Introduction

Morphological characters are often related to functions that influence ecology (Wainwright 1996). Common subjects for ecomorphological analysis include the relationships between the structure of the feeding apparatus and diet (Freeman 1981a, Schluter 1993, Wainwright 1996); morphology of the locomotory apparatus and habitat use (Scheibe 1987, Rydell et al. 1996).

Morphological studies not only describe the outlook of an organism but also extend beyond the descriptive anatomy like genetics, physiology and developmental biology. There is also greater awareness that a particular morphology embodies not only the requirements of present life but also helps an organism’s developmental and evolutionary history (Bookstein et al. 1985, Altringham 2011). Ecomorphology comprises morphology within the context of its biological role and also analyses how the physical forms of living organisms help species to adapt to their natural environments.
Despite the species richness and their important role as control agents of insect control (Cleveland *et al.* 2006), their relationship between the structure and their interactions with the environment make it complicated and multifactorial (Freeman 1981b, Kalko and Handley 2001, Flaquer *et al.* 2007). One basic and widely applied approach of ecomorphological analysis assesses the aspects of organismal structure as well as its ecological attributes. This helps to describe the patterns of interrelationship between the bat and its habitat (Findley and Black 1983, Aldridge and Rautenbach 1987, Entwistle *et al.* 1996, Erickson and West 1996, Barclay and Kurta 2007). Assessment of morphology can range from a simple description of characters like shape to exhaustive characterization of the trait (Birch 1997, Bookstein 1997, Bookstein *et al.* 1985, Strauss and Altig 1992).

In this chapter, investigation was done over the recent advances in the study of the relationships among ecology, morphology and behavior of the members of the family Rhinolophidae present in KMTR. The study provides ecomorphology as a discipline, and highlights the relevance to understand how the morphology of these
bats relates to their ecology, with special attention to their feeding apparatus (teeth and skull), their dietary preferences, and wing morphology to that of their flight performance. The morphology influences the behavior and ecology and is the basis for further detailed study of rhinolophid bats.

1.1 Habitat Ecology

Morphology dictates an individual’s performance limits and restricts its behavioral repertoires; regardless of habitat, a bat cannot fly faster or eat larger than its anatomy will allow. However, while morphology may constrain potential activities, prey selection primarily depends on the availability and abundance of prey. The ecology of an animal is also strongly influenced by the local environment in which it functions day to day.

Bats exhibit greater diversity in behaviour, diet and morphology than any other mammals. As they are the primary predators of nocturnal insects, bats play a significant role in all forested ecosystem (Harvey 2002, Fenton 2003). Despite the importance of bats in forests, the information available on the foraging behaviour of many bat species is limited. A suite of morphological factors influences foraging behavior in insectivorous bats, including body mass and the size and shape of the skull, jaws and wings. Ecomorphological studies show that the structure of insectivorous bat assemblages is influenced by the correlation between diet and morphology, with morphologically similar species feeding on similar foods (Hayssen and Kunz 1996, Findley and Black 1983).

1.2 Roosting ecology

Roosting ecology of bats is a complex interaction of physiological, behavioral and morphological adaptations. The roost selection in bats mainly
depends on the population size, risk of predators and abundance of prey. Animals need a place for shelter to rest, protect them away from extremes of temperature, rain or wind and keep them preferably close to their food supply. Forest dwelling bats use various diurnal roosts, including those in caves, rock crevices, abandoned buildings, the foliage of trees, tree cavities and crevices and spaces under bark.

A considerable part of a bat’s life is spent in roosts (Kunz 1982). In addition to providing shelter, breeding place and retreats for hibernation, roosts are also important places for social interactions among bats. Roost selection in bats is based on many characteristics such as reduction of predation risk, commuting costs, roost microclimate and its impact on thermoregulation (Fujitha and Tuttle 1991, Ormsbee and McComb 1998, Waldlen et al. 2000, Menzel et al. 2001, Weller and Zabel 2002). The availability of suitable roost is therefore critical for the survival of forest bats.

2.1 Craniodental Structure

Bats exploit a wider range of food types than any other mammals. Teeth and jaws are the morphological locus of direct interaction with food, and the relationship between dietary diversity and craniodental structure has been the subject of a series of ecomorphological analyses. (Fenton 1989, 1990, 1995, Dumont 1997a, 1997b, 1999, Freeman 1979, 1981a, 1981b, 1984, 1988, 1992, 1995, 1998, 2000). Several studies on diverse diet of varied taxonomic groups has confirmed the skull and dentition as the main component to be analysed. The structure of the teeth and their skeletal supports are relatively consistent among insectivorous bats but are distinctive in groups that have more specialized diets. For example, carnivorous phyllostomids,
megadermatids, and nycterids have undergone evolutionary transitions from eating “a hardcovered package with soft insides [insects, especially beetles] to a softcovered package with hard insides [vertebrates]” (Freeman 1984). This distinctive feeding ecology is correlated with a suite of morphological specializations.

The morphological pattern observed in carnivorous species is also seen in lesser degrees among insectivorous bats that primarily eat on soft-bodied insects. For example, bat species that feed on relatively hard or tough prey like beetles (Freeman 1979, 1981a) have robust skulls with thick dentaries, elongated canines, and short, wide faces. Skulls of these insectivorous bats that eat tough prey show a convergence toward felids and hyaenids (Freeman 1984, 2000). These independent lineages share short, wide faces that bring the canines close to the fulcrum of the jaw and allow increased volume of the masseter muscle and, in some cases, the temporalis as well; the two large jaw-closing muscles are the primary determinants of the bite force magnitude. From a broad comparative perspective, species within microchiropteran families are unevenly distributed throughout the relatively large morphospace representing ecologically significant craniodental features (Freeman 2000).

Skull and dentition not only reflect the size and shape of food the animal devour, but also associated with static mechanical models of masticatory function. The cranial morphology of bats give the architectural details about the skull, including muscle size, muscle fiber orientation and bony morphology which contributes to variation in bite force (Freeman and Weins 1997, Dumont 2003). These mammals use many species-specific combinations of bite points and gap angles during feeding (Dumont 1999, 2003).
These insectivorous bats have high crowned cheek teeth with well developed shearing crests which are designed to predict and recognize relatively subtle difference among the dentitions of these bats. Bladed shearing crests are necessary on the dentitions of mammals that eat either hard or soft insects. The ‘W’ shaped cusp pattern has been likened to pinking shears because the teeth fit together in an interdigitating manner, a mechanism called “intercuspidation. The pinking shear configuration holds the item being cut on the cutting edge and keeps the item from sliding away when the two cutting edges come together (Freeman 1979).

Cranial shape of these bats is quite variable because their food items exhibit a wide range of physical properties. Most insectivorous mammals consume an extensive variety of invertebrate food item including beetles, moths, hoppers, caterpillars and worms. Many insectivorous bats concentrate on invertebrate prey community (Black 1974, Freeman 1979, Fleming 1986). Variations in several features of the jaws and skulls indicate that some species are best adapted for hard – shelled insect prey and others for soft – shelled insect prey. Smith and Savage (1959) and Freeman (1979, 1981) demonstrated that characters such as jaw robustness and cranial cresting of the predator vary predictably with the hardness of the prey insect exoskeletons.

2.2 Wing Morphology

Bats are known to fly with amazing maneuverability and agility, in part because of their unique aeromechanical attributes such as highly elastic wing membranes and deforming wing bones. The wings of bats are flexible and adjustable through the action of many different muscles. This gives them an agility and maneuverability
that could never be achieved by birds. They are capable of rapid acceleration and braking. This capability is especially useful when the bat is hunting insects. Insectivorous bats are unbelievably nimble when they are flying in pursuit of prey. They can make right angle turns, dive straight down, climb nearly vertically, fly on their side, turn flips and even occasionally fly upside down. Small species of bats are so skillful at flying in a confined space that they can capture insects from among thick underbrush.

Flying animals have need of different wing designs to do flight performance to match their ecological role. To suit their diet preference they show considerable diversity in wing morphology (Fenton 1972) and flight style (Neuweiler 1984). Although bats are nocturnal, their ecology is equilant to birds, but morphological adaptations of bats for flight and foraging are vastly different (Norberg 1976, Norberg and Rayner 1987). Being flying mammal, their forelimbs are webbed and developed as wings, making them the efficient sustained flyers. The structure of the wing is an important morphological parameter characterizing the ecological groups of bats (Racey 1998, Racey and Entwistle 2003).

Several indices have been introduced to characterize specific features of form, size and aerodynamic parameters of the wings like aspect ratio index (ARI), wing tip index (WTI), area index (AI), wing loading index, etc. (Findley et al. 1972).

An important element in ecomorphological factor is the recognition that if interspecific morphological variation is associated with variation in behavior and ecology, then morphological variation within species might also have behavioral consequences. For example, wing morphology varies not only with body size but
also between sexes and among developmental stages within a single species. This variation influences wing loading, aspect ratio, and mass distribution, which, in turn, affect flight performance characteristics such as turning ability, speed, and metabolic cost (Dobson 1872, Jones and Kokurewicz 1994, Adams 1996, 1997, Hughes et al. 1989, 1995). Wing loading in developing horseshoe bats, decreases with age as length of the hand wing increases disproportionately relative to length of the arm wing.

During postnatal growth, as wing size increases, aspect ratio increases wing loading decreases; simultaneously, growing bats forage in increasingly cluttered habitats. Interestingly, adult bats forage in a variety of habitats but shift to more cluttered habitats when juveniles became volant. Fecal samples also show a shift in diet with age, suggesting that adults may selectively limit competition with juveniles (Adams 1997).

The most frequently used predictors of flight performance are wing loading and aspect ratio. High values for wing loading are predicted to increase flight speed and reduce maneuverability. Wings with a high aspect ratio are narrow and long, experience little drag, and are associated with fast, efficient flight. Associations between flight morphology and habitat use have been used as a way of assessing resource partitioning in bat communities (Crome and Richards 1988, Swartz et al. 1992, Fullard et al. 2000).

The above reviewed informations on ecology and morphology have provided predictions about the ecomorphological features of bat species. The studies on the skull and wing morphology of bats reveal their food selection and foraging strategies.
Therefore it is necessary to study skull morphology in terms of dietary diversity and wing morphology in terms of aerodynamics. Very few studies have loomed the correlation between the morphology of the feeding apparatus and the locomotory apparatus (Freeman 1981, Scheibe 1987, Schluter 1993, Wainwright 1996). The present study is an endeavor to investigate the ecomorphological relationship among the identified rhinolophids of KMTR which will serve as an important foundation to design future studies.

**Methodology**

The field work was conducted between May 2011 and December 2013 at Kalakad Mundanthurai Tiger Reserve, a part of southern Western Ghats (hot spot) that treasures the diversity of bat species. The study area constitutes four research stations: Mundanthurai plateau, Kodamadi, Kodayar and Sengaltheri. Initially, the study sites were surveyed to collect baseline data on bat species and abundance. This work provided the baseline data required to select the bat species of special conservation concern, which were then investigated in more detail. The *Rhinolophus* sp., *Rhinolophus indorouxii, Rhinolophus pusillus, Rhinolophus lepidus and Rhinolophus beddomei* were selected as the study species in relation to current forest management practices.

The distribution of these bats has been confirmed by erecting mist nets, setting canopy, harp nets and hand nets. Mist nets (12m and 6m, 70 denier nylon, four shelves 36mm mesh size) were setup at dusk in different types of habitat. These nets were positioned in the ground level and also at the canopy level of bats flying path (Plate 2). The results documented in all the research stations were pooled and analysed to determine the ecomorphological features of rhinolophids of KMTR.
Morphometric parameters

Information about the cranial and wing structures was obtained by studying the feeding and the flight apparatus. The feeding apparatus like teeth, jaw and skull of the available rhinolophids were studied from the voucher specimen of Bat Research Laboratory of Zoology department, Sarah Tucker College, Tirunelveli, India. The flight adaptations like the body size, tail and wing morphology were documented on captured rhinolophids in research stations either near the roosting site or in the foraging grounds of KMTR. Foraging mechanism was predicted from following and adapting the skull morphology by morphometric techniques of Bates and Harrison (1997) and the flight performance by following the calculation of Norberg and Rayner (1987).

Cranial morphology-Skull extraction

The excavated skull from the voucher specimen was allowed to dry. The skull was then kept near ant nests and closed with a lid to clear off the muscles attached to the skull bones for three to five days depending on the size. Neat and clear skull was recovered. Cranial and dental measurements were done by using dial calipers with the nearest accuracy of 0.01 mm. Skull morphological parameters were measured by following the methods described by Bates and Harrison 1997. The diagrammatic figure on cranial and dental morphology is given in Figure 2 and the abbreviations used to describe the parts of the skull morphology are given below.

GTL (Greatest length of the skull): from the extreme end of the anterior to the extreme end of the posterior parts of the skull.

CBL (Condylobasal length): from occipito-condyle to the anterior edge of alveolus of the anterior incisor.
CCL (Condylocanine length): from occipito-condyle to the anterior edge of alveolus of the canine.

ZB (Zygomatic breadth): Greatest width of the skull across the zygomatic arches.

BB (Breadth of the braincase): Greatest width of the brain case.

IC (Interorbital constriction): the narrowest width across the interorbital region.

PC (Postorbital constriction): the narrowest width across the constriction posterior to the orbits.

M (Mandible length): from the extreme end of the condyle to the extreme end of the anterior of the mandible including the incisors.

RW (Rostral width): taken across the front of the orbits at their most anterior point.

C-Mُ (Maxillary toothrow): from the front of the upper canine to the back of the crown of the last upper molar.

C-Mُ (Mandibular toothrow): from the front of the lower canine to the back of the crown of the last lower molar.

Mُ-Mُ (Width across the last molars): taken from the outer borders of the crown of the last upper molars.

Cُ-Cُ (Anterior palatal width): taken across the outer borders of the upper canine.

All the measurements were converted into log data. Each log-transformed measurements was regressed against a composite size character (\( \text{SIZE} = \text{Sum of the natural logs of Condylo-canine length, Zygomatic breadth and temporal height} \)).

This composite character (\( \text{SIZE} \)) is actually an estimate of head volume. The \( \text{SIZE} \) of each bat species is correlated with other variable measures of skull. This correlates help to predict the dental and jaw morphology.
According to Freeman (1988, 1995, 1998), the cranial and dental measurement ratios such as zygomatic breadth / condylo-canine length, upper canine / Maxillary tooth row, dentary thickness / dentary length can predict the important head shape relationships in bat species. These ratios correlates with that of the SIZE and indicate the various adaptations in the feeding apparatus. Dorsal, ventral and full view of skulls, upper jaw, lower jaw were observed under dissection microscope and viewed as digital photographs.

**Wing morphology**

The aerodynamic structural relationship was studied by correlating wing morphological parameters (wingspan, wing area, aspect ratio and wing loading) and body mass. The wing morphology calculation must be carried out in fresh or fluid – preserved specimen. The overall size of the bat was measured by the total body mass, M (kg) weighed to the nearest 0.5 g using Avinet spring scales. The morphological parameters of the wings such as wing area, hand wing area arm wing area were measured by placing each individual on a graph sheet extending the wing and the tail membranes and the perimeter was traced. The morphological parameters of the wings were calculated using the following method of Norberg and Rayner (1987).

Wing area, $S$ (m$^2$) : Area of wings, the entire tail membrane and the body area between the wings excluding head.

Hand wing area, $S_{hw}$ : Area of membrane spanned by the second to fifth digit.

Arm wing area, $S_{aw}$ : Area of wing between the fifth digit, the body and the legs.
Wing area measurements were calculated to the nearest 1 mm² by directly counting the squares (mm) from the tracings on the graph sheet.

Wing span, B (m): Distance between the wing tips of the bat with extended wings (leading edges should be held along a straight line of the body).

Arm wing length, $l_{aw}$: Distance from the shoulder joint to the wrist.

Hand wing length, $l_{hw}$: Distance from the wrist to the wing tip.

From these measured morphological values the wing loading, aspect ratio, tip area ratio and tip shape index were calculated by following the formulae of Norberg and Rayner (1987) as given below.

$$ \text{Aspect ratio (A)} = \frac{\text{Square of wingspan}}{\text{Wing area}} = \frac{B^2}{S} $$

$$ \text{Wing loading} = \frac{\text{Body mass}}{\text{Wing area}} \times g = \frac{Mg}{S} \text{ (Nm}^{-2}) = \frac{\text{Body mass}}{\text{Wing area}} \times g $$

$g = \text{gravitational acceleration which is } 9.81$

The aerodynamic abilities of the bat species were expressed when wing loading index was plotted against the aspect ratio. The resulting values were correlated with the isometric scaling model of Norberg and Rayner (1987) to predict the flight performance and the foraging behaviour.

Tip length ratio, $T_l = \frac{\text{Hand wing length}}{\text{Arm wing length}}$

$$ = \frac{l_{hw}}{l_{aw}} $$

Tip area ratio, $T_s = \frac{\text{Hand wing area}}{\text{Arm wing area}}$

$$ = \frac{S_{hw}}{S_{aw}} $$

Tip shape index, $I = \frac{T_s}{(T_l - T_s)}$
Statistical analysis

Statistical analysis includes statistics expressed as mean and standard deviation. The morphological measurements and aerodynamic parameters were analysed statistically through SPSS software. The resulting values were tabulated.

Results

The study area Kalakad Mundanthurai Tiger Reserve is situated in the southern Western Ghats region (Latitude 8° 25’ North to 8° 53’ North, Longitude 77° 10’ East and 77° 35’ East) and extends over 895 sq. km. The Rhinolophus species were captured from the foraging and roosting area by setting mist nets, harp trap and hand nets in their flight pathways (Plate 2). The roosting sites of rhinolophids studied in the present project were identified and a sample is represented in plate 3. Table 1a and 1b shows the roost location and characters of Rhinolophidae family members of KMTR.

The identification of the study animals were done by following the standard methodology of Bates and Harrison (1997), and the morphological measurements were taken following Norberg and Rayner (1987) (Figure 3). Methods of cranial and dental measurements of chiroptera are shown in figure 2. The skull morphology of the Rhinolophus species is depicted in plate 4. The wing morphology of the Rhinolophus species is depicted in plate 5. The statistically analysed measurements of external morphology and body weight of the studied rhinolophids are shown in Table 2. By studying the wing shape and size, morphology of bats can give information about their flight performance. Table 3 describes the body mass, wing parameters,
morphological measurements and the predicted aerodynamic parameters of the *Rhinolophid* sps. which were statistically analysed. The analysis of feeding apparatus, the skull, the jaws and the dental formula can give predictions about the nature of food the bats can consume. Table 4 explains the cranial measurements and Table 5 gives the details of dental measurements of the studied rhinolophids of KMTR.

**Discussion**

KMTR, a valuable repository of biodiversity, in the southern end of the Western Ghats, covers nearly 63% of the India’s arborescent evergreen endemic taxa. Because of the occurrence of numerous rivers and streams, this area is also called river sanctuary. The reserve is the southernmost home to some of the charismatic and endangered mammals (Johnsingh 1986). The reserve proudly treasures some of the largest and intact extents of natural forests, which harbor a variety of altitudinal climax forest communities (Gadgil and Homji 1986). KMTR, sprawling across a diverse terrain is ecologically rich.

Bats (Chiroptera), currently with 1240 recognized extant species (Schipper et al. 2008), are major contributors to mammalian biodiversity, comprising about 20% of mammalian species globally (Simmons 2005a). According to the reports of Vanitharani (2003, 2004), KMTR aboards about 45 bat sp. Among them, the distribution studies of the forest bats reveal that the family Rhinolophidae dominates the other species. The present study has selected these bats to know more about their interaction and impact in the forests of KMTR. The study selected the identified four rhinolophid sp. namely *Rhinolophus indorouxii*, *Rhinolophus pusillus*, *Rhinolophus lepidus* and *Rhinolophus beddomei*. 
Roosting ecology

The rhinolophids are highly sensitive and vulnerable to threats to their roosting sites. They enjoy a diverse range of structures as diurnal roosting sites in both natural and man-made structures. In the present study, *R.indorouxi* was located from their roosts like tunnels and caves. *R.lepidus* and *R.pusillus* were sighted in caves. *R.beddomei* prefers to roost in caves and rarely in the abandoned estate bungalow located in the forest interior. Numerous studies have proved that insectivorous bats prefer such kinds of roost sites (Vonholf and Barclay 1996, Menzel *et al.* 2002, Lacki and Baker 2003, Kalcounis *et al.* 2005). The rhinolophids prefer to select caves located near water sources like rivers, streams and waterfalls of the forests of KMTR. Earlier reports also confirm their roost selection frequently lies in proximity to water (Fenton and Barclay 1980, Kunz 1982, Herd and Fenton 1983, Brigham *et al.* 1992).

Ecomorphological features of *Rhinolophids of KMTR.*

*Rhinolophus indorouxi* is a medium sized rhinolophid with forearm length ranges from 44.4-52.3 mm. Generally observed to fly around bushes and amongst tree, with a flapping flight, avoiding twigs and other obstacles (Brosset 1962b).

*Rhinolophus pusillus* is a small horseshoe bat which is intermediate in size with forearm ranges from 34.9-38.7 mm. The horseshoe nose leaf is relatively wide with sella constricted in the middle. The wing shape made the *R.pusillus* to adapt their foraging in cluttered environments with slow flight performance.

*Rhinolophus lepidus* is a medium-sized horseshoe bat with an average forearm length of 37-41.8 mm. The peculiar noseleaf is lacking of lateral lappets,
which are brightly coloured with dark orangish tinge. The connecting process is clearly notched and pointed, the sella concave. They are slow and low fliers and explores the foliage of trees. *Rhinolophus beddomei*, is larger than *R.indorouxii* with an average forearm ranges from 54.9- 64.3 mm. They are fast fliers and forage in less cluttered habitat, along the paths in the jungle and jungle margins.

The statistical analysis of body weight of available rhinolophids of KMTR documented are (*R.indorouxii*: 12.17±0.28 g, *R.pusillus*: 4.53±0.06g, *R.lepidus*: 5.26±0.18g and *R.beddomei* : 21.40±1.01g). The mean (±SD) forearm length varies from 49.63±0.35mm to 57.43±0.59mm. The body size (Head to Body length) of studied rhinolophids ranges from 37.27±1.26mm to 49.46±0.66mm.

**Skull Morphology in studied Rhinolophus species**

Morphology of bats is related to their ecology. Knowledge about the diet of an organism is thereby essential for a study in ecology and behaviour of any organism. Norberg and Rayner (1987) have given explanations that dietary adaptations of bats reflect their skull (feeding apparatus) and wing morphology (flight apparatus). They differ in their choice of foraging sites, flight behavior and diet selection. They choose species-specific types of food items and can detect the same according to their flight ability (Jennings et al. 2004).

The structure of feeding apparatus, particularly the skull, teeth and the form of the jaw provides a perfect evidence of its diet. Teeth and skull are the morphological indicators of food and the relationship in dietary diversity. The differentiation of the teeth and mandibular joint provide a guide to the type of diet that differ species of bats consume as well as the general dietary references within
genus. It is proved that there is predictable link between skull morphology and foraging strategies in these flying vertebrates.

In the case of *R. pusillus*, connecting process of sella is triangular in shape. The skull is small with a narrow palate. The Condylo Canine Length (CCL) varies from 13-14 mm and also averages narrower across the zygomata and braincase. The rostrum and palate are narrower. According to Corbet and Hill (1992), the shape of the rostral profile of *R. pusillus* is nearly straight or horizontal. The dentition is less robust and upper and lower canines exceeded in size.

Bates and Harrison (1997) noted that there is some overlap in all the external and cranial measurements between *R. lepidus* and *R. pusillus*. According to Corbet and Hill (1992), the shape of the rostral profile of *R. lepidus* curve upwards near tip, and is slightly concave behind the nasal inflations and are well developed. The skull is larger than that of *R. pusillus* and the palate is broader. The CCL averages from 13.8-15.5 mm. The upper canine is well developed.

The cranial measurement on documented bat species shows that *R. pusillus* and *R. lepidus* has lesser Zygomatic Breadth (ZB) /Condylo Canine Length (CCL) ratio. *R. pusillus* exhibit ZB of 7.22mm and CCL of 13.24mm; *R. lepidus* expose ZB of 8.28mm and CCL of 14.8mm. All these rhinolophids exhibit lesser coronoid process with thinner jaws. This characteristic assume that these rhinolophids prefer soft food items like moth, butterflies, grasshoppers, termites, dipterans etc. This assumption confirmed the behavior of bats as reported in others findings (Brosset 1962a, Phillips 1980).
In *R. indorouxii*, skull size varies considerably with the CCL ranging from 17.4 to 21.0 mm. The Zygomata are less flared posteriorly. Palatal length tends to be longer. The dentition is less robust and upper canine is not in contact with upper premolar. These bats are characterized by their small cranial measurements but relatively large wings. In the case of *R. beddomei*, the CCL ranges from 23.4-24.4 mm. the Zygomata and the anterior border of the palate are relatively wider. This species can be distinguished cranially by its broader rostrum and anterior rostral chambers.

Both *R. beddomei* and *R. indorouxii* has higher ZB/CCL ratio as well as coronoid process (*R. beddomei* -ZB: 13.48mm, CCL: 23.45mm and *R. indorouxii* - ZB: 11.17mm, CCL: 18.34mm ) allowing for the attachment of well developed jaw muscle which is essentially robust to counter the reaction forces while biting hard prey like beetles. This type of feeding behaviour in *R. beddomei* was strongly confirmed by Phillips (1980). *R. beddomei* mainly feed on hard insects like beetles, locusts and other flying insects. Bogdanowicz *et al.* (1999) said that the well developed coronoid process allows increased leverage and accommodated large jaw muscle. Increase in the size of temporal muscle can allow an animal to resist the increased stress of struggling, crush hard shelled items and facilitate more extensive use of canines (Maynard and Savage 1959, Bates and Harrison 1997, Whitaker *et al.* 1999, Advani 1980, 1981, 1982, Philips 1980).

The results indicated that distinct morphological modification is associated with diet. Well connected and predicted analysis of skull morphology with their feeding strategies also confirmed the importance of morphological studies.
**Wing Morphology in *Rhinolophus* species**

Flying animals require different wing design and energy expenditures (Norberg 1990, 1994, Powers *et al.* 1991). Variation in the wing shape of bats results through different flight demands. Body mass, wingspan and wing area are the primary measures of design in flying organisms. From these parameters, wing loading and aspect ratio are derived, which describe the size and shape of the wings respectively (Norberg and Rayner 1987). Interaction between aspect ratio, wing loading and wing tip shape index affect flight. Predictable links occur among wing shape, flight morphology, flight performance and foraging strategies in bats (Norberg and Rayner 1987, Neuweiler 1989, Habersetzer and Storch 1989, Fenton 1990). Manoeuverability and agility are the two factors that are strongly influenced by flight adaptation. These two factors explain the ability of bats to change the flight direction without loss of speed and with small turning radius.

The bat species with lesser wing loading and low aspect ratio usually prefer to fly among vegetation. In the present study, the wing loading and aspect ratio of *R.indorouxii* (7.81±1.50, 7.32±0.69), *R.pusillus* (5.27±0.10, 5.64±0.39) and *R.lepidus* (5.61±0.44, 6.17±0.42) are low and thereby they prefer to fly in and around thick vegetation and fly among foliage canopy catching insects among branches. These rhinolophids have short wing tips, slow flight and low manoeuvrability they can fly with same hovering often within clutter (Bonacorrso 1979, Jones and Rydell 1994). The low wing loading and the short, cambered wings permit slow light turns, which are essential for insect hawking near vegetation. The low aspect ratio of these bats would suggest that their cluttered habitat is a severe constraint on
their wing span. Despite their short wing tips, they fly slowly and can hover. Earlier studies prove that these insectivores with long wings have low wing loadings and they have slow, maneuverable and inexpensive flight (Brosset 1962b, Simmons et al. 1979, Neuweiler 1984). Many of these bats may also glean resting insects.

The mean (±SD) of the wing loading and aspect ratio of *R. beddomei* is 9.846±0.344, 5.96±0.27. Since these species have higher wing loading and aspect ratio they prefer to fly in less cluttered and open foraging ground. These bats rely on speed and agility to catch insects away from clutter. They often fly at considerable altitudes, above canopy level or within clearings or pathways and typically in wide circles (Simmons et al. 1979). Aerial feeding insectivorous bats perform complex maneuvers to catch insects (Barclay and Brigham 1991). The *beddomei* species also shows the same foraging strategy in open and uncluttered habitat. They have high wing loading for fast flight and relatively long, pointed wingtips for low wing inertia and hence good agility at high speeds. Therefore, in bats the wing morphology has evolved to do flight performance to match their foraging behavior (Norberg 1987, Habersetzer and Storch 1989). Flight adaptation in bats allows them to radiate widely to adopt highly specialized tropical strategies (Fenton et al. 1992).

The predicted results of the rhinolophids have confirmed that morphology reflects flight capabilities and that different flight dynamics to traverse different distances and maneuvering in different habitats. Factors such as wing shape, maneuverability and echolocation-call structure may affect the ability of bats to exploit cluttered and non-cluttered habitats (Brigham et al. 1997). In the present study also the *R. indorouxii* are slow hawkers and usually they prefer less cluttered
vegetation and fly around bushes. *R.pusillus* and *R.lepidus* are slow hawkers and prefer highly cluttered and thick bushes to forage. The species *R.beddomei* are fast hawkers and they prefer to fly in open uncluttered area.

The consequences obtained here point out that the distinct wing morphological modification associated with diet. Well connected and predicted analysis of wing morphology with their feeding strategies also confirmed the evidence from other findings.

**Conclusion**

The connection between ecology and morphology are reflected by the authentication of skull and wing adaptation. The outcomes accessible here specify that small differences in skull and wing morphology can have significant effect on the feeding and flying performance of bats. Identifying functional correlates of bat flight behaviour and identifying these with morphological adaptations, clarifies the ecological and morphological relationships of bats.

Studies that have identified patterns of association between morphology and behavior have provided a big-picture view of the ecomorphology of feeding and flight and serve as important foundations to expand our knowledge on the ecology and behavior of rhinolophid bats in their natural environments, and experimental work and detailed kinematic studies which in turn will help to identify functionally important morphological adaptive characters.