G. doson* and *G. nomius.*

Gnathos

Gnathos was weakly developed in all species studied. It was short, broad and rounded as in *Atrophaneura hector* or oval and united in the middle as in *P. demoleus*. It was slender and moderately sclerotised in *Papilio polymnestor, P. polytes, P. paris, P. buddha, P. helenus, P. demoleus, P. dravidarum, P. liomedon, P. polymnestor, Graphium sarpedon, G. doson, G. agamemnon* and *G. nomius.*

Vinculum

Vinculum was longer than the tegumen and sclerotised in almost all species studied. It was broad and U-shaped in *A. pandiyana* and *A. aristolochiae* and dome-shaped in *P. hector*. It was elongated with narrow arms in *P. polytes, P. paris, P. buddha, P. helenus, P. demoleus, P. dravidarum, P. liomedon, P. polymnestor, Graphium sarpedon, G. doson, G. agamemnon* and *G. nomius*.

Valvae

Valvae was well developed and symmetrical in all species studied. It was relatively short and compressed in *Atrophaneura pandiyana, A. aristolochiae* and *A. hector*. Valvae was broad, ovate, densely setosed with long stiff hairs on the inner surface in *Troides minos*. Valvae was flap-like and apically conical in *A. pandiyana.* Valvae broad, elongated and sclerotised with sickle-shaped ventral half in *A. aristolochiae* and *A. hector.* It was broad and conical in *C. clytia clytia* and *P. demoleus;* ovate and flap-like in *C. clytia dissimilis, P. dravidarum, P. polytes, P. buddha* and *G. doson.* Valvae broad in the apical half with the apical and outer margins bordered by a setosed, sclerotised band in *Papilio polymnestor* and *P. paris*. Valvae with the outer margin round, setosed and sclerotised in *P. helenus.* Valvae short, broad, ear-shaped, setosed, with a band fringed with hairs surrounding all around the outer margin and another sub-marginal band just below the outer band in *P. liomedon.* It was ovate with a deep invagination in *G. sarpedon*. Valvae short, oval with the apex slightly drawn out in *G. nomius* and broad and more or less round in *P. helenus* and *G. agamemnon*. The modifications pertaining to the different parts of the valvae are of discussed below:

Costa

Costal sclerotisation was well developed in most members of Papilionini and less in Leptocercini. Sclerotisation of valvae was found to extend as far as the apex in *Troides minos*, *Atrophaneura pandiyana, A. aristolochiae* and *A. hector.* While sclerotisation of costa was not distinct in *P. helenus*. Costal margin was straight in *Atrophaneura pandiyana,* slightly convex in *P. polymnestor.* In *G. sarpedon, G. doson* and *G. agamemnon*, costal sclerotisation were low. Costa was straight with a patch of small hairs in *G. nomius*.

Sacculus

Sacculus was well sclerotised in most of the species. Sclerotisation extended as far as the apex in *Troides minos*, *Papilio dravidarum, P. helenus, P. polytes, P. demoleus, P. liomedon, P. paris, P. buddha* and upto the sub apical area in *P. polymnestor.* It was almost oval in shape in *Troides minos*, *A. hector*; short with a globular outline in *Atrophaneura aristolochiae* and *G. nomius;* straight in *P. paris, P. buddha, P. polymnestor, P. dravidarum* and *Graphium sarpedon;* prominent in *P. demoleus* and slightly convex in *P. helenus.*

Harpe

Harpe serves as a prehensile organ and was well represented in all species belonging to Papilionidae. It showed a wide range of modification in different species. It was stout, apically curved at about the valvula and its apical boarder dentate in *T. minos*; stout, apically curved and with a narrowed, pointed and hook-shaped process in *A. pandiyana*; stout, L-shaped with an apical bent in *A. aristolochiae* and *A. hector* and spatulate *in Papilio polymnestor* and *P. paris.* Harpe was distinct with apex more or less sigmoid and strongly sclerotised in *P. helenus*; broad, blunt, finger-like bearing a short conical lobe in *P. dravidarum*; with an apical hook in *P. buddha*; mouse-shaped in *P. polytes*; ring-shaped in *P. demoleus*; flat with two lobes in *Chilasa clytia dissimilis, Chilasa clytia clytia*; flat, plate-like with narrow lobes in *G. sarpedon*; flattened with four lobes in *G. doson*; broad with spines in *G. nomius* and expanded in *G. agamemnon.*

Cucullus

Cucullus was well developed in all the species studied. In *Troides minos*, cucullus was developed into a curved process with a median single sharp cornuti and are fringed with short hairs. It was curved and fringed with short hairs in *Atrophaneura hector, Papilio liomedon, P. helenus, P. polytes, Graphium doson* and *G. nomius.* It was narrow and lobate in *Atrophaneura aristolochiae.* It was roughly broad and somewhat pointed in *A. pandiyana, Chilasa clytia dissimilis, Chilasa clytia clytia, Papilio buddha, P. polymnestor, P. paris,* and. *P. dravidarum, P. demoleus* and dentate in *Graphium agamemnon* and *G. sarpedon.*

Juxta

Juxta showed considerable variations in size and shape. It was membraneous and poorly developed *Troides minos*, *Atrophaneura pandiyana, A. hector*, *A. aristolochiae*, *Papilio dravidarum, Graphium sarpedon* and *G. nomius.* It is very prominent and globular in *Chilasa clytia clytia.* It was broad with a globular apical part in *P. liomedon* and *P. polytes*. Juxta indistinct was in *P. helenus*, *P. dravidarum, C. clytia dissimilis, Graphium agamemnon, G. nomius, G. doson* and *G. sarpedon;* broad, conical with a small middle cleft in *P. demoleus;* triangular-shape in *P. paris* and with an apical notch in *P. buddha.*

Saccus

Saccus was U-shaped in *Troides minos*, *Atrophaneura pandiyana, A. hector*, *A. aristolochiae, Papilio polytes, P. paris, P. buddha, P. helenus, G. doson, G. agamemnon* and *G. nomius*; V-shaped in *P. dravidarum* and deeply indented in *G. sarpedon.*

Phallus

Phallus was well developed in all the species studied. It exhibited considerable variation in shape and size. Phallus short, stout, apically conical and blunt with a wavy margin on one side in *T. minos*. It was very long with pointed apex and membraneous vesica in *Atrophaneura aristolochiae, A. pandiyana* and *A. hector.* It was medium sized and apically blunt in *Chilasa clytia clytia*; medium sized with broadened apex in *Chilasa clytia dissimilis*; very long with a pointed tip bearing membraneous vesica in *P. polytes*; long and bow-shaped in *P. polymnestor*; short, stout and broad at the basal end in *Papilio liomedon, P. helenus, P. buddha, P. paris,* and *P. demoleus*; short, arched and apically pointed in *P. dravidarum*; long with a sharp cornuti in *G. agamemnon* and long with blunt apex, highly setosed and strongly sclerotised in *G. sarpedon, G. doson* and *G. nomius.*

6.1.2 Comparative morphology of female external genitalia

Ovipositor

Consistent with the egg laying habits, the ovipositor is well developed in Papilionidae. It may be with flattened lobes as in *T. minos*; elongated or oval and fringed with short hairs as in *Atrophaneura aristolochiae, A. hector, A. pandiyana*; broad and triangular as in *G. nomius*; elongated and swollen in *G. agamemnon*, *G. doson* and *G. sarpedon*; broad, oval or round in outline fringed with short hairs in *Chilasa clytia*, *Papilio helenus, P. polytes, P. polymnestor, P. demoleus* or bean-shaped as in *P. dravidarum.*

Apophyses

Two pairs of apophyses, attached to the inner walls of the ovipositor are often variously modified in most of the species. The posterior apophyses was shorter than the anterior and having an apical club in *T. minos*, *Chilasa clytia clytia, Chilasa clytia dissimilis, Atrophaneura pandiyana, G. agamemnon, G. sarpedon* and *G. nomius*. It was short and narrow in *Papilio helenus, P. dravidarum. P. polytes, P. polymnestor, P. demoleus* and *G. doson.*

Ductus bursae

Ductus was very small and narrow in *T. minos;* moderately long in *A. pandiyana;* short, wide at the base and distally narrow in *Atrophaneura aristolochiae* and *A. hector;* short with uniform width as in *Chilasa clytia clytia* and *dissimilis*, *Papilio polytes, P. helenus, P. dravidarum, P. polymnestor* and *P. demoleus;* medium sized and of uniform width as in *G. agamemnon, G. sarpedon* and *G. doson* or elongated in *G. nomius.*

Corpus bursae

Corpus bursae was roughly oval with parallel rows of scobinations in concentric rings covering half of the bursa as in *T. minos*; elongate and tubular as in *Atrophaneura aristolochiae, A. hector* and *A. pandiyana;* elongate, large, basal half tubular and distal half globular, with truncated apex as in *P. dravidarum*; large and balloon-shaped in *P. helenus* and *P. polytes* form *stichius*; elongated with basal half narrower than the apical half in *P. polytes* form *romulus*; oval as in *P. polytes* form *cyrus* ; oval, elongate proximally and narrowed as in *P. polymnestor, P. demoleus* and *C. clytia clytia*; more or less globular in *C. clytia dissimilis*; more or less globular as in *G. agamemnon* or tubular as in *G. sarpedon, G. nomius* and *G. doson.*

Signum

Signum was prominent and well developed in all the species studied. There was no distinct signum in *T. minos* and *Papilio helenus*. Signum was elongated, sclerotised and spindle-shaped in *Atrophaneura aristolochiae, A. hector* and *A. pandiyana*. In most members of the genus *Papilio*, it was lamellate as in *Chilasa clytia clytia, Chilasa clytia dissimilis*, *Papilio dravidarum, P. polytes, P. polymnestor and P. demoleus.* Tubular signum was noticed in *Graphium sarpedon, G. agamemnon* and *G. doson* which was very small in *G. nomius.*

6.1.3 Morphological similarities and dissimilarities of the external genitalia in different tribes

A comparison of the external genitalia of seventeen species of the family Papilionidae has shown remarkable variations in the structure of uncus, valvae, harpe, sacculus and phallus. However, in the case of female, the structure of external genitalia showed more similarities than dissimilarities. The major similarities and dissimilarities among the tribes of the subfamily Papilioninae are discussed below.

Tribe: Troiidini

Four species *viz.*, *Troides minos*, *Atrophaneura aristolochiae, A. hector* and *A. pandiyana,* belonging to the tribe Troiidini were covered in this study. These species showed marked dissimilarity in the structure of the male genitalia especially with respect to uncus, valvae, sacculus, harpe and phallus although there were some similarities in the structure of tegumen, juxta and saccus. In *Troides minos*, the uncus was in the form of a broad, conical process with a median notch, which in *Atrophaneura aristolochiae* was bilobed with a constriction at the base. In *A. hector* it was bud-shaped, swollen and terminally notched while in *A. pandiyana,* it was sharply pointed with a broad base.

Vinculum was cylindrical in *T. minos*, U-shaped in *A. pandiyana*, dome-shaped in *A. hector* and basally broad and apically narrowed in *A. aristolochiae.*

Sacculus was oval in *T. minos* and *A. hector*; broad and semi membraneous in *A. pandiyana* and globular in *A. aristolochiae.* The valvae was well developed in all the four species; it was ovate and densely setosed in *T. minos*; flap-like, apically conical in *A. pandiyana*; ventrally sickle-shaped in *A. aristolochiae* and *P. hector*.

Harpe was well developed in almost all species of Papilionidae. Stout harpe was present in the tribe Troiidini, which in *T. minos* was apically dentate and curved. In *A. aristolochiae* and *A. hector*, it was L-shaped and apically curved. In *A. pandiyana,* harpe was apically curved and with a narrow pointed, hook-shaped process.

Phallus exhibited considerable variations in shape and size. It was very long and slender, with a sharply pointed apex and membraneous vesica in *Atrophaneura aristolochiae, A. hector* and *A. pandiyana* or *T. minos*, phallus was short, stout, apically conical and blunt with a wavy margin on one side.

The main similarities among these species were in the structure of tegumen, vinculum, juxta and saccus. The tegumen was expanded and elongated in *A. pandiyana* and *A. hector* but it was short in the remaining species. Juxta was small, fused with sacculus and was indistinct in most species. The saccus was broadly U-shaped in all the four species.

The female genitalia of these species also showed similarities and dissimilarities. The ovipositor lobes were flattened, conical lobes in *T. minos*; elongated, oval and fringed with short hairs as in *Atrophaneura aristolochiae, A. hector* and *A. pandiyana*. Posterior apophyses was narrow and shorter than the anterior. Ductus bursae was very short and narrow in *T. minos* but it was elongate and distally narrowed in *A. aristolochiae*, *A. hector, A. pandiyana.*

Corpus bursa was large and variously shaped. It was roughly oval with scobinations arranged in concentric rings covering half of the bursa in *T. minos* while it was elongate and tubular in *Atrophaneura aristolochiae, A. hector* and *A. pandiyana.* A prominent spindle-shaped signum was present in *A. aristolochiae*, *A. hector, A. pandiyana* but in *T. minos*, signum was not distinct.

Tribe: Papilionini

Nine species, *Chilasa clytia, Papilio polymnestor, P. demoleus, P. liomedon, P. buddha, P. paris, P. dravidarum, P. helenus* and *P. polytes* belonging to the tribe Papilionini were studied. The study revealed morphological dissimilarities in uncus, valvae, harpe, sacculus and phallus, although there was a close similarity in the structure of saccus and juxta. Uncus was generally short and well developed in all the species, but it was tubular in *Chilasa clytia clytia, P. buddha, P. paris, P. dravidarum* and *P. liomedon*. It was broadly conical in *P. demoleus* and finger-shaped in *P. polytes* and *P. helenus.* It was short and blunt in *P. polymnestor* and swollen in *C. clytia dissimilis.*

Valvae was broad, symmetrical and well setosed in all species. Conical in *P. demoleus* and *Chilasa clytia clytia*; ovate in *Chilasa clytia dissimilis, P. polytes, P. buddha* and *P. dravidarum;* ear-shaped in *P. liomedon.* A distinct harpe was present in all species. It was spatulate in *Papilio polymnestor* and *P. paris*; more or less sigmoid in *P. helenus;* mouse- shaped with the proximal end drawn out into a tail-like structure in *P. polytes*; thumb-shaped with an apical lobe in *P. dravidarum*; ring-shaped in *P. demoleus*; with an apical hook in *P. buddha* and bearing two lobes in *C. clytia*.

Phallus was short and stout in *Papilio demoleus, P. liomedon, P. helenus, P. buddha, P. paris* and *P. dravidarum;* medium sized in *Chilasa clytia clytia* and *C. clytia dissimilis;* long and tubular with a pointed tip bearing membraneous vesica as in *Papilio polytes* or bow-shaped with an apical flat edge as in *P. polymnestor.*

There was some similarity in the structure of tegumen, vinculum, juxta and saccus. Tegumen was narrow, slender with elongated arms, inwardly produced into two lobes in all Papilionini *viz., Chilasa clytia, P. buddha, Papilio polymnestor, P. paris, P. liomedon, P. dravidarum, P. polytes, P. helenus* and *P. demoleus*. The vinculum was narrow with elongated arms in *Chilasa clytia, P. buddha, Papilio polymnestor, P. Paris, P. polytes* and *P. demoleus*. But in *P. helenus,* it was V-shaped and longer than the tegumen in *P. liomedon*. Juxta was very prominent in *Chilasa clytia, Papilio polymnestor, P. buddha, P. paris, P. liomedon, P. polytes* and *P. demoleus* except in *P. dravidarum* and *P. helenus.* Saccus was low and U-shaped in *Chilasa clytia, Papilio buddha, P. polymnestor, P. paris, P. liomedon, P. helenus, P. polytes* and *P. demoleus* except in *P. dravidarum*, in which it was V-shaped.

The female genitalic characters of only five species could be studied. In most of these, the ovipositor lobes were broad, roughly oval, strongly sclerotised and fringed with short hairs as in *P. demoleus, P. helenus, P. polytes* and *Chilasa clytia* and roughly bean-shaped in *P. dravidarum.* Posterior apophyses was small and narrow compared to anterior apophyses. Ductus short, narrow, broad and of uniform width in all species.

Corpus bursa was large and variously shaped. It was large, elongate with basal half tubular and distal half globular with truncated apex as in *P. dravidarum*; large and balloon-shaped as in *P. helenus* and *P. polytes* form *stichius*; elongated with the basal half narrower than the apical half in *P. polytes* form *romulus*; oval in *Papilio polytes* form *cyrus*; oval, proximally elongated and narrow in *P. polymnestor, P. demoleus* and *C. clytia clytia* and more or less globular in *C. clytia dissimilis.* Signum was prominent in *Chilasa clytia, Papilio polymnestor, P. polytes, P. demoleus* and *P. dravidarum* except in *P. helenus*. It was lamellate in *P. polymnestor, P. demoleus*, *P. dravidarum, P. polytes* form *romulus*; spindle-shaped in *C. clytia clytia, C. clytia dissimilis; P. polytes* form *stichius*; very broad with tapering ends as in *cyrus* form.

Tribe: Leptocercini

Four species *viz., Graphium sarpedon, G. agamemnon, G. nomius* and *G. doson* belonging to this tribe have been studied. Uncus was distinct and well developed in all the four species. In *G. sarpedon,* it was finger-shaped with a broad proximal part and a blunt apical part. In *G. agamemnon* and *G. nomius,* uncus was ligulate with a middle invagination forming lobes. It was broad and rectangular with lateral lobes in *G. doson.*

Valvae ovate with an invagination at the apex near cucullus in *G. sarpedon.* In *G. doson,* it was lobate whereas in *G. agamemnon,* it was round. In *G. nomius,* it was short with the apex slightly drawn out giving a conical appearance. Harpe showed wide range of variations in shape. It was flat, plate-like having a narrow lobe-like appendage at the distal end in *G. sarpedon.* An expanded, sclerotised harpe bearing a short distal blunt lobe was present in *G. agamemnon*. Harpe consisted of two basally expanded and distally pointed sclerotised spine-like processes in *G. nomius*. In *G. doson,* harpe was flattened lobe-like bearing four prominent spines- one pair pointing towards the ventral margin, the second pair towards cucullus and the third pair towards the costal margin. The modifications of the phallus mostly involved its shape and size. It was long and narrow with an apical notch leaving a small spine in *Graphium sarpedon.* Phallus long with sharply pointed apex and pouch-like vesica situated subapically in *G. agamemnon* and *G. doson.* It was long with a blunt tip in *G. nomius*. Thus the members of the tribe Leptocercini showed great similarity in the structure and shape of the tegumen, vinculum and saccus. Tegumen and vinculum is elongated with narrow arms. Saccus is broadly oval in all four species.

The female genitalic characters of all the four species were studied and they showed great similarity in structure. Ovipositor lobes were broad and triangular in *G. nomius*; while they were elongated and swollen in *G. agamemnon, G. doson* and *G. sarpedon.* Ductus bursa was elongated in *G. nomius* whereas it was of moderate length and uniform width in the remaining species. Corpus bursae were more or less globular in *G. agamemnon* and tubular or oval in *G. sarpedon, G. nomius* and *G. doson*. Signum was prominent and tubular in *Graphium sarpedon, G. agamemnon* and *G. doson* while short in *G. nomius.*

Investigations made in this study have shown that except for a few species, most of the Papilionids reported from Kerala are well represented in this area. Although most of these are easily identifiable using colour/wing pattern, morphology of the external genitalia has shown clear cut affinities among various species and genera. Morphology of uncus, valvae, harpe, saccus and phallus of the male genitalia were found to provide a satisfactory basis for taxonomic segregation. Structure of the uncus was found to be very useful for segregating most of the Papilionids. Out of all species covered in the study, *Troides minos* was quite distinct from all others in the structure of uncus, harpe and phallus. It possessed a low uncus with a median notch which was very unique. Similarly, *A. pandiyana* possessed a sharply pointed uncus. Based on an evaluation of resemblances shared by various species, the following species-groups were identified:

Group I: Included *Troides minos* having a low, notched uncus.

Group II: Included nine species *viz., Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus* having slender tubular uncus. Of these, *P. polytes, P. polymnestor, Papilio paris* and *P. buddha* having spatulate harpe, formed a subgroup. Similarly, *Chilasa clytia* showed broad flattened and lobate harpe formed another subgroup. *P. demoleus, P. liomedon, P. dravidarum* and *P. helenus* with distinctly produced harpe, stood separately.

Group III: Included *Atrophaneura pandiyana* with a sharply pointed uncus.

Group IV: Included six species *viz., Atrophaneura hector, A. aristolochiae, Graphium doson, G. agamemnon, Graphium sarpedon* and *G. nomius* having apically broad and lobate uncus. This group was quite distinct because it includes species belonging to the tribe Troiidini (*A. aristolochiae* and *A. hector)* and Leptocercini (*Graphium doson, G. agamemnon* and *G. nomius*). Within this group, two subgroups were also identified based on the structure of saccus. *A. aristolochiae* and *A. hector* having long blunt U- shaped saccus formed a subgroup and *Graphium doson, G. sarpedon G. agamemnon* and *G. nomius* having short saccus formed another subgroup. Among these, *G. sarpedon* stood out distinctly with a deep invagination at the apex of the valvae.

The morpho-taxonomic studies on the external genitalia have showed the uniqueness of *Troides minos* and *A. pandiyana*. In this context, it may also be noted that, certain species belonging to the tribe Troiidini (*A. aristolochiae* and *A. hector*) and Leptocercini (*Graphium doson, G. agamemnon* and *G. nomius*) shared close resemblance necessitating a shift from their original inclusions.

6.1.4 Phenetic and phylogenetic analysis

The phenetic and phylogenetic analysis showed that all the species studied herein formed a well differentiated clade indicating their monophyletic nature with respect to Pieridae clade and received 100% bootstrap support. The dendrogram segregated the Papilionids into two primary clusters (A and B) at a dissimilarity coefficient of 1.49 and the outgroup (Pieridae) differed from all other groups. The primary cluster (A) was subdivided into two sub- clusters (A1, A2) and second primary cluster (B) consisted of four sub-clusters (B1, B2, B3, B4). A1 consisted of *G. sarpedon, G. agamemnon, G. doson* and *G. nomius* and A2 included of *A. pandiyana, A. aristolochiae* and *A. hector*. B1 consisted of *P. liomedon, P. paris, P. buddha, P. helenus, P. polytes* and *P. polymnestor*. B2 consisted of *P. demoleus* and *P. dravidarum*; B3 and B4 consisted of single individuals *viz., C. clytia* and *T. minos* respectively. The monophyletic nature of papilionidae is in conformity with the studies carried out by Ehrlich and Ehrlich (1967) who reported a close relationship between Pieridae and Papilionidae through numerical taxonomic methods. Scott (1985) generated a cladogram that categorized Pieridae and Papilionidae into one group and Lycaenidae (including Riodinidae as a subfamily) and Nymphalidae into another, thus recognizing essentially two true groups of butterflies.

In the phylogenetic analysis, *T. minos*, formed the basal clade with one synapomorphic character *ie.,* shape of uncus. *A. pandiyana* diverged from rest of the *Atrophaneura* with a pointed uncus; *A. aristolochiae* and *A. hector* formed the sister clades. Among the members of the genus *Papilio*, the species *demoleus* which is a tail-less Papilionid butterfly was shown to be the basal taxa. The clade of *Papilio* (*polymnestor, helenus, polytes, liomedon, buddha, paris* and *dravidarum*) shared unique characters including the features of slender tubular uncus and *C. clytia,* which has branched off from the basal lineage with the characters of phallus and harpe. *P. paris* and *P. buddha,* which formed the sister clades, shared common characters pertaining to uncus and harpe. *Atrophaneura* group and *Graphium* group were splitted into two clades with 59 % of bootstrap support including one synapomorphic character *ie.,* the size of saccus. As regards to the members of Leptocercini, *G. sarpedon, G. doson* and *G. nomius* shared one synapomorphy *ie.*, the presence of hairs on the anal papillae. *G. agamemnon* had branched off from other three *Graphium* members on basis of the presence of distinct juxta and shape of corpus bursae.

Based on the cladistic analysis, two main clades have been recognized.

Clade I: Included ten species *viz., Troides minos*, *Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus.* Of these, *T. minos* was unique in the shape of uncus and formed a subclade. All the remaining nine species formed a distinct group. Of these, *C. clytia,* branched off from the basal lineage on the basis of the characters of phallus and harpe. Species belonging to the genera *Papilio* (*polymnestor, helenus, polytes, liomedon, buddha, pari*s and *dravidarum*) were more or less similar in possessing tubular uncus with *P. paris* and *P. buddha* formed sister clades.

Clade II: Included seven species *viz., Graphium sarpedon, G. doson, G. agamemnon G. nomius, Atrophaneura pandiyana*, *Atrophaneura hector* and *A. aristolochiae.* Of these, *Atrophaneura pandiyana* possessing a sharply pointed uncus formed a distinct subclade. *Atrophaneura hector* and *A. aristolochiae* formed sister clades, possessing U- shaped saccus. The remaining 4 species (*Graphium sarpedon, G. doson, G. agamemnon* and *G. nomius)* formed another distinct subclade.

A comparison of the morpho-taxonomical and cladistic analysis showed some similarities and dissimilarities. The main similarities included the distinctness of *T. minos* and *A. pandiyana.* In the phylogenetic analysis, *T. minos* stood out separately based on the shape of the uncus within clade I. *Atrophaneura pandiyana* possessed sharply pointed uncus formed a separate group. In the phylogenetic analysis, *Atrophaneura* group and *Graphium* group formed a common clade which later got splitted into two sub-clades with 59 % of bootstrap support. A close resemblance was observed between *Papilio paris* - *P.*

buddha and *Atrophaneura hector* - *A. aristolochiae*. The main dissimilarity was that, *T. minos, C. clytia* and all species of the genus *Papilio* belong to clade I although they stood separately within the clade.

The findings of the present study have brought out the phylogenetic relationships of various taxa belonging to the family Papilionidae. The cladistic analysis using 42 characters provided a well-resolved tree showing that some genera do not constitute monophyletic groups since species having the same characteristics are widely separated under different tribes. This is shown by the resemblences of the species included under the tribe Troiidini (*A. aristolochiae* and *A. hector*) and Leptocercini (*Graphium doson, G. agamemnon* and *G. nomius*). Ehrlich (1958) and Munroe (1961) are of the opinion that Papilionini arose from the Leptocercini stem. Based on the features of antennae, tentorial crests of larvae and patagia, Hancock (1983) assumed that Papilionini has originated from the Troiidini stem. The present study, based on the morphology of the external genitalia also recognized a common origin of Troiidini (*Troides minos*) and Papilionini (*Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus*). Thus, the findings of this study are in agreement with the assumption made by Hancock. However, Scott (1985) is of the opinion that other traits such as pigmentation, pupal shape and wing venation are too variable or too weak to be of any use in the classification at the level of "Tribes". Talbot (1939) has classified the family Papilionidae of Kerala into 3 tribes based of wing venation and larval feeding preferences. Based on the characters of the external genitalia, Papilionidae of Kerala has been regrouped under 4 tribes. Since sexual isolation is the key factor in segregating species, classification based on the external genitalial characters is supposed to be more reliable in grouping organisms. However, more detailed investigations involving molecular studies are needed to resolve the exact ranking of various taxonomical categories of Papilionidae.

6.2 Biological studies

Investigations on the biology of 13 species of Papilionid butterflies both in the laboratory as well as under field conditions have revealed that survival of butterflies in the wild depends on the availability of foraging area, freedom from natural enemies and availability of conducive environment for courtship. This highlights the significance of site amelioration programmes in enhancing butterfly population in specific habitats.

The feeding patterns of the immature stages of Papilionidae present wide variations ranging from monophagy (in which a single species of food plant is utilized) to polyphagy (in which plants belonging to several genera or families are utilized). Of the various species covered in this study, *Atrophaneura pandiyana* and *Papilio dravidarum* are monophagous specialists; *Troides minos, Atrophaneura aristolochiae, Atrophaneura hector*, *Papilio polymnestor, P. helenus, P. demoleus, P. polytes* and *Chilasa clytia* are oligophagous (host plants belongs to one family) and others like *Graphium agamemnon, Graphium doson* and *Graphium sarpedon* are polyphagous (host plants belongs to 2-4 different families). In South-East Asia, the Papilionids are known to utilize upto eight plant families and Aristolochiaceae is the most important host plant family, followed by Rutaceae and Lauraceae (Fiedler, 1998). Due to their adaptability to a variety of host plants, high survival rate and incredible egg production during the breeding season, polyphagous species are best suited for butterfly gardening and captive breeding programmes. The study has also led to the discovery of additional host records for three butterflies (Plate XLVIII). These included *Litsea coriacea* (Lauraceae) (host plant of *Chilasa clytia); Euodia ridleyi* (Rutaceae) (host plant of *Papilio polymnestor)* and *Kingiodendron pinnatum* (Leguminosae) (host plant of *Graphium agamemnon*).

Natural mortality factors especially, the incidence of natural enemies is an important factor affecting the survival of many butterflies. It has been stated that only about 2% of the progeny is destined for survival. However, many species of butterflies have relatively high fecundity and adaptability to escape from natural enemies to ensure survival. In Papilionids, frequent incidence of parasitic wasps and flies has been noticed. *Papilio polytes* parasitized by the wasps of Ichneumonidae and *Chilasa clytia* parasitized by flies of Tachinidae suffered drastic reduction in field population. In addition to the parasites, various predatory birds and garden geckos were also found to feed on butterflies particularly the palatable ones (mostly belonging to the genera *Graphium* and *Chilasa*) while the unpalatable ones (especially the Troiidini) were generally avoided by the predators. In order to escape from natural enemies, Swallowtails have evolved various protective adaptations, right from the egg to the adult stage. All the species studied here were found to lay only one egg per leaf which was often on the underside of a leaf for ensuring protection. Similarly, caterpillars of all the species studied herein possessed osmetarium as a defensive mechanism to thwart the attack by predators. In many species, the immature stages showed extreme degrees of camouflage, wherein the larval appearance and colouration was found to change in different instars. For instance, the larvae of *Papilio* spp. which resemble bird-droppings in its first instar, turn greenish with bands or markings on the body during the subsequent instars, thereby rendering a superb blending of the larva with its immediate surroundings. Similar adaptations have been noticed in the pupal stage as well. The pupa may be variously coloured or show curious shapes. The pupa is greenish in *Papilio* spp. and brownish or blackish in colour in *Troides minos*, *Atrophaneura* spp. so as to match with their substratum. In *Chilasa clytia*, the pupa exhibits the extreme adaptation by appearing as part of the twig on which it rests.

Protective adaptations, in the form of mimicry have been developed in many Swallowtails. For instance, in *P. polytes,* the *stichius* form mimics *A. aristolochiae* and the *romulus* form mimics *A. hector* and it is a good example for Batesian mimicry. Similarly, *Atrophaneura pandiyana* and *A. aristolochiae* shows Mullarian mimicry. The protective adaptations observed in Swallowtail butterflies are indicative of the evolutionary pathways through which these butterflies have passed through in the past before emerging as a successful group of butterflies in the current era. With regard to the life history patterns, many butterflies such as *Papilio demoleus, P. polytes, Chilasa clytia, Graphium* *agamemnon, G. doson* and *G. sarpedon* required only short duration (24-35 days) to complete their life cycle while, others like *Troides minos, Atrophaneura aristolochiae, A. hector, Papilio helenus, P. dravidarum* and *P. polymnestor* required relatively longer period (36-56 days) to complete their lifecycle. This is attributed to the choice of larval host plants as well as adaptability to a wide range of environmental conditions.

6.3 Behavioural studies

Observations made on the behavioural aspects have shown that butterflies demonstrate complex behaviour of foraging, patrolling and oviposition.

Oviposition behaviours involved the repeated visits of the females to the host-plants and probing the leaves for ascertaining conditions suitabile for egg laying like the tenderness of foliage and the availability of protected environment. In many cases, egg laying commences only after repeatedly flying around the host plants for about 5-8 minutes. During oviposition, the female continuously flutters its forewings and it takes only about 5 seconds to lay the egg. A complex sequence of behaviour, utilizing a range of stimuli, may be involved foe locating the right oviposition site (Courtney and Chew, 1987). Considering the relative immobility of caterpillars, the selection of oviposition sites assumed to be the crucial process. Of the 13 species of Papilionids observed, all of them were found to lay their eggs singly. The single egg-laying habit has an advantage in that it averts the possibilities of larval saturation by resource exhaustion and enables effective utilization of isolated plants (Davies and Gilbert, 1985).

Of the various types of behavior covered in this study, patrolling was noted to be very pronounced in Papilionidae which is an attempt to enforce monopoly over the area for mate and resources. The Southern Birdwing, Blue Mormon, Red Helen and Malabar Banded Peacock exhibited patrolling behaviour and they were found to chase away the rival males. Butterflies are known to make use of a variety of sensory modalities in foraging and the integration of visual, olfactory and gustatory cues are usually involved in their orientation to and finding of food sources (Dobson, 1994). In certain cases, flowers of particular plants are more preferred by particular butterfly species and flower constancy is sometimes prominent (Goulson *et al.*, 1997). Most of the Swallowtails preferred the blossoms of *Pentas, Ixora, Clerodendrum paniculatum* L., *Marigold, Cuphea, Zinnia, Lantana camara* and *Mussaenda* for nectaring. Tt was also observed that most of the Swallowtails preferred red coloured flowers for nectaring. Flower constancy, which varies with both the species of butterfly and the species of plant, appears to be an outcome of learning through the recognition of rewarding flowers (Lewis and Lipani, 1990). Flight behaviour of Swallowtails was very interesting. Birdwings generally soar slowly and royally on the tops of trees, the Jays skip quickly and suddenly from flower to flower, the Peacocks fly swiftly in the canopy and others such as the Red Helen and Mormons have a lazy flight. However, all of them have the ability for rapid progression if any danger threatens them.

6.4 Ecology

Ecology of Papilionid butterflies pertaining to three eco-climatic zones *viz.,* south, central and northern Kerala have been collected and compared. A discussion on the various parameters studied.

6.4.1 Faunal elements and population abundance

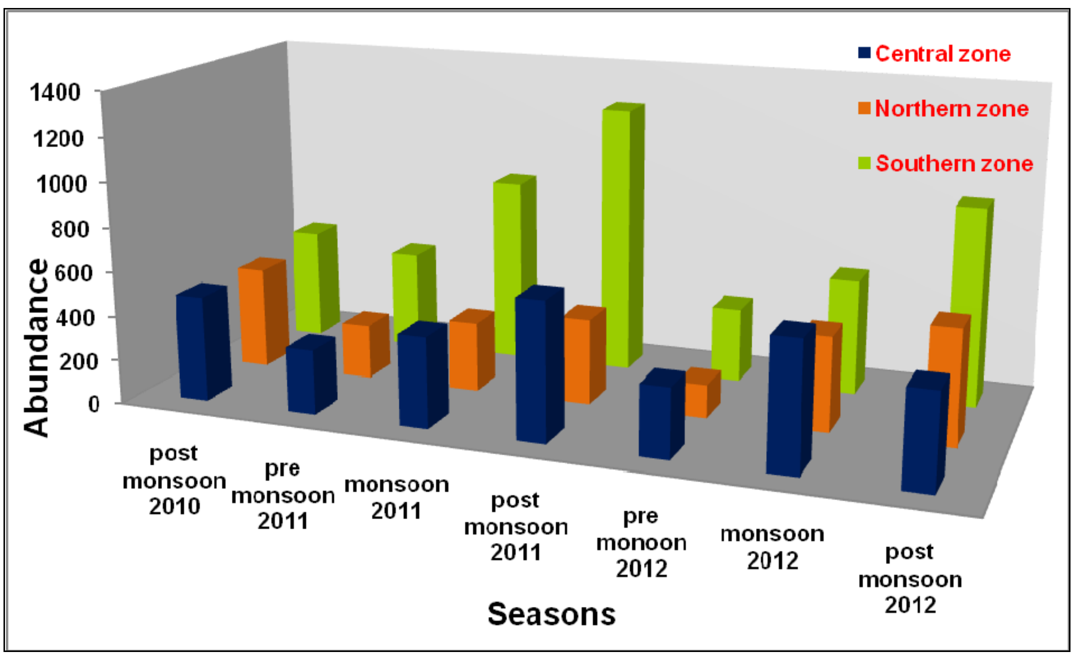
As regards to the Papilionid fauna, 15 species belonging to 5 genera were recorded from southern zone (Thenmala) compared to 13 species under 5 genera from northern zone (Nilambur) and 12 species under 5 genera from Central zone (Peechi). The faunal elements comprised of protected and endemic species. The former included *A. hector* and *P. liomedon* at Thenmala and Nilambur and *A. hector* and *P. buddha* in Peechi. With regard to the endemic species, seven species *viz., T. minos, A. pandiyana, A. hector, P. buddha, P. liomedon, P. dravidarum* and *P. polymnestor* were recorded from each of these locations compared to eight Western Ghats endemics already reported by Gaonker (1996). With regard to the faunal assemblage of Papilionid butterflies in three geographical zones, maximum sightings was recorded at southern zone (4,601) followed by central zone (3,128) and northern zone (2,466). The abundance in butterfly population at Thenmala is attributed mainly due to the fact that this area was located right within the Shendurney Wildlife Sanctuary. Availability of a relatively large stretch of natural vegetation offers ample oppourtunities for the survival of a wide spectrum of butterflies compared to the other two locations which are situated in the outskirts of natural forests. As a result, the butterfly abundance in these areas is relatively less compared to that the southern zone.

Similarly, the occurrence of butterflies in the three zones was interesting. Among various species observed, *Troides minos, Atrophaneura aristolochiae, A. pandiyana, A. hector, Chilasa clytia, Papilio helenus, P. polytes, P. demoleus* and *P. polymnestor* were found to have more or less continuous population in all the areas throughout the year. *P. liomedon, P. paris* and *P. dravidarum* were sighted only from the southern and northern zones although this does not exclude their presence in the central zone. Similarly, the Malabar Banded Peacock, *Papilio buddha* was sighted only from the central zone and the Swordtail, *Graphium nomius* from the southern zone. Although these species are known to occur in several locations in Kerala, their absence from the other zones only indicate that these species have a restricted distribution even within a given habitat. Their occurrence in specific zones was found to be correlated with the availability of specific host plants as well as eco-climatic conditions. Species having a wide range of distribution are adapted to a wide variety of habitats and have the ability to survive in different environmental conditions. Studies in various locations revealed that the species like *T. minos, A. aristolochiae, A. hector, C. clytia, P. polytes, P. polymnestor, P. helenus, G. agamemnon, G. sarpedon* forms the open populations and these species will be relatively broader species having a wide range of habitats. Species having restricted distribution have very narrow tolerance to environmental conditions and most of them require specific habitats and host plants and therefore those species are considered to be ideal indicators to monitor environmental changes. They have greater risk of extinction, since conservation of circumscribed tight populations may necessitate preservation and maintenance of the limited habitats. In this study, some of the species such as *A. pandiyana, P. buddha, P. paris, P. liomedon, P. dravidarum, G. nomius,* have made their appearance in specific locations designate as indicator taxa due to their tight populations, required restricted ecological requirements. Investigations on these species composition of an area can provide valuable clues on the level of degradation taking place in a given habitat. Observations on the diversity, distribution and habitat utilization of butterflies are essential for understanding the population abundance, seasonality and their behaviour within a given habitat.

6.4.2 Seasonal Population trends and weather correlations

An examination of pooled data on the population trends of Swallowtails is plotted in Graph 13. As regards to the seasonal abundance of butterflies in the southern zone, peak abundance was noticed during the post monsoon season in 2011 and lowest in the pre monsoon of 2012 seasons. In the central zone, highest abundance was in the post monsoon season of 2011 and lowest abundance in the pre monsoon of 2011. In the northern zone, the highest abundance was noted during the post monsoon seasons in 2012 and lowest in the pre monsoon season of 2012.

In all locations, the highest seasonal index was observed during June to November and lowest in January to May. From June onwards the population showed a gradual increase reaching its peak during the months August to November. It indicates that weather parameters play a major role in regulating butterfly populations. It may be noted that Mathew and Anto (2007) have shown that for many species of butterflies an average temperature ranging from 25-26 ◦C and relative humidity ranging between 80-90% are the most preferred and this range is available during monsoon and post monsoon seasons. The onset of the monsoon triggers the sprouting of tender foliage on which the larvae feed. The availability of adequate larval and adult nectar sources coupled with appropriate eco-climatic conditions definitely influence the abundance of butterfly population. The gradual decline of butterfly population during the post monsoon seasons might be due to the unfavourable conditions with the onset of summer reaching its peak during March-April. In fact, this dry period was least favourable to many butterflies probably due to the scarcity of water, nectar and fresh foliage. Earlier, Hussain *et al.* (2011) have also reported that maximum butterfly activity was observed during North East monsoon season and least during the summer season. Availability of nectar and larval host-plants, predator avoidance and mate location are some important factors which affect the resource utilization and habitat exploitation of any species confined to a given geographic range.



Graph 13. Schematic representation of the overall population trends of Papilionids at three locations in Kerala. (Pre monsoon: January - April; Monsoon: May- August; Post monsoon: September – December)

With regard to the species-wise abundance, *T. minos*, *A. aristolochiae*, *A. pandiyana*, *C. clytia*, *P. polytes* and *P. polymnestor* maintained more or less constant population throughout the year in all the locations. Their sightings showed strong positive correlation with weather parameters being most abundant during the monsoon season. The sightings of some endemic and rare Swallowtails such as *Papilio dravidarum, P. paris, P. helenus* and *P. liomedon* were during the monsoon season in southern and northern zones. These species showed a significant negative correlation with temperature and significant positive correlation with humidity and rainfall. The abundance of *P. buddha* in the central zones during the monsoon and post monsoon seasons also showed negative correlation with temperature, but it was not significant. Therefore, it can be assumed that the sightings of these Papilionids decrease with increasing temperature and increases with increasing humidity and rainfall and *vice versa*. Similarly, certain species such as *G. nomius* recorded from Thenmala during February-May showed a significant positive correlation with temperature and significant negative correlation with humidity and rainfall. This shows the significance of weather parameters on butterfly populations.

Spitzer (1993) has shown the positive relations between butterfly diversity and environmental variables such as climate, habitat complexity and plant diversity. Microclimatic conditions created by temperature and moisture gradients, which are quite independent of habitat types, can also help in determining the distribution and local abundance of butterflies on a small scale. Correlation analysis has shown that different butterfly species respond differently to the environmental/weather parameters, thus highlighting the importance of maintaining the environmental heterogeneity for the conservation of different butterfly species. Information related to the community structure, composition and seasonal fluctuations of the butterfly fauna are very important and form a baseline data for the future conservation programmes.

Summary

The Swallowtails are a group of extremely colourful and large sized butterflies having tremendous ecological and economic significance. Due to large scale destruction of habitat, many species of Swallowtails are on the verge of extinction. In the present study, an attempt has been made to investigate the identity, biology and ecology of the Swallowtail butterflies of Kerala. Information on the fauna was collected by making a sample survey. The areas covered included Nilambur, Nadukani Ghat, Vazhikkdavu, Aralam, Thirunelli, Thrissur, Palakkad, Peechi, Vazhani, Athirappilly, Vazhachal, Vettilappara, Malakkappara, Chinmoni and Thenmala. Of the 19 species of Papilionids reported from Kerala, 17 species have been recorded from the above locations. Of these, three species were protected, seven endemic, two rare and the remaining ones common.

In order to confirm the taxonomic identities of various species, detailed investigations were made on the general morphology of the external genitalia of various species. A comparison of the structural details of the external genitalia has shown that various species differ in the structure of the genitalia. Morphology of uncus, valvae, harpe and phallus of the male genitalia and corpus bursae and signum of the female genitalia was found to provide a satisfactory basis for taxonomic segregation. Based on the features of the external genitalia, a taxonomic key was prepared for the segregation of various species.

Based on the analysis of morphological details of the external genitalia, the 17 species covered in this study were grouped under 4 categories. Of all the species covered in this study, *Troides minos,* which possessed a low uncus, was quite distinct from the rest with a median notch, formed the first category.

Nine species *viz., Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus* having slender, tubular uncus formed the second category. Of these, *P. polytes, P. polymnestor, P. paris* and *P. buddha* having spatulate harpe, formed a subgroup within this category. Similarly, *Chilasa clytia* possessing a broad, flattened and lobate harpe formed another subgroup. *P. demoleus, P. liomedon,*

P. dravidarum and *P. helenus* were quite distinct from the above species particularly on the morphological details of the harpe.

Atrophaneura pandiyana, another species studied, possessing a sharply pointed uncus thus forming third category. Six species *viz., Atrophaneura hector, A. aristolochiae, Graphium doson, G. sarpedon, G. agamemnon* and *G. nomius* having apically broad and lobate uncus formed fourth category. This group was quite interesting since it contained certain species drawn from the tribe Troiidini (*Atrophaneura aristolochiae* and *A. hector)* and Leptocercini (*Graphium doson, G. agamemnon, G. sarpedon* and *G. nomius)*. These findings have shown that although the above species are currently grouped under two separate tribes, they show strong similarities in the morphological details of the external genitalia warranting transfer from their original placements.

The phenetic and phylogenetic analysis of various species was also undertaken and it was found that all the Papilionids studied herein formed a well differentiated clade indicating the monophyletic nature of Papilionidae. Based on the cladistic analysis, two main clades have been recognized. The first clade included ten species *viz., Troides minos, Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus*. Of these, *T. minos* was unique in the shape of uncus and formed a subclade. All the remaining nine species formed a distinct group. Of these, *C. clytia,* branched off from the basal lineage on the basis of the characters of phallus and harpe. Species belonging to the genera *Papilio (polymnestor, helenus, polytes, liomedon, buddha, pari*s and *dravidarum*) were more or less similar in possessing tubular uncus with *P. paris* and *P. buddha* forming sister clades.

The second clade included seven species *viz., Graphium sarpedon, G. doson, G. agamemnon G. nomius, Atrophaneura pandiyana*, *Atrophaneura hector* and *A. aristolochiae.* Of these, *Atrophaneura pandiyana*, *Atrophaneura hector* and *A. aristolochiae* formed a distinct group. Within this group, *Atrophaneura pandiyana* with a sharply pointed uncus remained distinct. *Atrophaneura hector* and *A. aristolochiae* possessing U- shaped saccus, formed sister clades. The remaining 4 species (*Graphium sarpedon, G. doson, G. agamemnon* and *G. nomius)* formed another distinct sub group.

A comparison of the morpho-taxonomical and cladistic analysis showed some similarities and dissimilarities. The main similarities included the distinctness of *T. minos* and *A. pandiyana.* In both analyses*, T. minos* stood out separately based on the shape of the uncus within clade I. *Atrophaneura pandiyana* possessed sharply pointed uncus formed a separate group. In the phylogenetic analysis, *Atrophaneura* group and *Graphium* group formed a common clade which later got splitted into two sub-clades with 59 % of bootstrap support. A close resemblance was observed between *Papilio paris* - *P. buddha* and *Atrophaneura hector* - *A. aristolochiae*. The same trend was observed in the morphological analysis as well. The main dissimilarity was that, *T. minos, C. clytia* and all species of the genus *Papilio* belong to clade I although they stood separately within the clade.

The findings of the present study have brought out the phylogenetic relationships of various taxa belonging to the family Papilionidae. The cladistic analysis using 42 characters provided a well-resolved tree showing that some genera do not constitute monophyletic groups since species having the same characteristics are widely separated under different tribes. This is shown by the resemblences of the species included under the tribe Troiidini (*A. aristolochiae* and *A. hector*) and Leptocercini (*Graphium doson, G. agamemnon* and *G. nomius*). Ehrlich (1958) and Munroe (1961) are of the opinion that Papilionini arose from the Leptocercini stem. Based on the features of antennae, tentorial crests of larvae and patagia, Hancock (1983) assumed that Papilionini has originated from the Troiidini stem. The present study, based on the morphology of the external genitalia also recognized a common origin of Troiidini (*Troides minos*) and Papilionini (*Chilasa clytia, Papilio paris, P. buddha, P. liomedon, P. dravidarum, P. demoleus, P. polytes, P. polymnestor* and *P. helenus*). Thus, the findings of this study are in agreement with the assumption made by Hancock (1983). However, Scott (1985) is of the opinion that other traits such as pigmentation, pupal shape and wing venation are too variable or too weak to be of any use in the classification at the level of “Tribes”. Talbot (1939) has classified the family Papilionidae of Kerala into 3 tribes based of wing venation and larval feeding preferences. Based on the characters of the external genitalia, Papilionidae of Kerala has been regrouped under 4 tribes. Since sexual isolation is the key factor in segregating species, classification based on the external genitalial characters is supposed to be more reliable in grouping organisms. However, more detailed investigations involving molecular studies are needed to resolve the exact ranking of various taxonomical categories of Papilionidae.

Biology of 13 species of Swallowtails has been studied. Of these, *Papilio demoleus, Graphium agamemnon, G. doson* and *G. sarpedon* required only short duration (24-35) to complete their life cycle while others like *Troides minos, Atrophaneura aristolochiae, A. hector*, *Papilio helenus, P. dravidarum, C. clytia, P. polytes* and *P. polymnestor* required more than a month to complete their life cycle. With regard to host plant associations, certain species such as *Atrophaneura pandiyana* and *Papilio dravidarum* were found to be monophagous; *Troides minos, Atrophaneura aristolochiae, A. hector*, *Papilio polymnestor, P. helenus, Papilio demoleus, Chilasa clytia, Papilio polytes* were Oligophagous and others like *Graphium agamemnon, Graphium doson*, *Graphium sarpedon* were polyphagous. The present study has also led to the discovery of additional host records for three butterflies. These included *Litsea coriacea* (Lauraceae) (host plant of *Chilasa clytia); Euodia ridleyi* (Rutaceae) (host plant of *Papilio polymnestor)* and *Kingiodendron pinnatum* (Leguminosae) (host plant of *Graphium agamemnon*). Information on the choice of host plants is useful in their conservation and also for utilizing them in butterfly exhibitory. The polyphagous species are the best suited for butterfly gardening or captive breeding programmes due to their adaptability to a variety of host plants, high survival rate and incredible egg production during the breeding season. Observations on the behavioural aspects of the Papilionids were also undertaken and it was found that butterflies demonstrate complex behaviour of foraging, patrolling and oviposition.

Specific studies pertaining to the ecology of Papilionids were carried out at three locations in Kerala *viz.*, Nilambur, Peechi and Thenmala representing northern, central and southern zones. Maximum sightings were recorded from the southern zone (Thenmala) followed by the central zone (Peechi) and the northern zone (Nilambur). Continuous monitoring in the study sites have shown 4,601 sightings in southern (Thenmala), 3,128 sightings in central

(Peechi) and 2,466 sightings in northern (Nilambur) zones. Regarding the relative abundance of Papilionids, maximum abundance was noticed in the monsoon and post monsoon seasons and least in the pre monsoon season. Among the three study sites, Thenmala had the highest population abundance compared to the other two locations. Length of life history, range of host plants, response to environmental and weather parameters, incidence of natural enemies etc., are some of the factors that affect the abundance of butterflies.

Sightings of Swallowtails in the three locations were found to be correlated with the weather parameters *viz.,* mean monthly temperature, average relative humidity and total monthly rainfall. The results indicate that *Troides minos*, *Atrophaneura pandiyana, Papilio dravidarum, P. paris, P. helenus, P. polymnestor* and *P. liomedon* require moderate temperature, high humidity and high rainfall. The number of sightings of these species decrease with increasing temperature and increase with increasing humidity and rainfall. It was interesting to note that sightings of some of the rare and endemic species such as *Papilio dravidarum, P. paris, P. helenus* and *P. liomedon* were observed in the monsoon and post monsoon seasons. These species showed significant negative correlation with temperature and significant positive correlation with humidity and rainfall. *P. buddha* which was abundant in the central zone during the monsoon and post monsoon seasons showed a negative correlation with temperature, but it was not significant. The species *G. nomius* was sighted only at Thenmala and its occurrence showed significant positive correlation with temperature and significant negative correlation with humidity and rainfall. Thenmala is noted for dry conditions and extreme high temperature during summer months.

The ill effects of climate change on butterfly population have also been brought out by this study. A change in the climate may alter the structure and phenology of flora leading to subtle changes in the composition and population structure of its insect associates leading to irreversible changes in the functioning of natural ecosystems and food webs. This may also lead to the spread of alien weeds and organisms which has profound implications on the native flora and fauna. Climate change may also affect the survival of butterflies having narrow ecological requirements especially the rare and endemic species. Conservation of natural habitats is very essential for ensuring the survival of our diversified native biota.

The distribution of the Swallowtails in Kerala was found to be interesting. Of the various species covered in this study, *Troides minos, Atrophaneura aristolochiae, A. hector, Chilasa clytia, Papilio polytes, P. polymnestor, P. helenus, P. demoleus, Graphium agamemnon, G. doson and G. sarpedon* were found to be highly dispersive enjoying a wide geographical range. Among these, *Troides minos, Atrophaneura aristolochiae, A. hector, Chilasa clytia, Papilio polytes, P. polymnestor, P. helenus* and *P. demoleus* were found to be oligophagous and *Graphium agamemnon, G. doson and G.* sarpedon were found to be polyphagous species. They formed more open populations with wide spectrum of adaptabilities and these species have better survival chances compared to the species having narrow distribution. However, the species *viz.*, *A. pandiyana, Papilio buddha, P. paris, P. liomedon, P. dravidarum* and *Graphium nomius* showed restricted abundance in specialised habitats. *A. pandiyana* and *Papilio dravidarum* are monophagous and *P. paris, P. liomedon P. buddha* and *G. nomius* are oligophagous. The sightings of these butterflies were rather erratic and coincided with optimum weather conditions.

Information generated on the taxonomy, biology, seasonality and distribution of Papilionid butterflies tend to show that the fauna of Swallowtail butterflies of Kerala is rich and varied despite wide spread ecological degradation of their natural habitats. Although, the natural landscapes in countrysides have been thoroughly altered, areas adjoining the Western Ghats as well as rural areas in the state still support a rich fauna mainly due to the occurrence of specific larval host plants. The study has also shown that many species of rare, protected and endemic butterflies are to be found only in the forest areas on account of the availability of specialised habitats. This indicates the necessity for conserving and monitoring the natural habitats for tracking changes taking place in the environment and for adapting timely conservation programmes.

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Appendices

Appendix I - List of characters selected for phenetic and phylogenetic analysis

No. assi-gned	Characters selected	Character states with scores assigned
0	Phallus: size	Short (length less than three times width) - 0; medium (length up to five times width) - 1; long (more than five times width) - 2
1.	Phallus: shape	Straight - 0; slightly curved - 1; strongly curved - 2
2.	Phallus: other attributes	Apically pointed - 0; blunt - 1
3.	Uncus: size	Short - 0; elongate - 1
4.	Uncus: shape	Single point - 0; forked - 1
5.	Uncus: cleft of uncus	Not cleft - 0; cleft - 1
6.	Saccus: size	Saccus equal to or shorter than total length of genital armature) - 0; medium - 1; saccus longer than total length of genital armature - 2
7.	Saccus: length	length equal to or less than two times width - 0; narrow (length more than two times width) - 1
8.	Tegumen: size	Short - 0; elongated - 1
9.	Valvae: size	Short (length equal to or less than width) - 0; elongate (length more than twice the width) - 1
10.	Valvae: contour	Smooth contour - 0; with appendages - 1
11.	Valvae: other attributes	Absent - 0; present single - 1; double - 2
12.	Costa: sclerotisation	Well sclerotised - 0; poorly sclerotised - 1
13.	Harpe: shape	Elongated and narrow - 0; broad - 1
14.	Harpe: contour	Smooth contour - 0; appendages or spines - 1
15.	Gnathos: presence or absence	Present - 0; absent - 1
16.	Gnathos: structure	Continuous - 0; discontinuous (two arms below the uncus) - 1
17.	Juxta: appearance	Distinct - 0; indistinct - 1
18.	Sacculus: shape	Straight - 0; short and ovate - 1
19.	Corpus bursae: shape	Short, rounded - 0; ovate or elongate - 1

20.	Ductus bursae: shape	Long - 0; short - 1
21.	Corpus bursae: presence of signum	A prominent signum - 0; small or without signum - 1
22.	Signum : ornamentation	Spines on ends - 0; without spines - 1
23.	Signum: location	At the neck of the corpus bursae - 0; away from the neck - 1
24.	Signum shape	Long and heart shaped - 0; lamellate or tubular - 1
25.	Anal papillae: shape	Normal - 0;elongate - 1
26.	Anal papillae: presence of setae	Normal hairs - 0; very short hairs - 1
27.	Posterior apophyses: size	Short -0; long, more than the length of the papilla - 1
28.	Posterior apophyses: presence of apical club	Apical club present - 0; absent - 1
29.	Appendix bursae: presence or absence	Present - 0; absent - 1
30.	Eggs: color	White or creamy - 0; yellow or orange - 1
31.	Eggs: presence of longitudinal ridges	Present - 0; absent - 1
32.	Eggs: place of oviposition	Under leaf or upper leaf surface - 0; other places - 1
33.	First instar larvae: presence of caudae	Absent - 0; present - 1
34.	First instar larvae: presence of thoracic tubercles	Absent - 0; present - 1
35.	First instar larvae: presence of body rings	Absent 0; present 1
36.	Last instar larvae: presence of Predominant ventral color	Light (green, white, or yellow) - 0; dark (black, brown, or red) - 1
37.	Pupa: colour	pale brown to maroonish - 0; entirely green - 1
38.	Pupa: presence or absence of anterior projections	Absent - 0; present - 1
39.	Pupa: shape of anterior projections	a small, rounded bump (0); a pointed, anterior projection - 1
40.	Adults wing span	Less than 1.9 (normal wing) - 0; equal or more than 1.9 (elongate wing) - 1
41.	Hind wing: presence of hair tufts	Absent - 0; present - 1
42.	Hind wing: presence of tails	Tailed - 0; tailless - 1

Appendix II - Data matrix of phenetic and phylogenetic analysis

Species	Character selected with scores																																										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
T. minos	0	1	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	0	1	0	0	0	1	1	1	1	0
A. pandiyana	1	1	0	1	0	0	1	1	0	0	0	0	1	0	0	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	1	0	0	0	1	0	0	0	1	0	1	0	1
A. aristolochiae	2	0	0	1	1	1	1	1	0	0	0	0	1	0	0	1	?	1	1	1	1	0	1	1	1	1	0	1	1	0	1	0	0	0	1	1	0	0	1	0	1	0	1
A. hector	2	0	0	1	1	1	2	1	0	0	0	0	1	0	0	1	?	1	1	1	1	0	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	1	0	1	0	1
C. clytia	0	2	1	0	0	0	0	0	1	1	0	1	1	1	1	0	1	0	0	1	1	0	1	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0
P. demoleus	0	1	1	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0	1	1	1	0	1	1	1	0	0	0	1	0	0	1	0	1	1	0	0	1	1	0	1	1	0
P. liomedon	0	1	1	0	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0	1	?	?	?	?	?	?	?	?	?	?	1	1	0	1	0	1	1	1	1	0	1	0	1
P. dravidarum	0	2	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	1	0	1	1	0	1	0	1	1	0	0	1	0	0	1	0	1	0	0	1	1	1	0	1	1	0
P. helenus	0	1	0	0	0	0	0	0	1	1	0	1	1	0	0	0	1	1	0	1	0	1	0	0	0	1	0	1	1	0	0	1	0	1	0	0	1	1	1	0	1	0	1
P. polytes	1	0	0	1	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	0	1	1	0	0	1	0	1	0	0	1	1	1	0	1	1	1
P. polymnestor	1	2	1	1	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	1	1	0	0	1	1	1	0	0	0	1	1	0	1	0	0
P. paris	0	1	1	0	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0	?	?	?	?	?	?	?	?	?	?	?	0	1	0	1	1	1	0	1	1	0	1	0	1
P. buddha	0	1	1	0	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0	?	?	?	?	?	?	?	?	?	?	?	0	1	0	1	1	1	0	1	1	0	1	0	1
G. sarpedon	2	1	0	1	0	0	1	1	0	1	1	0	1	1	1	0	0	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	1	0	1	1	1	1	0	1	0
G. doson	2	1	0	1	1	0	1	0	0	1	0	0	0	1	1	1	?	1	0	1	1	0	1	1	1	0	1	1	1	0	0	1	0	1	1	0	1	1	1	1	0	1	1
G. agamemnon	2	1	0	1	1	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	1	0	1	1	1	1	0	1	0	0	0	1	0	1	1	0	0	1	1	1	0	1	0
G. nomius	2	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	0	0	1	0	1	1	0	0	1	1	1	0	1	1
Pieridae	0	1	0	0	0	0	0	1	0	0	0	0	0	?	?	0	0	0	0	0	0	0	0	0	0	0	0	0	?	1	0	0	0	0	0	0	0	1	0	0	0	1	0

Appendix III - ANOVA table

Stage	Source of variation	df*	MSS	F ratio
First instar Length	Between species	12	11.260	24.771**
	Within species	98	.455	
Second instar length	Between species	12	85.414	99.119**
	Within species	98	.862	
Third instar length	Between species	12	181.037	216.494**
	Within species	98	.836	
Fourth instar length	Between species	12	331.767	112.289**
	Within species	98	2.955	
Fifth instar length	Between species	12	556.281	223.791**
	Within species	98	2.486	
First instar breadth	Between species	12	5.613	66.528**
	Within species	98	.084	
Second instar breadth	Between species	12	17.692	67.860**
	Within species	98	.261	
Third instar breadth	Between species	12	12.707	42.722**
	Within species	98	.297	
Fourth instar breadth	Between species	12	16.795	43.950**
	Within species	98	.382	
Fifth instar breadth	Between species	12	54.899	120.091**
	Within groups	98	.457	

*df: Degrees of freedom; **significant at p= 0.01

Appendix IV - Duncan's multiple range test on the length of various instars of different species (Mean ± SE)

Sl. No	Species	I Instar Length	II Instar Length	III Instar Length	IV Instar length	V Instar length
1.	*T. minos*	$7.7^{g} \pm 0.15$	$16.80^{g} \pm 0.25$	$23.10^{fg} \pm 0.35$	$38.70^{i} \pm 0.42$	$59.80^{g} \pm 0.57$
2.	*A. aristolochiae*	$4.0^{abc} \pm 0.21$	$8.00^{a} \pm 0.39$	$13.20^{a} \pm 0.25$	$27.20^{d} \pm 0.32$	$35.80^{b} \pm 0.49$
3.	*A. hector*	$5.0^{de} \pm 0.26$	$12.60^{cd} \pm 0.27$	$22.70^{f} \pm 0.26$	$27.40^{d} \pm 0.16$	$41.60^{d} \pm 0.34$
4.	*A. pandiyana*	$4.90^{d} \pm 0.18$	$14.00^{ef} \pm 0.21$	$25.90^{j} \pm 0.23$	$35.40^{gh} \pm 0.34$	$45.50^{ef} \pm 0.34$
5.	*P. helenus*	$4.50^{bcd} \pm 0.50$	$15.00^{f} \pm 1.00$	$25.50^{ij} \pm 0.50$	$34.00^{fg} \pm 1.00$	$44.50^{ef} \pm 0.50$
6.	*P. dravidarum*	$4.75^{cd} \pm 0.25$	$13.25^{de} \pm 0.48$	$25.25^{ij} \pm 0.48$	$36.25^{h} \pm 0.25$	$46.00^{f} \pm 0.41$
7.	*P. polymnestor*	$5.70^{ef} \pm 0.15$	$18.00^{h} \pm 0.21$	$24.70^{hi} \pm 0.21$	$33.00^{f} \pm 0.33$	$44.00^{e} \pm 0.30$
8.	*P. demoleus*	$3.60^{a} \pm 0.27$	$12.20^{cd} \pm 0.29$	$23.90^{gh} \pm 0.23$	$29.70^{e} \pm 1.13$	$37.60^{c} \pm 0.40$
9.	*C. clytia*	$3.90^{ab} \pm 0.23$	$10.60^{b} \pm 0.27$	$18.00^{d} \pm 0.45$	$29.80^{e} \pm 0.81$	$39.30^{c} \pm 0.98$
10.	*P. polytes*	$5.90^{f} \pm 0.28$	$10.00^{b} \pm 0.30$	$19.10^{e} \pm 0.28$	$23.50^{c} \pm 0.40$	$32.70^{a} \pm 0.40$
11.	*G. Agamemnon*	$4.80^{cd} \pm 0.20$	$8.20^{a} \pm 0.25$	$14.20^{b} \pm 0.25$	$18.60^{a} \pm 0.31$	$33.00^{a} \pm 0.49$
12.	*G. doson*	$4.20^{abcd} \pm 0.13$	$12.10^{c} \pm 0.28$	$16.10^{c} \pm 0.28$	$22.50^{c} \pm 0.34$	$32.40^{a} \pm 0.43$
13.	*G. sarpedon*	$4.80^{cd} \pm 0.37$	$10.60^{b} \pm 0.75$	$15.20^{c} \pm 0.49$	$20.60^{b} \pm 1.20$	$33.00^{a} \pm 0.63$

*Figures superscribed with same letter are homogeneous ** significant at 0.01 levels*

Appendix V - Duncan's multiple range test on the breadth of various instars of different species (Mean ± SE)

Sl. No	Species	I Instar Breadth	II Instar Breadth	III Instar Breadth	IV Instar Breadth	V Instar Breadth
1.	*T. minos*	$3.4^{c} \pm 0.27$	$5.30^{e} \pm 0.15$	$7.20^{e} \pm 0.25$	$11.00^{e} \pm 0.26$	$17.00^{i} \pm 0.26$
2.	*A. aristolochiae*	$0.50^{a} \pm 0.00$	$2.30^{b} \pm 0.15$	$4.90^{bc} \pm 0.23$	$7.20^{ab} \pm 0.20$	$8.900^{b} \pm 0.23$
3.	*A. hector*	$1.00^{b} \pm 0.00$	$3.60^{c} \pm 0.16$	$5.50^{cd} \pm 0.17$	$6.70^{ab} \pm 0.15$	$10.40^{de} \pm 0.16$
4.	*A. pandiyana*	$1.00^{b} \pm 0.00$	$3.40^{c} \pm 0.16$	$5.60^{d} \pm 0.16$	$7.40^{b} \pm 0.16$	$9.40^{bc} \pm 0.16$
5.	*P. helenus*	$0.50^{a} \pm 0.00$	$5.50^{e} \pm 0.50$	$8.00^{f} \pm 0.00$	$10.00^{d} \pm 0.00$	$14.50^{h} \pm 0.50$
6.	*P. dravidarum*	$1.00^{b} \pm 0.00$	$3.25^{c} \pm 0.25$	$5.25^{cd} \pm 0.25$	$8.75^{c} \pm 0.25$	$13.50^{g} \pm 0.29$
7.	*P. polymnestor*	$0.50^{a} \pm 0.00$	$6.10^{f} \pm 0.17$	$8.20^{f} \pm 0.13$	$9.50^{d} \pm 0.17$	$12.20^{f} \pm 0.13$
8.	*P. demoleus*	$0.50^{a} \pm 0.00$	$2.30^{b} \pm 0.15$	$5.40^{cd} \pm 0.16$	$6.60^{a} \pm 0.22$	$8.00^{a} \pm 0.21$
9.	*C. clytia*	$1.00^{b} \pm 0.00$	$1.50^{a} \pm 0.16$	$4.20^{a} \pm 0.13$	$8.80^{c} \pm 0.25$	$10.70^{e} \pm 0.30$
10.	*P. polytes*	$0.76^{ab} \pm 0.12$	$2.30^{b} \pm 0.15$	$4.40^{ab} \pm 0.16$	$6.60^{a} \pm 0.22$	$9.70^{bcd} \pm 0.21$
11.	*G. agamemnon*	$0.65^{ab} \pm 0.08$	$4.60^{d} \pm 0.16$	$6.70^{e} \pm 0.15$	$8.30^{c} \pm 0.15$	$9.90^{cd} \pm 0.23$
12.	*G. doson*	$1.00^{b} \pm 0.00$	$4.30^{d} \pm 0.15$	$5.70^{d} \pm 0.15$	$7.40^{b} \pm 0.16$	$9.10^{b} \pm 0.18$
13.	*G. sarpedon*	$1.00^{b} \pm 0.00$	$4.40^{d} \pm 0.24$	$5.80^{d} \pm 0.20$	$7.40^{b} \pm 0.24$	$9.00^{b} \pm 0.31$

*Figures superscribed with same letter are homogeneous ** significant at 0.01 levels*

Appendix VI - Seasonal index of Swallowtails sighted from the northern zone during 2010-2012

Species	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T. minos	21.13	33.81	25.36	16.91	54.95	114.17	169.06	185.97	224.01	156.38	160.61	38.04
A. hector	230.33	355.08	230.33	80.3	19.19	0	0	0	0	0	28.79	153.55
A. pandiyana	0	0	0	0	60.48	110.89	161.29	216.74	287.3	181.45	161.29	20.16
A. aristolochiae	90.36	62.75	37.65	37.65	70.28	90.36	110.44	143.07	168.17	143.07	158.13	87.85
P. liomedon	0	0	0	0	50.68	118.24	152.03	185.81	185.81	152.03	236.49	118.24
P. polymnestor	95.18	63.45	31.73	19.04	120.56	120.56	126.91	139.59	101.52	114.21	133.25	133.25
P. paris	50	0	0	0	100	250	100	150	150	150	150	100
C. clytia	107.53	71.68	44.8	35.84	71.68	98.57	116.48	89.61	170.25	143.37	161.29	89.61
P. polytes	110.96	79.75	52.01	10.4	58.95	93.62	114.42	145.63	138.69	149.1	152.57	93.62
P. dravidarum	0	0	0	0	28.57	2	228.57	257.14	2	142.86	142.86	0
P. demoleus	109.09	145.45	72.72	72.72	218.18	72.72	72.72	36.36	36.36	72.72	145.45	145.45
G. agamemnon	160	220	180	100	80	20	60	60	60	140	80	40
G. sarpedon	0	0	44.44	88.88	133.33	177.78	44.44	222.22	133.33	222.22	88.88	44.44

Appendix VII - Seasonal index of Swallowtails sighted from the central zone during 2010-2012

Species	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T. minos	44	25	25	51	156	146	127	148	139	114	164	61
A. hector	184.62	246.15	215.38	235.9	20.51	0	0	0	20.51	51.28	41.03	184.62
A. pandiyana	0	0	0	0	92.31	200	196.15	207.69	276.92	130.77	96.15	0
A. aristolochiae	112.52	19.7	164.08	58.6	75.01	114.86	53.91	75.01	133.61	75.01	140.35	117.2
G. agamemnon	77.59	77.59	0	0	61.5	61.5	0	0	155.04	193.8	155.04	387.6
P. polytes	73.48	94.91	85.73	58.18	131.66	104.1	94.91	97.98	91.86	94.91	125.54	146.97
P. demoleus	107.91	251.8	179.86	71.94	107.91	0	0	0	17.99	17.99	53.96	89.93
P. helenus	83.87	45.16	51.61	38.71	51.61	70.97	90.32	245.16	161.29	141.94	180.65	19.67
P. Polymnestor	124.1	51.71	51.71	20.68	113.75	77.56	118.92	93.07	160.29	129.26	160.29	98.24
P. dravidarum	0	0	0	0	0	0	0	0	625	625	0	0
P. buddha	0	0	0	0	0	19.05	95.24	133.33	200	200	228.57	188.89
C. clytia	87.6	74.12	74.12	121.29	215.63	94.34	87.6	94.34	87.6	67.39	87.6	107.82

Appendix VIII - Seasonal index of Swallowtails sighted from the southern zone during 2010-2012

Species	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T. minos	51.63	39.24	28.91	20.65	41.31	105.33	117.72	140. 44	169.35	179.68	231.31	74.35
A. hector	331.71	321.95	195.12	1136.58	0	0	0	0	0	9.76	19.51	185.47
A. pandiyana	6.79	4.85	3.88	2.91	35.87	108.56	144.44	186.11	197.75	226.83	253.97	22.3
A. aristolochiae	144.26	181.09	98.22	73.66	67.53	67.53	49.12	98.22	79.8	101.29	150.4	89.01
P. helenus	83.8	0	0	0	55.87	195.53	83.8	139.66	139.66	167.6	251.4	83.8
P. polymnestor	59.49	38.8	36.21	20.69	62.08	116	116.4	160.37	131.92	157.79	204.34	64.67
P. paris	34.25	0	0	0	0	68.49	68.49	171.23	205.48	239.73	308.22	102.74
C. clytia	112.44	104.95	67.47	89.96	82.46	104.95	67.47	74.96	82.46	89.96	172.41	149.93
P. polytes	63.61	36.05	24.29	16.59	36.05	80.2	96.79	138.27	157.63	165.92	271.02	113.38
P. demoleus	155.76	124.61	155.76	140.19	77.88	46.73	31.15	62.31	62.31	62.31	109.03	171.34
P. dravidarum	4.28	4.28	0	4.28	34.28	115.68	175.66	149.95	175.66	222.79	265.64	47.13
P. liomedon	22.62	0	0	0	67.87	203.62	158.37	135.75	90.5	180.1	248.87	90.5
G. nomius	158.23	284.81	379.75	284.81	31.65	0	0	0	0	0	0	63.29
G. agamemnon	97.56	224.39	234.15	175.61	97.56	39.02	58.53	58.53	29.27	19.51	48.78	117.07
G. sarpedon	92.17	115.21	161.29	92.17	115.21	115.21	46.08	92.17	69.12	46.08	138.25	115.21

Appendix IX - Correlation coefficient of butterfly abundance versus weather parameters for northern zone

Sl. No.	Species	Correlation coefficient (r) Rainfall
1	*T. minos*	0.386*
2	*A. hector*	-0.458*
3	*A. pandiyana*	0.349
4	*A. aristolochiae*	0.058
5	*P. liomedon*	0.382*
6	*P. polymnestor*	0-.015
7	*P. paris*	0.531**
8	*C. clytia*	0.096
9	*P. polytes*	0.149
10	*P. dravidarum*	0.661**
11	*P. demoleus*	-0.211
12	*G. agamemnon*	-0.334
13	*G. sarpedon*	0.537**

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed)

Appendix X - Correlation coefficient of butterfly abundance versus weather parameters for central zone

Sl. No	Species	Correlation coefficient (r)		
		Temperature	Humidity	Rainfall
1	*T. minos*	-0.018	0.620**	0.641**
2	*A. hector*	0.210	-0.661**	-0.717**
3	*A. pandiyana*	-0.320	0.582**	0.784**
4	*A. aristolochiae*	-0.037	-0.070	-0.206
5	*P. helenus*	-0.267	0.415*	0.400*
6	*P. polymnestor*	0.052	0.283	0.072
7	*P. buddha*	-0.274	0.365	0.093
8	*C. clytia*	0.464*	0.084	-0.028
9	*P. polytes*	0.105	0.210	-0.040
10	*P. demoleus*	0.199	-0.700**	-0.660**
11	*G. agamemnon*	-0.188	0.011	-0.278

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0. 05 level (2-tailed)

Appendix XI - Correlation coefficient of butterfly abundance versus weather parameters for southern zone

Sl. No.	Species	Correlation coefficient (r)		
		Temperature	Humidity	Rain fall
1	*T. minos*	-0.692**	0.551**	0.475*
2	*A. hector*	0.264	-0.775**	-0.398
3	*A. pandiyana*	-0.428*	0.483*	0.306
4	*A. aristolochiae*	-0.037	-0.475*	-0.085
5	*P. helenus*	-0.666**	0.600**	0.342
6	*P. polymnestor*	-0.729**	0.684**	0.491*
7	*P. paris*	-0.695**	0.512*	0.424*
8	*C. clytia*	-0.307	0.034	-0.150
9	*P. polytes*	-0.727**	0.476*	0.396
10	*P. demoleus*	0.108	-0.256	-0.339
11	*P. dravidarum*	-0.655**	0.631**	0.500*
12	*P. liomedon*	-0.668**	0.685**	0.271
13	*G. nomius*	0.572**	-0.794**	-0.412*
14	*G. agamemnon*	0.508*	-0.610**	-0.381
15	*G. sarpedon*	0.276	-0.220	-0.360

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed)

Plates

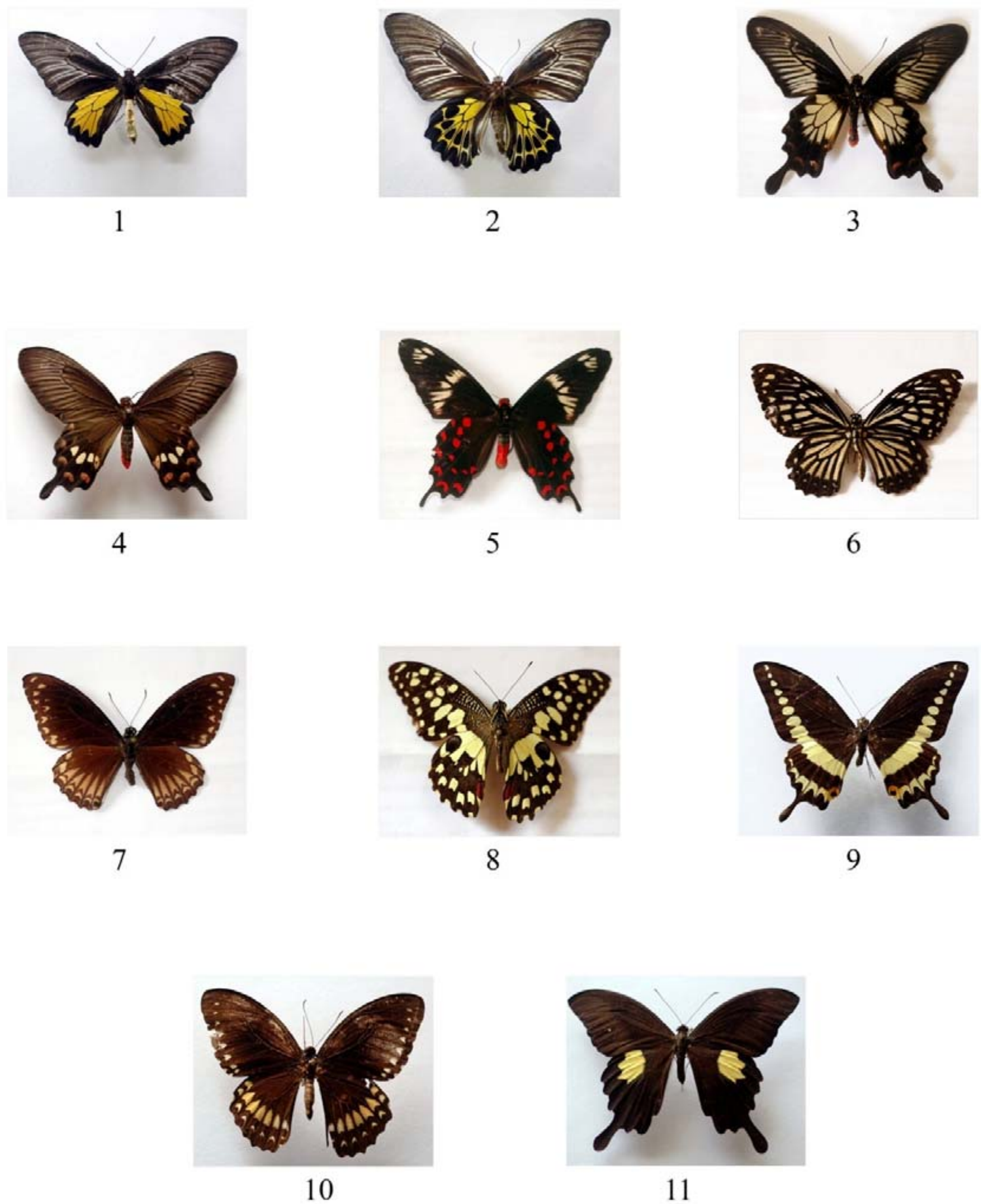


Plate XLVI. Figures 1-11. Papilionids collected from the study area. Fig. 1. *Troides minos* ♂; 2. *Troides minos* ♀; 3. *Atrophaneura pandiyana*; 4. *A. aristolochiae*; 5. *A. hector*; 6. *Chilasa clytia dissimilis*; 7. *C. clytia clytia; 8. Papilio demoleus*; 9. *P. liomedon*; 10. *P. dravidarum*; 11. *P. helenus.*

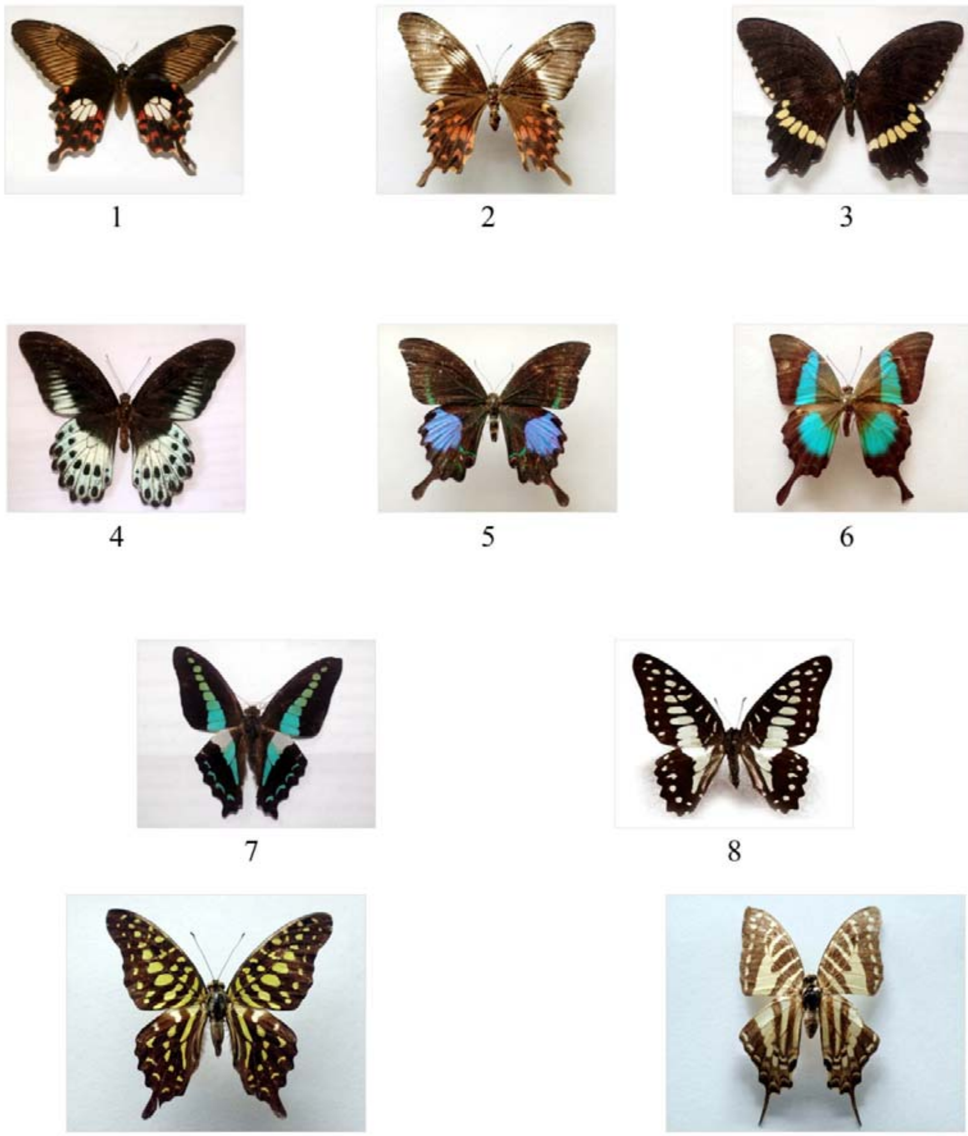
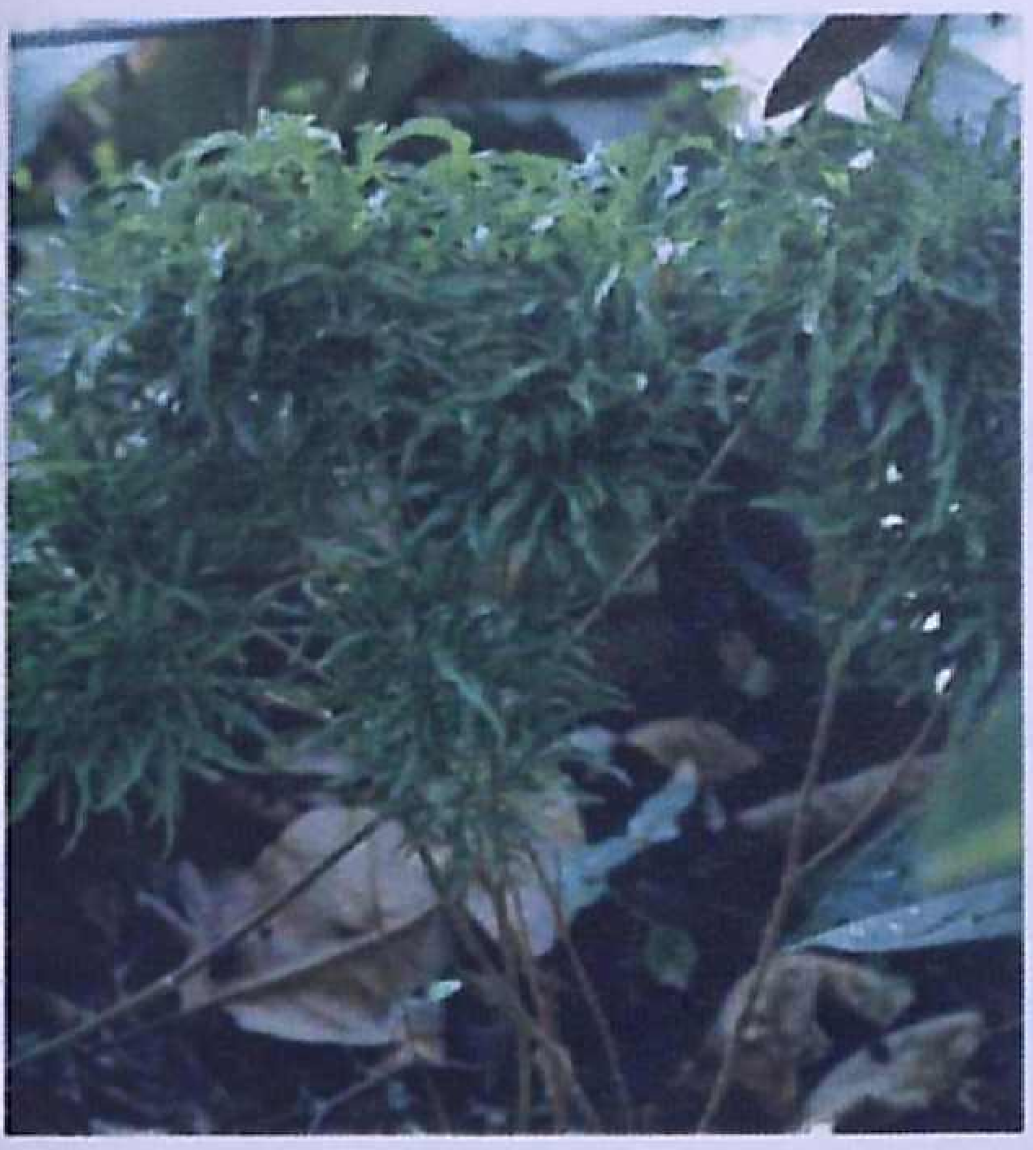


Plate XLVII. Figures 1-10. Papilionid butterflies collected from the study area; Fig. 1. *P. polytes stichius*; 2. *P. polytes romulus*; 3. *P. polytes cyrus; 4. P. polymnestor;* 5. *P. paris; 6. P. buddha;* 7. *Graphium sarpedon*; 8. *G. doson*; 9. *G. agamemnon*; 10. *G. nomius.*



Euodia ridleyi

Larva of *P. polymnestor*

Litsea coriacea

Larva of *C.clytia*

Kingiodendron pinnatum

Larva of *G.agamemnon*

Plate XLVIII. Figures 1-6. New larval host plants recorded during the study. On the right are the caterpillars of the butterflies associated with the host plants.

List of Publications

Papers Published in Journals

1. **Revathy V. S.** and George Mathew. 2013. Role of niche breadth and resource availability on the life history of butterflies: a case study at Peechi, Kerala. *Biosystematica,* 7 (2): 43-46. http://www.tcntrust.org/journal.php

2. **Revathy V. S.** and George Mathew. 2014. Seasonal fluctuations of butterfly population: a study in butterfly garden at Peechi, Kerala, India. *International Journal of Agriculture, Environment & Biotechnology,* 7(1): 29-35.
DOI 10.5958/j.2230-732X.7.1.005. http://www.indianjournals.com.

3. **Revathy V. S.** and George Mathew. 2014. Identity, biology and bionomics of the Common Mormon, *Papilio polytes* Linnaeus (Lepidoptera: Papilionidae). *IOSR Journal of Environmental Science, Toxicology and Food Technology, 8 (1): Ver. IV, 119-124.*
DOI. 10.9790/2402-0814119124. http://www.iosrjournals.org

4. T. P. Narayanan kutty, **Revathy V. S.** and George Mathew. 2014. Diversity and distribution of butterflies in the Shendurney Wildlife Sanctuary. *International Journal of Engineering Research & Science & Technology,* 3 (1): 85-106. http://www.ijerst.com

5. **Revathy V. S.** and George Mathew. 2013. Seasonality of Rhopalocera (Lepidoptera) species in the Butterfly Garden at Nilambur in Kerala, Southern India. *Colemania*, 35: 1-9.

6. **Revathy V. S.** and George Mathew. 2014. Taxonomic segregation of the Swallowtails of the genus *Graphium* (Lepidoptera: Papilionidae) of Kerala part of Western Ghats using morphological characters of external genitalia. *Journal of entomology and zoology studies,* 2 (4): 72-77.

Papers Communicated

1 **Revathy V. S.** and George Mathew. 2014. Identity and biology of the Blue Mormon, *Papilio polymnestor* Cramer (Lepidoptera: Papilionidae) with a new host plant record. *Entomon* (*in press*).

2 **Revathy V. S.** and George Mathew. 2014. Identity, biology and bionomics of the Common Mime, *Chilasa clytia* Linnaeus (Lepidoptera: Papilionidae). *Journal of Threatened Taxa: The International Journal on Conservation and Taxonomy.*

3 **Revathy V. S.,** George Mathew, N. Sasidharan and K. Muhammad Anaz. 2013. A note on the occurrence of *Bindahara phocides* (Fabricius) (Lepidoptera: Lycaenidae) as a fruit borer of *Salacia fruticosa* Heyne ex Lawson at Peechi, Kerala, India. *Journal of Bombay Natural History society.*

4 **Revathy V. S.** and George Mathew. 2014. Biology of three Western Ghats Endemics, the Malabar Raven (*Papilio dravidarum* Wood-Mason), Malabar Rose (*Atrophaneura pandiyana* Moore) and Crimson Rose (*A. hector* Linnaeus) (Lepidoptera: Papilionidae) at Kerala, India. *IJE - Annales de la Société entomologique de France (International Journal of Entomology).*

Papers Presented in Conferences

1. **Revathy V. S.** & George Mathew. 2013. Role of niche breadth and resource availability on the life history of butterflies: a case study at Peechi, Kerala. Proceedings of the 25th Kerala Science Congress, 29-1 January, Thiruvananthapuram.

2. **Revathy V. S.** & George Mathew. 2013. Taxonomy of Lepidoptera. Workshop on Insect taxonomy, 15-16 March, St. Thomas' College, Thrissur.

3. **Revathy V. S.** & George Mathew. 2012. A report on the population trends of butterflies in the butterfly garden at Nilambur, Kerala (India). Second Indian Biodiversity Congress, 8-11 December, Bangalore.

4. **Revathy V. S.** & George Mathew. 2012. Seasonal abundance of butterfly population and species diversity in the butterfly garden at Peechi Kerala (India). First National Biodiversity Congress, 27-30 December, Thiruvananthapuram.

5. **Revathy V. S.,** George Mathew and Narayanan kutty T. P. 2012. Seasonal trends of butterfly populations in the butterfly safari at Thenmala, Kerala (India). Proceedings of UGC sponsored National Seminar on Managing Environment - The Human Dimension organized by PG & Research Dept of Zoology, Malabar Christian College, Kozhikode on 8-9 March 2012

6. **Revathy V. S.** & George Mathew. 2011. Biology of the Swallowtail Butterflies, The Common Mime (*Chilasa Clytia* L.) And Common Mormon (*Papilio Polytes* L.) At Peechi, Kerala (India*). Proceedings of the 23rd Kerala Science Congress, 29-31 January, Thiruvananthapuram.*