Breeding Ecology of the Edible-nest Swiftlet *Aerodramus fuciphagus* and the Glossy Swiftlet *Collocalia esculenta* in the Andaman Islands, India

THESIS SUBMITTED TO THE

BHARATHIAR UNIVERSITY, COIMBATORE

for the
DEGREE OF DOCTOR OF PHILOSOPHY
in Zoology

by
Manchi Shirish Sheshnarayan

Sálim Ali Centre for Ornithology and Natural History
Coimbatore 641 108
May 2009

This work is dedicated to

Dr. Ravi Sankaran (1963 - 2009)

Dr. Ravi Sankaran still remains a renowned ornithologist who developed his own approach to wildlife conservation issues. He had worked to conserve several charismatic and highly endangered bird species like the Lesser Florican, the Nicobar Megapod, the Narcondam Hornbill and the Edible-nest Swiftlet. Other than these, he also worked in several exclusive conservation programs.

Dr. Sankaran with his unique line of thoughts designed the *in-situ* and *ex-situ* conservation of the Edible-nest Swiftlet in the Andaman and Nicobar Islands, which he put into action in 2001.

Part of his immense volume of work has been described in this thesis. Dr. Sankaran guided, designed and supervised the Swiftlet research work that took place from January 2004 to February 2009 and is described in this thesis.

He was a dedicated naturalist, a dear friend, a caring mentor, an exceptional guide and a perfect teacher.

CERTIFICATE

This is to certify that the thesis entitled "**Breeding Ecology of the Edible-nest Swiftlet** *Aerodramus fuciphagus* **and the Glossy Swiftlet** *Collocalia esculenta* **in the Andaman Islands, India**" submitted to the Bharthiar University, in Partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in **Zoology** is a record of original research work done by **Mr. Manchi Shirish Sheshnarayan** during the period of January 2004 – May 2009 of his research in the Division of Conservation Ecology, Sálim Ali Center for Ornithology and Natural History, under my supervision and guidance and the thesis has not formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to any candidate of this or any other University.

Signature of the GUIDE

Dr. P. PRAMOD
Nature Education Officer
Salim Ali Centre For Ornitholo
And Natural History
Anaikatty Post
Coimbatore 641 108

Countersigned

Head of the Department

Dr. Lalitha Vijayan
Senior Principal Scientist
Division of Conservation Ecology
li Centre for Ornithology and Natural History
Coimbatore - 641 108.

Director

Dr. PA. AZEEZ
Director In Charge
Sa lim Ali Centre for Ornithology
and Natural History
Anaikatty (Po), COIMBATORE-641 108.

DECLARATION

I, **Manchi Shirish Sheshnarayan** hereby declare that thesis entitled **"Breeding Ecology of the Edible-nest Swiftlet** *Aerodramus fuciphagus* **and the Glossy Swiftlet** *Collocalia esculenta* **in the Andaman Islands, India"** submitted to the Bharathiar University, in Partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in **Zoology** is a record of original research work done by me during January 2004 – May 2009 under the supervision and guidance of **Dr. P. Promod**, Nature Education Officer, Sálim Ali Center for Ornithology and Natural History, Coimbatore, and it has not formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to any candidate of this or any other University.

Signature of the Candidate

Countersigned

Head of the Department

Dr. Lalitha Vijayan
Senior Principal Scientist
Division of Conservation Ecology
n Ali Centre for Ornithology and Natural History
Coimbatore - 641 108.

Acknowledgment

At the start, I express gratitude to Dr. Ravi Sankaran for giving me an opportunity to work with him. This thesis is a result of a thought that germinated in his mind. Mere words cannot acknowledge the effort he put in to design and supervise this study of an extraordinary bird species. He was a supervisor, a teacher, a mentor, a colleague and a true friend. He taught me all I know about research and conservation in wildlife biology today. This document would have been very different had I not lost my Boss, Dr. Ravi Sankaran. I hope that this thesis, which is the outcome of six years of work under his supervision, would have met his approval. I extend my heartfelt gratitude to the Sankaran family for supporting me in every way and making me feel part of the family.

I thank Dr. P. Pramod, SACON for agreeing to supervise my doctoral thesis at a crucial time and giving me his complete unconditional support.

I am thankful to Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore for the institutional support and also for supporting the Swiftlet Conservation program during several occasions by providing loans from their corpus funds.

I thankfully acknowledge Dr. P. A. Azeez, Director In-charge, SACON for his boundless encouragement at every stage of the study, his statistical and logical insights and moral support. I also thank the Drs, P. A. Azeez, P. Pramod and P. Balasubramaniam for reading through the thesis drafts at short notice and giving valuable suggestions and comments. I am also thankful to Dr. Lalitha Vijayan, SACON for her support in several ways.

I acknowledge the Department of Environment and Forests, Andaman and Nicobar Islands for initiating such an imperative conservation program with SACON and also for providing funds. I thank the Chief Wildlife Wardens for their support during the period of this research. Dr. Alok Saxena, Conservator of Forests, and Mr. Ajai Saxena, Conservator of Forests have taken special interest in the progress of this study. It was a pleasure to work in the Andaman Islands and I would not have had this

feeling of freedom to work without the active participation of the Wildlife Division, Mayabunder, especially Mr. Graham Dorai, Mr. Ashok Kumar Paul and Mr. Paritosh Saha who held the chair of the Deputy Conservator of Forests during my field work. Their support, interest and encouragement were my mainstay during the tribulation of field work. I am also thankful to the field and office staff of Wildlife Division, Mayabunder.

The cave protectors (Tapori, Mangal, Andrew, Thow thow, Tercius, Jerom, Ingnecius, Pius, Joseph, Rijus, Deus, Aves, Michell, Pitrus, Robin, Parimal and Shorod) deserve much more than an acknowledgement. Without their truthful dedication to the conservation of the Edible-nest Swiftlet this study would have fallen flat on its face. I thank all the protectors for their whole hearted involvement and participation in the conservation of the Edible-nest Swiftlet and also for assisting me in the field. Receiving such dedicated protection and research assistance from a group of ex-poachers with little education is in itself an achievement. I hope that the hard work they have put in for the past six years yields them good returns in future. They were a splendid team.

Saw Alexander and his family have contributed greatly to the research and conservation of the Edible-nest Swiftlet in the Andaman and Nicobar Islands. I thank Alexander for being my local guardian, and his family for all their support and love, for innumerable delicious home-cooked meals and for making me a part of their joys and sorrows. Their lovely house was a home-away-from-home for me. I thank all Karen families of Burma Dera and Webi at Mayabunder for their help and love.

I am obliged to my special friend Gunasekharan, owner of the Sathya Enterprises at Mayabunder, and his family for helping me during every financial crisis I faced in the project. Another good friend who deserves mention is Mr. Anil Kishan, Forest Guard, Mayabunder. He has helped me on several occasions and in several ways throughout the study period.

I am grateful to Sarika Kshirsagar, Prasad Pathak, Archana Waran and Sagar Mysorekar for financial support on the ground of our personal relationship at times of fund crisis during the work. Sarika Kshirsagar and Prasad Pathak helped me

immensely with literature collection. I also thank all of them for every support they gave me as a friend.

I want to thank Dr. P. Balakrishnan and Dr. Anoop Das, Wildlife Research and Conservation Trust (WRCT), Calicut for discussing several innovative ideas and giving inputs throughout the study. I thank Dr. P. Balakrishnan also for correcting drafts and filling it with comments and suggestions.

I thank Dr. K. Thiyagesan, AVC College, Mailathurai for teaching me statistics. His statistical and logical inputs have fortified this thesis.

I acknowledge Rachna Chandra especially for her moral support in the last stages of my thesis and also for reading thesis drafts. I thank Archana Waran and her aunt Ms. Shobha Phaniraj for editing multiple drafts of my thesis. I also thank Madhuri, Nikhil and Dhanajayan for commenting on different chapters of thesis. I want to thank all my colleagues in SACON: Balakrishnan, Anoop, Debanik, Eshwaran, Joya, Madhuri, Anjan, Prashant, Riyas, Vivek, Zaibin for fruitful discussion on different topics which helped me improve my logic and knowledge. I also want to acknowledge Sheeba, Ezilarasi, Rajamamannan, Nikhil, Dhanya and Madhu for helping me in various ways.

Mr. A Srinivasan, Computer Assistant, SACON helped in various ways during this exercise. I thank Mr. V Vaidyanathan, PA to Director, for the helps in several ways. I owe my sincere thanks to Mr. Manoharan, Library assistant, and Finance and Administration staff, SACON for logistic support.

I am deeply in dept of my family, especially my mother and my brothers, for allowing me to be away from home for so long and supporting me in every manner. The kindness, care, love and patience they have shown has kept me going strong.

These six years have been very educative, exciting and also filled with numerous anxieties. I received guidance, affection, help and support from a great number of people, some of whom I've mentioned and many others who have inadvertently slipped out of this eulogy. Please accept my sincere gratitude.

CONTENTS

TABLES

FIGURES

APPENDICES

MAPS

Summary

The intriguing biological feat of making nest with its saliva is threatening the survival of the edible-nest swiftlet. Ever since the16th century when bird's nest became a delicacy in Chinese cuisine and an important item in their pharmacy, edible nest swiftlets are found overexploited all over. In the past two to three decades the production of the edible bird's nests has reduced drastically because of over-exploitation and uncontrolled harvesting that is directly affecting the population of this cave-dwelling species. The high demand in the international markets has put so much pressure that despite strict regulations on nest collection, the wild populations of the edible-nest swiftlets is plummeting by as much as 80% to 90% and has reached local extinction across some of their ranges.

India has four species of swiftlets: the Indian Edible-nest Swiftlet *Aerodramus unicolor* (Jerdon 1840), the Himalayan Swiftlet *Aerodramus brevirostris* (McLelland 1840), the Glossy Swiftlet *Collocalia esculenta* (Beavan 1867) and the Edible-nest Swiftlet *Aerodramus fuciphagus* (Hume 1873). Edible-nest swiftlet, the producer of edible nests, is distributed only in the oriental region of the world and the Andaman and Nicobar Islands of the Indian Territory. The collection of these commercially valuable nests started in the Andaman and Nicobar Islands in the 18th century. International demand led to widespread and uncontrolled nest collection in these islands leading to a serious fall in population.

A programme to conserve the edible-nest swiftlet in the Andaman and Nicobar Islands commenced in 1995, and is being implemented by the Department of Environment and Forests, Andaman & Nicobar Islands (ANF) and Sálim Ali Centre for Ornithology and Natural History (SACON) since 2001. The programme is implemented in 28 caves at Chalis-ek, Pattilevel, North Andaman Island and in 1 cave at Interview Islands Wildlife Sanctuary, Middle Andaman Islands. These 29 caves hosting colonies of the edible-nest swiftlet are protected during the breeding season between January and August. The species *Aerodramus fuciphagus inexpectatus* (Hume 1873) was studied in its natural habitat as part of the programme. Though data collection began in 2001, it was largely collected between 2004 and 2007. As the glossy swiftlet *Collocalia esculenta affinis* (Beavan 1867) of the island group has a major role to play in the *ex-situ* conservation of edible nest swiftlet in urban areas, wild populations of this species were initially studied along with the edible-nest swiftlet to know the ecology of these species in their natural habitats.

The two sympatric species, i.e. the edible-nest swiftlet and the glossy swiftlet were studied for their breeding ecology with reference to their habitat requirements and the impact of protection on the population of the edible-nest swiftlet in the Andaman and Nicobar Islands.

To understand the nest-site requirements of the species, their nest-site characters, preference and the relationship with nesting success were studied. Results showed that the edible-nest swiftlet and the glossy swiftlet are cave dwelling trogloxenes and do not nest randomly inside the caves. The ability to echolocate allows the edible-nest swiftlets to nest and roost in the dark zones of the caves. The glossy swiftlet does not echolocate and therefore builds its nests near cave openings in the dim-lit zones of the cave. The edible-nest and glossy swiftlet have shown their preference for rough and slightly rough textured rocks, inwardly inclined walls, with a presence or absence of supports and the different combinations of these characteristics during nest-site selection. These preferred characteristics and their combinations contribute substantially in nesting success among edible-nest swiftlet. Micrometeorological parameters were studied inside the caves. The mean temperature showed a negative relationship with nesting success, while relative humidity showed a positive relationship in the case of edible-nest swiftlets. This information gives clear solutions to engineer better *ex-situ* swiftlet houses for edible nest swiftlets.

Foraging habitat requirements were studied near the breeding colonies of the species at Chalis-ek. The aerial and foraging behaviours and their occurrence in different habitats and microhabitats helped to estimate the foraging habitat requirements of both species. Both these exclusively aerial foraging species showed noticeable difference in their foraging habitat requirements near their breeding sites. The edible-nest swiftlets depend on forest canopy to a great extent, whereas the glossy swiftlets forage in both forest and open land habitats. Edible-nest swiftlets preferred heights above the canopy level and also close to the top of the canopy. Glossy swiftlets were seen foraging close to the canopy top in forested areas and below canopy levels in the loose vegetations along streamsides in the deforested open patched. The current rate of deforestation can severely affect the populations of the edible-nest swiftlets, whereas the glossy swiftlets are much better adapted to forest alterations.

Nests of both the species were visited daily to study their breeding seasonality and chronology. The study shows that the edible-nest swiftlets in the Andaman and Nicobar Islands have well marked breeding season with two broods from December to August, whereas, the glossy swiftlets in the wild breed throughout the year and fledge almost four broods per year. The breeding seasonality in the edible-nest swiftlet is linked with rainfall. Glossy swiftlets do not show any relation with meteorological parameters. Edible-nest swiftlets use only saliva as the nest material whereas the glossy swiftlets use moss, twigs, grass, vegetation matter etc. glued together with their saliva. The behavioural study of the edible-nest swiftlets showed that they copulate mostly on the nests and have a slightly longer incubation and fledgling period as compared to the glossy swiftlets. Both the species have a normal clutch size of two eggs. In both the species the first clutch is more successful than the second clutch. Detailed information on the breeding biology of the species provides support for planning the fostering programme and also to predict the hatching and fledging success of the edible-nest swiftlet eggs in the glossy swiftlet nests. This information can be utilized for proper scheduling of cave protection and nest harvest timings and to develop a protection system for *in-situ* conservation.

The continuous improvement in the population growth has proved that the strategy of protecting the populations of edible-nest swiftlet in their natural habitat with the involvement of motivated nest collectors is a successful method of conserving edible-nest swiftlets in the Andaman and Nicobar Islands. However, a population decline of over 73% in the unprotected caves and local extinction from more than 60% of the unprotected caves surveyed within a decade is alarming. This calls for the expansion of the edible- nest swiftlet conservation programme all over the islands arc to prevent the extinction of the species.

Since the species was included in the Scheduled-I of the Wildlife Protection Act, 1972 in September 2003, the post-breeding harvest of the bird's nests is not possible. As a result, the protectors deputed at the cave mouths are getting demoralized. It is to be noted that the protectors were nest collectors who worked for the protection of the colonies with an incentive to harvest the nests at the end of the breeding season. Their de-motivation could hinder the expansion of the *in-situ* conservation programme. It is imperative to consider the removal of the species from the schedules and to ensure the survival of the species through sustainable practices, local participation and the scientific management.

CHAPTER 1

Introduction

1.1. Introduction

Islands avifauna has 40 times greater probability of being threatened with extinction than continental populations. Consequently, oceanic islands contain 39% of globally threatened bird species. Furthermore, 90% of the threatened island avifauna is restricted to a few islands (Johnson and Stattersfield 1990, Pimm *et al* 1988). Johnson and Stattersfield (1990) identified three main causes of extinction in island-endemic bird species: habitat destruction, limited range, and the introduction of exotic species. Island avifauna is a special concern in global conservation efforts because of its high rate of endemism and susceptibility to extinction. Furthermore, if the species is of economic value then it faces an additional risk. So is the case with the producers of the edible nest, the edible-nest swiftlets of the oriental region. In the past two to three decades the production of the bird's edible nest has reduced drastically because of over-exploitation and uncontrollable harvesting (Koon and Cranbrook 2002, Nguyen *et al* 2002). The fascinating biological trait of nest-making with its saliva is threatening unique members of Aves, since the 16th century when swiftlet's nests became an important item in Chinese cuisine and pharmacy.

Its great demand in International trade has put so much pressure on the species that despite strict regulations and controlled nest collection the wild populations of the edible-nest swiftlet continue to decline by as much as 80% to 90% and even reach local extinction in some parts of its range (Koon and Cranbrook 2002, Sankaran 2001, Nguyen *et al* 2002).

1.2. Classification of Swiftlets

Based on the DNA-DNA hybridization analysis Sibley and Ahlquist (1990) suggested that owls (Strigiformes), nightjars (Cprimulgiforms), swifts and hummingbirds are broadly related in the monophyletic assemblage, but the relation of swifts and hummingbirds was closely justified. Hence, Trochiliformes was arranged with the Apodiformes comprising Apodidae and Hemiprocnidae within the super order Apodimorphae (Josep *et al* 1999, Chantler and Driessens 1995). Two sub-families Cypseloidinae and Apodinae are generally recognized under the family Apodidae. The most ancient and least contentious thirteen species of Cypseloidinae, comprises the genera *Cypseloides* and *Streptoprocne*. Apodinae are distinguished with minimal sexual dimorphism and all except the needletails (*Hirundapus*) use saliva in nest building. Collocaliini, Chaeturini and Apodini tribes that fall in the sub-family Apodinae. Cheturini includes 24 species of spinetails from seven genera. Twenty seven species of swifts comprising of six genera were included in Apodini and Collocalini is with 28 species comprising of genus *Hydrochous*, *Collocalia*, *Aerodramus* and *Schoutedenapus*.

According to Peters (1940) description of Apodidae, it is one of the most difficult of all groups of birds to classify. Initially *Collocalia* was a single genus. Then, Brooke (1970) split *Collocalia* into *Hydrochous*, *Collocalia* and *Aerodramus* and his proposal was supported by recent studies in phylogeny and specifically of the correlation between phylogeny and behaviour. In the parsimonious phylogenetic tree, presented by Holmgren (1998), *Schouteden apus* was included in the tribe Apodini and treeswifts were included as Hemiprocnini within the Apodinae. Finally, he concluded for the use of all the available techniques before establishing any consensus about the taxa (Josep *et al* 1999).

The present document follows the classification by Brooke (1970) cited and described in the Josep *et al* (1999) and refers the echolocating, glossy swiftlets under genus *Aerodramus* and non-echolocating, Glossy Swiftlets under genus *Collocalia*.

1.3. General Characters of Swiftlets

Swiftlets (Order: Apodeformis) roost and nest inside caves or in cavern-like places, where they cling to the surface of walls and ceilings or on self-supporting bracket-shaped nests (Ford and Cullingford 1976, Langham 1980, Koon and Cranbrook 2002). These aerial foragers do not perch anywhere other than roosting and nesting sites and breed in colonies (Josep *et al* 1999). Swiftlets are the only birds other than the South American oilbirds, which have the ability to echolocate (Fenton 1975). Unlike bats (Chiroptera) however, swiftlets apparently do not have the echolocation acuity needed for preying on the insects in the dark. Rather, this adaptation gives them the advantage of being able to nest in dark caves, as well as to feed later into the night. So they can return to their caves after dark (Medway 1959, Nguyen *et al* 2002, Langham 1980). A distinguishing feature of all members of the sub-family Apodinae, except probably the needletails, is the use of saliva as a binding medium for nesting materials. Swiftlets use saliva to bind nest material that includes vegetation matter such as moss, twigs, leaves and their own feathers (Medway, 1962, 1963, Kang et al, 1991). Swiftlets tend to build nest repeatedly at the same site year after year (Koon and Cranbrook 2002, Nguyen *et al* 2002, Lau and Melville 1980). The edible nest Swiftlets *Aerodramus fuciphagus* (Hume 1873), exclusively use saliva for constructing their nest. This salivary glue is composed largely of glycoproteins that, according to the Chinese medicine, hold remarkable properties that make it attractive to human in various ways.

The wings of Apodidae are easily recognizable by its nine or ten primaries and eight to eleven very short secondaries. Both the primaries and secondaries provide powerful lift and forward force, which gives the members of this family great speed. The chimney swift *Chaetura pelagica* (Linnaeus 1758) was the fastest of the twelve species monitored for flight speed using Doppler radar at the mouth of the cave, with a record of flying at up to 110 km/h. Higher speeds have been claimed for the larger species, notably the white throated needletails *Hirundapus caudacutus* (Latham 1802) that have allegedly been recorded flying at 170 km/h. Contrary to their effectiveness, the feet of swiftlets are too strong with sharp curved claws, which are very essential for griping on to vertical surfaces. Evidence from blood testing, shows profound physiological adaptation of these birds to a high altitude way of life. Haemoglobin is sensitized for optimum delivery of oxygen in conditions of low oxygen pressure (Josep *et al* 1999). The gape of the mouth is very large, facilitating the aerial capture of the insects, although the bill itself is quite tiny.

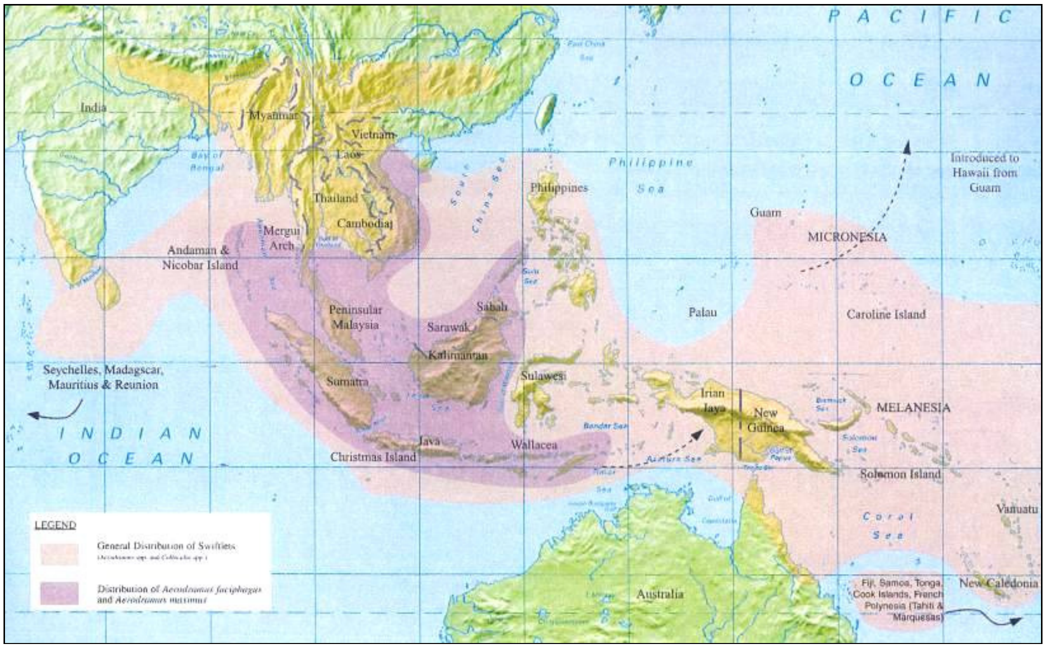
The plumages of all are dull except for the black and brown plumage. In two closely related Neotropical species the *Cypseloides rutilus* (Vieillot 1817) and the

Cypseloides phelps (Collins 1972), all adult males and some adult females have a bright reddish chestnut throat. Many species such as *Mearnsia picina* (Tweeddale 1879), *Hirundapus celebensis* (Sclater 1865), *Hirundapus caudacutus* (Latham 1802) and *Collocalia esculenta* (Beavan 1867) have a decidedly glossy plumage. Nearly all swifts show at least a slight gloss in fresh plumage. It is difficult to determine the function of this sheen. Perhaps, the increased albedo of glossy feathers is vital in protecting the plumage, or the gloss could have some effect on thermoregulation and aerodynamics (Josep *et al* 1999).

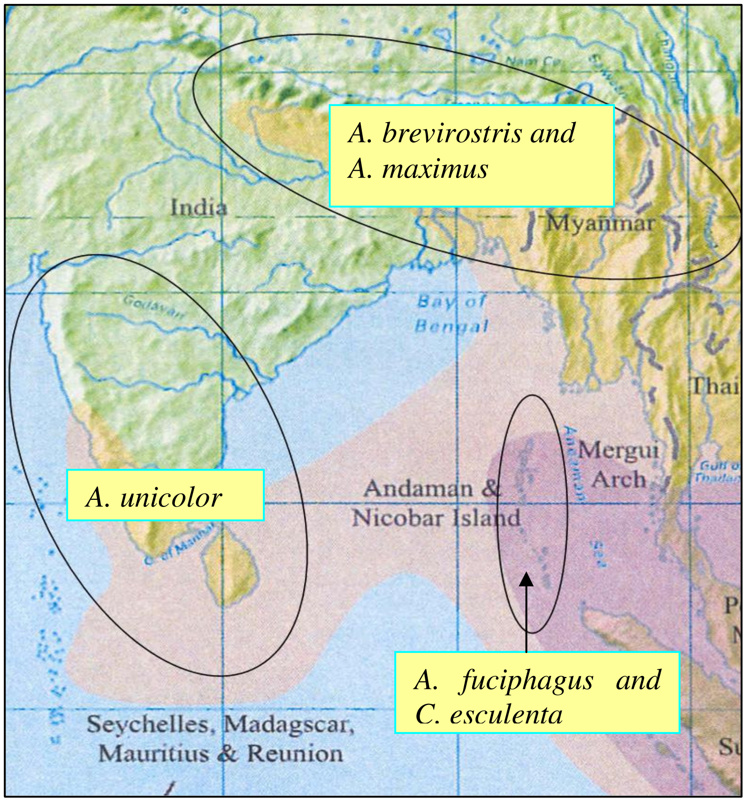
1.4. Distribution

1.4.1. Global Distribution

Swiftlets are found from the western Indian Ocean to southern continental Asia, Indonesia, northern Australia and New Guinea to islands of the west and south Pacific. Northwards they extend to the Himalayas and Szechwan in China. The southern range reaches Mauritius in the Indian Ocean, and Queensland, Australia, and to the east New Caledonia in the south-western Pacific region. South-east Asian countries or regions within this geographical range that currently produce edible nests of commercial value include the Andaman and Nicobar islands, Hainan Island in China, Palawan Island in the Philippines, the coasts and islands of Vietnam, Cambodia, Thailand, Myanmar, Malaysia and Singapore, and the Indonesian archipelago including Sumatra, Java, the Lesser Sunda Islands, and Borneo (Map 1; Nguyen *et al* 2002, Koon and Cranbrook 2002).



Map 1 Distribution of Swiftlets (Map Source: Koon and Cranbrook 2002)



Map 2. Distribution of Swiftlets in India
(Base map source: Koon and Cranbrook 2002)

1.4.2. Swiftlets in India

India has four species of Swiftlets distributed in its territory. The Indian edible-nest swiftlet *Aerodramus unicolor* is endemic to the Western Ghats and Sri Lanka. It makes black edible-nest using saliva and its own feathers. The Himalayan swiftlet *Aerodramus brevirostris* is found in the North-eastern region of India and could be a migrant to the Northern parts of Andaman and Nicobar Islands (Osmaston 1906, Ali and Ripley 1970, Sankaran 1998). The Himalayan swiftlet uses very little saliva to construct its nest which is mostly composed of plant material. The glossy swiftlet *Collocalia esculenta* which is found commonly in the Andaman and Nicobar Islands uses moss, twigs, leaves, flowers, etc. bound together with a little saliva. Saliva is also used to attach the nest on the rock surface. The most important species found in India is the edible-nest swiftlet *Aerodramus fuciphagus.* Locally known as Hawabill, it is widely distributed in the Andaman and Nicobar Islands (Map 2).

1.4.3. Swiftlets in the Andaman & Nicobar Islands

Two species of swiftlets, the commercially important edible-nest swiftlet *Aerodramus fuciphagus* and the glossy swiftlet *Collocalia esculenta*, are present in the Andaman and Nicobar Islands. Both the distinctly recognized sub-species, *Aerodramus fuciphagus inexpectatus* and *Collocalia esculenta affinis*, are endemic to the Andaman and Nicobar Islands.

1.5. Study Species

1.5.1. Edible-nest Swiftlet *Aerodramus fuciphagus inexpectatus* (Hume 1873)

All swiftlets use large amounts of saliva produced by the enlarged sublingual glands during the breeding season to bind the nesting material like moss, twigs, vegetable matter, own feathers, etc (Lack 1954, Marshall and Flolley 1956, Bernstein 1859, Medway 1962c). Species like German's swiftlet *Aerodramus germani* (Oustalet 1876) and Indian edible-nest swiftlet *Aerodramus unicolor* use considerably more saliva to bind their own feathers. These nests appearing dark in colour are known as black nests, and the producers are recognized as black nest swiftlets. The species is always of human interest as it produces valuable edible nests, believed to have medicinal properties. After the discovery of its use in Chinese medicine during the 16th century, edible nests of swiftlets were under exploitation in most population ranges and by 18th century they were being collected from all its ranges. Edible-nest swiftlet has 8 subspecies. The great demand of the bird's nests resulted in the escalation of prices in the international market and soon the white nest of the swiftlets became one of the most expensive natural products of the world (Plate 1; Lau and Melville 1994, Koon and Cranbrook 2002). Increase in demand and high value has resulted in the overexploitation of all the known colonies of the edible-nest swiftlets throughout their distribution leading to a severe decline in the populations.

Wang (1921) and Frank (1926) described that the swiftlets' salivary secretion consists of a mucin-like glycoprotein and the composition of edible birds'-nest averages 9% moisture, 20% inorganic ash, 32.3% protein and 38.7% carbohydrate. Analysis using high performance liquid chromatography has revealed that the protein consists of 17 amino acids; aspartic acid, glutamic acid, serine, glycine, histidine, threonine, arginine, alanine, proline, tyrosine, valine, methionine, cystine, isoleucine, leucine, phenylalanine and lysine in various quantities. The carbohydrate is made up of one sialic acid, two hexosamines, three hexoses and one deoxyhexose. The sialic acid is identified as N-acetylneuraminic acid. The two most abundant sugars are the hexosamines, namely glucosamine and galactosamine. The hexoses are galactose, mannose and glucose; however merely 2.2% of the total sugar content. The only deoxyhexose is fucose (Koon and Cranbrook 2002). Some early analytical studies used edible nest extract as a substrate to investigate viral sialidase activity and the haemagglutination inhibiting actions against influenza virus (Koon and Cranbrook 2002). The first avian epidermal growth factor (EGF) was discovered in partially purified swiftlet's nest extract (Kong *et al* 1987). It has been suggested that this water-soluble glycoprotein with a complex protein composition might influence more than one physiological parameter to affect its purported medicinal properties. However, this substance is present in such minute quantities or perhaps so tightly bound to the salivary matrix that prolonged heating is required to release it. One milligram of nest is estimated to contain 2.23 nanogram of EGF (1 ng = 10"6 mg; Medway 1962a and 1969, Kong *et al* 1987, Koon and Cranbrook 2002).

1.5.2. Glossy Swiftlet *Collocalia esculenta affinis* (Beavan 1867)

Having almost 31 sub-species throughout South Asia, glossy swiftlets are easily distinguished from other swiftlets by their smaller size and glossy plumage. They are also known as the white-bellied swiftlet because of the clear white patch on the abdomen. The typical pipistrelous flight (continuous beating of wings during flight) makes them easily identifiable in the field. As the Andaman and Nicobar Islands have only two species of swiftlets, it is fairly easy to identify them apart in the field.

Glossy swiftlets make nests of no commercial value using saliva to bind twigs, grasses, moss, and vegetation matter (Plate 2). The species is known to breed commonly in the Andaman and Nicobar Islands. They breed in caves, crevices, in abandoned houses, buildings, under jetties and bridges, etc. The species uses saliva at the base of the nest for which it is being exploited in some colonies in the Andaman and Nicobar Islands (Sankaran and Manchi 2008). Glossy swiftlets, which mostly foraging close to the forest canopy, are the only swiftlet species known to forage below the forest canopy as well (Medway 1962b).

In some South-East Asian countries colonies of glossy swiftlets in breeding houses are being used for cross fostering the eggs of the edible-nest swiftlets. So once the eggs of the edible-nest swiftlets are transferred to the nests of the glossy swiftlets. Thence, the latter raise and fledge chicks of the former. As swiftlets are known for nest site fidelity these fledged chicks come back to the houses from where they have been fledged. This leads an increase in the population of the edible-nest swiftlets in houses for commercial use (Koon and Cranbrook 2002). Thus the glossy swiftlets are of much commercial importance in some countries in their range.

1.5.3. Conservation of the Edible-nest Swiftlets in Andaman and Nicobar Islands

Collection of edible nests started in the 18th century in the western extremity of the species' range, in the Andaman and Nicobar Islands. While local consumption of the nests was insignificant, an international demand led to a widespread and uncontrollable nest collection in these islands leading to a serious decline in the bird's population. A program to conserve the edible-nest swiftlet in the Andaman & Nicobar Islands commenced in 1995, and is being implemented by the Department of Environment and Forests, Andaman & Nicobar Islands (ANF) and Sálim Ali Centre for Ornithology and Natural History (SACON), Coimbatore. Based on the action research done and currently underway, and the empirical data collected since 1995 by SACON, it is clear that the conservation of the edible-nest swiftlet can be achieved only when economic benefits accrue to nest collectors in particular and local people in general (Sankaran and Manchi 2008). The Department of Environment & Forests, Andaman & Nicobar Islands, and SACON recognise, and strongly believe that the only way to conserve the edible-nest swiftlet in the Andaman and Nicobar Islands is by way of a participatory approach whereby nest collectors are intrinsically involved, and play a pivotal role, in the effective conservation and management of the species in the islands as well as by development of house ranching.

The strategy that has therefore been evolved to conserve the edible-nest swiftlet in these islands includes both *in-situ* conservation within caves as well as house ranching. This strategy has been endorsed by the State Wildlife Advisory Board, the Planning Commission, by the Hon'ble Supreme Court of India vide the Shekhar Singh Commission's Report, as well as several scientific and conservation organisations. It is based on a well deliberated understanding of the issues involved, and some of the criteria that have enabled this are:

i. The edible-nest swiftlet is not globally critical endangered, nor threatened. It is listed as a Species of Least Concern in Red Data Lists.

ii. Scientifically managed harvesting regimes have been widely recognized as the appropriate conservation strategy for swiftlets, and recommended by CITES, on whose appendices the swiftlets therefore have not been included.

iii. Scientific harvesting of swiftlet nests is ethically acceptable, as it neither involves killing nor are the birds constrained in anyway; that by scientific harvesting both people and the swiftlets win.

iv. Innovative conservation strategies are required, not only to conserve the edible-nest swiftlet but also to provide a source of livelihood to nest collectors.

v. The implementation of innovative programs based on sustainable utilization of resources to develop livelihoods alternating with current development strategies are crucial to the economic development of fragile bio-diversity hotspots like the Andaman and Nicobar Islands. Such high value initiatives are expected to significantly reduce the dependence on unsustainable development paradigm that these islands are currently subjected to.

vi. Sustainable harvesting of the nests of the edible-nest swiftlet does not create a precedence, since in all other forms of exploitation of animals, either killing or constraining the animal is involved, whereas neither is the case with this species.

The edible-nest swiftlet was inadvertently placed in Schedule I of the Indian Wildlife (Protection) Act in 2003. A representation made to the Ministry of Environment and Forests to de-list the species is under active consideration.

1.6. Origin of the study

One of the main reasons to study the edible-nest swiftlet is its nest carrying high value in the international market. The nests can also fetch large amount of revenue for the local people and the administration through an in-depth understanding of this species for better management of the population and the harvesting system. Once the sustainable way of harvesting the edible-nest is traced via scientific research of the species, an alternative livelihood can be generated for the local people. This can ultimately lead to the economic growth of the Andaman and Nicobar Islands as seen in some of the Southeast Asian countries like Indonesia, Vietnam, Borneo, etc. As the islands are known to have limited resources, natural resources like edible nests can provide a strong economic support to the islands.

Lack of evolutionary and taxonomic information about the Apodidae makes the study of any species under it very important. This study hopes to contribute to the knowledge about its evolution and taxonomic complexes of the family. Study of cave dwelling swiftlets can add to speleological studies. This study can add to our limited knowledge of caves, cave fauna and its ecology in the Indian region, particularly in the Andaman and Nicobar Islands.

The conservation program, initiated in 1999 by SACON with Department of Environment and Forests, Andaman and Nicobar Islands (ANF), has been with both *in-situ* and *ex-situ* approach. *In-situ* conservation involves the protection of swiftlet caves, by motivated nest collectors, with an incentive for post breeding harvest of the nests. The *ex-situ* approach involves development of populations of edible-nest swiftlets within houses by transfer of eggs of edible-nest swiftlets into the nests of glossy swiftlets.

The glossy swiftlet can play an important role in the *ex-situ* conservation of the edible-nest swiftlet, because it is the only other swiftlet found in the Andaman and Nicobar Islands and it has been used in Southeast Asian countries for the same. However, it is very important to understand the ecology and behaviour of the glossy swiftlet for the successful *ex-situ* conservation of the edible-nest swiftlets in Andaman and Nicobar Islands.

1.7. Objectives

The study was designed for the purpose of the *in-situ* and *ex-situ* conservation of the edible-nest swiftlets. Therefore, edible-nest swiftlets were studied in detail than the glossy swiftlets. Both the species were planned to be studied in the wild initially to understand their co-existence. Keeping this in mind, the present study of the edible-nest swiftlet and the glossy swiftlet was designed in Andaman Islands with the following objectives:

1. to study the breeding ecology of the edible-nest swiftlet and glossy swiftlet with reference to their habitat requirements and breeding biology and
2. to study the impact of protection on the population of the edible-nest swiftlets in Andaman and Nicobar Islands.

1.8. Organization of Thesis

This dissertation is organized into six chapters as follows:

Chapter 1 briefly introduces the species, and presents the aims and objectives of the study.

The second chapter describes the Andaman and Nicobar Islands; its geography, climate and geology. This chapter briefly describes the number, location and types of caves in the island groups with information on cave complexes and caves chosen for the study of the edible-nest swiftlet and glossy swiftlet.

Chapter 3 investigates nest-site selection and preference by the edible-nest swiftlet and the glossy swiftlet. Rock surfaces used as nest site were inspected for physical characteristics like texture, presence of supports, wall inclination, height from the ground and slope of the rock. The influence of nest site characters and the micrometeorological characters inside the caves on the nest success of the edible-nest swiftlets was investigated.

Chapter 4 describes the aerial and foraging habits of both the species to understand their habitat requirements near the breeding caves. The forest type of the area near the breeding caves was also described. The habitats were classified into microhabitats via further vertical stratification of the area.

Chapter 5 includes details on the breeding seasonality and chronology of the species under study in the Andaman Islands. The edible-nest swiftlets were also studied for their select behaviour at the nests and its contribution to successful breeding. Breeding success of the edible-nest swiftlet and glossy swiftlet is explained according to the study sites. Some aspects of post natal dispersal movements in the edible-nest swiftlets are included in the study.

Chapter 6 examines the impact of protection on the wild populations of the edible-nest swiftlets in the Andaman and Nicobar Islands. The impact was evaluated by surveying the protected and unprotected caves in the North and Middle Andaman Islands, and comparing the changes in population.

Finally the important outcomes of the research are compiled for further strengthening of the conservation of the edible-nest swiftlets in the Andaman and Nicobar Islands.

CHAPTER 2

Study Area

2.1. The Andaman Islands

2.1.1. Geography

Andaman and Nicobar Islands in the northeastern Indian Ocean, known as the southern extension of Arakan Yoma mountain range, are the peaks of a submerged continuous mountain ridge arching from Arakan Yoma in the north to Sumatra in the south, between latitude 6°45’ and 13°41’N and longitudes 92°12’ and 93°57’E . The islands are divided into two major groups Andaman to the north and Nicobar 160 km to the south separated by the Ten Degree Channel. The Island group comprises of over 500 islands and covers 8,249 sq. km. with the Andaman group comprising of over 325 islands covering 6,408 sq. km., and the Nicobar group, with more than 24 islands with an area of 1,841 sq. km. The length between the extremities is about 355 km, while the maximum width is about 60 km. The islands have a coastline of 1,962 km. The highest point in these island groups is Saddle Peak that rises to 732 meters above sea level, in North Andaman (Kumar 1981, Saldanha 1989, Sankaran 1998, Andrews and Vasumati 2002, Jayaraj and Andrews 2005, Sankaran *et al* 2005).

The Andaman group of islands is further subdivided into (a) North Andaman (b) Middle Andaman and (c) South Andaman. North Andaman includes the northernmost Lanfall Island, the Narcondam Islands which is the only live volcano of Indian region, and also the Saddle Peak. To its south lies the Middle Andaman group consists of many islands including Baratang Island. The south Andaman Island group includes the capital Port Blair and several other islands. The islands of Ritchi’s Archipelago are located to the east of Middle Andaman and the labyrinth group of islands is situated southwest to the South Andaman. Little Andaman Island is 55 km south to the South Andaman Island and is the southernmost part of the Andaman Islands, across Duncan Passage.

The Nicobar group is divided into three subgroups. To the south is the Great Nicobar Island group consisting of two islands larger than 100 sq. km., nine islets smaller than 05 sq. km. and a few rocks. About 58 km north of Great Nicobar is the Nancowry group, which consists of three islands larger than 100 sq. km., two islands of 36 sq. km. and 67 sq. km., three islands less than 17 sq. km., two islets and a few rocks. The northern subgroup, comprising of Batti Malv and Car Nicobar, is 88 km north of the Nancowry group.

2.1.2. Climate

Andaman and Nicobar Islands are endowed with year-round true humid, tropical coastal climate with least variation in temperature between 20^{o}C and 32^{o}C. Temperatures between May and December are moderated by rain. The maximum temperatures are experienced during the dry season between January and April. Since these islands are under the influence of both the south-west and north-east monsoons, they receive rain from April to December. The mean annual precipitation is around 3100 mm, unevenly distributed throughout the year with maximum rains occurring from May to December. Average relative humidity ranges from 68% to 86%. The islands receive north-eastern winds between November and March and south-western winds between May and October. Cyclone winds and gales are usually common with change of monsoons and sudden depressions in the sea around. Maximum daily sunshine of 8-10 hrs is usually observed during the dry months while in the rainy season clouds restrict this to 3-8 hrs. Due to a fairly dust-free and clean sky, solar radiation is intense during the peak of the day (Saldanha 1989, Andrews and Vasumati 2002, Jayaraj and Andrews 2005).

2.1.3. Geology

Andaman-Nicobar arc extends from the southern strip of Burma to the northeastern strip of the Java-Sumatra trench. The origin of these islands is believed to be in late Pliocene to Pleistocene from a single eruption. The region of the Burmese arc through Arakan and the Andaman Nicobar Islands to Sumatra and beyond is characterized by highly seismic, seismic and aseismic zones with earthquake segments of shallow to intermediate foci in the earth crust (Kumar 1981, 1990). As these islands are in a geosynclinals basin, the rocks are highly folded due to frequent tectonic movements. The tectonic activity of the Andaman area is intense along two broad belts: western non-volcanic arc comprising the Andaman Nicobar Islands, and the eastern volcanic arc. The eastern island arc is the most active belt along which a lithospheric convergence has taken place (Srinivasan 1979, Kumar 1981, Jafri *et al* 1993). The strongly folded thrust of segmented layer is removed repeatedly from the place of deposition. Late Cretaceous ophiolites occur in limestone, sandstone, shale and radiolarite. They are basic and ultrabasic submarine flows. Acid submarine tuffs occur inter-bedded in the fossiliferous lower Miocene or post-Pliocene rocks, along with plugs of basic and intermediate lava and agglomerate rocks (Kumar 1981). The sedimentation and the surface depositions are believed to be from the Cretaceous to the Sub-Recent period and from the Recent respectively. The present arrangement would have taken shape recently, only 26 million years ago with two volcanic islands, Narcondam and Barren Islands (ANI F&E 2001). The oldest sedimentary strata known in the Andaman-Nicobar Islands is the Archipelago group. This group overlying the Late Cenozoic sediments of the Andaman-Nicobar region consists of well developed marine deposits near Baratang, Middle Andaman.

2.2. Caves in Andaman and Nicobar Islands

2.2.1. Formation of Caves

According to Ford (in Ford and Cullingford 1976) sedimentary rocks are composed of the remains of plants and animals which secrete calcium carbonate as part of their metabolism from the bulk of all limestones. Other components are those precipitated chemically or as a by-product of biochemical processes. Present together on the sea floor at the time of sedimentation, they are partly geo chemical and partly organic; and this non-uniform character of sedimentation creates variations in the composition of limestones. As Clements *et al* (2006) explained, limestone karsts are sedimentary rock outcrops that consist primarily of calcium carbonate and were formed by calcium-secreting marine organisms millions of years ago (e.g., corals and brachiopods) before tectonic movements lifted them above sea level. Over the years, mechanical and chemical weathering exposes the karsts and usually produces “tower karsts” characterized by tall, precipitous (60° to 90° gradient) cliffs riddled with caves, and sinkholes or the “cockpit karsts” that are generally cone-shaped and have gentle slopes (30° to 40° gradient; MacKinnon *et al* 1996).

The birth of a cave system is termed as speleogenesis. Caves can form only in lithified rocks i.e. the rocks formed of aggregates of particulate matter (Ford and Cullongford 1976) and their location is controlled by the original sediment character and diagenetic history i.e. changes that result from the sedimentary processes during the transformation of the sediments into rock. So it is very important to understand the enclosing limestone as much as possible to explain why a particular cave or feature is where it is (Challinor 1967, Ford and Cullongford 1976). The Andaman and Nicobar Islands has several caves and cave complexes. Most caves in the Andaman and Nicobar Islands fall into two broad categories; (a) those formed by underground drainage and erosion in limestone formations and (b) those formed in sea cliffs by marine erosion of rocks (Challinor 1967). Channels formed by underground drainage get cut by sub-aerial erosion and are exposed later.

2.2.2. Cave fauna

Though caves have very diverse and severe conditions inside, they support a huge number of life forms in them. The life forms found in caves belong to different systematic groups and fall into several distinct classes according to their habitats. According to Jeferson (in Ford and Cullingford 1976) the classification given below is as old as cave biology:

Troglobites: Species which are obligatory cavernicolous and are unable to survive except in caves or similar habitats underground.

Troglophiles: Species which are facultative cavernicolous. These species live successfully in caves and complete their life cycle in caves but can be equally successful in cave-like conditions.

Trogloxenes: Species that occur in caves but do not complete their life cycle there. The species that frequent the dark zones of the caves are called Habitual Trogloxenes, while those that do not visit the dark zones frequently are called Accidental Trogloxenes.

Stygobites: Aquatic cave species.

2.2.3. Number, location and types of caves in Andaman and Nicobar Islands

Of the several caves in the Andaman and Nicobar islands, Sankaran (1998) located and mapped 384 caves, of which 61.5% (236) were inland caves (located within the forest) and the rest were coastal (located on the shore). Among the 236 inland caves, 86% were underground, of which 1% was located at the origin of a stream. 14% of the caves seen above ground were sub-divided into those located above ground on inland cliffs (3%) and those seen on inland hills (97%). Of the 384 caves mapped, 342 caves were found to have swiftlet populations, a total of 291 caves with edible-nest swiftlets and 93 caves with glossy swiftlet were identified. Of these, 249 caves consisted exclusively of edible-nest swiftlet populations, 51 were inhabited exclusively by glossy swiftlets, and 42 caves had both the species co-existing (Sankaran 1998; Appendix 1, Map 3 and Map 4).

2.3. Intensively Studied Cave Areas

2.3.1. Interview Island, Middle Andaman

Interview Island, the biggest Wildlife Sanctuary of the Andaman and Nicobar Islands, is spread over 133 sq. km. between the latitudes 12º 46’ 56” and 12º 59’ 02” N and longitudes 92º 39’ 04” and 92º 43’ 23” E. This westernmost uninhabited island of North and Middle Andaman has four major types of forests: Tropical Evergreen Forest, Andaman Semi-Evergreen Forest, Littoral Forest and Mangrove Forest. It also has a rich faunal diversity (Pande *et al* 1991).

There are more than 34 caves on the Interview Island, 13 of which are located on the shore and the rest in the interior. Of these, 18 inland caves are known to have edible-nest swiftlets and 2 caves also have glossy swiftlets (Sankaran 1998). All caves with the population of edible-nest swiftlets are underground caves. Most of these caves are tunnels or cracks where nests can be plucked by hand. According to Sankaran (1998), Cave-17 is the only large cave having a large population of edible-nest swiftlets and also small population of glossy swiftlets in it. The cave was under an immense pressure of nest collection. Collectors built scaffolding from which bamboo poles were used to reach the nests. As Sankaran (1998) described, this cave complex was discovered not before the 1990's. So it is assumed that despite rigorous and unsustainable nest collection, there has been no apparent decline in bird population because nest collection has begun recently. In addition to the known caves there are still more caves, crevices and tunnels that could have small populations of the edible-nest swiftlet.

Cave-17, a large cave with a good population of edible-nest swiftlets nesting in inaccessible nooks, was chosen for the *in-situ* conservation program of the edible-nest swiftlet. The cave has two openings, both under protection during the breeding season since 2001 (Sankaran and Manchi 2008). This cave was selected for the study of the breeding ecology of the edible-nest swiftlet and glossy swiftlet nesting and roosting inside. The other 16 caves containing colonies of the edible-nest swiftlet were surveyed in April 2008 to study the population trend in unprotected caves, the impact of the Great Tsunami Earthquake on the caves and dispersion among edible-nest swiftlets.

2.3.2. Chalis-ek, Pattilevel, North Andaman

Chalis-ek is a group of inland limestone caves within a single hillock. It is located at Pattilevel near Ramnagar, in the southeastern part of the North Andaman Island. As the vernacular name suggests, Chalis-ek is reported to have 41 caves in it. Chalis-ek and Pattilevel have Semi Evergreen Forest and Dry Deciduous Forest. People inhabiting the area converted part of a forest land into paddy fields. There are two open paddy lands (one within 1 km of the Chalis-ek hillock and the second about 2 km away) owned by several families. The remaining forest in the area is under immense pressure of deforestation.

According to Sankaran (1998), Chalis-ek in North Andaman Island is one of the four most important cave complexes in the island groups for edible nest swiftlets. Currently, only 30 caves are known in the hillock out of which 28 were reported to have population of edible-nest swiftlets. The area has a history of nest collection from the days of Great Andamanese (primitive tribe of the Andaman Islands). Great Andamanese are known to have begun collecting the nests in the 1940s, followed by the Karens (settlers from Burma brought by the Japanese). Karens taught nest-collection to the other settled communities in the Islands i.e. Ranchies/Biharies during the 1970s, and later Bengalis too joined the trade. Presently, there is a tremendous pressure of nest collection on the breeding population of the edible-nest swiftlets at Chalis-ek. Collection was periodic in the past, once in ten or fifteen days. But nowadays nests are collected almost everyday and the number of people collecting nest has increased.

Since 2001, the 28 caves having population of the edible-nest swiftlets are under round–the-clock protection every year during the breeding season as part of the *in-situ* conservation program (Sankaran and Manchi 2008). The edible-nest swiftlets roosting and nesting in these caves were studied for their breeding ecology. Apart from the forest land, the foraging habitat requirements of the edible-nest swiftlets and the glossy swiftlets were also studied in the paddy fields at Pattilevel.

2.3.3. Naya Dhera, Wraffter’s Creek, Baratang Island

Baratang Island is the southernmost part of Middle Andaman and is situated between the Middle and South Andaman Islands. It has the most important cave complex in the Andaman and Nicobar Islands located between Wraffter’s Creek and Naya Dhera on the Baratang Island. The forest patch comes under Reserve Forests. The forest type here is the Andaman Evergreen and Semi-Evergreen Forest. It also has a long stretch of Mangrove Forest.

The area consists of over 170 caves located in a 1 sq. km. area. The entire terrain is of jagged rocks, below which is a warren of clefts, crevices, tunnels and a few caverns. Majority of these are clefts and cracks are barely 1-2 m wide, but 10-12 m deep and over 20 m long. The Great Andamanese were known to collect the nests in these caves since historic time. They were followed by the Burmese and subsequently by others. During the survey by Sankaran (1998), over 50 nest collectors were found active. However, now the number has reduced to about 10 nest collectors because of the rapid decline in the population of the edible-nest swiftlets.

Of the total 170 caves, only 152 were surveyed during March 2008 to estimate the population trends in the unprotected caves. Data on the nest-site characters of the edible-nest swiftlets was also collected from all the possible caves in this group.

2.4. Microclimate inside caves

The microclimate of caves depends on the type of cave and air ventilation. The other possible contributory factors to the cave environment could be the type of limestone, water seepage inside the caves and the amount of moisture-holding guano deposited in the caves (Ford and Cullingford 1976, Nguyen *et al* 2002).

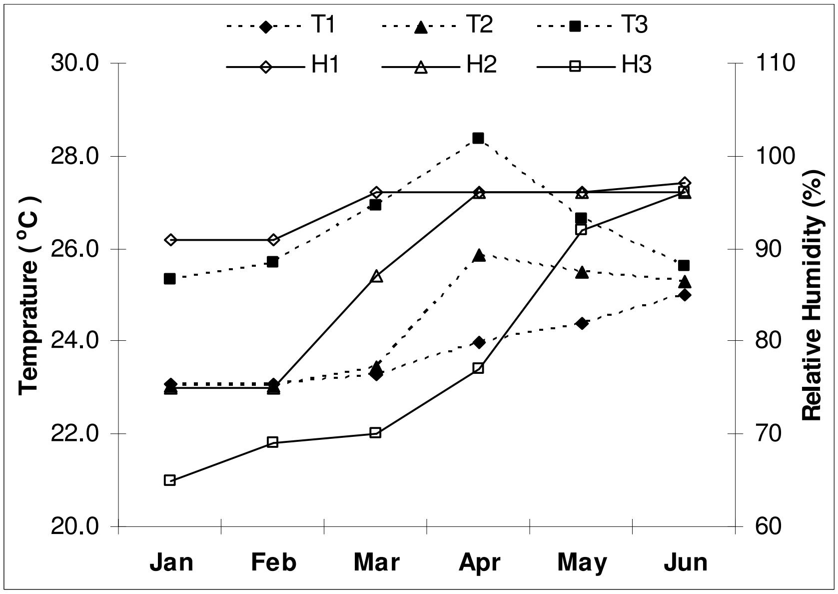


Figure 1 Seasonal variation in the mean temperature and relative humidity in the caves at Chalis-ek **T1**: Average temperature inside the caves; **T2**: Average temperature at the caves mouth; **T3**: Average temperature outside the caves; **H1**: Relative Humidity inside the caves; **H2**: Relative Humidity at the caves mouth; **H3**: Relative Humidity outside the caves.

In two caves at Chalis-ek micrometeorological parameters such as maximum and minimum temperature and relative humidity (RH, %) were measured inside the caves, near the cave openings and outside at 06:00hrs, 12:00hrs and 17:00hrs daily during the breeding season between January to June from 2004 to 2008. The mean temperature recorded inside caves was 23.8°C±0.8°C showing a small gradual increase from January to June. The temperature recorded inside the caves was considerably lesser than the 24.5°C±1.3°C temperature recorded at the cave openings and 26.4°C±1.1°C recorded outside the caves. The relative humidity inside caves was

94.5%±2.7% showing little increase from January through June. It was much higher compared to the relative humidity of 87.5%±10.3% at the cave openings and 78.2%±12.9% outside caves (Figure 1). The caves in North and Middle Andaman mostly have small openings, preventing wind circulation and leading to almost constant temperature and RH inside the caves.

2.5. Impact of the Great Tsunami Earthquake on the caves

A subduction of the Indo–Burma plate occurred due to the M 9.15 earthquake of 26th December 2004, the epicenter of which was located 150 km off the west coast of the northern Sumatra Island in Indonesia. The Andaman and Nicobar Islands lie within the subduction zone of the Burma plate, north of the epicenter, and was the most affected region in India (Rao and Chary 2005, Sankaran *et al* 2005). In the subsequent months after the major earthquake a series of small aftershocks were experienced, following which an earthquake of magnitude 8.7 on the Richter scale occurred on 28th March 2005. The earthquake and the series of minor and major tremors have affected the islands in several ways (Gahalaut and Kalpna 2005, Jain *et al* 2005, Rao and Chary 2005).

The impact of the earthquake was observed on 27 above-ground caves in the Chalis-ek cave complex and 16 underground caves situated on the Interview Island. The extent of damage within the caves was estimated by counting the number and size of fallen rocks. The fallen rocks were measured and categorized into size classes: large boulders (> 1.5 m), medium sized boulders (1 - 1.5 m), small boulders (0.6 - 1 m), big rocks (0.3 - 0.6m), medium sized rocks (0.15 - 0.30 m), small rocks (0.10 - 0.15 m) and chips (<0.10 m). While the number of boulders and rocks were counted, the number of fallen chips was visually estimated as an approximate proportion of the total fallen rocks. Structural changes like formation of new openings or the closure of existing ones were also recorded. The damage to the cave was qualitatively categorized as high, medium, low and nil. The extent and size of rock fall and the overall damage to caves was analysed according to cave type and size.

Visible damages due to the earthquake included (1) widening, narrowing, partial or complete closure of existing cave mouths, (2) fallen rocks within caves and (3) development of cracks and fissures. Damage that was not visible included a shift in position of the rocks, loosening of rocks and development of internal cracks. Sixteen of the 43 caves (37%) were damaged while 27 caves (63%) had no apparent signs of damage. Cave mouths had widened in 5 (31%) of the damaged caves. In the case of one cave each the mouth was narrowed, partially or completely closed (6%). Rock fall within the caves had occurred in 15 caves (35%). One cave had developed cracks (2%).

Rock fall differed significantly between caves that were below or above ground (Z= -3.543, $p < 0.001$). There was zero or negligible rock fall in caves that were below ground, while in 15 of the 27 caves above ground (56%) suffered rock fall. The amount of rock fall varied significantly with the size of the cave being least in the small caves and highest in the large caves (χ^2= 18.545, df= 3, $p < 0.001$). In terms of the overall extent of damage categorized by the amount of rock-fall and other visible signs of damage, 8 caves were highly damaged, 2 were moderately damaged, 6 less damaged. The damage was proportionate with the cave size (Figure 2 and Appendix 2). The proportion of the size of the fallen rocks to the total fallen rocks varied between caves (χ^2= 43.325, df= 6, $p < 0.001$), but showed no difference with respect to cave size (Figure 3).

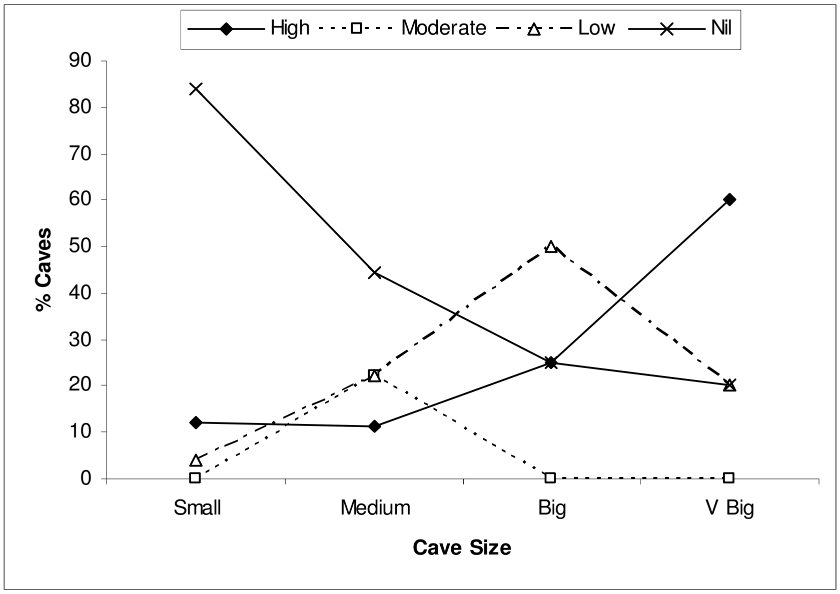


Figure 2 The damage inside the caves with respect to cave size.

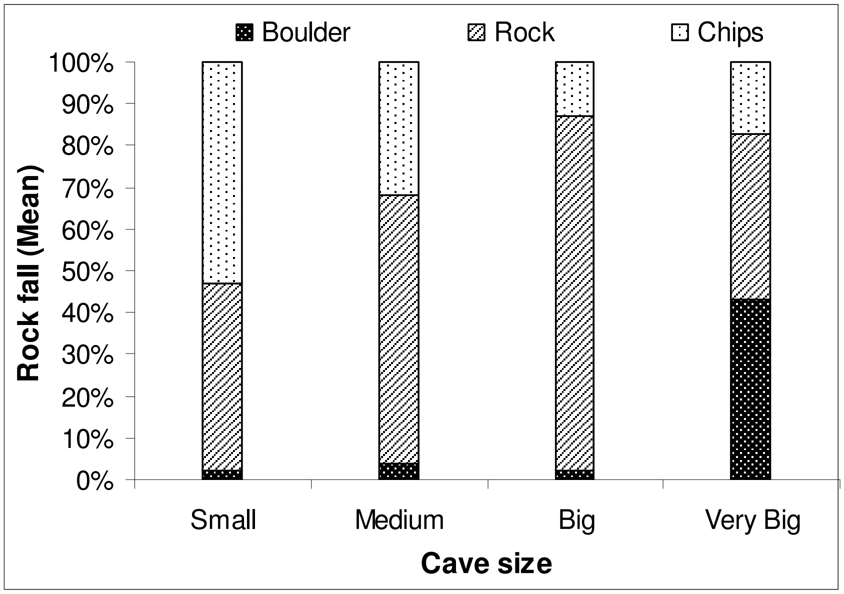
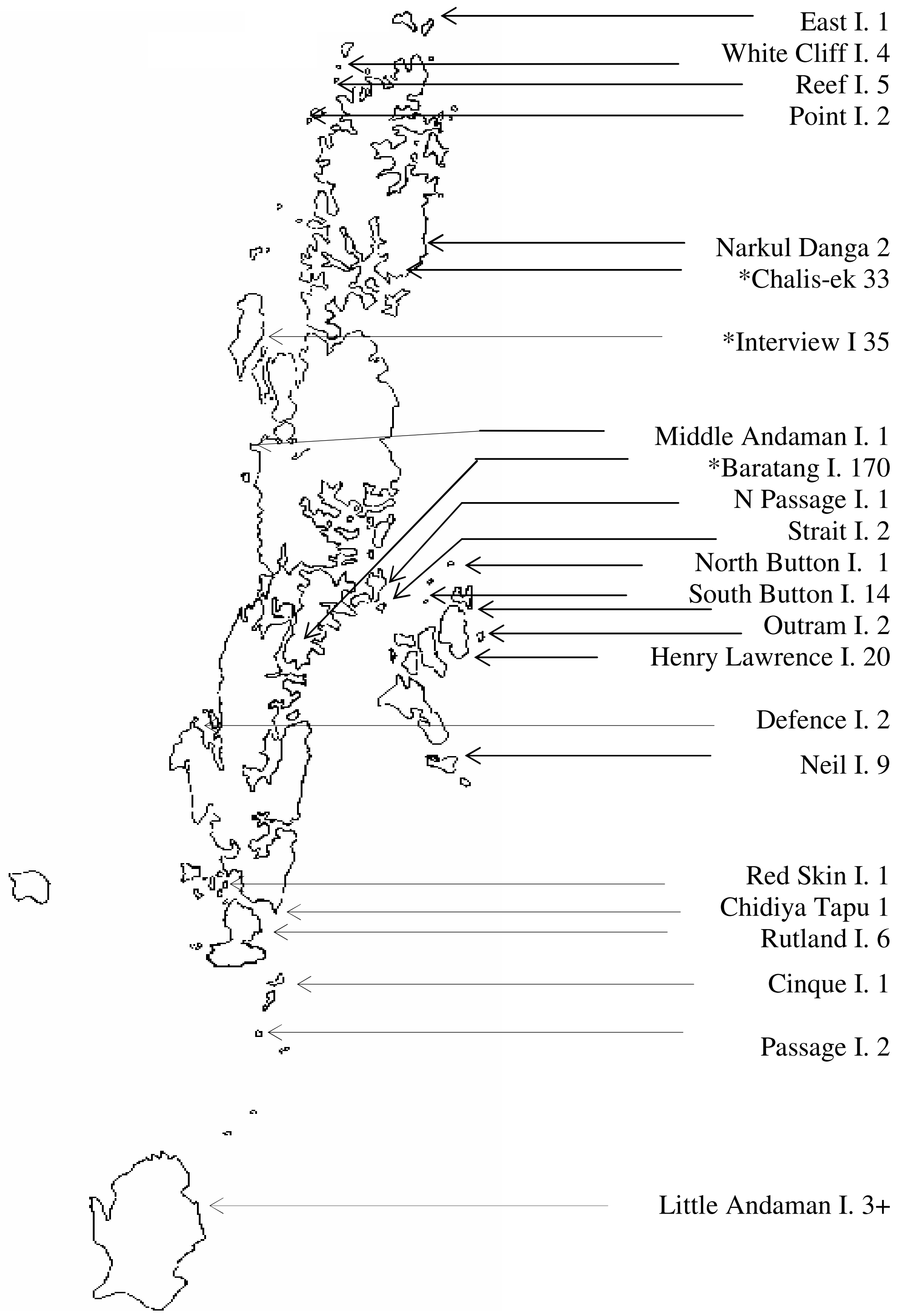


Figure 3 Rock fall inside caves in North and Middle Andaman Islands

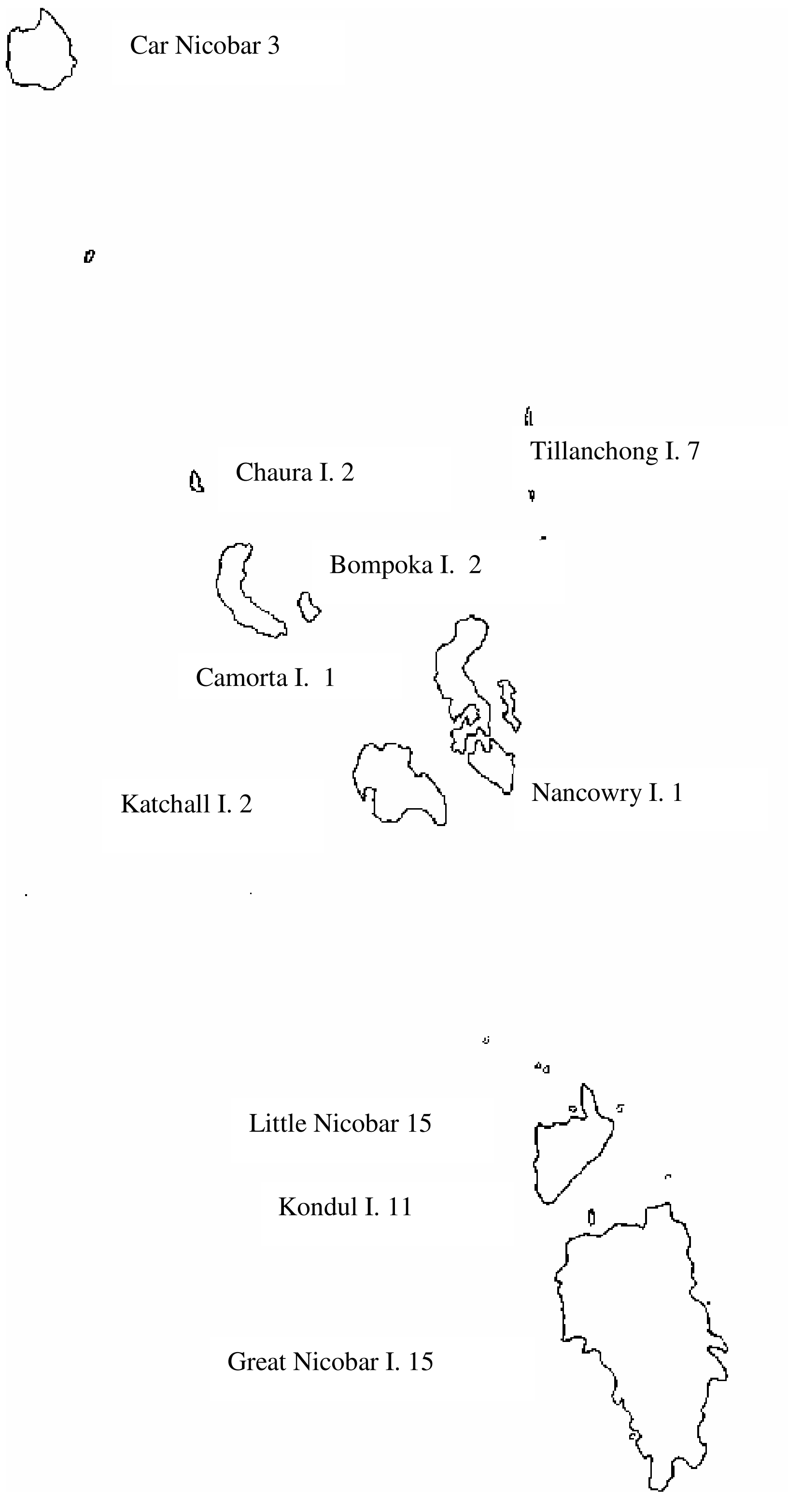
The most significant finding of this study has been that there was far more damage due to the earthquake in caves that were above-ground than in caves that were underground. This can be attributed to the structure of the caves, size, rock type and the location of the cave and the presence of buffers against the earthquake waves. Most of the caves above ground had irregular walls and ceilings with projecting rocks whereas, underground caves had more regularly standing walls and dome shaped ceilings with almost no boulders or rocks projecting out of the wall or ceiling except the stalactites hanging from the roof or running down the walls.

The implications of the damage caused to the cave fauna due to the earthquake depended on the type of fauna and the nature of its association with the caves. No troglobites were sighted in any of the damaged caves. Stygobites were observed in 2 of the 43 caves under study. However, these caves were not damaged in the earthquake. We observed that the damage to caves affected trogloxenes with the most significant changes that impact them being increased light penetration and light availability within caves due to widening of the existing openings. In two out of five caves, this resulted in the bats and edible-nest swiftlets abandoning their roosting and nesting sites or shifting to darker areas of the caves. There was no instance of complete blocking of the cave mouth among the caves under study. The main entry of one of the caves with two entry points was completely blocked. While bats continued to access the caves through the second opening, edible-nest swiftlets stopped using the cave in 2005. This species uses the same path and cave openings for entry and exit (Medway 1962b, Fenton 1975). However, in subsequent years the swiftlets started using the second opening. The impact of habitat destruction on the population of the edible-nest swiftlets in the study caves is described in chapter 6.

While the rock fall must have killed some organisms present in the cave, no larger troglobite, primarily bat or swiftlet was found dead. While swiftlets leave the cave before dawn, bats would have been present in the cave at the time of the earthquake (06:30 hrs). Perhaps they sensed the quake and left the cave in time. However, such behaviour was never observed in bats or swiftlets during the mild aftershocks. Loosening of rocks on the walls and ceilings inside the caves increased water seepage during the rainy season, adversely affecting the nests of swiftlets at those sites. The increase in seepage in some caves may also have affected the invertebrate fauna on the cave floor that depend largely on guano. There is a possibility of several micro level effects on the ecosystem which is beyond the scope of the present discussion.



Map 3 The location and number of the caves in the Andaman Islands (**Note**: *Caves Surveyed for data collection)



Map 4 The location and number of caves in the Nicobar Islands (Sankaran 1998).

CHAPTER 3

Nest site habitat requirements of the Edible-nest Swiftlet and the Glossy Swiftlet in the Andaman Islands

3.1. Introduction

The choice of habitat and nest-site are important factors in reducing the risk of predation for successful breeding and is believed to be the result of natural selection (Cody 1983, Martin 1995, Velando and Marquez 2002). However, specialized search strategies of predators may limit the ability of birds to select nest-sites that provide significant protection from an assortment of potential predators (Martin 1995), and hence swiftlets must have adapted to nesting on walls and ceilings in complete darkness and dim-lit zones of caves or cave-like structures to make access difficult for most predators.

Swiftlets are trogloxenes and breed inside caves or in cavern-like spaces, where they cling to the surface of walls and ceilings while roosting or on their self-supporting bracket-shaped nests (Ford and Cullingford 1976, Langham 1980, Koon and Cranbrook 2002). The ability to echolocate enables edible-nest swiftlet to navigate in total darkness and to roost and nest in the dark zones of caves (Medway 1959, Nguyen *et al* 2002). Swiftlets use their saliva to bind nest material such as moss, twigs, leaves and their own feathers (Medway 1962, 1963, Kang *et al* 1991), and tend to build nest at the same site year after year (Koon and Cranbrook 2002, Nguyen *et al* 2002). Unlike in their other ranges of distribution edible-nest swiftlets in Andaman and Nicobar Islands nest only in limestone caves. The non-echolocating glossy swiftlets nest in the dim lit zones of caves or cave like places such as abandoned houses, buildings, under jetties and bridges, etc. The nests of glossy swiftlets are built using saliva as an adhesive to cement the base of the nest to the supporting surface and also to bind the nest materials (Medway 1962b).

The nest-site characters and the impact of microclimate on breeding of the edible-nest swiftlets have been previously addressed (Nguyen 1998, Supaluck *et al* 2002). During the study of nests-site characters Supaluck *et al* (2002) concluded the preference without quantifying availability of the nest-sites in the caves. The present study has attempted to bridge gaps in knowledge and also to find the relation between nest-site characters and nest success. Unlike the edible-nest swiftlets, the glossy swiftlets were never before studied for their nest-site characters as they are not of economic interest. Glossy swiftlets play a major role in the *ex-situ* conservation of the edible-nest swiftlets, where they foster the chicks of edible nest swiftlets. To attract a population of edible-nest swiftlets into an *ex-situ* house, it is important to know their nest site requirements and preferences.

3.2. Objectives

The main objectives of this study were

1. to identify the nest-site characters and the preferences of edible-nest swiftlets and glossy swiftlets.
2. to identify the characters of successful nest-sites in the edible-nest swiftlets.

3.3. Study area

The microhabitat characters of the nest-sites of the edible-nest swiftlet were studied in 1 cave on Interview Island, 11 caves at Chalis-ek and 42 caves on Baratang Island in the North and Middle Andaman Islands (details are given in chapter 2).

3.4. Field methods and data analyses

3.4.1. Nest-site Characters

Nests of edible-nest swiftlets were serially marked and monitored periodically during the breeding season, from January to June (2001 to 2008) at Chalis-ek and from January to August (2000 to 2008) on the Interview Island. At the Baratang Island in Middle Andaman, nest site data was collected during a single survey in March 2008. The characteristics of active sites as well as previously-used sites, identified by the marks left behind by nests on the rock surface, were analysed. Data collected on the nest-site characters for 643 nest-sites comprising of 296 active nests and 347 old nest sites included:

a. texture at the nest site (classified as rough, slightly rough or smooth surface) which was observed by a single observer to minimize error and to avoid bias in characterization;

b. presence of nest support (usually an accumulation of calcium carbonate at the base of the nests);

c. inclination of the cave wall at the nest-site location with respect to the ground (qualitatively classified on visual basis into three categories, I) *flat*: wall approximately at 90° to the ground, II) *inwardly inclined*: wall making an acute angle with the ground and III) *outwardly inclined*: wall making an obtuse angle with the ground).

Data was also collected on the characters (a, b and c explained above) at 114 nest-sites of the glossy swiftlet in three caves at Chalis-ek and one cave on the Interview Island. As the glossy swiftlets are non-seasonal breeders, data could be collected only in the initial period of nest construction.

Random points were taken on the cave walls and ceilings at various distances along a horizontal line transect to assess the characters of the wall and rock faces available in the caves.

3.4.2. Other Nest-site Characters

1. Slope at the nest-sites of the edible-nest swiftlet was measured in the caves at Chalis-ek and Interview Island with a clinometer SUNTO MC-1 mirror compass. The slope at the nest-sites of the glossy swiftlets could not be measured as they were never found vacant and removing the nest or the nest material from the nest-site was not permitted.
2. The height of the nest was considered to be the point where droppings of the bird from the nest fell. Usually it is an accessible point below the nest, which could be easily reached.

3. Data on the density of the nests was collected from 6 caves at Chalis-ek. Density was estimated by counting the number of nests per square meter.

3.4.3. Nest-site Character Combinations

The individual nest-site characteristics (a, b and c explained under 3.4.2) were pooled together in all possible combinations to identify the most used and successful combination.

3.4.4. Predators

Predators were recorded by visual encounter in all the known caves of Andaman and Nicobar Islands for almost 13 years, from 1997 to 2009. Observations by Sankaran (from 1997 to 2001) were also included. Potential predators were estimated according to the species encountered and the literature available from the other ranges of distribution.

3.4.5. Micrometeorological Parameters

Micrometeorological parameters such as mean temperature (ºC) and relative humidity (RH, %) were measured near the nests everyday at 6:00hrs during the breeding season of the edible-nest swiftlets inside three caves. Zeal thermometers and hygrometers were used for recording the micrometeorological parameters.

3.4.6. Nest Success

The apparent nest success (Jehle *et al* 2004) in the edible-nest swiftlet was determined based on daily observations from the date of the laying of the egg through fledging.

3.4.7. Statistical analyses

Nest site preference in the edible-nest swiftlet was assessed using both pooled and un-pooled data of select nest-site characteristics (texture of the rock, inclination of the wall and presence of support) after estimating the proportionate difference between nest-sites in use and non-used points on the rock surface using contingency tables (Moore and Cobby, 1998). The data was sorted into combinations of characters; 16 in the caves at Chalis-ek, 11 in the Interview Island cave and 18 combinations in the Baratang caves. The probable combination preferred at each study site was reckoned separately. Ivlev's Electivity Index (*E*) $Ei = (ui - ri) / (ui + ri)$ was followed to estimate the preference of the characters in nest site (Alwany 2003), where ui is the proportion of rock character or the combination i at nest sites (used) and ri is the proportion of this rock character or combination at random sites (available) in the caves. *E* values range from -1 to +1, with values above zero indicating preference, values below zero indicating avoidance, and values equal to 0 indicating no selection. A character or combination with less than five observations was merged with most closely associated neighbouring character and/or combination for the analysis. Each clutch was considered as a separate breeding attempt and 'apparent nest success' was calculated separately with nest site characteristics and combinations. Binary logistic regression was used to relate nest characters with the success of the nest.

The slope at the nest-sites was computed using Circular Statistics (Oriana Version 2.01c; Kovach Computing Services 2004). Slope values were categorized into twelve class intervals of 10° each. The difference in the slopes at the nest site was assessed through Mann-Whitney U test. Density of the nests was calculated as the number of nests per square meter and correlated to nesting success. Spearman's correlation was used to understand the correlation of mean temperature (ºC) and relative humidity (RH, %) with nesting success. Statistical analyses were performed using SPSS Version 10.0 (Norusis 1996).

3.5. Results

3.5.1. Nest-site Characters

Rock characters (surface texture, presence of support and inclination of wall and their combinations) were significantly different in proportion at the nest-sites and at random sites in the pooled data and at all the study locations.

Edible-nest swiftlets preferred building their nests on inwardly inclined walls (88%; $\chi^2 = 352.612$, $p < 0.05$; $E = 0.3$). There was a difference in the proportion of nests constructed on inwardly inclined walls among the three cave sites (Chalis-ek 79.9%; $\chi^2 = 169.13$, $p < 0.05$; E 0.5; Interview 100%; E = 0.1 and Baratang 87%; $\chi^2 = 85.495$, $p < 0.05$; E = 0.2). Outwardly inclined and flat walls were avoided at all the sites (Figure 4).

Overall 72% of nests had supports ($\chi^2 = 87.3$, $p < 0.05$; $E = 0.2$). This percentage varied among sites with 63.4% at Chalis-ek ($\chi^2 = 100.806$, $p < 0.05$; $E = 0.5$) and 90% at Baratang ($\chi^2 = 44.436$, $p < 0.05$; $E = 0.1$). Sites without support were avoided at both these locations. At Interview Island, however, 61% nest sites were without support ($\chi^2 = 48.261$, $p < 0.05$; $E = 0.6$) (Figure 5).

Overall, 77% of nest sites were on rough textured surfaces and 19% of nests on slightly rough surfaces ($\chi^2 = 61.922$, $p < 0.05$; $E = 0.08$). At Chalis-ek, while 72% of nest sites were on rough textured surfaces and 14% were on slightly rough textured surfaces, the latter was preferred ($\chi^2 = 18.144$, $p < 0.05$; Slightly rough: $E = 0.1$, Rough: $E = 0.02$). At Interview Island showed, over 84% nest sites were on rough surface and a preference was shown towards it ($\chi^2 = 37.499$, $p < 0.05$; $E = 0.3$). At Baratang, 75.4% of nest sites were on rough surfaces, which were preferred ($\chi^2 = 11.325$, $p < 0.05$; $E = 0.1$) over smooth surfaces ($E = 0.01$). Smooth surfaces were avoided at Chalis-ek and Interview Island while slightly rough surfaces were avoided at Baratang and Interview Island (Figure 6).

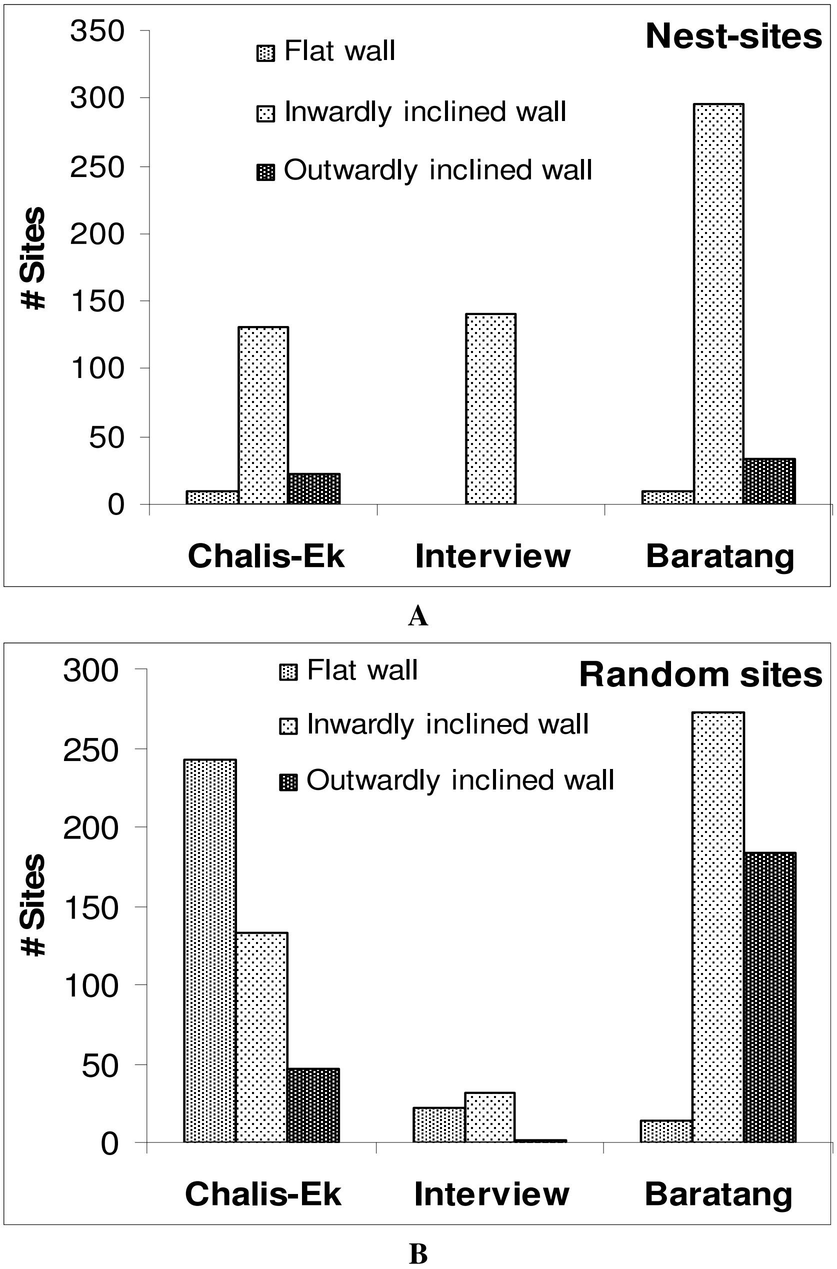
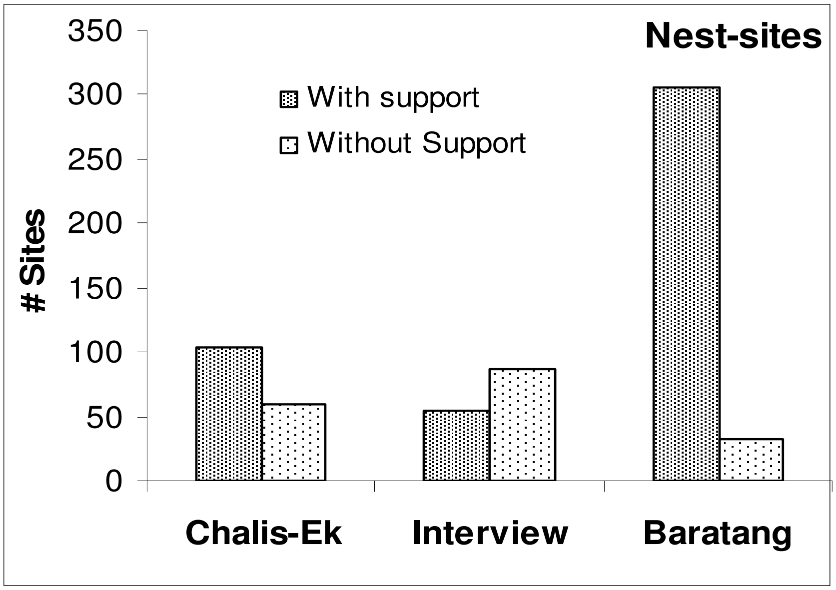
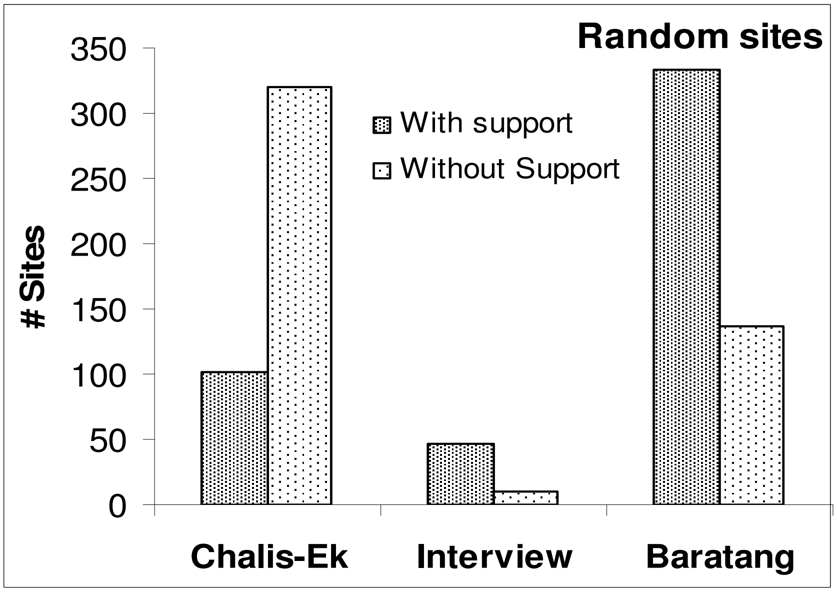


Figure 4 Number of used nest-sites (**A**) and the random sites (**B**) by the edible-nest swiftlet at various wall inclinations at the three study locations in the Andaman Islands

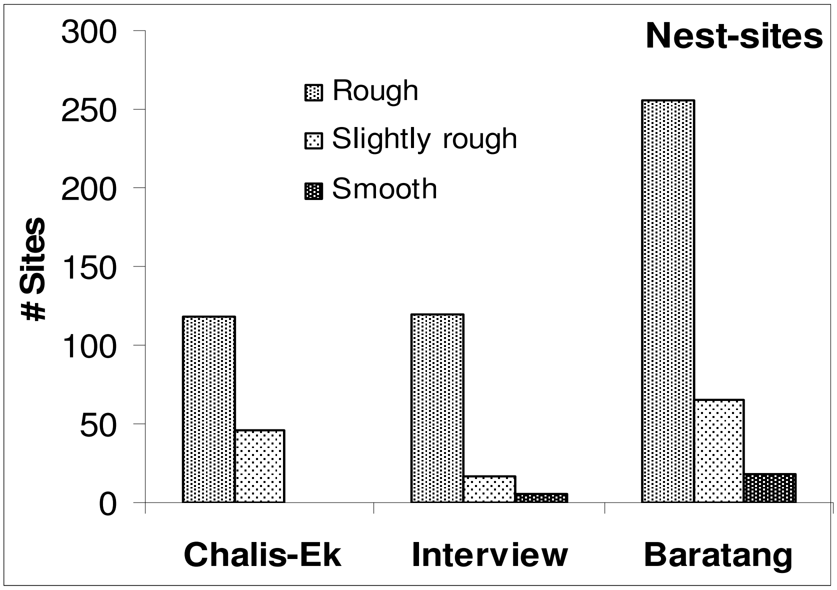


A

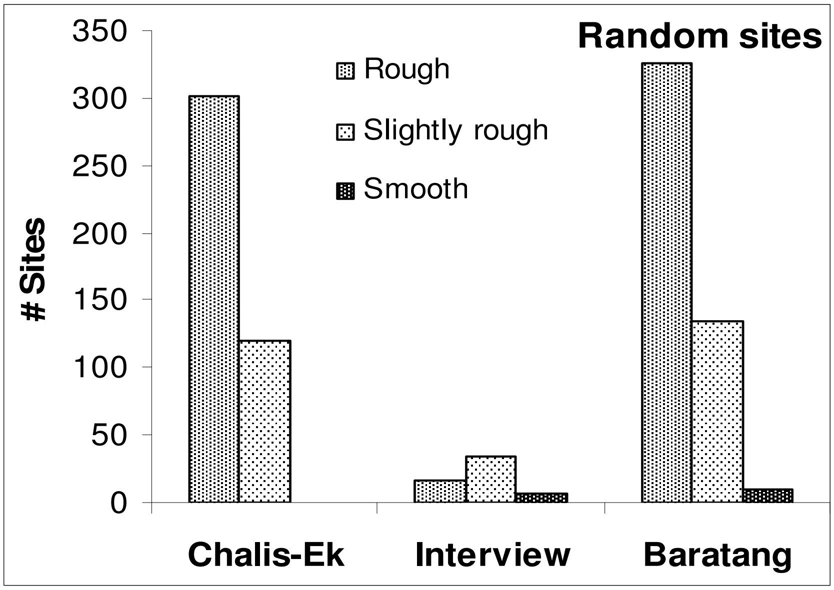


B

Figure 5 Number of used nest-sites (**A**) and the random sites (**B**) by the edible-nest swiftlet with and without supports at the three study locations on the Andaman Islands



A



B

Figure 6 Number of used nest-sites (**A**) and the random sites (**B**) by the edible-nest swiftlet with different textures at the three study locations on the Andaman Islands

All the glossy swiftlet nests observed were built on the inwardly inclined walls with 100% preference (E = 0.4), while outwardly inclined and flat walls were completely avoided. More than 95% of the glossy swiftlet nests were built preferably on sites with no supports (E = 0.2). As compared to rock surfaces with rough (25%) and smooth (8%) texture, nest-sites with slightly rough texture were preferred (67%, E = 0.4) for nest building (Figure 7).

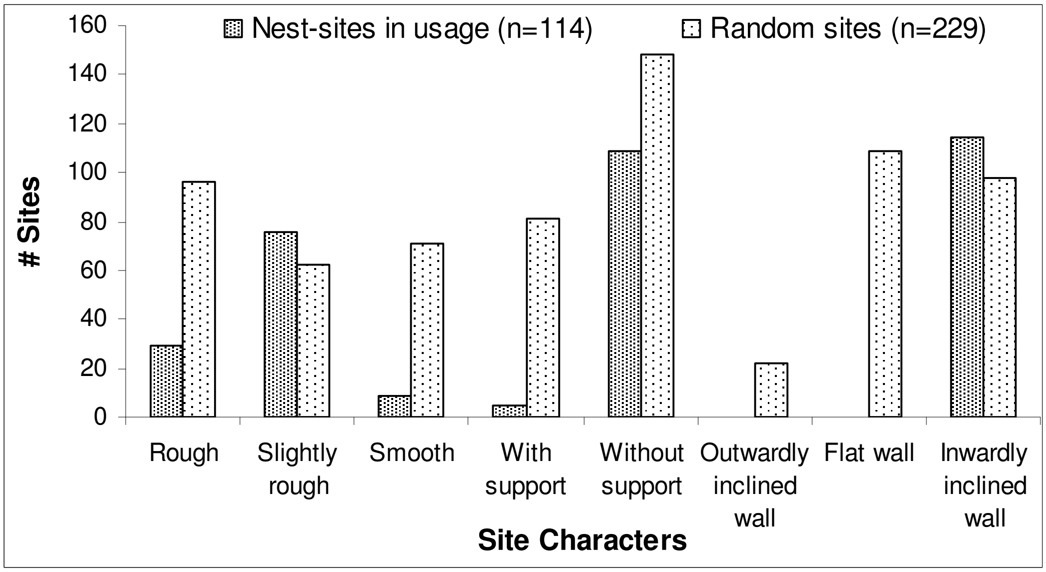


Figure 7 Number of nest-sites by the edible-nest swiftlet with different characteristics in usage and at random sites.

3.5.2. Other Nest-site Characters

The average slope of the rock at the nest-sites of edible nest swiftlets on Interview Island was more than double at Chalis-ek (Mann Whitney U statistic Z = -14.8, $p < 0.001$; Figure 8).

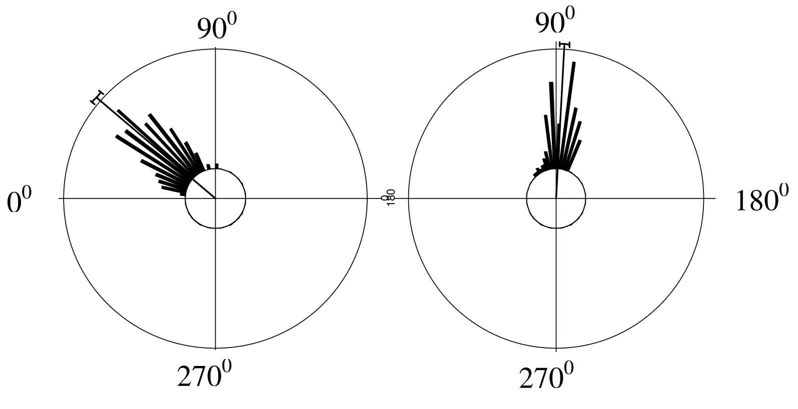


Figure A. ***Mean = 40.82°*** *Figure B.* ***Mean = 93.18°***

Figure 8 The slopes at the nest site with the Mean and the Standard Error of Mean are represented in a circular graph. A: Slope at nest sites in the caves at Chalis-ek, B: Slope at nest sites in the cave at Interview Island

The average height of the nests of edible-nest swiftlets was observed to be 5.57±2.66m (Range: 1-10m). Edible-nest swiftlets nest in loose colonies with an average density of 15±7 nests per square meter. In contrast, glossy swiftlets nest in compact colonies with a density of 74±19 nests per meter square. Nests were observed touching each other.

3.5.3. Nest-site Character Combinations

There was a significant difference in the proportion of nest-sites and random sites of different combinations in the pooled data and also at all three sites.

Pooling the data showed that nest-sites of the edible-nest swiftlet with a combination of rough surfaces on inwardly inclined walls with or without support were preferred ($\chi^2 = 385.686$, $p < 0.05$; $\boldsymbol{E} = 0.3$ and $\boldsymbol{E} = 0.3$). At Chalis-ek, however, the combination of rough or slightly rough surfaces, on outwardly or inwardly inclined walls, with support was preferred ($\chi^2 = 234.405$, $p < 0.05$; $\boldsymbol{E} = 0.8$). At Interview Island, a combination of rough surfaces on inwardly inclined walls, without support were preferred ($\chi^2 = 111.992$, $p < 0.05$; $\boldsymbol{E} = 1$), while at Baratang a combination of rough ($\boldsymbol{E} = 0.3$), or slightly rough ($\boldsymbol{E} = 0.2$) surfaces with supports on inwardly inclined walls were preferred ($\chi^2 = 120.468$, $p < 0.05$; Table 1).

Glossy swiftlets used 5 different combinations out of the available 16 combinations in the caves. Over 23% of the nests were built on highly preferred rough surfaces on inwardly inclined walls with no support (E = 0.9), 67% on slightly rough surfaces on inwardly inclined wall without support ($E = 0.6$) and 6% on smooth surface on inwardly inclined wall without support ($E = 0.3$). Two nest-site combinations, i.e. rough surface with support on inwardly inclined wall (used in 2% cases) and smooth surface with support on inwardly inclined wall (used in 2%cases), were avoided (Table 2).

Table 1 The proportionate (%) distribution of nest site combinations used by Edible-nest Swiftlets and the random sites inside the caves at the study sites in North and Middle Andaman Islands.

S. No.	Combinations of nest-site characters	Nest-site character combinations in usage & the random sites					
		Chalis-ek		Interview Island		Baratang	
		Usage (%)	Random (%)	Usage (%)	Random (%)	Usage (%)	Random (%)
1	RF	0.0	31.7	0.0	0.0	0.0	0.9
2	RI	20.1	11.5	61.0	0.0	5.6	10.2
3	RO	4.9	7.4	0.0	2.3	2.7	9.6
4	RSuF	3.0	7.4	0.0	4.7	0.6	2.3
5	RSuI	34.8	9.9	23.4	32.6	61.8	40.6
6	RSuO	9.1	1.1	0.0	7.0	4.7	16.6
7	SF	0.0	7.1	0.0	0.0	0.3	2.6
8	SI	0.0	1.2	0.0	0.0	0.3	0.2
9	SO	0.0	0.5	0.0	2.3	0.0	0.4
10	SrF	1.2	13.8	0.0	9.3	0.6	1.3
11	SrI	10.4	2.8	0.0	0.0	0.3	3.0
12	SrO	0.0	1.9	0.0	0.0	0.0	6.8
13	SrSuF	1.8	1.4	0.0	9.3	0.0	2.8
14	SrSuI	14.6	1.4	12.1	27.9	15.7	14.0
15	SrSuO	0.0	0.0	0.0	0.0	2.7	7.0
16	SSuF	0.0	0.0	0.0	2.3	1.2	0.6
17	SSuI	0.0	0.7	3.5	2.3	3.6	2.8
18	SSuO	0.0	0.2	0.0	0.0	0.0	0.6
	Total (n)	164	567	141	86	338	575

- **Note: R**: rough; **Sr**: slightly rough; **S**: smooth; **Su**: with supporter; **I**: Inwardly inclined wall; **F**: flat wall; **O**: outwardly inclined wall

Table 2 The proportionate (%) distribution of the nest site combinations used by Glossy Swiftlets and the random sites inside the caves at the study sites in North and Middle Andaman Islands.

Combinations of nest-site characters	Nest site character combinations in usage & the random sites			
	Usage (N)	Usage (%)	Random (N)	Random (%)
SrI	76	66.66	33	14.41
RI	26	22.80	4	1.74
SI	7	6.14	7	3.05
RSuI	3	2.63	31	13.53
SSuI	2	1.75	10	4.36
Others	0	0	144	62.88

Note: R: rough; **Sr**: slightly rough; **S**: smooth; **Su**: with supporter; **I**: Inwardly inclined wall; **F**: flat wall; **O**: outwardly inclined wall

3.5.4. Predation

Several instances of predation of nests, eggs, nestlings and adult swiftlets were observed in the Andaman and Nicobar Islands. Along with the known predators of swiftlets, some potential predators were also observed inside caves (Appendix 3).

3.5.4. Micrometeorological Parameters

All three caves had different mean temperatures near the nest-sites, ranging from 22.27ºC to 25.35ºC and the relative humidity was in the range 84 – 91%. Mean temperature and relative humidity were negatively correlated ($r_s = -0.993$, $p < 0.001$).

3.5.6. Nest Success

The nesting success of edible nest swiftlets was calculated from 983 breeding attempts at 350 nests, 80.7 % of which were on rough rocks, 16.8% on slightly rough and 2.5% on smooth rock surfaces. 58% of the nest had supports. Over 90% of the nests were on inwardly inclined walls, 7% on outwardly inclined walls and only 3% were on flat walls (Figure 9).

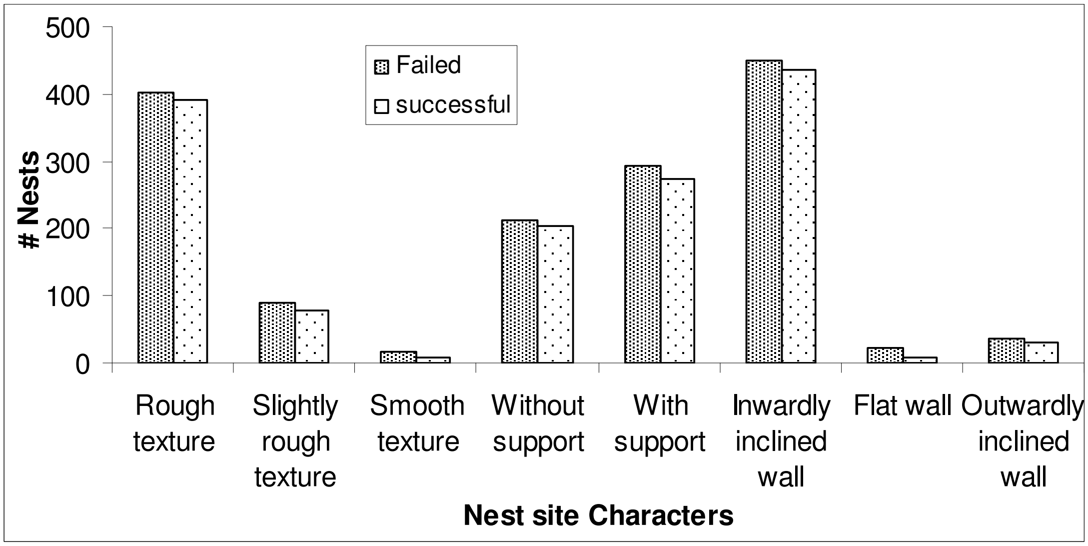


Figure 9 Nesting success of Edible-nest Swiftlet at the nest sites with different characters

A binary logistic regression was used to predict nest success through the nest-site characters. Slope was the only significant predictor of nest success, though a slightly rough rock surface and the height of the nest also contributed to it (Table 3). About half the nesting attempts made on the following three combinations were found successful; slightly rough, outwardly inclined walls with support; rough, inwardly inclined walls with support and rough, inwardly inclined walls without support (Table 4).

Table 3 The binary logistics regression performed to predict nest success through the nest-site characters. (**Note**: **R**: rough; **Sr**: slightly rough; **S**: smooth; **Su**: with supporter; **I**: Inwardly inclined wall; **F**: flat wall; **O**: outwardly inclined wall)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Density(1)	-.551	1.131	.237	1	.626	.576
	Slope	.007	.004	4.295	1	.038	1.007
	R(1)	-.220	.582	.143	1	.705	.803
	Sr(1)	.230	.598	.148	1	.700	1.259
	Su(1)	-.105	.199	.278	1	.598	.900
	I(1)	-.497	.848	.344	1	.557	.608
	F(1)	-5.316	7.838	.460	1	.498	.005
	Height	.000	.000	.069	1	.792	1.000
	Constant	4.862	7.868	.382	1	.537	129.252

a. Variable(s) entered on step 1: Density, Slope, R, Sr, Su, I, F, Height

Table 4 The number of nest-sites with different combinations of the nest-site characteristics of Edible-nest Swiftlets (*Aerodramus fuciphagus*) with the percentage of successful attempts in North and Middle Andaman Islands.

Combinations of nest-site characters	# Nest sites	# Breeding attempts	# Successful attempts	% of Success
RI	119	354	177	50
RO	8	20	8	40
RSuI	91	350	176	50.3
RSuF	5	22	6	27.3
RSuO	15	47	24	51
SrI	15	37	14	37.8
SrF	2	2	2	100
SrSuI	39	120	60	50
SrSuF	2	6	0	0
SI	2	2	2	100
SSuI	7	23	7	30.4
Total	305	983	476	

Note: **R**: rough; **Sr**: slightly rough; **S**: smooth; **Su**: with supporter; **I**: Inwardly inclined wall; **F**: flat wall; **O**: outwardly inclined wall

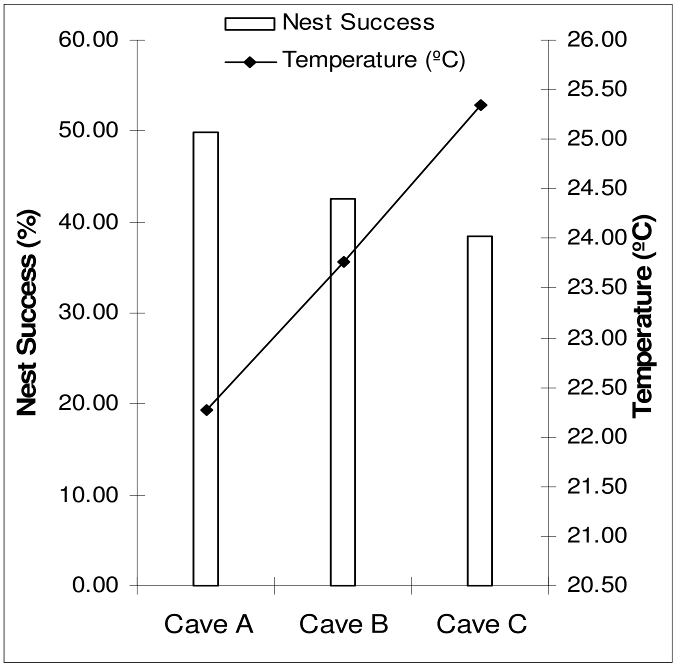
Table 5 The binary logistics regression performed to predict nest success through the nest-site character combinations. (**Note**: **R**: rough; **Sr**: slightly rough; **S**: smooth; **Su**: with supporter; **I**: Inwardly inclined wall; **F**: flat wall; **O**: outwardly inclined wall).

Variables in the Equation

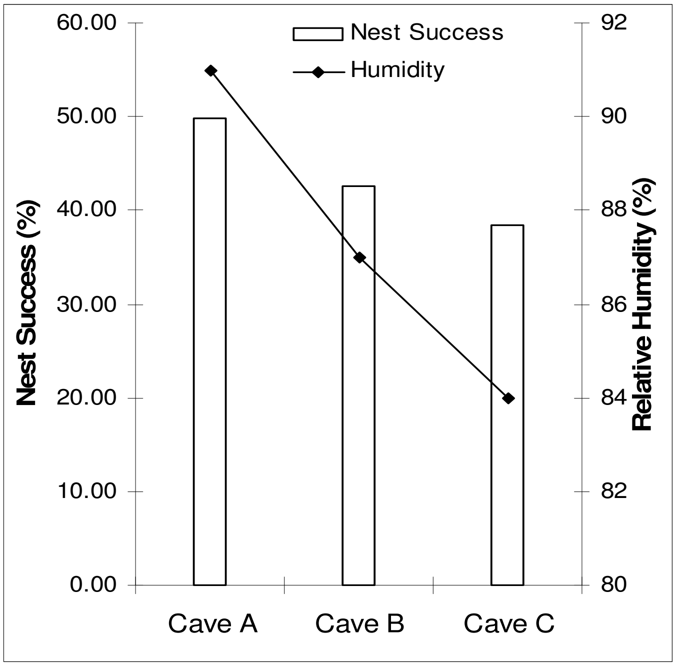
		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Density(1)	-.560	1.131	.245	1	.620	.571
	Slope	.009	.004	5.642	1	.018	1.009
	RI(1)	-.213	.595	.129	1	.720	.808
	RSuI(1)	-.187	.583	.103	1	.749	.830
	RSuF(1)	-5.036	7.814	.415	1	.519	.006
	RSuO(1)	.306	1.002	.093	1	.760	1.358
	SrI(1)	.805	.719	1.252	1	.263	2.236
	SrSuI(1)	.105	.606	.030	1	.863	1.110
	Height	.000	.000	.091	1	.763	1.000
	Constant	3.644	8.345	.191	1	.662	38.253

a. Variable(s) entered on step 1: Density, Slope, RI, RSuI, RSuF, RSuO, SrI, SrSuI, Height

A binary logistic regression was used to predict nest success through the nest-site character combinations. The combination of slightly rough, inwardly inclined walls, with or without support, and of rough, outwardly inclined wall with support seem to contribute the most to nesting success (Table 5). The nest density did not show any correlation with the nest success. Nest success was significantly correlated with the mean temperature ($r_s = -0.985$, $p < 0.001$) and relative humidity ($r_s = 0.997$, $p < 0.001$; Figure 10).



A



B

Figure 10 The graph represents the micrometeorological parameters (mean temperature and relative humidity) inside three caves with the nest success in the respective caves.

3.6. Discussion

Caves provide the best shelters from most predators and adverse weather conditions. This may be the reason for the swiftlets' adaptation to roost and nest inside the dark or dim lit zones of the caves, given the ability of echolocation in some species (Medway 1959 and 1967, Nguyen and Voisin 1998). Likewise, in their other distribution ranges, almost all the nests of the edible-nest swiftlet were recorded in complete darkness or in dim lit zones of the caves. Sankaran (1995, 1998 and 2001) reported swiftlets nesting in the bright zones of caves and also on rocky cliffs outside the caves in the Nicobar Islands. Glossy swiftlets nest in the dim lit zones as they lack echolocating abilities and cannot navigate in the dark.

3.6.1. Nest-site Characters

The unique physical characteristics of the walls and ceilings inside caves are also important factors to be considered while selecting a breeding site (Charles 1987, Supaluck *et al* 2002). With emphasis on the characters of the rock at the point of nest attachment as reported by Supaluck *et al* (2002), it was found that the edible-nest swiftlets and glossy swiftlets of North and Middle Andaman Islands do not nest randomly at any place on the rock inside caves. Instead, they choose their nest-sites after much consideration.

Secured adhesion of the nest to the surface of the rock must be the main factor considered by both the species in the Andaman Islands. Both the species prefer rough and slightly rough rock surfaces, clearly indicating that they provide a better grip to nests than smooth surfaces. In contrast, Supaluck *et al* (2002) found that the edible-nest swiftlets in Si-Ha Island prefer smooth surfaces to rough. Since there are no standards fixed yet to measure the surface texture of the rock, the texture categories of Supaluck *et al* (2002) and of the present study could not be compared. However, the rough texture considered in this study cannot be regarded as smooth.

The U-shaped supports used by edible-nest swiftlets may be a geological feature on the rock surface or the result of re-nesting at the same point for several years, or a combination of the two (Supaluck *et al* 2002). This formation was not seen at the nest-sites of glossy swiftlets in Andaman and Nicobar Islands. Glossy swiftlet repair and reuse the nests for three to four years. As observed in the cave at Si-Ha Island, Thailand, support is an important nest-site character for the edible-nest swiftlets of the Andaman Islands. With a suitable surface texture, the presence of support can reinforce the nest during incubation and fledgling period and in the rainy season when the adhesiveness of saliva reduces due to water seepage through limestone walls and ceilings of the cave.

If the fastening of the nests is a priority of the glossy swiftlets too, then it is the inability to echolocate and the character of nesting in clumped colonies that makes them different from the edible-nest swiftlets. Clumped nesting and enough saliva at the nest base binds the nest strongly with the wall providing extra support to keep the nest attached to the wall (Medway 1962a, Langham 1980). Nesting in dim lit zones near the cave mouth has another advantage in that the cave wall rarely gets wet at this point, which helps the birds to reuse the nest for many seasons.

Nest-sites on inwardly inclined walls are the most preferred by both the species, especially by glossy swiftlets. This characteristic helps avoid predators nesting at the cave mouths. Outwardly inclined walls have their own advantage as they can provide a better support to the nests than inwardly inclined walls, especially in the absence of support. In case of a lack of nest-sites on inwardly inclined walls the birds are likely forced to build on outwardly inclined walls. Supaluck *et al* (2002) had also found all the nest-sites of edible-nest swiftlets on inwardly inclined walls. My findings support Supaluck *et al* (2002)'s discussion that inwardly inclined walls prevent predators from gaining access to the eggs and nestlings. Inwardly inclined walls also help to maintain nest hygiene in the colony. On the inwardly inclined walls the birds can make nests one below the other, availing of every site with favourable characters. In two incidences of nests built on outwardly inclined walls, the lower nest was deserted after construction because the faecal matter from the nest above fell directly into it. This could be the mistake of an inexperienced breeding pair, since the population of edible nest swiftlets is sparse and nest-sites aplenty in the caves of Andaman Islands. Placement of nest is more vital for glossy swiftlets as their nests are close to one another and maintenance of hygiene is a priority.

The combination of inwardly inclined wall and rough texture was found to be valued by the edible-nest swiftlet, where they preferred sites with or without support. This shows that the presence of a support has little role in selection of a combination of nest-site characters. This may substantiate the presumption that U-shaped supports originate because of the calcium deposition or other geological features at the base of the nest constructed repeatedly at the same point year after year. Glossy swiftlets have shown a greater preference for nest-sites on inwardly inclined walls and in the absence of support built on rough, slightly rough and smooth textured walls respectively.

Slope and height of the nest-site seem to depend on the structure of the cave. The height of nest-sites in the Andaman and Nicobar Islands was recorded much less than that in the caves of Sarawak and Vietnam, which are much larger and higher than the caves here (Nguyen and Voisin 1998, Koon and Cranbrook 2002, Nguyen *et al* 2002). According to Nguyen and Voisin (1998) edible-nest swiftlets in Vietnam prefer marine caves because although they are large and have big openings, they provide better protection. In Andaman Islands most of the caves have a narrow opening which restricts the entry of many predators and allows the swiftlets to nest on the cave walls even close to the cave floor.

Density of the nests per square meter is less inside the caves studied in the Andaman Islands compared to the dry caves studied by Nguyen and Voisin (1998) in Vietnam. This may be because of the current declining population status of the endangered edible-nest swiftlets in the Andaman Islands.

Avoidance is an important element of preference in nest-site selection. Supaluck *et al* (2002) did not report the nest of edible-nest swiftlets on a stalactite or stalagmite in the caves at Si-Ha Islands, concurring with our findings at North and Middle Andaman Islands. In the present findings only 2 nests were built on the stalactite during 2006 and 2007 in the caves at Baratang Island. The success of these nests is unknown. In Rajani cave (Cave # 9) at Chalis-ek, more than 50 nests have been made on wall A while the facing wall B, only 3m away and sharing the same microclimate, had no nests on it. The wall B shows formation of stalactites, resulting from seepage of water during rains, a much-avoided feature for nest-site selection. A nest in Baja cave (Cave # 5) built on a new point late in the breeding season was found deserted mid-way due to water streaming over it during the rains. The delay in nest construction and the selection of a new site indicate that the breeding pair might be first time breeders lacking experience in nest-site selection. It was observed that nests at lesser heights on outwardly inclined walls were staggered strategically to avoid predation and faecal droppings from the birds nesting or roosting above. None of the nests were built on the surfaces covered with water, bird droppings, bat guano, mud or dust.

3.6.2. Nest Success

The results of nest success in relation to the nest-site characters have revealed that the nest-site selection has its importance in nest success. With limited access to nests, the available slope and height in the caves could not be studied. So it was difficult to understand their preference. But the results from binary logistic regression revealed their importance in nest success. Thus it can be firmly established that slope and height have a role in nest-site selection. Regression analysis also proved that amongst the preferred characters at the nest-site of the edible-nest swiftlets, the slightly rough texture of the rock contributed most to nest success. The results also showed that all the preferred individual characters i.e. slightly rough and rough texture of the rock surface, presence of support and inwardly inclined walls contribute together in different combinations to nest success.

As the population of the edible-nest swiftlets is greatly affected by rampant nest collection, the present density of the nests does not show any relation to nest success. As we are aware, among birds breeding in colonies nest density plays an important role in nest success. But in the case of edible-nest swiftlets, the population is disturbed by human intervention and the nest density data is skewed. It is expected that the density of the nests will show a relation to nest success once the population of the edible-nest swiftlets improves in the caves of the Andaman and Nicobar Islands.

Apart from the nest-site characters, the micrometeorological parameters also play an important part in nest success. As the results show, nest success increases with the increase in relative humidity. This phenomenon was also observed in Vietnam by

Nguyen and Voisin (1998) where they found that the marine caves with higher relative humidity had greater breeding success. In contrast, nest success reduces with an increase in temperature. This study supports Nguyen and Voisin's (1998) postulation that humid climates ensure attachment of nests to the substratum, whereas dry climates make the nest hard and result in high nest-fall. Predation is an important factor as it decides the safety of the nests. Predation can affect the population of colonial breeders, as was proved in one of the cave under continuous observation (refer chapter 6). Predators of swiftlets include both vertebrate species (e.g., owls, raptors, snakes, geckoes, bats, cats and rats) and invertebrate species (e.g., cockroaches, lice, flies, giant crickets and centipedes) (Sankaran 1998, Koon and Cranbrook 2002, Naguyen *et al* 2002). Even though natural predation does not seem to affect nesting success and population of the colony (Medway 1962b), it certainly is of importance in nest-site selection.

In brief, it can be concluded that edible-nest swiftlets select nest-sites with discretion, which plays an important role in nesting success. There are some gaps in knowledge about how cave structure impacts the population of edible-nest swiftlets. Further research focussing on cave structures, the role of the co-existing flora and fauna, etc could bridge this lacuna. The information from the present exercise can definitely help to improve the nest-sites provided in the Swiftlet Houses built under the *ex-situ* conservation program, thereby improving nest success in the Swiftlet Houses and raising the population growth rate.

CHAPTER 4

Foraging habits and habitat requirements of the Edible-nest Swiftlet and the Glossy Swiftlet in the Andaman Islands

4.1. Introduction

Swiftlets are exclusive aerial insectivores and perch only on their own nesting and roosting sites (Medway 1962b, Charles 1987, Chantler and Driessens 1995, Nguyen *et al* 2002). Swiftlets have wings well adapted for long and fast flights (Norberg 1986, Josep *et al* 1999). Much of the habitat studies in the past presented the occurrence of different species of swiftlets in different habitats and altitudes in relation to the breeding seasonality and weather conditions (Medway 1962b, Langham 1980, Hails and Amirrudin 1981 and Waugh and Hails 1983, Nguyen *et al* 2002, Koon and Cranbrook 2002). Detailed information about aerial and foraging habits, habitats and microhabitat requirements of most swiftlet species is scarce. Where previous studies concentrated more on the diet and gave information in brief about the general foraging habits of the swiftlets, the present study will throw light on the details of the aerial and foraging habits in relation to the habitat and microhabitat requirements of the edible-nest swiftlet and glossy swiftlet breeding in the Andaman and Nicobar Islands. In addition, the variation in aerial and foraging activities, changes in activity with time and season, differences in the use of two major habitat types available near the breeding sites and the abundance in different habitats and microhabitats were examined for both the species.

Diet is one of the most important resource axes along which ecological isolation has been achieved by many bird species (Moreau 1948, MacArthur 1958). Salmonsen (1983) did a gape-size analysis of the swiftlets in the central Bismarck Archipelago, Papua New Guinea and suggested that each species has its own food niche. Studies of the equivalent guild in the temperate regions have shown that differential prey selection resulting from flight behaviour is an important isolating mechanism for closely related species (Waugh and Hails 1983). Since major studies related to food preferences (Harrison 1976, Hails and Amirrudin 1981, and Nguyen *et al* 2002, Laurie and Tompkins 2000) were based on the gut content and bolus collection, these were not attempted in the present study, thereby avoiding the sacrifice of any individual or interference with the feeding visits of the adults. Gut content analysis could have adversely affected the nesting success, as the population of edible-nest swiftlet has already declined by over 80% within a decade (Sankaran 2001). Instead, aerial and foraging behaviour of these two closely related sympatric swiftlets breeding in the Andaman and Nicobar Islands was examined as a tool to understand their habitat utilisation patterns.

The intention was to gather detailed information about the foraging habitat requirements of the edible-nest swiftlets to improve the ongoing conservation programme for the species. Glossy swiftlets are being used to establish an *ex-situ* population of edible-nest swiftlets through cross-fostering. The study presented here could have great importance in the success of the *ex-situ* conservation program. As the species shares the breeding caves with the edible-nest swiftlet, the habits, habitat and microhabitat requirements of the wild populations of the glossy swiftlets were analysed simultaneously.

4.2. Objectives

The objectives of the study were fixed according to their requirement and importance in the conservation of the edible-nest swiftlets. The investigation was carried out:

a) to identify the patterns in the foraging habits of the edible-nest swiftlets and the glossy swiftlets

b) to identify the habitat and microhabitat requirements of the edible-nest swiftlets and the glossy swiftlets near their breeding caves.

4.3. Study Area

Data for the present study was collected near the breeding caves of the edible-nest swiftlets and glossy swiftlets at Chalis-ek. The observations were recorded at four locations near the breeding site. Two of them were fixed on the Chalis-ek hillock (forest habitat), one at the base and the second on the hill top. From these two sites, activities of both the species in all the forest canopy levels could be observed. The other two locations were fixed in the open land (paddy field), one within the distance of 1 km from the Chalis-ek hill and the other between 1 and 2 km from the hill. For further details about the study area please refer to chapter 2.

4.4. Field Methods and Data Analyses

4.4.1. Breeding Population

In 2004, the Chalis-ek cave complex had 650 breeding pairs of edible-nest swiftlets. Five caves in the complex were also used by 117 breeding pairs of glossy swiftlets. Another hillock nearby had 16 breeding pairs of edible-nest swiftlets and 7 pairs of glossy swiftlets in four caves.

4.4.2. Behavioural Sampling

Scan sampling method (Altman 1974) was followed to record the foraging behaviour of the edible-nest swiftlet and glossy swiftlet between 0500hrs to 1800hrs fortnightly from January 2004 to June 2004. Observations were made for ten minute durations, with a five minute interval between observation sets. At the end of each observation the number of birds was recorded. A total of 2,086 sets of observations were made in 624 hours for both the species. Edible-nest swiftlets were encountered 41,959 times in 719 sets of observations with an average of 58.4 ± 41.6 activities per set. Likewise, a total of 36,906 encounters of glossy swiftlets were made in 1,265 sets of observations with an average of 29.2 ± 36.5 activities per set. In each encounter the activity performed, habitat, microhabitat type and flock sizes were recorded. The terminologies for different behaviours observed were not definite I preferred using my own terminologies for the aerial behaviours of the swiftlets. The types of behaviours recorded were;

a. *fly/glide*: The aerial foragers are always on wing when not at roost or nest site. The flight with wing beats was recorded as ‘fly’ and the flight without wing beat was recorded as ‘glide’. These two flying patterns are combined together as the fly/glide. Fly/glide is believed to be used for scanning the foraging area in the air for food item.

b. *feeding attempts (foraging manoeuvres)*: swiftlets feed on wings and capture 49 to 1,104 airborne insects ranging in the body length from <0.5 to >10 mm (Lim 1999). Observing the successful and unsuccessful capture of the prey item is very difficult as the prey is small and the distance of the prey and predator from the observer is very large. So, observations were limited to recording feeding attempts by presuming that different behaviours/activities were performed to capture different kinds of prey. Five types of behaviours were recorded as foraging manoeuvres;

   i. *twist (TST)*: While gliding, the bird makes a sudden twist, perhaps to capture its prey or to control its flight.

   ii. *fly-pause (FP)*: A fast-flying individual occasionally takes a sudden pause for a second and then moves on with a slight twist. This may be caused by an unexpected prey encountered in the flight path.

   iii. *roll (ROL)*: When the prey is larger than usual, the individual catches the prey in its beak and rolls down to keep its grip on the prey. Birds were observed rolling down for about 2 seconds.

   iv. *flutter (FLR)*: It is a kind of a hover performed with a rapid wing beat and a pause of a second in flight, attributable to a sudden encounter with prey.

   v. *tail & wing open (TWO)*: This seems to be a pre-planned position to capture prey once it is sighted. Wing and the tail feathers are stretched while approaching the prey and a small twist or flutter is performed during capture. This event takes at most 2 seconds. The two actions were difficult to split, so both were merged in the same group.

c. *call*: There are two type of calls tik-tik-tik and chirk-chirk-chirk made in flight

d. *follow*: Individuals were observed chasing each other in flight

e. *preen*: Preening during flight

f. *defecate*: Defecating during flight

g. *Carry nest material*: Swiftlets collect and carry their nest materials in flight.

4.4.3. Foraging Habitat Evaluation

Point-centered quarter method (Mitchell 2001) was used to study the tree diversity and density in the forests of Chalis-ek. Habitats were classified as per Hails and Amirrudin (1981), with further classification of habitats into microhabitats according to the foraging heights in airspace. The heights considered for segregating the microhabitat were different from those of Hails and Amirrudin (1981) as per the suitability and limitations in the study area. Forest habitat was categorised into four microhabitats based on the canopy levels; a) *below forest canopy* (BFC), b) *inside forest canopy* (IFC), c) *0-10 meters above forest canopy* (AFC) and d) *>10 meters above forest canopy* (HaFC). The open lands (paddy fields) developed through deforestation had streams with vegetation along the stream banks. Such vegetation was also included in the open land habitat. The open land habitat was divided into six microhabitats; a*) 0-5 meters above ground* (NG), b) *5-30 meters above ground* (LaG) and c) *>30 meters above ground* (HaG), d) *below stream bank canopy* (BSC), e) *inside stream bank canopy* (ISC), and f) *0-10 meters above stream bank canopy* (ASC).

4.4.4. Meteorological Parameters

Minimum and maximum temperature was recorded using Zeal thermometer. A rain gauge placed at the top of the hill in an open canopy area was used to record the amount of rainfall. The number of rainy days was also recorded.

4.4.5. Statistical Analyses

Percentage of time spent on each activity was estimated in each set of observations from instantaneous scan samples. The proportion of time spent on different aerial activities was calculated. Behaviour like preening, defecating and carrying nest material was observed for less than 0.1% of the time and hence was not considered during the statistical analyses. Variations in the activities of the edible-nest swiftlet and glossy swiftlet were calculated by Mann-Whitney *U* Test. The days were divided into four periods: 0500-0815hrs (early morning), 0815-1130hrs (late morning), 1130-1445hrs (afternoon) and 1445-1800hrs (late afternoon). Data was treated for arcsine transformation to perform One Way ANOVA. Kruskal-Wallis test and One Way ANOVA were performed to get the temporal (monthly and hourly) and spatial (location wise) variations in activities *in toto*, different behaviours separately and activities performed in different microhabitats. Tukey's Post hoc analysis was done for the detailed activity patterns. All the aforementioned statistical analyses were also performed with the data on feeding attempts to know the pattern of foraging manoeuvres. Pearson's correlation test was performed to determine the relation between foraging frequency and the foraging flock size. Hourly variation in the size of the foraging flock was also described. IVI values of the trees were calculated following Mitchell (2001). Chi-square test (Crosstab: contingency table) was used to confirm the distinctness of the species in terms of their microhabitat usage. Binary Logistic Regression analysis was performed to estimate the usage and relative importance of each microhabitat. All statistical tests were performed using Microsoft Excel 2003 and SPSS software version 10.0 (Norusis 1996). The significance level was set at $p < 0.05$ for all the tests.

4.5. Results

4.5.1. Aerial Behaviour

Aerial Activity Budget

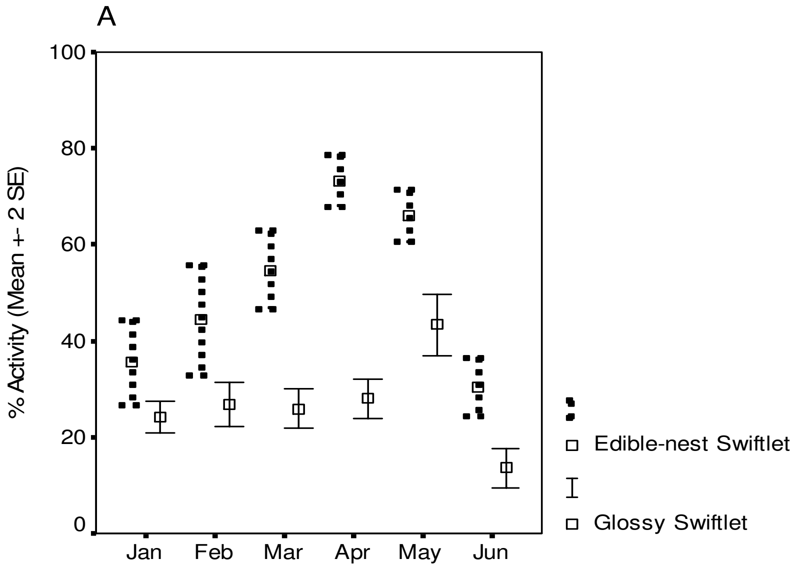
Edible-nest swiftlets and glossy swiftlets perform the following activities in flight, in descending order of frequency of occurrence: fly/glide, feeding attempts, follow and call. The proportions of time spent by the two species on different activities varied significantly (Table 6).

Table 6 Variation in the activity budgets of Edible-nest Swiftlet and Glossy Swiftlet near breeding caves.

	Edible-nest Swiftlet	Glossy Swiftlet	Mann-Whitney Test	
Activity	(%) N=719	(%) N=1265	*Z*	*p*
Fly/Glide	74.42±16.1	84.6±17.5	-13.609	<0.001
Feeding attempts	14.03±12.3	13.75±17.2	-5.217	<0.001
Call	2.08±5.1	0.67±3.3	-14.572	<0.001
Follow	9.47±12.1	0.98±4.2	-25.020	<0.001

Spatio-temporal Variation

Edible-nest swiftlets and glossy swiftlets have significant temporal and spatial variations in their activity budgets near breeding sites (Figure 11). The variation in monthly activity budget is χ^2=105, df = 5, $p < 0.001$ for the edible-nest swiftlets and χ^2=23, df = 5, $p < 0.001$ for the glossy swiftlets. The hourly activity budget shows variance of χ^2=55.896, df = 3, $p < 0.001$ for the edible-nest swiftlets and χ^2=8.464, df = 3, $p = 0.037$ for the glossy swiftlets. Spatial variation is χ^2=58.081, df = 3, $p < 0.001$ for the edible-nest swiftlets and χ^2=293.654, df = 3, $p < 0.001$ for the glossy swiftlets.



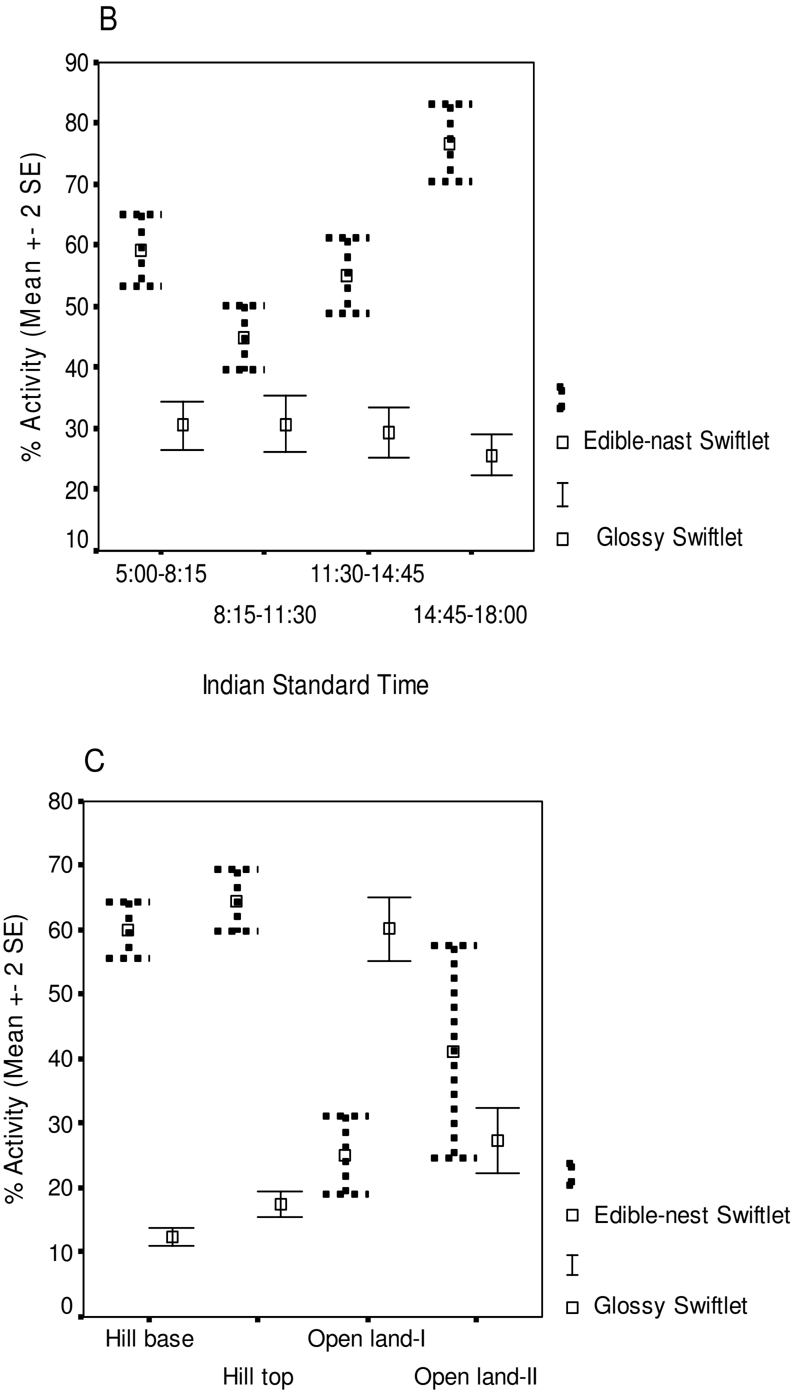


Figure 11 Spatio-temporal variation (Monthly-A and Hourly-B and Location wise-C) in the proportion of time during which the Edible-nest Swiftlets and Glossy Swiftlets were active

Except for feeding attempts, the time spent on all behaviours of edible-nest swiftlets showed significant temporal variation across months. Unlike other activities, the time spent on feeding attempts across the day does not vary significantly in both the species. Time spent on calls by the edible-nest swiftlets doesn't vary significantly throughout the day. The proportion of time spent on different activities by the edible-nest swiftlets and the glossy swiftlets shows significant spatial variation at all the four study locations. Further, Tukey's Post Hoc analysis revealed that the edible-nest swiftlets spent significantly greater time on fly/glide in June than in the other five months, whereas the glossy swiftlets showed significantly greater fly/glide activity between April-June than between January-March. The edible-nest swiftlets spent significantly less time in fly/glide in the early morning and late afternoon hours while the glossy swiftlets spent significantly less time on fly/glide during early and late morning hours. Spatially, the edible-nest swiftlets spent less time in fly/glide at the hilltop and at the base of the hill, whereas glossy swiftlets practiced fly/glide more in forested areas rather than in the open land. The glossy swiftlets spent significantly more time in making feeding attempts in February than in other months. No significant variation was seen in the feeding attempts made by the edible-nest swiftlets across the months. Time spent for feeding attempts by both the species does not vary significantly across the day. With very few encounters the proportion of feeding attempts by the edible-nest swiftlet is significantly more in the open lands than at the foothill and hilltop, and was opposite in case of the glossy swiftlet. Both species call significantly more often in January and March as compared to other months. The glossy swiftlets call more often in the early and late morning hours, whereas the edible-nest swiftlets do not show any significant change in call patterns through the day. Both the species were observed calling more frequently at the hill top than at the foothill. While glossy swiftlets did call in the open lands, though less frequently, the edible-nest swiftlets were not observed calling in these areas at all. Edible-nest swiftlets followed significantly more often in February and March, while glossy swiftlets performed it significantly less often in the April and May than in other months. The edible-nest swiftlets perform follow significantly more during early morning and late afternoon hours, whereas the glossy swiftlets perform follow significantly more in the early and late morning hours. The edible-nest swiftlets were not observed performing follow at locations in the open land while the glossy swiftlets perform follow significantly less in these locations compared to locations at the foothill and the hill top (Table 7A, B and C).

Table 7 Spatio-temporal variation (Monthly-A and Hourly-B and Location wise-C) in the proportionate activities of the Edible-nest Swiftlets and Glossy Swiftlets (Note: p<0.05 shows the significant difference)

Table 7A

		Percentage time spent on an activity in respective months (Mean ± SD)							
Species	Activity	January	February	March	April	May	June	ANOVA	
Edible-nest Swiftlet	N = 719	n = 49	n = 63	n = 133	n = 211	n = 188	n = 75	F	*p*
	Fly/Glide	72.3±22.2	69.4±24.9	71.6±17.2	75.9±13.1	74.3±11.9	81.1±14.2	5.354	<0.001
	Feeding attempts	14.3±15.2	16.7±20.1	11.5±10.6	14.3±11.4	14.9±9.6	13.2±12.2	2.030	0.073
	Call	4.4±8	1.7±6.3	1.3±2.8	1.4±2.5	1±2.8	2.1±5.1	9.577	<0.001
	Follow	9.1±16.3	12.7±19.7	12.7±13.1	8.5±10.3	9.3±9.4	4.7±7	5.260	<0.001
Glossy Swiftlet	N = 1265	n = 210	n = 214	n = 238	n = 292	n = 252	n = 59	F	*p*
	Fly/Glide	84.3±18.4	78.9±21	81.6±18.6	89.4±13.2	85.4±15.6	91.6±11.7	9.478	<0.001
	Feeding attempts	13.5±18	19±21.1	14.6±18.5	10.3±13.3	14.2±15.3	7.6±11	5.246	<0.001
	Call	0.9±3.3	0.7±3.7	1.9±5.7	0	0.2±1.5	0	15.654	<0.001
	Follow	1.3±4.5	1.4±5.3	1.9±5.4	0.3±1.8	0.3±3.1	0.8±4.5	9.042	<0.001

*N = Total number of sets of observations when the species was active, n = Number of sets of observations when the birds were active in particular month

Table 7B

		Percentage time spent on an activity during different hours of the day (Mean ± SD)					
Species	Activity	5:00-8:15	8:15-11:30	11:30-14:45	14:45-18:00	ANOVA	
Edible-nest Swiftlet	N = 719	n = 226	n = 194	n = 142	n = 157	F	*p*
	Fly/Glide	73.4±18.2	77.9±16.1	76.4±13.3	69.8±13.6	8.764	<0.001
	Feeding attempts	13.1±13.1	15.3±13.9	13.3±10.9	14.4±9.6	1.245	0.292
	Call	2.3±5.7	2±5.8	1.4±2.7	2.5±4.7	1.352	0.256
	Follow	11.2±14.9	4.9±8.7	8.8±9.6	13.3±11.5	17.244	<0.001
Glossy Swiftlet	N = 1265	n = 352	n = 324	n = 299	n = 290	F	*p*
	Fly/Glide	81.6±18.1	85.1±16.2	86.6±16.1	85.6±18.8	6.514	<0.001
	Feeding attempts	15.6±17.9	12.7±15.6	12.4±16	14.1±18.9	2.588	0.052
	Call	1±3.6	1±3.9	0.4±3.3	0.2±2.1	7.437	<0.001
	Follow	1.9±6	1.3±4.2	0.6±3.2	0.06±0.6	14.310	<0.001

*N = Total number of sets of observations when the species was active, n = Number of sets of observations when the birds were active during particular time

Table 7C

		Percentage of time spent on an activity at different locations (Mean ± SD)					
Species	Activity	Hill base	Hill top	Open land-I	Open land-II	ANOVA	
Edible-nest Swiftlet	N = 719	n = 333	n = 306	n = 67	n = 13	F	*p*
	Fly/Glide	74.8±15.1	72.9±15.8	79.3±20.8	73.9±13.3	3.069	0.027
	Feeding attempts	13.7±10.9	12.4±10.6	20.7±20.8	26.1±13.3	13.390	<0.001
	Call	2.4±5.9	2.3±4.6	0	0	5.130	0.002
	Follow	9.1±11.4	12.4±13.2	0	0	24.400	<0.001
Glossy Swiftlet	N = 1265	n = 359	n = 411	n = 358	n = 137	F	*p*
	Fly/Glide	90.4±13.6	90.3±14.9	74±17.8	79.9±18.6	57.552	<0.001
	Feeding attempts	7.4±12.2	6.7±12.9	25.9±17.7	19.8±18.6	152.767	<0.001
	Call	1±4.6	1.2±3.8	0.03±0.6	0.05±0.5	14.502	<0.001
	Follow	1.2±4.9	1.9±5.4	0.1±1.2	0.2±1.5	18.562	<0.001

*N = Total number of sets of observations when the species was active, n = Number of sets of observations when the birds were active at that location

4.5.2. Foraging Behaviour

Foraging Activity Budget

Of the total aerial activities, edible-nest swiftlets and glossy swiftlets spent 17.2±11.4% and 25.8±15.6% of their time in feeding attempts respectively. Both the species spent much time on twist, flutter, tail-wing-open, fly-pause and roll in descending order. The proportion of time spent on different foraging manoeuvres varied significantly (Table 8).

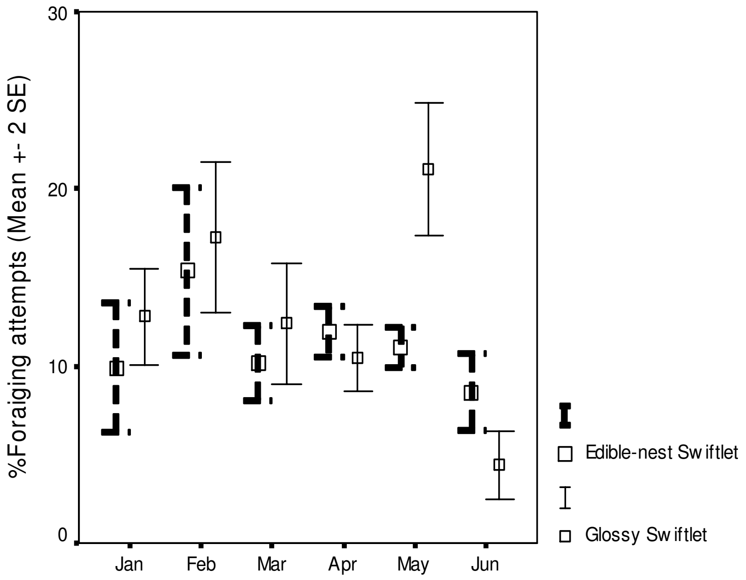
Table 8 Variation in proportions of the feeding manoeuvres in the Edible-nest Swiftlets and Glossy Swiftlets.

Feeding manoeuvre	Edible-nest Swiftlet (%) N=587	Glossy Swiftlet (%) N=673	Mann-Whitney Test	
			Z	*p*
Twist	44.12±47.44	61.29±31.26	-4.347	<0.001
Fly-Pause	2.43±8.82	0.17±1.59	-9.149	<0.001
Roll	2.4±9.59	0.15±1.43	-8.053	<0.001
Flutter	25.57±23.26	19.28±23.85	-3.516	<0.001
Tail-Wing-Open	25.48±22.92	19.11±23.83	-3.619	<0.001

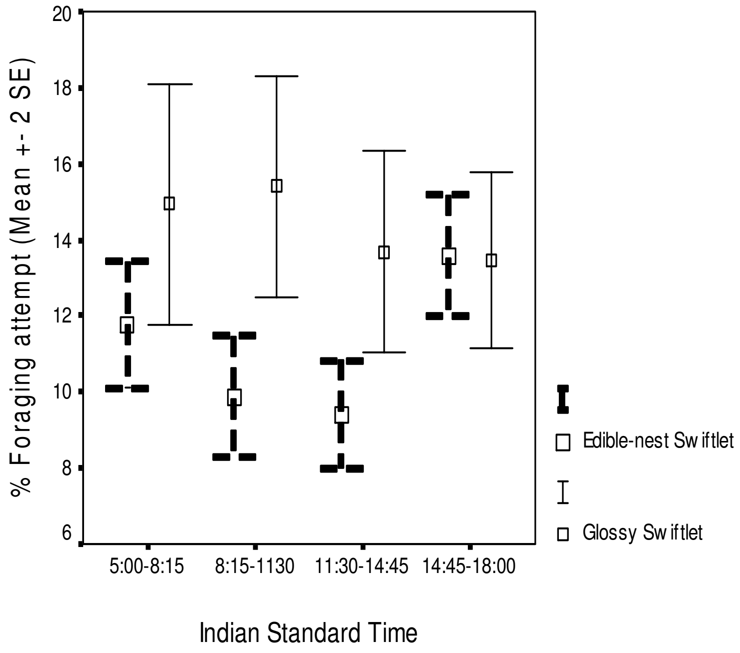
Spatio-temporal variation

The edible-nest swiftlets and glossy swiftlets has significant spatial (edible-nest swiftlets $\chi2=61.236$, $p < 0.001$; glossy swiftlets $\chi2=84.702$, $p <0.001$) and monthly (edible-nest Swiftlet: $\chi2=19.588$, $p < 0.001$; glossy swiftlet: $\chi2=53.952$, $p < 0.001$) variations in their time spent for feeding attempts, however they do not show significant variations across the hours of the day (Figure 12).

A


%Foraiging attempts (Mean +- 2 SE)
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Edible-nest Swiftlet
Glossy Swiftlet

B


% Foraging attempt (Mean +- 2 SE)
20
18
16
14
12
10
8
6
5:00-8:15
8:15-1130
11:30-14:45
14:45-18:00
Indian Standard Time
Edible-nest Swiftlet
Glossy Swiftlet

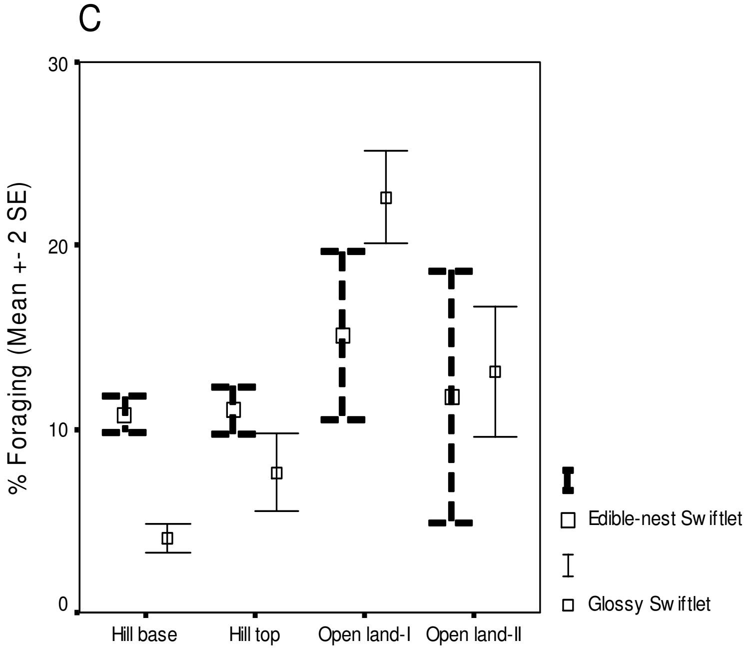


Figure 12 Shows the spatio-temporal variation (Monthly-A and Hourly-B and Location wise-C) in the proportion of feeding attempts of the Edible-nest Swiftlet and Glossy Swiftlet

The foraging manoeuvres varied across months in both the species except flutter in the edible-nest swiftlets and roll in the glossy swiftlets. Only tail-wing-open and roll in glossy swiftlets varied significantly through the day. The edible-nest swiftlets show variation only in the time spent on the twist and tail-wing-open activities between the observation points in the foraging manoeuvres, whereas the glossy swiftlets showed variation in twist, flutter and tail-wing-open activities. Tukey's Post Hoc analysis revealed that the edible-nest swiftlets twist significantly more in January over other months, the twist is significantly more between January-March than April-June in glossy swiftlets. Twist in both the species does not vary through the day. The edible-nest swiftlets show significantly less proportion of twist at the hill base and top in forests than the locations in the open land. Glossy swiftlets show significantly higher proportion of twist at the hill base and top than the locations in the open land. Edible-nest swiftlets perform significantly less fly-pause in April and May than in the other months while glossy swiftlets perform significant fly-pause only in January over other months. Fly-pause in either species does not vary significantly through the day or across locations. Roll is performed significantly more in March than in other months in the edible-nest swiftlets and does not show any monthly variation in the glossy swiftlets. Roll does not vary through the day in the edible-nest swiftlets while in the glossy swiftlets it is significantly higher late in the morning than at other times of the day. Roll does not vary across locations in either species but is seen more in March in the edible-nest swiftlets. Flutter in the edible-nest swiftlets does not vary significantly through the months but is seen more in February whereas, the glossy swiftlets flutter significantly less in February than in other months with the significant variation between February, March and May. Neither species of swiftlets have a significant diurnal variation in the proportion of flutter. Only glossy swiftlets show significant variation in the flutter between the locations at hill top and open land-I, with minimum proportion at hill top. Tail-wing-open is performed significantly less in January and February by the edible-nest swiftlets and is performed significantly less in January and more in May by the glossy swiftlets. During the day edible-nest swiftlets perform significantly less tail-wing-open in the early morning hours and more in the afternoon. In contrast, the glossy swiftlets show significant variations in the early morning, late morning and late evening hours with maximum proportion during the late morning hours. Tail-wing-open in both the species varies significantly between the locations at the foothill and hill top and the locations in the open land, with a higher proportion of edible-nest swiftlets performing tail-wing-open at the hill base and top and more glossy swiftlets performing the same in open land-I and II (Table 9A, B and C).

Table 9 Spatio-temporal variation (Monthly-A and Hourly-B and Location wise-C) in the proportionate activities of the Edible-nest Swiftlets and Glossy Swiftlets (Note: p<0.05 shows the significant difference)

Table 9A

Species	Foraging manoeuvres	Percentage time spent on different foraging manoeuvres in respective months (Mean ± SD)						ANOVA	
		January	February	March	April	May	June		
Edible-nest Swiftlet	N = 587	n = 33	n = 41	n = 97	n = 193	n = 173	n = 50	F	*p*
	Twist	65.4±30.5	46.9±33.4	40.5±29.2	45.7±25.4	42±23.8	36.2±29.2	5.564	<0.001
	Fly-Pause	5.2±9.4	6.8±17	5.7±14.2	0.8±3.1	0.5±1.8	3.7±11	12.108	<0.001
	Roll	0	4.4±8.7	7.2±19.7	1.3±4.6	1.1±4.8	1.8±6.7	7.740	<0.001
	Flutter	22.3±21.6	32.6±31.4	23.5±24.8	24.3±22.8	26.7±19.3	26.8±27.3	1.331	0.249
	Tail-Wing-Open	7.1±11.9	9.3±11.8	23.1±22.4	27.8±21.7	29.8±23.6	31.5±26.4	12.112	<0.001
Glossy Swiftlet	N = 673	n = 102	n = 121	n = 131	n = 151	n = 143	n = 25	F	*p*
	Twist	71±30.5	69.2±27.1	63.2±33.2	59.2±33	48.1±26.8	60.9±36.4	7.885	<0.001
	Fly-Pause	0.9±3.8	0	0.08±0.9	0	0.04±0.2	0	7.961	<0.001
	Roll	0.3±2.3	0.3±1.9	0.3±1.7	0	0	0	1.617	0.153
	Flutter	20.3±25.5	14.5±18.4	15.7±22.2	19.5±25.5	23.6±22.4	30.7±36.9	4.395	<0.001
	Tail-Wing-Open	7.5±14.7	16±19.6	20.7±27.3	21.2±26.1	28.2±23.2	8.5±17.9	12.588	<0.001

*N = Total number of sets of observations when the species was foraging, n = Number of sets of observations when the birds were foraging in particular month

Table 9B

		Percentage time spent on different foraging manoeuvres during different hours of the day (Mean ± SD)					
Species	Foraging manoeuvres	5:00-8:15	8:15-11:30	11:30-14:45	14:45-18:00	ANOVA	
Edible-nest Swiftlet	N = 587	n = 172	n = 155	n = 121	n = 139	F	*p*
	Twist	44.2±27.7	48.9±27.4	41.5±26.8	40.9±26.8	1.861	0.135
	Fly-Pause	3.4±11.2	1.3±4.7	1.8±6.4	3±10.5	2.246	0.082
	Roll	1.4±9	2±9.1	3.7±15.2	3±8	1.230	0.298
	Flutter	29.3±24	23.6±24.3	23.4±22.6	25.1±21.5	2.176	0.090
	Tail-Wing-Open	21.6±22	24.3±23.6	29.6±24.7	28.1±20.9	3.283	0.021
Glossy Swiftlet	N = 673	n = 211	n = 167	n = 152	n = 143	F	*p*
	Twist	65.4±29.7	59.1±33.1	56.9±32.9	62.4±28.8	2.380	0.069
	Fly-Pause	0.2±2.1	0.1±1	0.3±1.9	0.03±0.3	0.691	0.558
	Roll	0	0.08±1.1	0.6±2.7	0	7.209	<0.001
	Flutter	18.7±22.9	16.4±22.4	20.9±26.4	21.7±23.7	1.652	0.176
	Tail-Wing-Open	15.7±20.7	24.2±27.1	21.4±24.3	15.8±22.2	4.802	0.003

*N = Total number of sets of observations when the species was foraging, n = Number of sets of observations when the birds were foraging during particular time

Table 9C

Species	Foraging manoeuvres	Percentage time spent on different foraging manoeuvres at different locations (Mean ± SD) Hill base	 Hill top	 Open land-I	 Open land-II	ANOVA	
Edible-nest Swiftlet	N = 587	n = 276	n = 256	n = 42	n = 13	F	*p*
	Twist	43±25.5	42.4±27.6	56.6±31.4	63±35	5.977	<0.001
	Fly-Pause	2.4±8.8	2.4±9.3	2.8±6.9	2.4±5	0.248	0.863
	Roll	1.5±7.8	3.3±11.6	3.2±7.6	0.6±2.1	2.147	0.093
	Flutter	26.5±20.7	25.2±25.6	21.7±23.4	25.8±26.4	1.141	0.332
	Tail-Wing-Open	26.6±22.8	26.8±23.3	15.7±19.6	8.5±11.5	4.844	0.002
Glossy Swiftlet	N = 673	n = 141	n = 134	n = 306	n = 92	F	*p*
	Twist	65.7±36.9	69.3±33.6	56.5±25.7	58.9±32.4	6.407	<0.001
	Fly-Pause	0.3±2.8	0	0.2±1.4	0.07±0.4	1.127	0.337
	Roll	0.1±1.2	0.2±1.4	0.2±1.7	0	0.725	0.537
	Flutter	21.1±31.9	14.4±25.9	20.2±18.6	20.3±21.4	4.553	0.004
	Tail-Wing-Open	12.7±25.3	16.1±26	22.9±20.6	20.7±25.9	11.288	<0.001

*N = Total number of sets of observations when the species was foraging, n = Number of sets of observations when the birds were foraging at that location

4.5.3. Foraging flock size

Edible-nest swiftlets forage in large flocks (9.4±3.5 individuals; minimum = 3, maximum = 17) before returning to the caves between 1700hrs and 1800hrs ($\chi 2$=120.944, $p < 0.001$) as compared to the other times of the day. Glossy swiftlets also form comparatively large flocks (5.7±2.4 individuals; minimum = 0, maximum = 11) between 1700hrs and 1800hrs without any significant variation in flock size with respect to the time of the day (Figure 13). Edible-nest swiftlets and glossy swiftlets show significant correlation r=0.400, $p < 0.001$ and r=0.307, $p < 0.001$ respectively between the flock size. It was found that this correlation does not change when partial correlation is performed by controlling for the month, location and hours (edible-nest swiftlet: r=0.420, $p < 0.001$ and glossy swiftlet: r=0.370, $p < 0.001$).

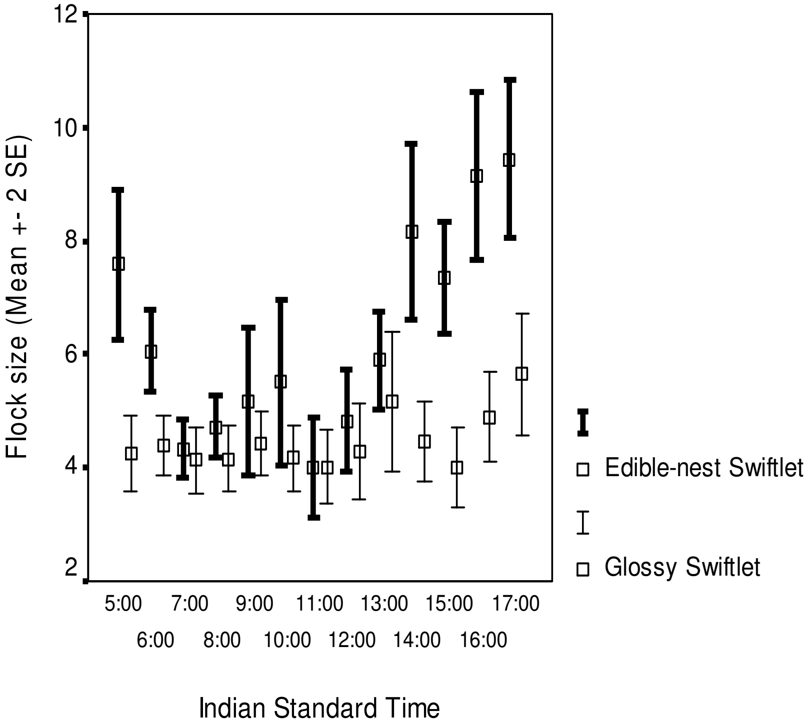


Figure 13 Temporal Variations in the hourly flock sizes of the Edible-nest Swiftlet and Glossy Swiftlet.

4.5.4. Foraging habitat evaluation

Quantification of Vegetation

Chalis-ek has moist deciduous type of forests with 63 species of trees recorded from the area. The forest community here was dominated by *Pterocarpus dalbergioides* (IVI= 35.7) followed by *Diospyros crumenata* (IVI= 22.4) and *Drypetes andamanica* (IVI= 21.3).

Habitats

Foraging individuals of both the species were seen more in the forest than the open land (edible-nest swiftlets: $\chi2=94.298$, $p < 0.001$ and glossy swiftlets: $\chi2=58.548$, $p < 0.001$; Figure 14).

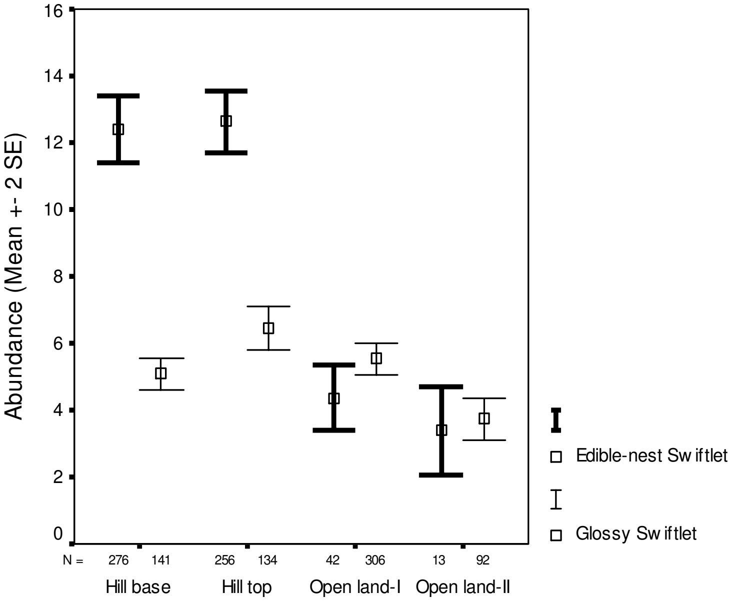


Figure 14 Variation in abundance of the Edible-nest Swiftlet and Glossy Swiftlet at four locations in Chalis-ek, Pattilevel.

Microhabitats

Edible-nest swiftlets have a monthly variation of feeding attempts in different microhabitats except in ISC, IFC, LaG and NG. Glossy swiftlets do not show monthly variation at HaFC, BSC, LaG and HaG. Edible-nest swiftlets show significant diurnal variation in the proportion of the activity in four microhabitats; ASC, NG, LaG and HaG. Glossy swiftlets showed variation through the day in most of the microhabitats except at HaFC, AFC, BSC and HaG (Table 10A, B).

Both the species shared all the microhabitats except IFC and ISC. The variations in the microhabitat used by them were proved except in the microhabitat BSC (Table 11). The microhabitats HaFC followed by HaG and AFC are important for edible-nest swiftlets, whereas IFC and ISC are important microhabitats for glossy swiftlet (Table 12). Foraging activities in both species were neither related to temperature nor to rainfall (Figure 15).

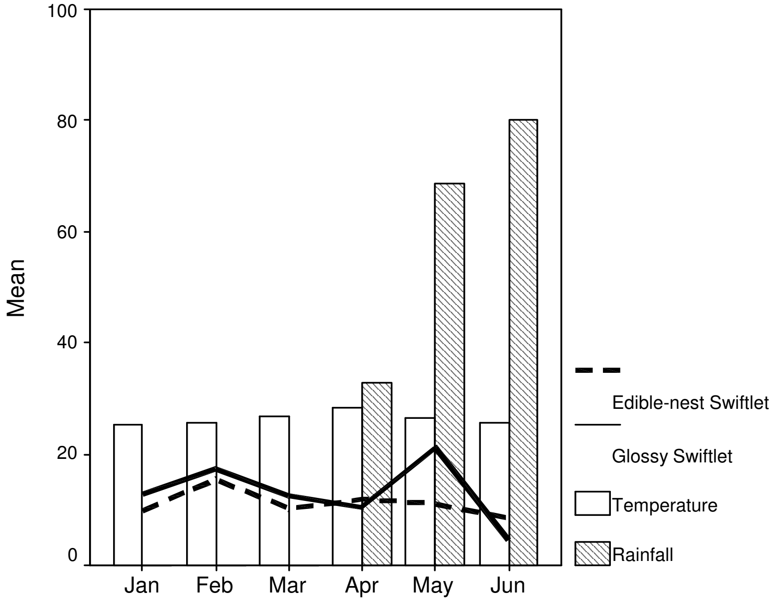


Figure 15 Bars representing the average temperature and rainfall at Chalis-ek and the lines shows the average foraging activity of Edible-nest Swiftlet and Glossy Swiftlet.

Table 10 Temporal (A: Monthly & B: Hourly) variations in activity of the Edible-nest Swiftlets and Glossy Swiftlets in different microhabitats.

Table 10A

		Percentage of feeding attempts in different microhabitats (Mean ± SD)							
	Microhabitats	January	February	March	April	May	June	Kruskal Wallis Test	
Edible-nest Swiftlet	N = 583	n = 32	n = 41	n = 96	n = 192	n = 172	n = 50	χ^2	*p*
	>10 m above forest canopy	64 ± 47.9	40.2 ± 49	69.8 ± 32.8	44 ± 35.1	36 ± 29.8	52 ± 28.4	43.128	<0.001
	0-10 m above forest canopy	6.3 ± 16.8	39 ± 48.1	30.2 ± 32.8	50 ± 36.2	64 ± 29.8	48 ± 28.5	132.985	<0.001
	Inside forest canopy	0	0	0	0	0	0	----	----
	0-10 m above stream bank canopy	10.9 ± 24.5	3.7 ± 13.2	0	0.3 ± 3.6	0	0	68.274	<0.001
	Inside stream bank canopy	0	0	0	0	0	0	----	----
	Below stream bank canopy	1.6 ± 8.8	0	0	0	0	0	----	----
	>30 m above ground	17.2 ± 37.3	14.6 ± 34	0	2.6 ± 14.2	0	0	56.374	<0.001
	5-30 m above ground	0	2.4 ± 15.6	0	2.3 ± 13.8	0	0	10.798	0.056
	0-5 m above ground	0	0	0	0.8 ± 6.2	0	0	----	----
Glossy Swiftlet	N = 656	n = 97	n = 112	n = 130	n = 149	n = 143	n = 25	χ^2	*p*
	>10 m above forest canopy	2.1 ± 14.3	0	0	0	0.3 ± 4.2	2 ± 10	10.552	0.061
	0-10 m above forest canopy	29.4 ± 44.3	37.1 ± 45.9	40 ± 45.1	37.7 ± 44.9	25.1 ± 38.3	58 ± 31.2	33.855	<0.001
	Inside forest canopy	13.9 ± 32.9	27.7 ± 42.4	38.5 ± 44.7	8.4 ± 22.1	8.6 ± 19.8	40 ± 32.3	74.086	<0.001
	0-10 m above stream bank canopy	34 ± 46.5	19 ± 39.2	8.1 ± 27	22.3 ± 28.6	28.3 ± 27.3	0	97.277	<0.001
	Inside stream bank canopy	7.2 ± 26	8.8 ± 27.7	6.9 ± 24.7	21.3 ± 29.3	31.1 ± 28.7	0	160.662	<0.001
	Below stream bank canopy	1 ± 10.2	0	0	0	0	0	----	----
	>30 m above ground	0.5 ± 5.1	0.3 ± 3.1	0	0.2 ± 2.7	0	0	2.547	0.769
	5-30 m above ground	11.3 ± 31	6.7 ± 23.7	6.5 ± 23.6	7.7 ± 22.5	6.2 ± 19.9	0	6.075	0.299
	0-5 m above ground	0.5 ± 5.1	0.4 ± 4.7	0	2.4 ± 11.4	0.3 ± 4.2	0	16.713	0.005

*N = Total number of sets of observations when the species was foraging, n = Number of sets of observations when the birds were foraging in particular month, ---- = cannot be calculated

Table 10B

		Percentage time spent on feeding attempts during different hours of the day (Mean ± SD)					
	Foraging manoeuvres	5:00-8:15	8:15-11:30	11:30-14:45	14:45-18:00	Kruskal Wallis Test	
	N = 583	n = 172	n = 152	n = 121	n = 138	χ^2	*p*
Edible-nest Swiftlet	>10 m above forest canopy	45.9 ± 36.8	42.1 ± 36.4	51.2 ± 37.3	51.8 ± 35.4	6.255	0.1
	0-10 m above forest canopy	50 ± 37.4	43.1 ± 36	48.8 ± 37.3	48.2 ± 35.4	2.168	0.538
	Inside forest canopy	0	0	0	0	----	----
	0-10 m above stream bank canopy	0.9 ± 8.5	2.6 ± 11.2	0	0	15.846	0.001
	Inside stream bank canopy	0	0	0	0	----	----
	Below stream bank canopy	0.3 ± 3.8	0	0	0	----	----
	>30 m above ground	1.7 ± 12	8.9 ± 27.1	0	0	32.251	<0.001
	5-30 m above ground	1.2 ± 10.7	2.3 ± 13.3	0	0	8.563	0.036
	0-5 m above ground	0	1 ± 7	0	0	----	----
	N = 656	n = 199	n = 165	n = 151	n = 141	χ^2	*p*
Glossy Swiftlet	>10 m above forest canopy	0	0.6 ± 7.8	1.3 ± 9.9	0	7.001	0.072
	0-10 m above forest canopy	32.8 ± 41.5	38.3 ± 44.7	34.4 ± 44.4	34 ± 44.8	1.865	0.601
	Inside forest canopy	28.1 ± 39.4	17.8 ± 33.9	11.9 ± 28.1	18.4 ± 35.6	17.271	0.001
	0-10 m above stream bank canopy	20.8 ± 37.5	17.2 ± 29	26 ± 35	20.9 ± 32.8	10.063	0.018
	Inside stream bank canopy	8.5 ± 24	15.3 ± 26.9	22.1 ± 32.4	18.8 ± 30.8	29.471	<0.001
	Below stream bank canopy	0.5 ± 7.1	0	0	0	----	----
	>30 m above ground	0.5 ± 2.4	0.3 ± 3.9	0.2 ± 2.7	0	0.885	0.829
	5-30 m above ground	8.1 ± 25.3	8.8 ± 23.5	3.6 ± 17.4	7.8 ± 26.2	10.117	0.018
	0-5 m above ground	0.9 ± 8.2	1.7 ± 8.2	0.3 ± 4.1	0	10.114	0.018

*N = Total number of sets of observations when the species was foraging, n = Number of sets of observations when the birds were foraging during particular time, ---- = cannot be calculated

Table 11 Association between the Edible-nest Swiftlet and the Glossy Swiftlet with their microhabitat usage at Chalis-ek, Pattilevel

Microhabitat	Species	N	Activity (Mean±SD)	χ2	*p*
HaFC	ENS	412	11.47±10.09	----	
	GS	4	6.75±2.06		
AFC	ENS	413	11.43±9.38	109.901	<0.001
	GS	277	8.32±13.02		
IFC	ENS	0	0	----	
	GS	174	6.95±7.53		
ASC	ENS	10	18.5±13.19	228.748	<0.001
	GS	209	24.82±20.74		
ISC	ENS	0	0	----	
	GS	169	24.07±19.54		
BSC	ENS	1	39	0.009	0.923
	GS	1	12		
HaG	ENS	20	15.05±12.53	----	
	GS	3	40±26		
LaG	ENS	7	5.43±5.29	48.672	<0.001
	GS	65	18.95±22.84		
NG	ENS	3	7±5.29	----	
	GS	11	17.64±8.58		

Note: HaFC: >10 meters above forest canopy, **AFC**: 0-10 meters above forest canopy, **IFC**: inside forest canopy, **ASC**: 0-10 meters above stream bank canopy, **ISC**: inside stream bank canopy, **BSC**: below stream bank canopy, **HaG**: >30 meters above ground, **LaG**: 5-30 meters above ground, **NG**: 0-5 meters above ground, ---- = cannot be calculated

Table 12 The following binary logistic analysis shows that among the habitat variables, HaFC> HAG> and AFC are used more by Edible-nest Swiftlet and IFC>ISC are used more by the Glossy Swiftlet. The log odds ratio (Exp (B)) in the following table is an indicator of relative importance.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	BSC(1)	-1.103	3.106	.126	1	.723	.332
	ISC(1)	-8.043	12.028	.447	1	.504	.000
	ASC(1)	-1.070	.488	4.814	1	.028	.343
	HaFC(1)	5.661	.587	93.061	1	.000	287.546
	IFC(1)	-9.375	12.113	.599	1	.439	.000
	AFC(1)	1.490	.425	12.269	1	.000	4.435
	NG(1)	1.913	.813	5.541	1	.019	6.772
	LaG(1)	-.945	.564	2.808	1	.094	.389
	HaG(1)	4.309	.834	26.687	1	.000	74.367
	Constant	8.891	17.457	.259	1	.611	7265.219

a. Variable(s) entered on step 1: BSC, ISC, ASC, HaFC, IFC, AFC, NG, LaG, HaG.

Note: BSC: below stream bank canopy, **ISC**: inside stream bank canopy, **ASC**: 0-10 meters above stream bank canopy, **HaFC**: >10 meters above forest canopy, **IFC**: inside forest canopy, **AFC**: 0-10 meters above forest canopy, **NG**: 0-5 meters above ground, **LaG**: 5-30 meters above ground, **HaG**: >30 meters above ground

4.6. Discussion

4.6.1. Aerial and Foraging Behaviour

Like other Apodidae, swiftlets have specialized for life on wings. Since their legs do not help in locomotion, they feed on the aerial insects in flight (Medway 1962b). Only one incidence of a glossy swiftlets perching on tree to feed was described by Spennemann (1928). Swiftlets have large foraging ranges, and they travel far from their breeding caves. Medway (1962b) could observe *Aerodramus maximus* and *Aerodramus salangana* flying more than 15miles away from the cave. With his limited visits he could not observe birds beyond 15miles. Swiftlets were mostly studied on the basis of their abundance in different habitats or airspaces and their behaviours were described only briefly (Medway 1962b, Harrisson 1972, Hails and Amrrudin 1981, Waugh and Hails 1983, Francis 1987, Koon and Cranbrook 2002, Nguyen *et al* 2002). The edible-nest swiftlet *Aerodramus fuciphagus inexpectatus* and the glossy swiftlet *Collocalia esculenta affinis* are endemic to the Andaman and Nicobar Islands. There is no study made on these species except the status survey by Sankaran (1995, 1998 and 2001). In the present study, an attempt has been made to quantify the aerial behaviours of the two species to identify their important foraging habitats and microhabitats. Both the birds perform fly/glide, foraging attempts (twist, fly-pause, roll, flutter and tail-wing-open), call and follow in decreasing order of their proportions. Their activities also seem to be dependent on different aspects.

Edible-nest swiftlets breed from January to August in the Andaman and Nicobar Islands. At Chalis-ek they can be seen breeding successfully only from January to June. Glossy swiftlets breed all through the year in the Andaman and Nicobar Islands. Swiftlets are known to be monogamous and have a bi-parental care system (Koon and Cranbrook 2002). The temporal variation in their total activity near the breeding caves appears to be related to their breeding seasonality. The swiftlets at Chalis-ek were found to be more active in April and May near their breeding sites, when most of their nests in the caves had chicks and eggs. Edible-nest swiftlets were never seen to be active between 0700hrs to 1700hrs near their breeding caves during the early nest construction period and were never seen foraging after 800hrs till 1400hrs in the late nest construction period. They spend most of the daylight hours away from the caves perhaps because they do not require to collect nesting material and so they explore new foraging grounds. Once egg-laying starts towards February end, the activity of the edible-nest swiftlets near the breeding caves increases and can be observed during all daylight hours as they frequently visit the nest for incubation, brooding and feeding the chicks. Further, the activity of the edible-nest swiftlets shows a sudden decline after May as the majority of the nests empty after successful fledging (for details about the breeding chronology and seasonality of the Edible-nest swiftlets in the Chalis-ek refer chapters 5 and 6). The changes in the activity of the birds near the breeding caves in Sarawak were explained by Medway (1962b), where he found the birds travelling more than 15miles. He also mentioned that they travel more in the non-breeding season. But the absence of the foraging birds during the nest construction period at Chalis-ek reveals that swiftlets travel away from the caves in the pre incubation period. Another reason for the change in the amount of activity can be the availability of food. Johnson (1969) reports that, the density and diversity of insects differs with the weather conditions. Glossy swiftlets were more active in the early and late morning hours, but did not show much diurnal variation in the activities. Glossy swiftlets have asynchronous breeding in the Andaman and Nicobar Islands. As the breeding stage of the species affects the activities near the breeding sites, glossy swiftlets do not show much variation in their diurnal activities.

Fly/glide is the most frequent behaviour believed to be used to scan the foraging grounds for food and to simultaneously pass on to different foraging grounds. Both the species spent much time in search of food. Assuming that the time spent in search of food depends on the availability of food, fly/glide too must vary with seasonal, diurnal and spatial variation and the density and distribution of the food items, though it may not be linked with insect diversity. Since relevant data on insect diversity and density is not available, it is difficult to corroborate this opinion. All the individual activities, except feeding attempts, have temporal variations in their proportions through the months. Feeding attempts and calls do not have diurnal variation. Activities such as call and follow are presumed to be a sort of mating/pair making display and are also performed in response to the foraging competition to chase out other foragers. These activities are performed throughout the breeding season but their greater occurrence in January and February shows their relation to nest construction period of the edible-nest swiftlets. The glossy swiftlets also leave most nests empty during this time of the year (for details about the breeding chronology seasonality in caves refer to chapter 5). Because of their lesser occurrence, calls may not show a diurnal variation but follow has a pattern with the breeding seasonality of the species.

The foraging manoeuvres were mostly believed to depend on the type of insects available and the significant temporal changes in the proportions of the different foraging manoeuvres. Except for rolling in the glossy swiftlets, neither species shows significant variation in the foraging manoeuvres in the day. Only activities such as twist and tail-wing-open in both the species, and flutter in the glossy swiftlet show variation. Assuming that different foraging manoeuvres are used for hunting different types of prey, the variation in foraging manoeuvres indicates either a significant seasonal variation in insect diversity from January to June or a change in prey base with their breeding cycle (Johnson 1969). The diurnal variation in insect diversity in the forest is uncertain, though it differs slightly in the open lands. This indicates that most of the foraging attempts made in the microhabitats HaFC and HaG may be because of the similar insect diversity at that height.

4.6.2. Habitat and Microhabitat

The majority of the activities by edible-nest swiftlets (88%) were seen in the forest areas, whereas the glossy swiftlets were comparatively more active towards the open paddy lands (40%). Previous studies (Medway 1962b, Harrisson 1972, Hails and Amrrudin 1981, Waugh and Hails 1983, Francis 1987, Koon and Cranbrook 2002, Nguyen *et al* 2002) also corroborate that edible-nest swiftlets were found only in forests areas. Glossy swiftlets are the only swiftlets known to occur in all habitats. The swiftlet diet study in Malaysia shows that glossy swiftlets are not selective about their food and display more consistency in their foraging habitats. On the other hand, edible-nest swiftlets are more selective regarding their food and limited in their choice of foraging habitats (Laurie and Tompkins 2000). The present study recorded very few edible-nest swiftlets in open paddy lands.

Edible-nest swiftlets were more active near the caves in the early morning as they left their roosting caves and in the late afternoons just before going to roost. During these hours they were also found in large foraging flocks. The frequency of feeding attempts in both the species correlated to the foraging flock size, as seen in many other colony foragers. Glossy swiftlets were more active in the early and late morning hours, after which they flew inside the forest canopy to avoid the heat of the day. As Johnson (1969) suggested, insects move upwards with an increase in ambient temperature, and so the birds also fly higher, which can result in the shift of the edible-nest swiftlets to higher altitudes. On the other hand, the glossy swiftlets may move inside the canopy at the forest edges or towards the loose canopies of vegetations on the stream banks close to open grounds. The glossy swiftlets did not have much diurnal difference in their foraging flock sizes.

The edible-nest swiftlets are known to feed high above the canopy, while the glossy swiftlets are known to forage at the canopy level and near the ground. The significant variations in their proportions of different foraging manoeuvres show the difference in their food preference, which is already proved by the gut content and the bolus analysis of these species in their different distribution ranges in South-East Asia (Medway 1962b, Hails and Amiruddin 1981, Waugh and Hails 1983, Harrisson 1972, Francis 1987, Collins 2000, Laurie and Tompkins 2000). The significant variation in different microhabitats gives a clear idea of the resource partitioning among the edible-nest swiftlets and the glossy swiftlets at Chalis-ek. When all the microhabitats were evaluated for their importance to the species, the edible-nest swiftlets clearly showed an affinity to HaFC > HaG >AFC, in that order. Except HaG, all microhabitats lie higher than the forest canopy. The affinity of the edible-nest swiftlets towards HaG, the microhabitat above open land, was surprising as the species is known to prefer forest areas for foraging. As discussed earlier, the spatial variation in the foraging manoeuvres of the edible-nest swiftlets indirectly explains the relative consistency of prey base in these two habitats and also indicates that the insect diversity in the HaG may not be changing much. On the other hand, the glossy swiftlets showed their affinity towards microhabitats IFC and ISC inside the canopy. The importance of the forest was evident for the edible-nest swiftlets, who prefer foraging grounds in forested areas and at heights above the canopy level. The wild population of glossy swiftlets showed their affinity towards both the available habitats.

In complete concurrence with the previous studies, it was inferred that the cave-dwelling edible-nest swiftlets are dependent on forests and can be severely affected by the current rate of deforestation and habitat alterations. Swiftlets require large areas to forage, which means that changes in landuse even at a distance from the caves may affect their population. Glossy swiftlets show much plasticity in their habitat use. Habitat alteration around the caves may not have a marked effect on their foraging activities, but it could definitely interfere with their natural routine.

It may be assumed that the chicks of the edible-nest swiftlets, if raised by the glossy swiftlets, would follow the glossy swiftlets for foraging. Consequently, these chicks may also show plasticity in their habitat utilization. It is possible that the destruction of forests would affect the wild population of edible-nest swiftlets more adversely than the population raised in *ex-situ* houses.

CHAPTER 5

Breeding Biology of Edible-nest Swiftlet and Glossy Swiftlet in North and Middle Andaman Islands

5.1. Introduction

Swiftlets are monogamous birds (Medway 1962b, Langham 1980, Francis 1987, Kang *et al* 1991, Cranbrook and Lim 1999, Koon and Cranbrook 2002). Trogloxenes (species that need caves or cave like conditions to spend part of their life, such as bats), nest and roost in colonies of various sizes (Ford and Cullingford 1976, Nguyen *et al* 2002). Swiftlets and their edible nests have been of interest to humans since ages and were studied for their economic importance in South-east Asia (Harrison 1959, Francis 1987, Lau and Melville 1994, Koon and Cranbrook 2002, Nguyen et *al* 2002, Gusset 2004). Edible-nest swiftlets stay protected in natural caves and are also reared in *ex situ* breeding houses in countries like Indonesia. To increase the yield and population growth it was necessary to understand the breeding biology of the edible-nest swiftlets in most of its ranges. Detailed studies conducted on the *Aerodramus fuciphagus* (Medway 1962, Langham 1980, Kang *et al* 1991, Cranbrook and Lim 1999, Koon and Cranbrook 2002, Nguyen *et al* 2002) are possibly the only major documents focusing on the breeding biology of the wild population of the species. Most of the studied were restricted to taxonomy, status, populations and trade of edible-nest swiftlets (Medway 1957, Ali and Ripley 1970, Holyoak and Thibault 1978, Sankaran 1998 and 2001). Limited knowledge of the species in its different ranges is leading to a decline in the wild populations of the edible-nest swiftlets despite legal restrictions on nest collection under sustainable harvesting systems. Glossy swiftlets are known to breed in diverse habitats such as caves, abandoned houses, under jetties, under roofs of building and in galleries. They were studied initially in the hope that that they can be used as a commercially viable species, an enterprise which failed. Later, the species was studied to facilitate cross fostering of edible nest swiftlets in breeding houses. Burgess 1961, Medway 1969 b, Hails and Turner 1985, Francis 1987, Lim 1999 and Koon and Cranbrook 2002, are some of the studies on the breeding biology of the glossy swiftlet.

The endemic swiftlet sub-species, *Aerodramus fuciphagus inexpectatus and Collocalia esculenta affinis*, breed throughout the Andaman and Nicobar Islands. They have not been studied before except for their population status with some records of breeding seasonality in the wild by Sankaran (1998 and 2001). Unlike in some South-east Asian countries, the endangered edible-nest swiftlets of the Andaman and Nicobar Islands breed only in limestone caves, whereas the glossy swiftlet colonies commonly occur inside caves, crevices, under manmade structures like bridges and jetties and at the corners inside buildings and houses on the islands (Ali and Ripley 1970, Sankaran 1998 and 2001). The present study was restricted to the wild populations of these two co-existing species of swiftlets.

5.2. Objectives

An understanding of the breeding biology of the edible-nest swiftlet and the glossy swiftlet is essential for strengthening the ongoing *in-situ* and *ex-situ* conservation efforts. So data regarding the breeding biology of the two species was collected to understand:

- breeding seasonality, breeding chronology, and breeding success.
- important breeding behaviours like mating, nest construction, incubation, chick raring and parental care in the edible-nest swiftlets.

5.3. Study Area

In Andaman and Nicobar Islands edible-nest swiftlets are known to breed successfully in 29 protected caves in North and Middle Andaman Islands (refer chapter 6). Data for the edible-nest swiftlets was collected from 28 caves at Chalis-ek and one cave at Interview Island during the breeding season between 2001 and 2008. The nests of glossy swiftlets were surveyed from January to August between 2003 and 2008 in a cave at Interview Island (for details of the study area, refer chapter 2). Glossy swiftlets could not be studied at Chalis-ek because of the inaccessibility of the nests inside caves.

5.4. Field Methods and Data Analyses

5.4.1. Breeding Seasonality and Chronology

All the observations were carried out from January to June at Chalis-ek and from January to August at Interview Island between 2003 and 2008. Data on breeding seasonality and chronology of the edible-nest swiftlet was collected from 1,147 nests. Breeding seasonality and chronology of the glossy swiftlet was observed in 379 nests between 2003 and 2008. Breeding seasonality of the edible-nest swiftlet was considered from the date of commencing of nest construction (4th January on Interview Island and 7th January at Chalis-ek) till the fledging of the last chick. All the nests under observation were visited daily. During each visit the data on the presence of nest and the number of eggs or chicks in the nest was documented.

5.4.2. Breeding Behaviour and Parental Care

18 nests of the edible-nest swiftlets were observed by the Focal Animal Sampling Method (Altmann 1974). Sony Handycam with infrared night vision was used to observe activity on the nest from an approximate distance of 8 feet. The observations were done fortnightly in two sets of 12hours (0500hrs – 1700hrs and 1700hrs – 0500hrs). The nests were selected on the basis of their breeding stages to obtain data on the behavioural patterns in all possible stages. In a total of 672 hours of observation, 10,710 activities were recorded lasting a total of 86,457 seconds. Nest-building, mating, incubation and egg rolling, chick brooding and chick feeding were recorded during the observations.

5.4.3. Nest, Egg and Chick Measurements

Nests of both the species were measured with the help of vernier callipers for length (L), breadth (B) and depth (D). The length of the nest edge along the outer side (R) was measured with the help of a thread and measuring scale (Figure 16).

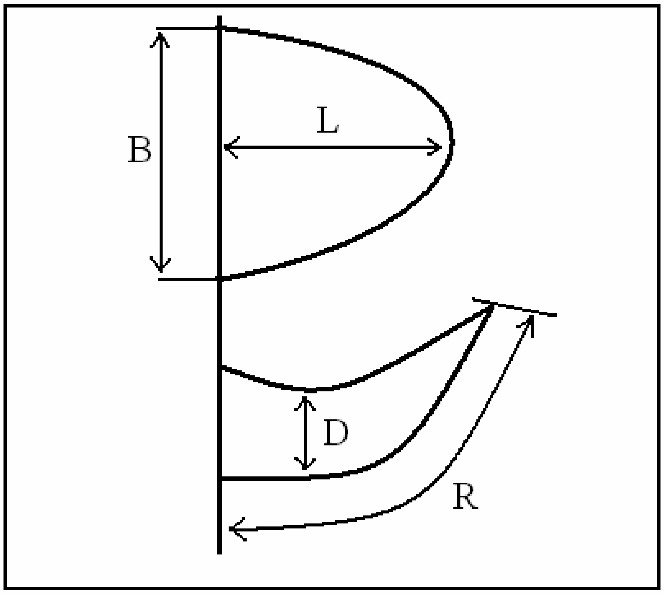


Figure 16 Diagram showing the measurements taken of the Edible-nest Swiftlet and Glossy Swiftlet nests. B: Length of the nest base along the rock wall, L: Length of the nest perpendicular to the rock wall, D: Depth of the nest at the place where eggs are laid, R: Length of the nest edge along the outer side (Nguyen *et al* 1998).

Eggs of both the species were measured for their length and breadth. Tail and wing length of the edible-nest swiftlet chicks were measured with vernier callipers and measuring scale. Eggs and chicks of both the species were weighed using a digital balance.

5.4.4. Dispersal Movements

As capturing and recapturing edible-nest swiftlets disturbs the colony and could lead to their relocation, recapture was limited to an hour at the cave opening on the Interview Island. It was done once in the first week of January and once again in the last week of July. Capture and recapture was done during early morning hours when the swiftlets leave their roosts. This exercise was very difficult and involved errors such as disturbance in the colony, escaping of the birds from mist-nets. The data thus collected could only be used for marking and identifying individuals, but not for population estimation.

5.4.4. Meteorological Parameters

Mean temperature (ºC), rainfall (mm) was recoreded everyday 6:00hrs and the number of rainy days were also recorded at the study area. Zeal thermometers were used for recording the meteorological parameters. Data on rainfall was collected using a rain gauge.

5.4.5. Statistical Analyses

Daily nest survey data was used to estimate breeding seasonality, chronology and success in both the species. Breeding success was estimated by calculating Apparent Nest Success (Jehle *et al* 2004). Spearman's correlation was performed to estimate the relation of breeding seasonality with temperature and rainfall in the area.

The period of nest construction was considered till the first egg was laid in the nest. The egg-laying period was defined from the day when the first egg was laid till the last egg is laid in the colony. The incubation period was estimated as the number of days between laying of the second egg and first hatchling in the nest. Fledgling period was estimated as the number of days between the hatching of the first egg and fledging of last chick. These parameters were estimated using data only from the nests where laying date, hatching date and fledging date were recorded with an error margin of ± 1 day.

Round the clock observations on the focal animal were grouped into six sets and each set was limited to four hours to estimate the activity budget and pattern. ANOVA and Kruskal-Wallis test were performed to get the temporal variations in the activities. Spearman's correlation was used to understand the relation of tail and wing length to the age of the chick.

5.5. Results

5.5.1. Breeding Seasonality

Edible-nest Swiftlet

Edible-nest swiftlets are seasonal breeders in the Andaman and Nicobar Islands and they breed from December to August. Nest construction starts December. Eggs are laid at the beginning of summer, around 20th February. Hatching takes place in the pre-monsoon season, after 15th March. The chicks start fledging during the pre-monsoon showers in April end and continue to fledge till the end of June. The second clutch of eggs is laid with the onset of the monsoon, around 15th May. Egg-laying continues through the peak monsoon till the end of July when the chicks starts hatching. The breeding season draws to a close with the fledging of the second brood during end of August (Figure 17). Breeding seasonality at Chalis-ek follows this general pattern, but the population at Interview Island delays its breeding by two weeks (Figure 18 and Figure 19).

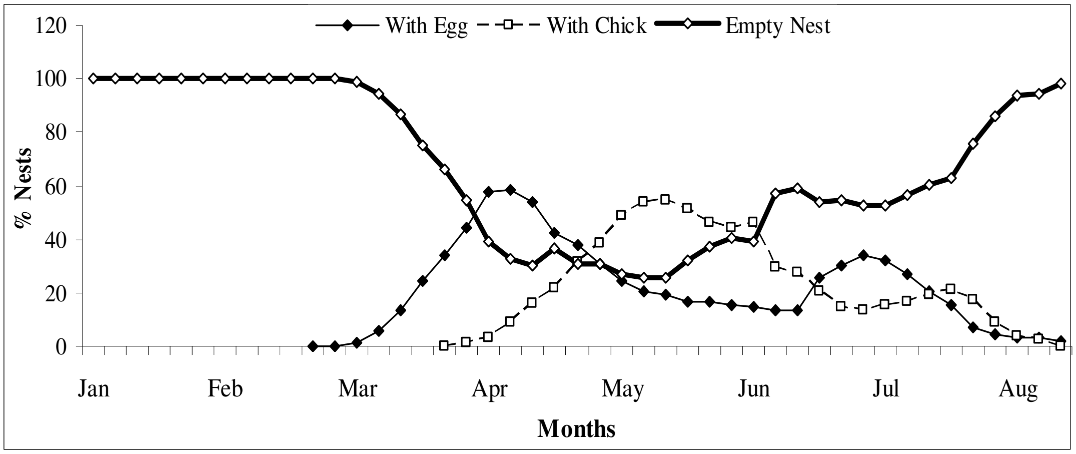


Figure 17 Breeding seasonality of the Edible-nest Swiftlets *A. fuciphagus* in the North and Middle Andaman Islands.

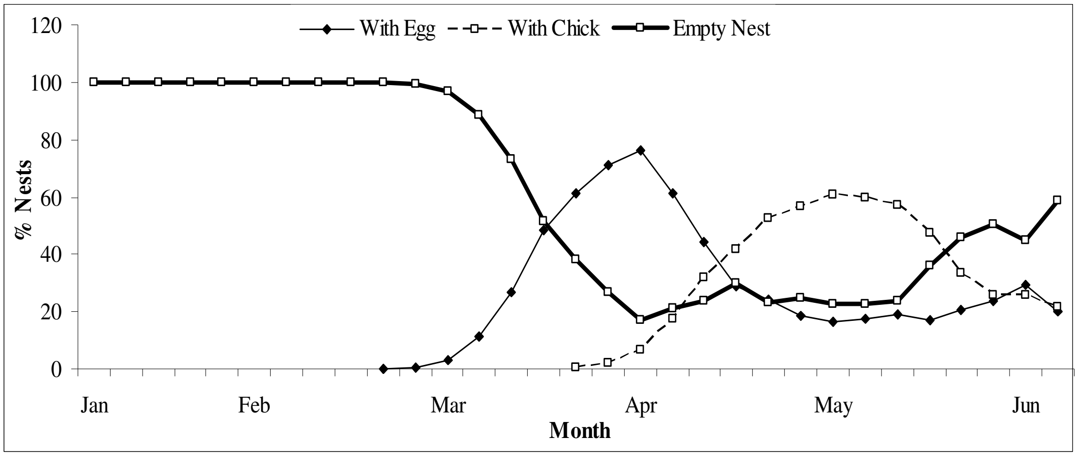


Figure 18 Breeding seasonality of the Edible-nest Swiftlets *A. fuciphagus* at Chalis-ek in the North Andaman Islands.

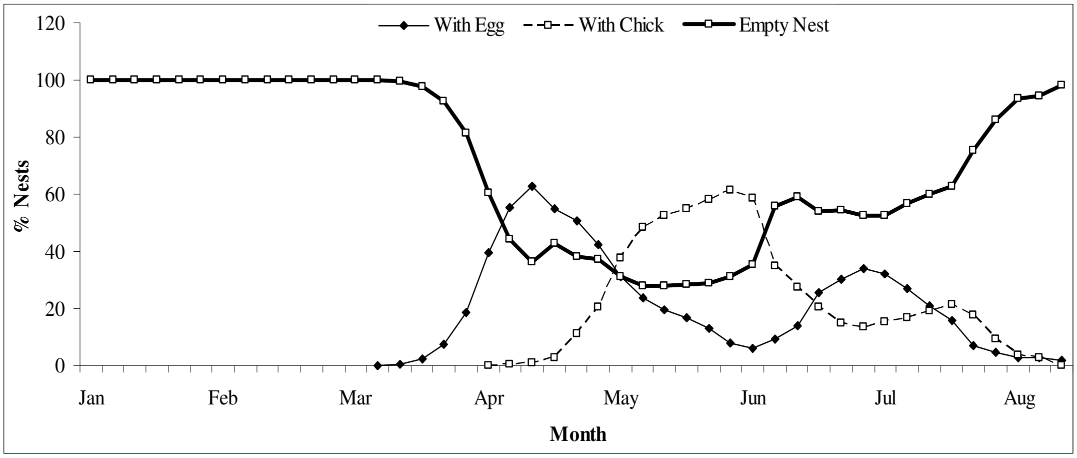


Figure 19 Breeding seasonality of the Edible-nest Swiftlets *A. fuciphagus* at Interview Island in the Middle Andaman Islands.

In case of the edible-nest swiftlets in Andaman and Nicobar, the proportion of nests with chicks (fledgling period) showed a significant correlation with the monthly average rainfall. Maximum precipitation was recorded in June as compared to the other observed months of the year ($r_2 = 0.743$, $p = 0.035$; Figure 20).

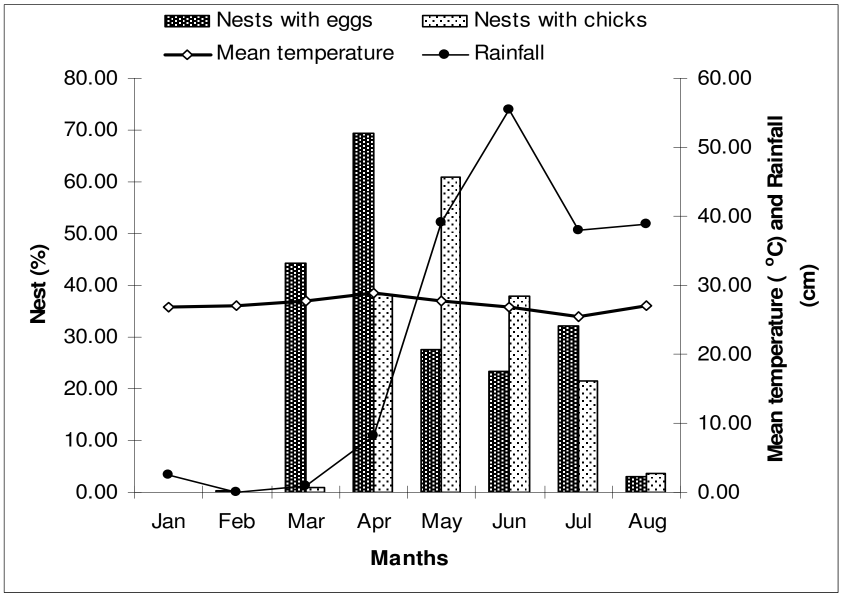


Figure 20 Bars represent the monthly proportion of nests with eggs and chicks of the Edible-nest Swiftlets in the North and Middle Andaman Islands and lines represent monthly variations in the temperature and rainfall.

Glossy Swiftlet

Glossy swiftlets of the Andaman and Nicobar Islands breed throughout the year. Observations made between January and August in the cave at Interview Island show that the first egg of the year is laid in winter by the end of December and the first hatchling comes after the 20th of January. As winter draws to a close by the end of February, most nests hold chicks. With the pre-monsoon showers in March the chicks starts fledging and a second clutch of eggs is laid. Most chicks finish fledging by the end of April and at the same time most nests has a second clutch of eggs. The second round of egg-laying finishes just before commencement of the monsoon, by which time most nests have chicks in them. As the monsoon progresses the proportion of nests with eggs or chicks declines continuously till the end of August (Figure 21).

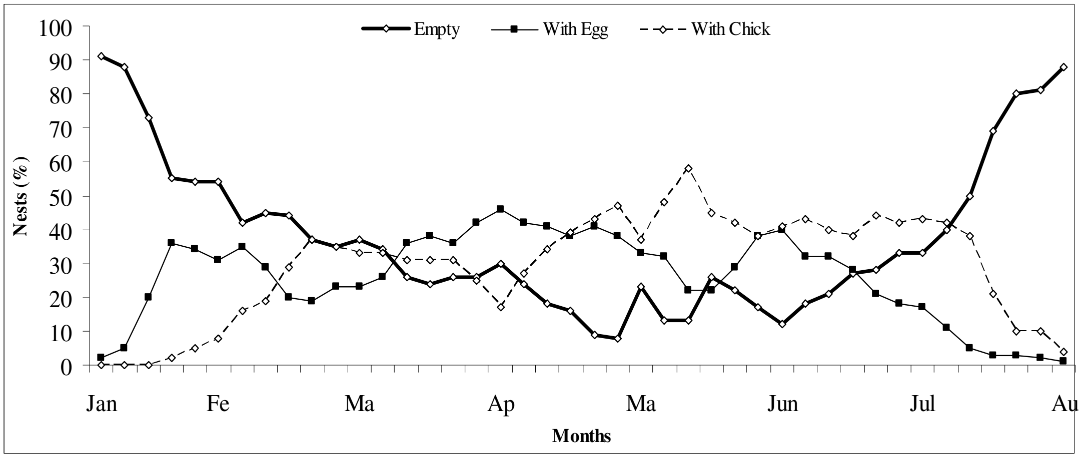


Figure 21 Breeding seasonality of the Glossy Swiftlets *C. esculenta* at Interview Island in the Middle Andaman Islands.

Spearman's correlation revealed that the breeding seasonality of glossy swiftlets does not have any significant correlation either with the rainfall or with the temperature (Figure 22).

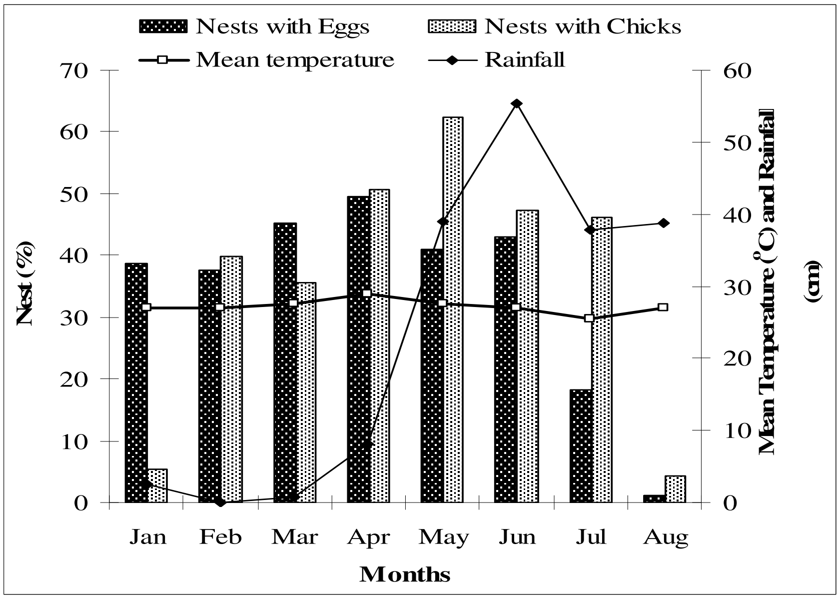


Figure 22 Bars represent the monthly proportion of nests with eggs and chicks of the Glossy Swiftlets in the North and Middle Andaman Islands and lines represent monthly variations in the temperature and rainfall.

5.5.2. Nest, Nest material and Nest building

The edible-nest swiftlets exclusively use their saliva as the nest material (Plate 3). The saliva is produced by their salivary glands, which get enlarged during the breeding season (Marshall and Folley 1956, Bernstein 1859 and Medway 1962).

As nest building begins, the breeding pair of edible-nest swiftlets clings to the wall at the point it has chosen as the nest-site. Each bird shakes its head several times to secrete saliva. The stringy saliva is taken out of its mouth and stuck on the rock wall with the help of its tongue. Clinging on the wall, the bird moves its body from side to side to spread the saliva. Once the base of the nest is made, the bird uses it as a perch and continues building the nest. Once the base grows large enough, it starts building the sides of the nest, giving it a cupped shape. After the curve is built the individual sits inside the half-built nest or hangs onto the edge of nest and builds it completely.

Nest building begins in early December. The raiding of caves by nest collectors starts simultaneously. Not a single nest is visible on the cave wall when the Forest Department opens its protection camps outside the caves on 4th January at the Interview Island and on 7th January at Chalis-ek every year. The date of commencement of the protection camps is considered the start of the nest construction period. Accordingly the edible-nest swiftlets were observed taking 75.3 ± 11.06 days to construct their nests. The glossy swiftlets took almost 70.2 ± 8.5 days for nest construction.

Glossy swiftlets use saliva to create a firm basal pad on the substratum. They bring in plant material and weave it using saliva (Plate 4). The materials used for nesting primarily consist of epiphytes, casuarina needles and grasses (>93%; n = 138). Twigs, barks, leaves, flowers, petals, roots and seed were also used present in the nests. Egg shells and feathers were also found embedded. In an accidental observation at the office of the Deputy Conservator of Forests, Mayabunder, an individual glossy swiftlet was observed bringing nest material, most probably an epiphyte, and weaving it using saliva as an adhesive. The individual took around 7 minutes and 21 seconds to finish weaving that piece of nest material before leaving the place probably to bring more material.

The nests of the edible-nest swiftlets were observed to be shorter, narrower and deeper as compared to the nests of the glossy swiftlets. The nest edge along the outer side of edible-nest swiftlet nests was longer than that of glossy swiftlet nests (Table 13).

Table 13 Measurements of the Edible-nest Swiftlet and Glossy Swiftlet nests. B: Length of the nest base along the rock wall, L: Length of the nest perpendicular to the rock wall, D: Depth of the nest at the place where eggs are laid, R: Length of the nest edge along the outer side (Nguyen et *al* 1998).

Species	L (cm)	B (cm)	D (cm)	R (cm)
Edible-nest Swiftlet	4.59 ± 0.59	6.15 ± 0.55	2.66 ± 0.50	4.65 ± 1.05
Glossy Swiftlet	4.68 ± 0.63	7.05 ± 0.55	2.52 ± 0.51	4.35 ± 1.05

Nest length (L) in both species was significantly correlated with the length of the nest edge along the outer side (R; Edible-nest Swiftlet: $r^2 = 0.397$, $p < 0.05$ and Glossy Swiftlet: $r^2 = 0.483$ $p < 0.001$). Nest length (L) of the Glossy Swiftlet was also negatively correlated with the depth of the nest (D; Edible-nest Swiftlet: $r^2 = -0.397$, $p < 0.05$ and Glossy Swiftlet: $r^2 = -0.307$ $p = 0.032$).

Among edible-nest swiftlets, both the members in the pair participate in nest building. With a significant variation, nest building was performed mostly at night (89%) between 1900hrs to 0500hrs when the individuals roost at their nesting sites inside the caves ($\chi2= 187.437$, df = 5, $p < 0.001$; Figure 23). Both individuals were estimated spending 95.52 ± 79.06 seconds for nest building every night with a significant variation in the different breeding stages of the nest ($\chi2 = 47.088$, df = 4, $p < 0.001$; Figure 24).

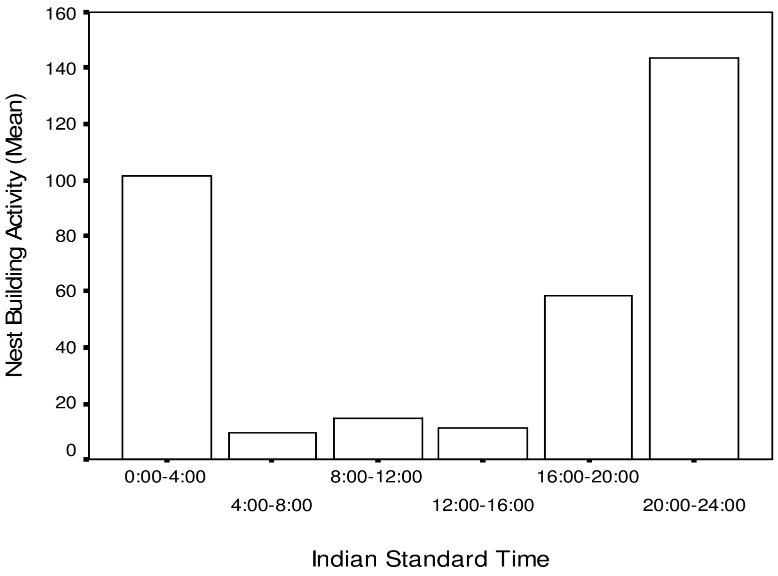


Figure 23 Temporal (hourly) variations in the Nest building activity of the Edible-nest Swiftlets in the North and Middle Andaman Islands.

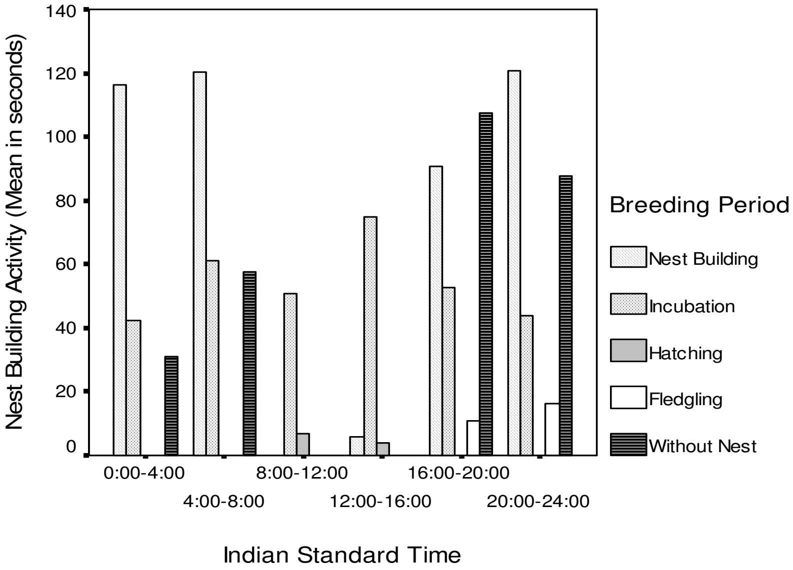


Figure 24 Bars representing temporal (hourly) variation the frequency of the Nest building activity in different breeding stages of the Edible-nest Swiftlets in the North and Middle Andaman Islands.

5.5.3. Copulation

Edible-nest swiftlets usually copulate on or beside their nests. Some species of swifts and swiftlets are known to mate in flight. Aerial mating could not be observed in edible-nest swiftlets during this study (refer chapter 4 for aerial behaviours). Male and female could be identified in the edible-nest swiftlets only during copulation. The male climbs onto the female with a soft chirp, while she is either sitting on the nest or hanging on the wall, she consents to his advances with partially opened wings to help him climb on. Then with another chirp the male mounts the female with a fluttering action and the female receives him with outstretched wings. After copulation the male returns to his position, sitting close to the female either on the wall or on the nest.

Copulation lasts for 3.5 ± 1.2 seconds (Range: 2–9 seconds n = 54). Pairs were observed copulating 3.3 ± 0.9 times in a single night. Edible-nest swiftlets were observed mating between 2400hrs-0400hrs on 45.5% of the occasions. 23.6% of mating observations were between 2000-2400hrs and 21.8% between 1600-2000hrs ($\chi2$= 50.838, df = 5, $p < 0.001$; Figure 25). The frequency of mating varies significantly with different stages of the breeding season ($\chi2$= 109.745 df = 4, $p < 0.001$; Figure 26) Copulation is most frequent during the construction of the nest (58.2%; n = 32).

5.5.4. Eggs, Egg laying and Incubation

Edible-nest swiftlets and glossy swiftlets generally lay a clutch of 2 eggs (n = 983), sometimes 1 (n = 41) and rarely 3 (n = 2; Plate 5 and Plate 6). The oval and white eggs are usually laid at night when the birds roost in the caves. Edible-nest swiftlets lay eggs with an interval of 2.07 ± 0.71 days (n = 1147) while glossy swiftlets take 1.79 ± 0.68 days (n = 379) between eggs. Almost similar incubation period was observed in both the species, with edible-nest swiftlets taking 19.6 ± 3 days (n = 1147) and glossy swiftlets taking 18.1 ± 2.3 days (n = 379) for incubation.

There is a significant variation in the length and breadth (Length: F = 290.134, df = 1, $p < 0.001$; Breadth: F = 921.211, df = 1, $p < 0.001$) of eggs of both the species. The eggs of the edible-nest swiftlet are 2.06 ± 0.11 cm long (n = 47) and 1.33 ± 0.03 cm in breadth while the eggs of the glossy swiftlet are 1.74 ± 0.06 cm long (n = 96) and 1.09 ± 0.03 cm in breadth (Figure 27).

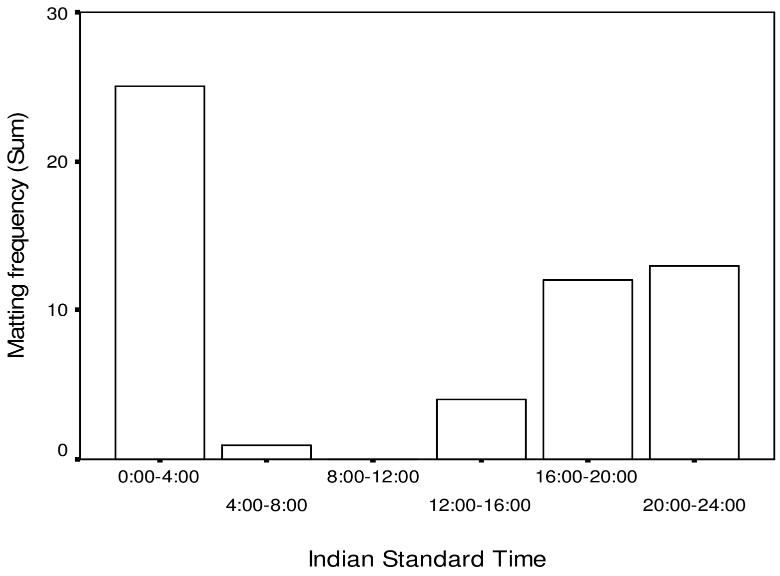


Figure 25 Temporal (hourly) variations in mating activity of the Edible-nest Swiftlets in the North and Middle Andaman Islands.

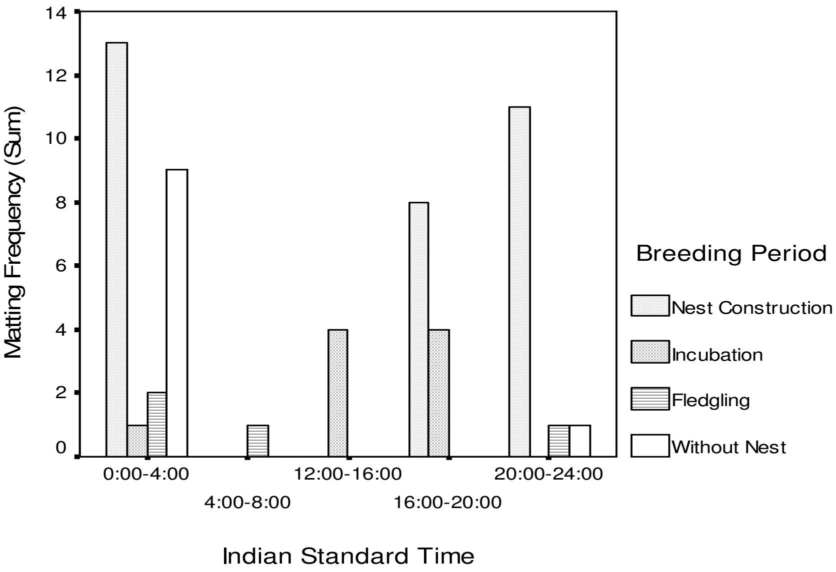


Figure 26 Bars representing temporal (hourly) variation in mating in different breeding stages of the Edible-nest Swiftlets in the North and Middle Andaman Islands.

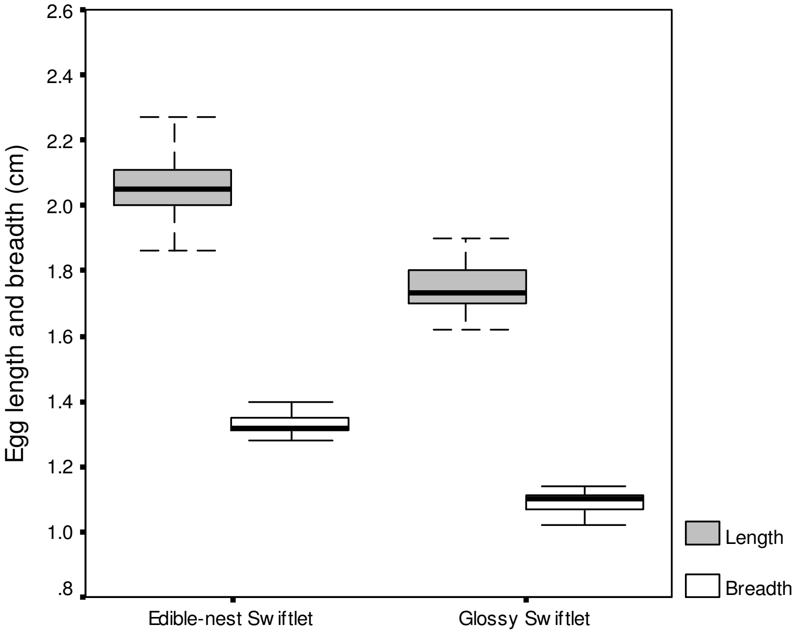


Figure 27 The Variations in the length and breadth of the eggs of the Edible-nest Swiftlet and Glossy Swiftlet

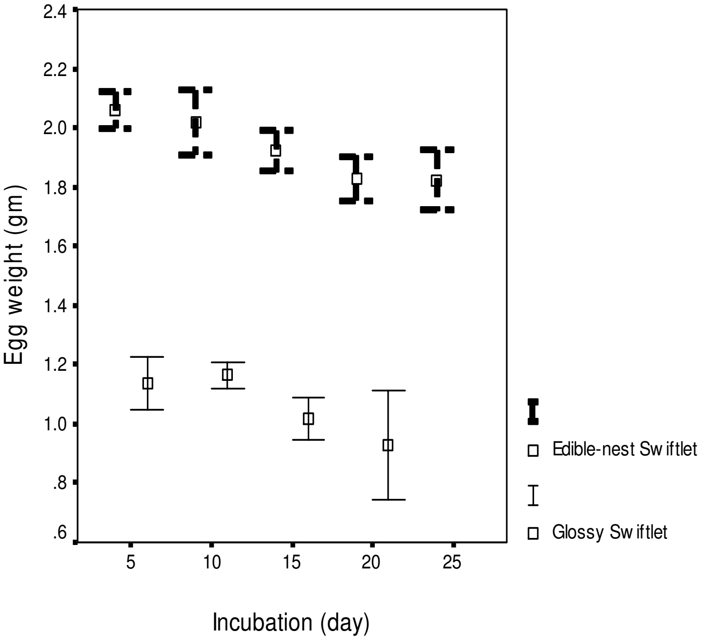


Figure 28 Variations in the egg mass according to the days of incubation in the eggs of the Edible-nest Swiftlet and the Glossy Swiftlet

The egg of the edible-nest swiftlet (n=107) weighed 1.92 ± 0.21 (Range: 0.8-2.4) gm and that of the glossy swiftlet (n=42) weighed 1.07 ± 0.16 gm (Range: 0.53-1.52;

Figure 28). The average weight of the egg reduces significantly as incubation progresses in both the species (Edible-nest Swiftlet: F = 6.501, df = 4, *p* < 0.001 and Glossy Swiftlet: F = 5.298, df = 3, *p* = 0.004).

Incubation in the edible-nest swiftlets starts after laying the last egg. Both the parents participate in incubation. The eggs were attended almost 93 % of the time. Each bout of incubation by an individual was observed to last for 5.45 ± 2.03hrs. The frequency of egg-rolling varies significantly according to the time of the day ($\chi 2$= 43.4, df = 5, *p* < 0.001; Figure 29).

5.5.5. Hatching

Eggs of the edible-nest swiftlets generally hatch at night. On one occasion hatching took place at 1600 hrs and it took 23min 17sec for the hatchling to come out of the shell, body-first followed by the head. The egg was broken into two and the eggshell was split in an almost homogeneous zig-zag pattern.

Swiftlets in Andaman have hatching asynchrony. It takes 2.6 ± 1.3 days (n = 1147) between hatching of two eggs of the edible-nest swiftlet, whereas it takes 2.3 ± 1.1 days in the case of the glossy swiftlet (n = 379).

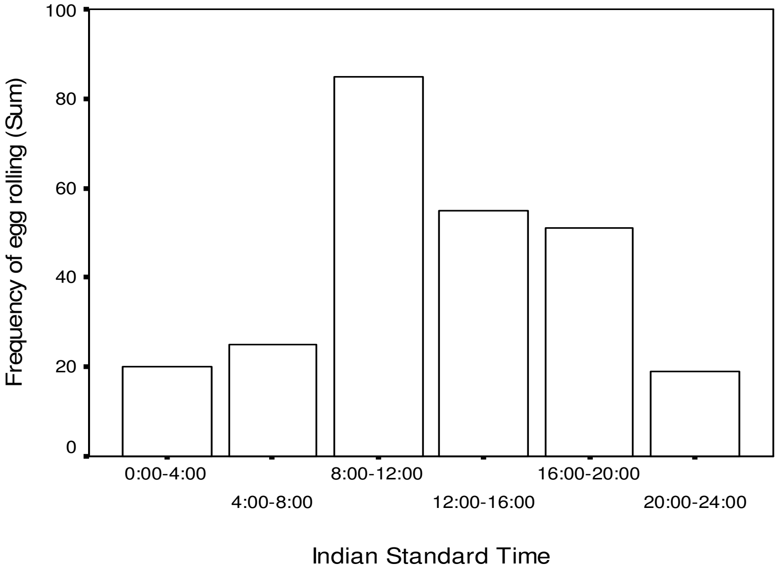


Figure 29 Temporal (hourly) variations in the egg rolling activity in the Edible-nest Swiftlets in the North and Middle Andaman Islands.

5.5.6. Chick growth, Fledging and Feeding visits

The chicks of swiftlets are psilopaedic (naked at the time of hatching), altricial (born with eyes closed and incapable of locomotion) and nidicolous (remain in the nest for a long time after hatching and are fed by parents; Pettingill 1970; Plate 7). In two observations, the parent bird was seen removing the egg shells from the nest at night after 2 or 3 days of hatching.

The fledgling period is longer in the edible-nest swiftlet (43.03±6.44 days; n=1147) than in the glossy swiftlet (40.6±3.6 days; n=379). Edible-nest swiftlets lay a second clutch 7.04 ± 5.11 (n = 471) days after successful fledging, whereas glossy swiftlets take 5.55 ± 3 days (n = 213) to lay their second clutch.

Tail and wing lengths of the edible-nest swiftlet chicks have shown a significant correlation with each other ($r_2 = 0.929$, $p < 0.001$). They also had a significant variation in their lengths with the age of the chick (Tail: F = 195.853, df = 4, $p < 0.001$ and Wing: F = 94.503, df = 4, $p < 0.001$; Figure 30).

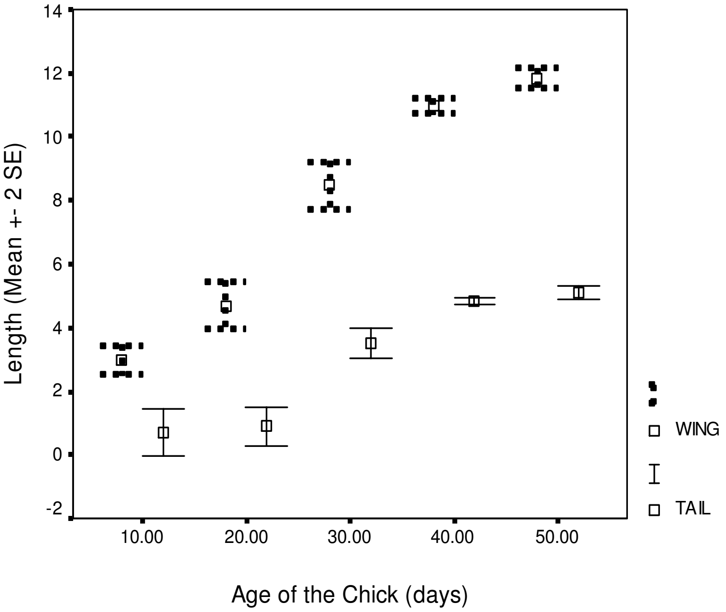


Figure 30 Variations in the tail and wing length of the chicks of the Edible-nest Swiftlets in different age classes

Chicks of the edible-nest swiftlets and the glossy swiftlets weigh 5.17 ± 2.57 gm (Range: 1.23-13.03; n = 158) and 5.62 ± 2.43 gm (Range: 0.88-8.84; n = 30) respectively. The body weights of chicks in both the species has shown a significant difference among different age groups (Edible-nest Swiftlet: F = 39.084, df = 3, $p <$ 0.001 and Glossy Swiftlet: F = 22.127, df = 3, $p < 0.001$; Figure 31).

In the edible-nest swiftlets, both parents take part in nest construction, incubation and care of the chicks. Parents were observed brooding the chicks for 6.44 ± 2.17 days (n = 31) of the initial stage after hatching. Both parents visit the nests separately for feeding the chicks. Feeding frequency in the edible-nest swiftlets varies significantly with the time of the day ($\chi2$ = 72.340, df = 5, $p < 0.001$) However, feeding visits (27.7%) were seen between 16:00hrs-20:00hrs. 27% of feeding visits were between 4:00hrs-8:00hrs (Figure 32).

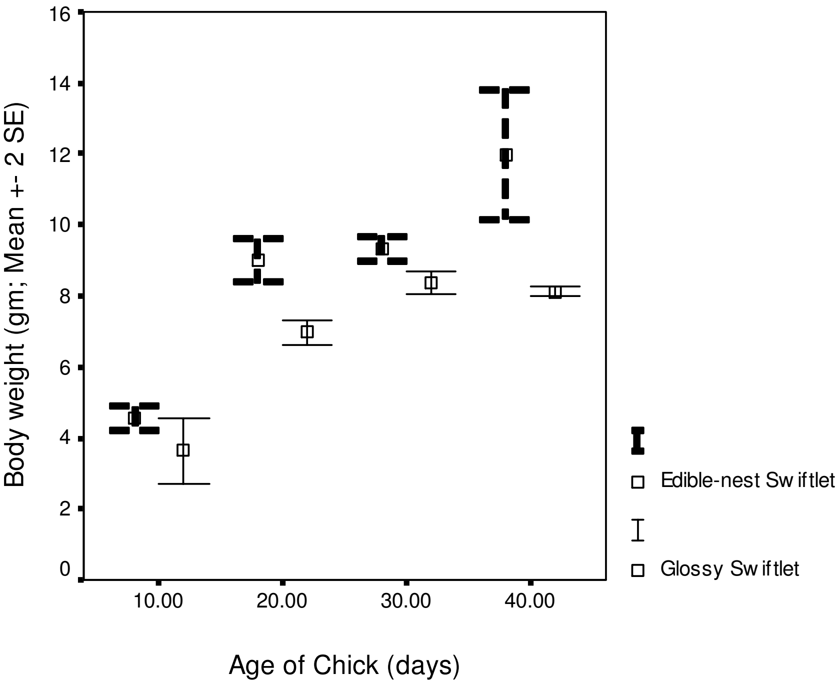


Figure 31 Variation in the body mass of the chicks of the Edible-nest Swiftlet and the Glossy Swiftlet in different age classes.

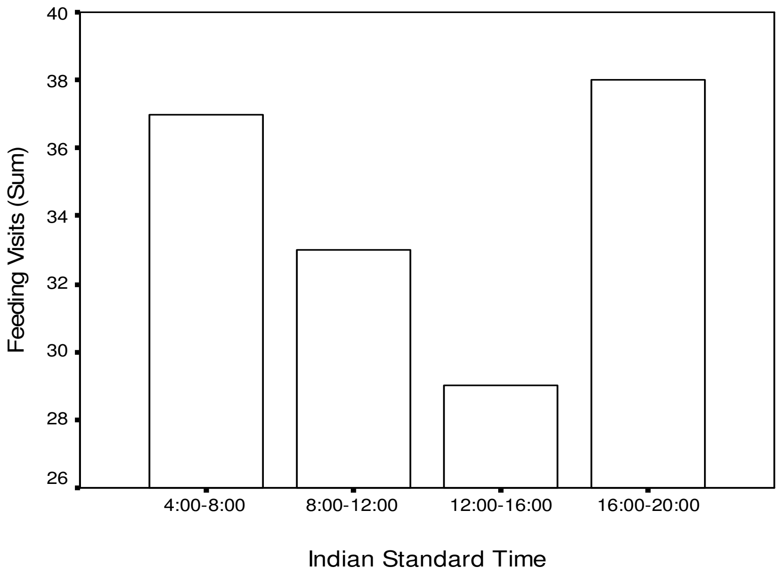


Figure 32 Temporal (hourly) variations in the frequency of feeding visits of the Edible-nest Swiftlet in the North and Middle Andaman Islands.

The feeding visits vary significantly according to the age of the chicks in the nest (t = 4.706, df = 16, $p < 0.001$), averaging at 2.25 ± 1.96 visits per day. Though feeding visits do not vary significantly with the number of chicks in the nest, there is a variation in the number of feeding visits with the age of the chicks (Nest with one chick: t = 3.935, df = 8, $p = 0.004$ and nest with two chicks: t = 3.215, df = 7, $p = 0.015$; Figure 33).

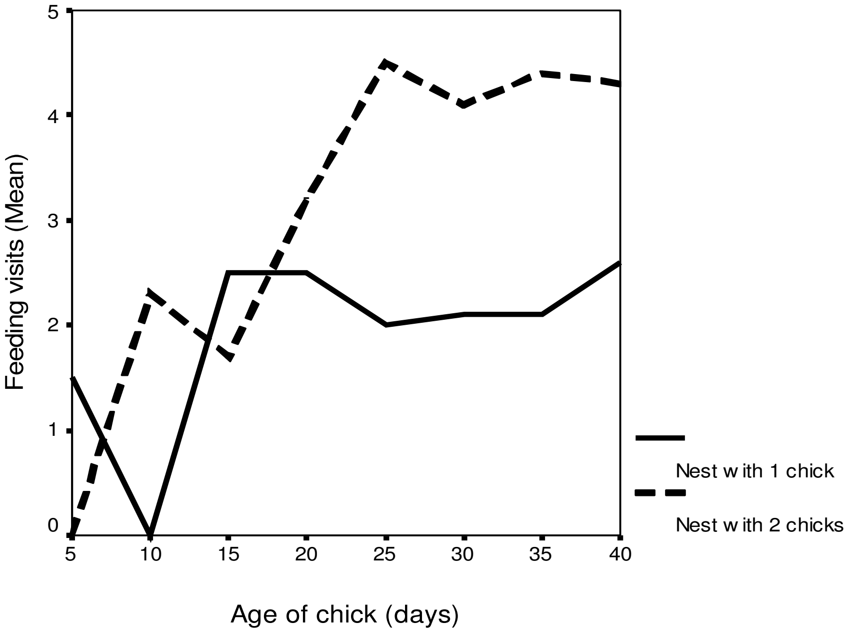


Figure 33 Variations in the feeding visits to the nest by parents in the Edible-nest Swiftlet during different age classes of the chicks in the nest

5.5.7. Breeding Success

Edible-nest swiftlets did not show any significant difference in success in hatching, fledging and breeding in the two study areas. There was a comparatively higher hatching success, lower fledging success and higher breeding success at Chalis-ek than at the Interview Island. The second clutch at the Interview Island had a higher hatching success but very little fledging and breeding success compared to the first clutch (Table 14).

Table 14 Table representing the clutch wise proportions of the hatching, fledging and breeding success observed in the Edible-nest Swiftlets of Chalis-ek and Interview Island, North and Middle Andaman Islands

Site	Clutch	# Nests	Hatching success	Fledging success	Breeding success
Chalis-ek	***1st***	921	63%	71%	42%
Interview Island	***1st***	390	47%	81%	40%
	2nd	226	69%	31%	21%

Glossy swiftlets at the Interview Island show the highest hatching success during the 2nd clutch, followed by the 3rd and the 4th clutch. The fledging and breeding success is also more in the 2nd clutch as compared to the 3rd clutch (Table 15).

Table 15 Table representing the clutch-wise proportions of the hatching, fledging and breeding success observed in the Glossy Swiftlets of Interview Island, Middle Andaman Islands

Site	Clutch	# Nests	Hatching success	Fledging success	Breeding success
Interview Island	***1st***	-----	----	----	----
	2nd	94	36%	73%	39%
	3rd	86	29%	61%	28%
	4th	51	31%	----	----

When the first and the second clutch of the edible-nest swiftlet was compared with the second and the third clutch of the glossy swiftlets for their hatching, fledging and breeding success, Mann-Whitney test did not show any significant difference.

5.5.8. Movement, Post-natal Dispersal and Breeding Age of Chicks and Adults

Swiftlets of Andaman and Nicobar Islands were never observed migrating out of their foraging ranges. Chicks ringed on the nests (n = 623) before fledging in the cave on the Interview Island were recaptured (n = 8) in other caves (n = 4) on the same island.

The farthest cave from which the bird was seen was around 5.79 km away. Of these chicks, more than 11% were recaptured in the same cave between 2001 and 2008. The chicks fledged in the first year were recaptured in the second year. They had returned to breed only after the first batch of the second year had fledged. Of the148 adults ringed in 2001, 4 were found still breeding in the same cave in 2008, indicating that the edible-nest swiftlets can breed for at least 10 years.

5.6. Discussion

5.6.1. Breeding seasonality

All the swiftlet species found in the Indian region, *Aerodramus unicolor* in the Western Ghats, *Aerodramus brevirostris* and *Aerodramus maximus* in the Himalayan region and North-East, and *Aerodramus fuciphagus* in the Andaman and Nicobar Islands, have well-marked breeding seasons. An exception to this is the *Collocalia esculenta* which breeds throughout the year in the Andaman and Nicobar Islands (Sankaran 1998, Josep *et al* 1999).

Observations of Langham (1980) on *Aerodramus fuciphagus amechanus* in Malaysia and of Medway (1962 a, c) on several other species in Sarawak show that the swiftlets nesting at low altitudes breed almost round the year. In contrast, Nguyen et *al*'s (2002) observations show that despite being the ones living in the farthest north, the *Aerodramus fuciphagus germani* and the *Aerodramus maximus msximus* in Vietnam have well marked breeding season. Likewise, the edible-nest swiftlet *Aerodramus fuciphagus inexpectata* of the Andaman and Nicobar Islands also has a well-marked annual breeding season with two broods (Sankaran 1998). Like some populations of the white-nest swiftlets *A. fuciphagus germani* in Vietnam, the edible-nest swiftlet of the Andaman Islands also breeds from December to August with two peaks in egg-laying and fledgling, as opposed to the smaller glossy swiftlet of the Andaman Islands which fledges four broods during a long annual cycle. Medway (1962b) observed three successive breeding peaks, in October, March and July for the glossy swiftlets at Niah. In Eastern Sabah, at a colony near Sandakan, Burgess (1961) observed two annually recurrent peaks, in April and July and nearby at Gomantong Francis (1987) reported four annual peaks in October, January, May and July. Comparable to these reports, the colony of glossy swiftlets at the Interview Island bred throughout the year with peaks in January, April and July, and probably a fourth peak in November. According to Lim's (1999) observations in the middle Baram, eggs were found at all times of the year in one of the colonies of the glossy swiftlet though the seasonal peaks coincided in the breeding colonies. The same may be true in the case of the glossy swiftlet colonies in the Andaman and Nicobar Islands.

Breeding seasonality of species depends on several aspects such as food availability, foraging and nesting climate. Edible-nest swiftlets are found foraging mostly in the higher altitudes above the canopy while glossy swiftlets are known as closed canopy foragers, mostly foraging at the tree canopy level (for details refer chapter 4). The tropical climate of Andaman provides high precipitation and wind from September to November. These conditions are not considered favourable to aerial foragers especially the species foraging at higher altitudes. Another reason for foraging above the canopy could be the abundance of insects, which reduces in number at higher altitudes in tropical climates due to strong winds (Medway 1962b, Hails and Turner 1985, Nguyen et *al* 2002, Anonymous 2007). This could be a plausible reason for the edible-nest swiftlets to complete most of their fledging in the pre-monsoon season, with a few late breeders completing by early monsoon. The seasonality of the edible-nest swiftlet is commonly linked to fluctuations in rainfall that affects plant growth and consequently insect population (Francis 1987, Nguyen *et al* 2002, Koon and Cranbrook 2002, Medway 1962a). Being low-altitude and closed-canopy foragers, glossy swiftlets may not be affected much by the windy conditions or high precipitation. Considering that glossy swiftlets show plasticity in their resource utilization (refer chapter 4), a wide range of food available could allow them to breed even under extreme climatic conditions.

5.6.2. Nest, Nest Material and Nest Building

Even during the non-breeding season, edible-nest swiftlets were observed coming to the same caves and roosting at or beside their nest-sites, even though they were never observed building nests (as reported by nest collectors). The salivary glands in this species enlarge only during the breeding season (Bernstein 1859, Marshall and Folley 1956, Medway 1962). Except *A. fuciphagus*, all the other swiftlets in India use an admixture to build their nests. *A. unicolor,* also known as Indian black-nest swiftlet, uses plant content sparingly and often lines the nest base with feathers and pure saliva (Ali and Ripley 1970, Josep *et al* 1999). *A. brevirostris* uses large quantities of vegetation material glued with very little saliva. *C. esculenta* also uses saliva sparingly to bind the nest material. The nest building behaviour in the Andaman Islands is similar to that reported of the edible-nest swiftlets by Nguyen et *al* (2002) in Vietnam. Nest building by the other races of the glossy swiftlet as described by Spennemann (1928) and Medway (1962b) in Java and Vietnam is very similar to that observed in Andaman and Nicobar Islands. The nest composition has been described in detail by Wang (1921), Frank (1926), Medway (1962a, 1969), Koon and Cranbrook (2002) and Kong *et al* (1987) (refer section 1.4.1).

The nest construction period of the edible-nest swiftlets was always studied in relation to the number of harvests, wherein the birds were compelled to repeatedly build nests under harvesting pressure (Medway 1962b, Kang *et al* 1991, Nguyen *et al* 2002). The population in the Andaman and Nicobar Islands was always under uncontrolled nest collection and this could be a reason for the swiftlets at Andaman to build their nests faster and the nest-building period to stretch longer than in other parts of their distribution.

Kang *et al* (1991) reported two peaks in nest building activities in A. maximus in Sarawak, midnight 1:00hr and between 5:00-6:00hrs in the morning. The peaks of the nest building in the Edible-nest Swiftlets of the Andaman Islands were observed between 20:00 and 24:00hrs followed by 0:00 to 4:00hrs but the time spent for the nest building during nest building period has three peaks between 20:00-24:00hrs followed by 4:00-8:00hrs and 0:00-4:00hrs. Compared with the White-nest Swiftlet's nest of Nguyen *et al* (2002), the nests of the Edible-nest Swiftlets were found smaller. In the same document Nguyen and others explains that temperature, atmospheric pressure, wind speed and the population size also can affect nest building in the Edible-nest Swiftlets.

5.6.3. Copulation

Lack (1956), Fischer (1958), Smith (1950) and Medway (1962b) described that coition may occur in flight as well as at the nest in several species of swifts and swiftlets. Medway (1962b) has described the copulation observed among *A. maximus* in Gomantong caves, North Borneo, and among *A. Salangana* at Niah. Glossy swiftlet *C. esculenta* were observed to copulate near the nest in Java (Spenneman 1928). Copulation in the edible-nest swiftlets was observed near and above the nests but aerial coition was not encountered in either species in the Andaman and Nicobar Islands. *A. brevirostris* is the only swiftlet found in India that has been observed in aerial coition (Ali and Ripley 1970). The copulation observed in the edible-nest swiftlets in the Andaman Island is similar to that of *A. salangana* and *A. Maximus* by Medway (1962b) in the Niah. Unlike Medway's (1962b) observation and akin to Nguyen *et al's* (2002) findings, most copulations in the edible-nest swiftlets of the Andaman Islands took place on the nest. Very few copulation events occured on the wall close to the nest. *A. unicolor* in Sri Lanka has been observed copulating near the nest. The copulation in the edible-nest swiftlet in the Andaman Islands was observed in all the breeding stages, although its frequency is more during the period of nest building and mostly at night. As Koon and Cranbrook (2002), Nguyen *et al* (2002) and Medway (1962a) explained in the other species, edible-nest swiftlets do not visit the nest during the day since their nests are made solely of saliva and they do not need to search for vegetative material for nest construction in the daytime.

5.6.4. Egg, Egg laying and Incubation

All swiftlets lay white and matt-surfaced eggs (Medway 1962b, Nguyen *et al* 2002, Koon and Cranbrook 2002). Species in the Andaman and Nicobar Islands lay two eggs in a clutch. The eggs of the edible-nest swiftlets are heavier than those of the glossy swiftlets. Nguyen *et al* (2002) compared the egg size of the edible-nest swiftlet *A. f. inexpectatus* eggs with that of other subspecies, *A. f. germani* (1) and *A. f. germani* (2) (as described in Nguyen *et al* 2002) and found it to be smaller, and the egg mass in *A. f. inexpectatus* was found to be less than in *A. f. germani* (1). These differences in the size and mass can be attributed to the size of the bird. The incubation period of the edible-nest swiftlets in Andaman and Nicobar seems to be shorter than the other subspecies studied by Langham (1980) in Malaysia, Lee and Kang (1994) in Singapore and Nguyen (2002) in Vietnam. The average size of the glossy swiftlet eggs measured in Sarawak by Medway (1962b) is almost similar to the eggs of the glossy swiftlets in the Andaman and Nicobar Islands, but the average incubation period in the glossy swiftlets of the Andaman and Nicobar Islands is slightly shorter compared to the glossy swiftlets observed by Medway (1962b) in Sarawak. The difference in the incubation period is presumably because of the vast difference in sample size. While Medway (1962b) observed only 10 clutches, 379 clutches were examined in the present study. As the incubation period could mostly depend on temperature and humidity mainly inside the caves and also outside, a shorter incubation periods in both the species could be the result of the cave structures and the temperature and humidity variations between the caves in the Andaman and Nicobar Islands and the caves in Vietnam, Sarawak, Singapore and Malaysia. Lengths of the incubation bout presumably depend on the foraging success of the individuals. In 98% of instances the incubating bird does not leave the eggs till its partner relieves it. Rolling of eggs is performed during incubation to maintain uniform temperature. It mostly depends on the ambient temperature. Egg-rolling was observed often from 0800hrs-1200hrs followed by 1200hrs-1600hrs and 1600hrs-2000hrs.

5.6.5. Hatching, Chick Growth, Fledging and Feeding Visits

Asynchronous hatching is observed in all subspecies of the edible-nest swiftlet all over its distribution. Many theories are proposed to explain this, one of them suggests that asynchronous hatching ensures successful fledging of at least one chick (Francis 1987).

Hatching successes in the *Aerodramus fuciphagus* observed by Langham (1980) in Malaysia, Nguyen (1992) and Nguyen *et al* (2002) is comparatively higher than the hatching success observed in the Andaman Islands. However the hatching success of edible-nest swiftlets in the Andaman Islands was higher than of the *A. maximus* and *A. salangana* observed by Medway (1962b). The hatching success was very high at Chalis-ek. The hatching of the second clutch observed at the Interview Island is slightly more successful than that of the Edible-nest Swiftlets in Malaysia (Langham

1980). The hatching success in the glossy swiftlets of Sarawak was given by Medway (1962b) and is found much higher than the glossy swiftlets on the Interview Island.

After hatching the chicks grow very slowly, resulting in a long nestling period. This may depend on food availability (Francis 1987) or the lack of the post- fledging parental care which results into a prolonged pre-fledging parental care. The edible-nest swiftlets in the Andaman Islands have almost the same fledgling period as in other subspecies (Langham 1980, Cranbrook 1984, Francis 1987, Lee and Kang 1994, Nguyen 1994 and 2002) in Vietnam, Malaysia, and Singapore. The body mass of the edible-nest swiftlets of the Andaman and Nicobar Islands is lesser than that of the white-nest swiftlets of Khanh Hoa and Da Nang in Vietnam. In case of the glossy swiftlet, both the incubation period and the fledgling period were shorter than the observations of Medway (1962b) in Sarawak, The fledging period of both the swiftlets of the Andaman and Nicobar Islands is less than that of the black-nest swiftlets and mossy-nest swiftlets of Sarawak.

The body mass of the chicks increases at a regular rate for 25 – 30 days, after which the growth rate slows down. After the age of thirty days, the chicks get a little heavier than the adults, but lose this excess weight at the time of fledging. The same was observed in the white-nest swiftlets of Vietnam and also in Malaysia (Nguyen *et al* 2002, Langham 1980). Nguyen *et al* (2002) has given a detailed description of the developmental stages of the chicks with their age, which is similar to the developmental stages of the edible-nest swiftlets of the Andaman and Nicobar Islands.

The chick that hatches first succeeds more often than the second chick, which is smaller and weaker. This competition for survival between the chicks may lead to adaptations in the behaviour of chick feeding, observed in the edible-nest swiftlets of the Andaman and Nicobar Islands. As in other swifts and swiftlets, the young ones are fed by regurgitation of a pellet of compressed insects. On an average, edible-nest swiftlets are observed feeding chicks far less often than other Aves, which has been attributed to foraging success and the growth rate of the chicks (Koon and Cranbrook 2002). Both the parents feed the chicks and the feeding visits vary according to the age of the chicks. When the first chick hatches both the parents feed the same chick and hence their feeding visits are few. When the second chick hatches, the feeding strategy changes and each parent bird starts feeding only one chick per visit. The chicks are fed according to the foraging success. Long period observations revealed that the parent birds feed the chicks alternately, one chick per visit. But as the parents cannot be differentiated morphologically, it is very difficult to say whether each parent feeds only one chick or if both the parents feed the two chicks alternately.

The fledging success of the first clutch in the edible-nest swiftlets in the Andaman Islands is higher than that in Malaysia and Vietnam (Langham 1980, Nguyen 1992 and Nguyen *et al* 2002) but the fledging success of the second clutch in the Andaman Islands is lesser than in Malaysia. The fledging success in the glossy swiftlets of the Interview Island is almost similar to the fledging success observed in Sarawak (Medway 1962b).

Langham (1980) estimated a slightly higher breeding success in the first clutch of the edible-nest swiftlets than in the second clutch in Malaysia. But in the Andaman Islands, the difference in breeding success was much wider. Since hatching, fledging and breeding success depends on several parameters, including rainfall of the area, breeding seasonality, the structure and microclimate in the caves (Nguyen *et al* 2002), physical parameters of the rock at the nest-sites, predation pressure (discussed in chapter 3), food availability, foraging success and the harvest of nests by humans, it may not be reasonable to draw comparisons. Despite the difference in the hatching and fledging success of the edible-nest swiftlets at Chalis-ek and at the Interview Island, the overall breeding success is almost the same. The difference in the hatching success and fledging success between Chalis-ek and the Interview Island can be the result of the differences in nest-sites characters, the micrometeorology inside the caves, the structure of the caves and also the general habitat around the caves (for details refer chapter 3).

5.6.6. Movements, Post natal Dispersal and Breeding age of chicks and adults

Swiftlets of the Andaman and Nicobar Islands were never observed migrating. Generally, the foraging ranges of the swiftlets are known to be very big, dispersing through vast ranges. But the birds return to their roosts at night. Sometimes glossy swiftlets were found not returning to the nests, perhaps because they had ventured too far for foraging and could not return before dark. However, they were observed coming back the next day. Only *A. brevirostris* was recorded migrating to the north Andaman Islands. There are two unconfirmed records of individuals migrating from the north during the winters when the conditions get extreme in the Himalayas and North-east India. Studies on the common swifts show that these birds fly almost 3000m above the ground for their aerial roosting and they come back to the ground only for feeding. This phenomenon is usually observed in year-old birds. The adult birds are also found in aerial roosting colony (Josep *et al* 1999). Under the conservation program for the edible-nest swiftlet, chicks were ringed in 2001 in the nests before fledging and attempts were made to recapture them. This revealed that fledged chicks return to the caves only halfway through the next breeding season and start breeding in their second year. It has been observed in many species that the fledglings starts breeding in the second year of their fledging or even take three years to attain sexual maturity (Medway 1966, Josep *et al* 1999, Koon and Cranbrook 2002). The aerial roosting studies suggest that year-old chicks of the edible-nest swiftlets in the Andaman and Nicobar islands go for aerial roosting and return the next year. During recapture attempts in some caves on the Interview Island, ringed chicks were recaptured from four caves that were not their fledging cave. This shows an inter-colonial dispersal in the fledglings of the edible-nest swiftlets. The adults were never recaptured from caves other than their own, indicating that adults do not disperse from their breeding caves. This dispersal among chicks may be because of several reasons such as to maintain genetic variations in the colonies and to avoid shrinking the gene pool. Also, the carrying capacity of the colony and the availability of nest-sites could force chicks to colonize other caves, since edible-nest swiftlets are known to show strong nest-site fidelity i.e. the same pair returns to nest at the same point. Until one or both of them either die or decide to leave the nest-site, a new pair cannot build its nest at that point. The youngest bird observed breeding in the cave on the Interview Island was two years old and the oldest known breeding bird was at least 10 years old, ringed in 2001. Considering that 2001 was its first breeding season, it must have fledged in 1999 or earlier.

This information can help us to understand the biology of the edible-nest swiftlet and use it to improve the *in-situ* conservation of the edible-nest swiftlets in the Andaman and Nicobar Islands. If harvesting of the edible nests takes place in the future, this information can help to schedule and plan harvests and control the frequency of harvests ensuring minimum disturbance to the breeding birds.

Though the glossy swiftlets breed throughout the year, their peak periods of egg-laying and fledgling in the wild coincide with that of the edible-nest swiftlets, hence they can be used as the most suitable surrogate parents to rear the chicks of the edible-nest swiftlets. Further studies of the glossy swiftlet's breeding biology in urban areas can also help us understand the viability of using the species for fostering the eggs of the edible-nest swiftlets in urban environs.

CHAPTER 6

Impact of Protection on the Wild Population of the Edible-nest Swiftlet *Aerodramus fuciphagus* in the Andaman and Nicobar Islands

6.1. Introduction

It was only during the 16th century that the edible-nests of swiftlets became an attraction to human beings. By the early 18th century, due to its rising demand, swiftlet nest production and trafficking became one of the biggest illegal trades. Because of the high demand and value in the international trade, today the edible nest is categorized among the world's most valuable natural products, resulting in its extensive exploitation throughout its range (Medway 1963, Lau and Melville 1994, Koon and Cranbrook 2002, Nguyen *et al* 2002). The intensity of nest collection reaches up to four or five times a year, which prevents the species from raising even a single brood. The over-exploitation of its nests in the last few decades has caused a drastic reduction in the wild populations of the edible-nest swiftlets across their range, some as much as 80%-90% and led to its local extinction in certain areas (Koon and Cranbrook 2002). According to Nguyen *et al* (2002) the available data shows that the population of the edible-nest swiftlets is declining all over its distribution except in Indonesia, where the species is cultured in houses, and in Vietnam where the wise management policies for nest collection are under strict governmental control and the number of harvests has been limited to twice in a year.

Recently, India has joined the list of edible-nest exporting countries (Nguyen *et al* 2002). Unlike in its other distribution ranges, the edible-nest swiftlet in the Andaman and Nicobar Islands nests and roosts only in limestone caves. The caves in the Island arc could not be spared from nest collection. Nest collection started in the Andaman and Nicobar Islands during the late 17th or early 18th century by Burmese and Thai poachers. The knowledge then came to the local settler communities like, Karen, Ranchi and Bengalis. Known caves were found to be under intense nest collection.

According to the nest collectors, the nests are gathered once or twice a week during the season (Sankaran 1998).

The wild populations of the endemic *Aerodramus fuciphagus inexpectatus* in the Andaman and Nicobar Islands were also identified under threat with more than 80% of population declining in a decade (Sankaran 1998). These alarming results compelled conservationists to immediately take measures to save the species from rapid decline. Thus the conservation of the edible-nest swiftlets was started in 2001 (refer chapter 1). In September 2002, the species was included in the list of endangered animals (Scheduled-I) under the Indian Wildlife Protection Act (1972), soon after the commencement of the Swiftlet Conservation Programme in the Andaman and Nicobar Islands.

6.2. Objectives

As this study is part of the ongoing conservation of the edible-nest swiftlets in the Andaman and Nicobar Islands, the present study aims to:

- to estimate impact of the protection system on the population of edible-nest swiftlets in the Andaman and Nicobar Islands and
- to estimate and compare populations in unprotected and protected caves.

6.3. Study Area

Data was collected from 29 caves (28 caves at Chalis-ek and 1 cave on Interview Island) protected under *in-situ* conservation of the edible-nest swiftlets, to find the trends in their populations. A survey was conducted in the pre-assessed 16 caves at the Interview Island Wildlife Sanctuary (Sankaran 1998) and 152 caves on the Baratang Island for the status of the breeding population of edible-nest swiftlets in unprotected caves of the Andaman and Nicobar Islands (refer chapter 2).

6.4. Field methods and data analysis

6.4.1. Protected Population

Breeding population of the edible-nest swiftlets in 29 caves was estimated through nest counts. As the edible-nest swiftlets are proved monogamous (Koon and Cranbrook 2002), each nest was assumed to be occupied by a pair to estimate the breeding population. Protection of the caves was done from January to June at Chalis-ek and January to August on Interview Island, according to the breeding seasonality of the species (refer section 5.5.1). The caves at Chalis-ek are protected from January to June and at Interview Island protection is from January till the end of the breeding season in August or September.

6.4.2. Unprotected Population

Following Sankaran (1998), to reduce the bias in the data, unprotected caves were surveyed for a nest count with the same field assistance used during the previous survey. Breeding population was calculated by counting the fresh nesting marks available during the survey between February and April 2008.

6.4.3. Statistical Analyses

Annual trends in the population growth rate was estimated as $N_{t1} = N_{t0}\, e^{rt}$ where N_{t0} is the initial population, e is the base of the natural logarithm, r is the *instantaneous coefficient of population growth*, t is the time and N_{t1} is the final population (Odum 1971). Population changes in the protected and unprotected caves were compared to assess the impact of protection on the edible-nest swiftlet in the Andaman and Nicobar Islands.

6.5. Results

6.5.1. Protected Population

After tremendous decline recorded from 1997-2001, the overall population of edible-nest swiftlets in the protected caves demonstrated considerable growth (average annual growth rate is 4.75 ± 6.21% per year) after the second year of protection (Figure 34).

The population of the edible-nest swiftlets in 28 protected caves at Chalis-ek show consistent 54% (n = 460) growth between 2001 and 2008 with an average population growth rate of 6.72 ± 9.84% per year (Figure 35).

In the protected caves at Chalis-ek, the average annual population growth rate reduced to 2.17 ± 1.25% (2005-2008) from 12.79 ± 13.84% (2002-2004) because of habitat destruction inside caves due to the mega earthquake in December 2004 and the aftershocks in 2005 (Manchi and Sankaran communicated; Figure 36).

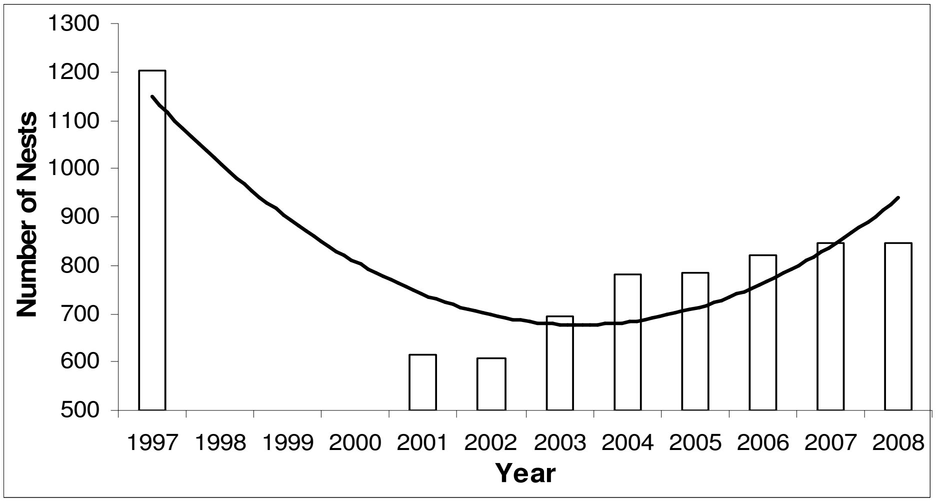


Figure 34 Population growth trend of the Edible-nest Swiftlets increased after commencement of the caves protection from 2001 in 29 caves of Chalis-ek and Interview Island in the Andaman and Nicobar Islands (Trend line is polynomial type).

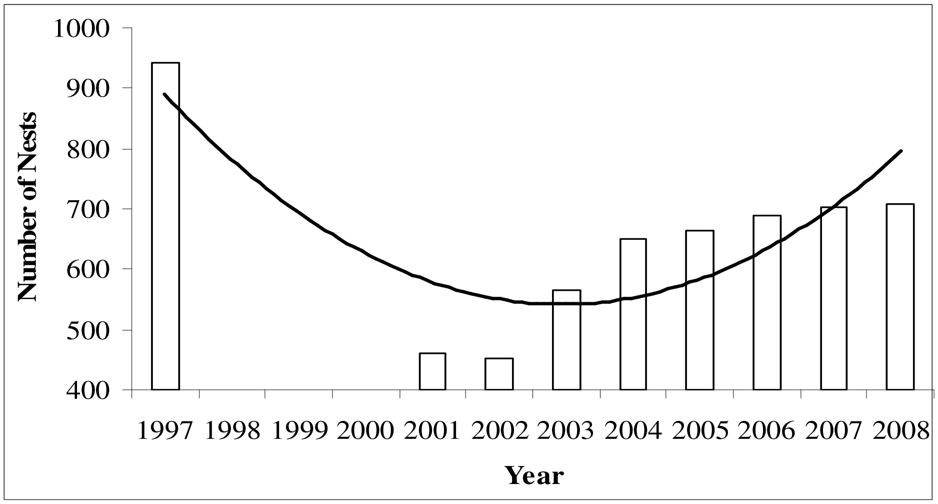


Figure 35 Population growth trend of the Edible-nest Swiftlets increased after commencement of the protection from 2001 in 28 caves at Chalis-ek in the North Andaman Island (Trend line is polynomial type).

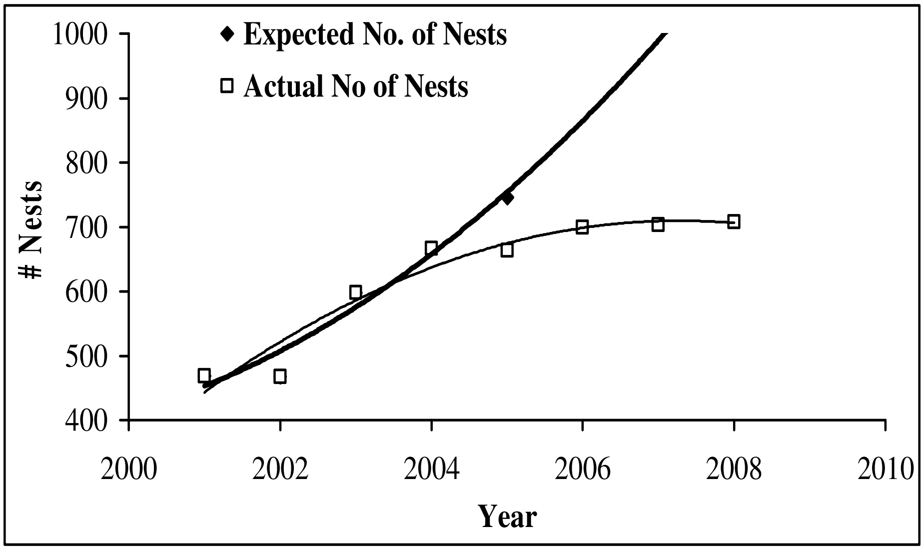


Figure 36 The expected and actual population growth shows significantly different trends after the tsunami earthquake on 26th December 2004. Expected population is found by calculation instantaneous coefficient of population growth (r) = (ln N_t – ln N_0)/t (Odum 1971; the trend lines are polynomial type).

A cave under protection at the Interview Island had 260 breeding pairs when protection began in 2001, after decline by 56.67% since 1997. Despite successful protection and breeding, the population of the edible-nest swiftlets declined further by 53.46% (n = 260) from 2000-2005, and increased to around 11.67% (n=121) in three years from 2006-2008 (Figure 37).

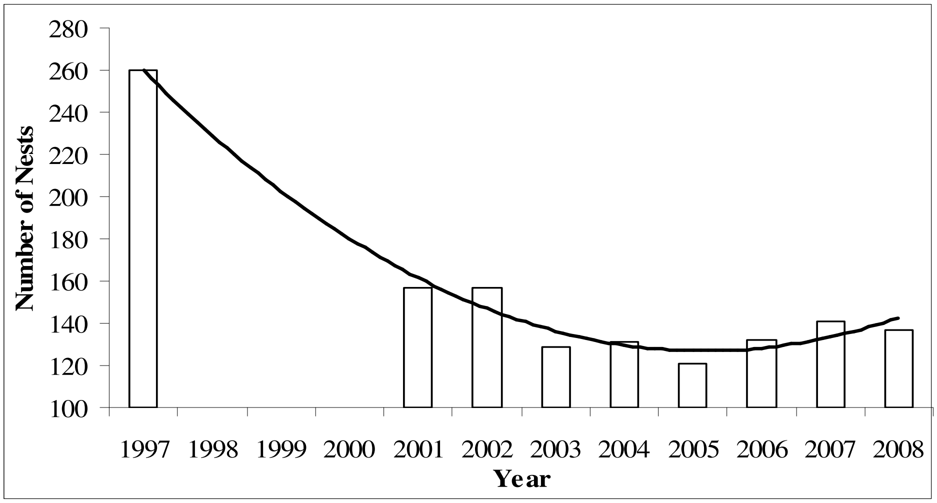
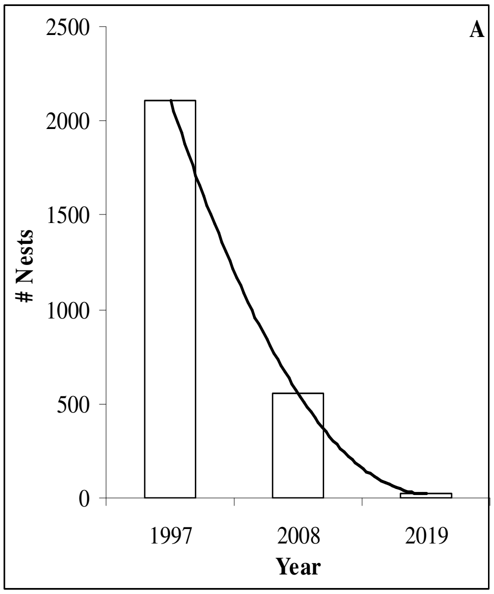
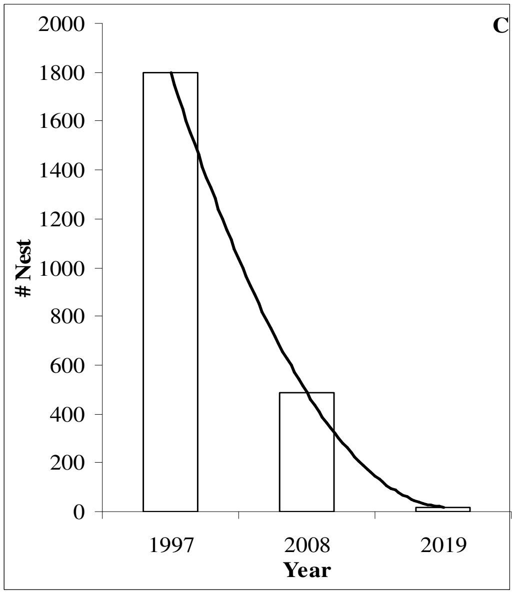


Figure 37 Population of the Edible-nest Swiftlets continue declining even after commencement of the protection from 2001 – 2005. After 2005, it started increasing in caves on Interview Island in the Middle Andaman Islands (Trend line is polynomial type).

6.5.2. Unprotected Population

Overall 73.68% (n= 2109; Sankaran 1998) downfall in the number of nests was recorded in 168 unprotected caves (Figure 38A). The unprotected populations of the edible-nest swiftlets in 16 caves at the Interview Island and 152 caves on Baratang Island showed 78.06% (n = 310; Figure 38B) and 72.93% (n = 1799; Figure 38C) decline respectively in the number of nests from 1997 to 2008. This depicts an estimated loss of approximately 2,249 breeding pairs (4498 individuals) out of the 3,716 breeding pairs (7433 individuals) recorded by Sankaran (1998).





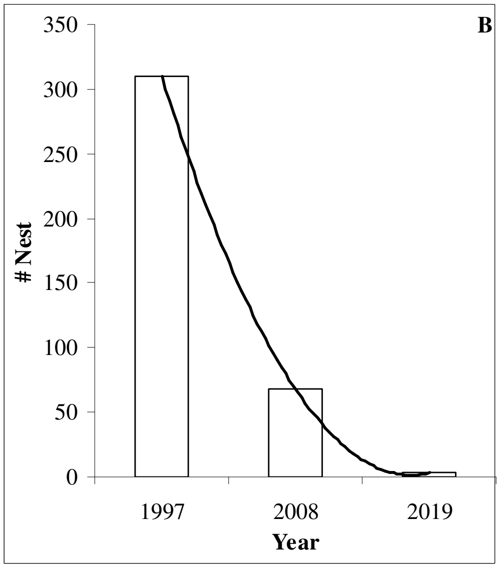


Figure 38 The populations of the Edible-nest Swiftlet in the unprotected caves demonstrated rapid decline between the years 1997 and 2008. Figure **A** shows the population trend in total 168 caves surveyed in North and Middle Andaman Islands, figure **B** shows the population trend in 16 caves on the Interview Island and figure **C** shows the population trend in 152 caves on Baratang Island (The trend lines are polynomial).

At Baratang, out of 152 caves, 60.5% of caves were found abandoned (Figure 39). Of the 291 caves known to support populations of edible-nest swiftlets in 1997, extinction of the populations from several caves is uncertain.

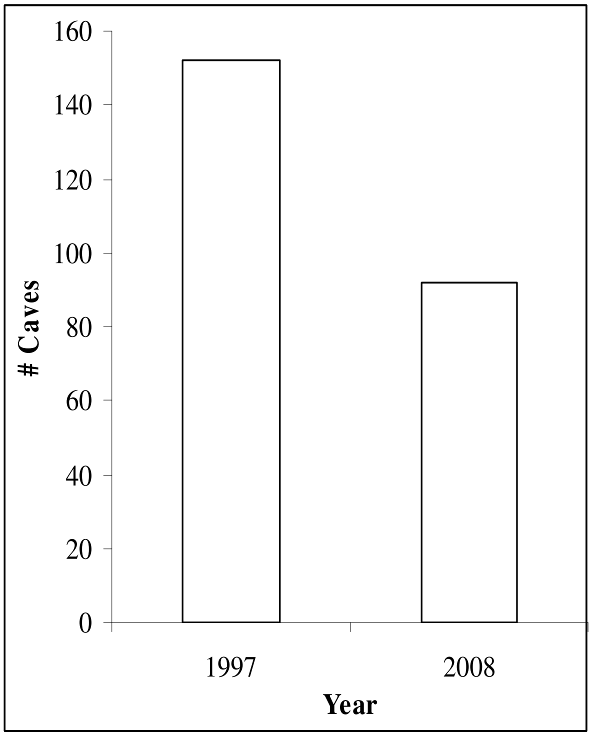


Figure 39 In the absence of protection more than 60% of caves were deserted by the Edible-nest Swiftlet on the Baratang Island.

6.6. Discussion

6.6.1. Protected Population

Sankaran (2001) estimated the predicted trend in the population of edible-nest swiftlets in the Andaman and Nicobar Islands based on the current intensity of nest collection. The study predicted the extinction of the species from the Islands arc by 2025 in the absence of any conservation measures (Sankaran 1998; Figure 40).

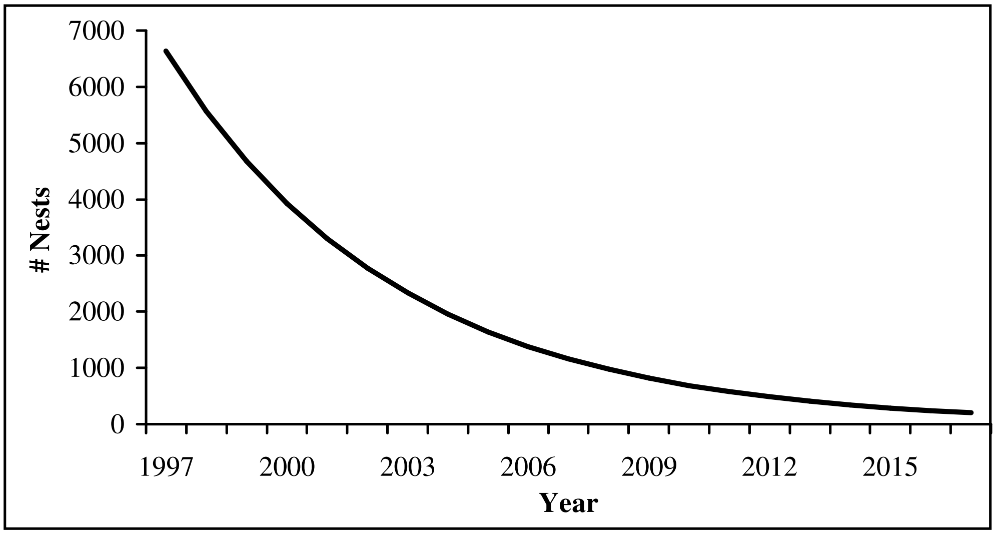


Figure 40 The predicted population trend of the Edible-nest Swiftlets in continuation of the nest collection with same intensity and in the absence of any conservation measures (Sankaran 2001).

The study highlighted the immediate need for implementing conservation measures to prevent nest collection, the sole reason for the decline in the population of the edible-nest swiftlets all over its distributional range. Discussion with local nest collectors revealed their heavy dependence on nest collection. This led to a scheme in which local nest collectors were motivated to protect the nests during the breeding season of the swiftlets (Plate 8). They were allowed to harvest the nests post the breeding season. Fourteen nest collectors were initiated into the protection programme, but they could not harvest the nests at the end of the season, as by then the species had been included in Scheduled-I of the endangered species list under the Wildlife Protection Act (1972), India. Nevertheless, the protection was continued successfully with the motivation of legalized nest collection opportunities in future. This resulted in a positive deviation of the population trends of the edible-nest swiftlet in the protected caves with significant growth. The population at Chalis-ek shows loss of population in the season immediately after the first year of protection as the edible-nest swiftlets were found to breed only after two years of fledging (refer chapter 5). The growth in the population was appreciable in the next season, which continued till the mega earthquake disturbed it indirectly by altering structures of the caves (refer chapter 3). After 2004, the population growth reduced to some extent.

A cave protected on the Interview Island was found to show continued decline in population of the edible-nest swiftlet even after the successful protection. Intensive research in 2005 could identify the following causes of decline:

1. A wooden scaffolding built in the cave to monitor the nests for information on breeding seasonality and nesting success of the species, was found being used by an Andaman brown hawk owl *Ninox scutulata obscura* and red-tailed trinket snakes *Gonyosoma oxycephalum* to prey on nests and birds.
2. The protection camps were placed at the cave mouth, exactly above the ceiling with the nests inside. Activity in the protection camps was disturbing the birds incubating and roosting inside the cave.

The scaffolding was removed immediately and the camps were shifted to around 15 meters away from the cave. These corrections resulted in the population rise by 9.5% from 2006 to 2008.

6.6.2. Unprotected Population

The population decline observed in the unprotected caves confirmed Sankaran's (1998) predictions about the extinction of the species from the islands within the next two decades. The predicted population trend in Figure 38A is very similar to the trend in Figure 40. In the absence of protection, the population is declining rapidly in the undefended caves of the Andaman and Nicobar Islands. Even after the dispersal of the chicks fledged in protected cave to the unprotected caves on the Interview Island (refer chapter 5), the population in unprotected caves shows immense fall. This indicates that the drop in the population would have been far greater than is the current estimate in the absence of successful fledging in the protected cave and their dispersal to the unprotected caves.

The biggest limestone cave complex of the Andaman and Nicobar Islands is on the Baratang Island with 169 caves (Sankaran 1998). Of these, 152 caves were holding the population of the edible-nest swiftlets almost a decade ago. However, as of today more than 60% of caves are deserted, indicating that the population of edible-nest swiftlets has gone extinct from more than 60% of caves at Baratang. The most potential caves holding the population of the edible-nest swiftlet are still under tremendous pressure of nest collection, and the extinction of the species from a number of other caves in the islands is unknown (Plate 9).

Population growth observed only in the defended caves depicts that the protection system developed for the conservation of the edible-nest swiftlets has proved itself to be effective towards conservation of this valuable natural resource of the Andaman and Nicobar Islands. However, the urgency of the issue has moved Sálim Ali Centre for Ornithology and the Natural History (SACON) in collaboration with the Department of Environment and Forests, Andaman and Nicobar Islands (ANF) to expand the current conservation programme with local participation in the Andaman and Nicobar Islands Efforts are being made to establish *ex-situ* populations of the edible-nest swiftlets in specially built houses for growing an extra population through a cross fostering process as has been done in Indonesia (Sankaran and Manchi 2008). SACON and ANF are also trying to remove the species from the schedules of the Indian Wildlife Protection Act (1972), so that the harvesting and international trade of the edible-nests may take place under scientific and legal guidelines. This will stop illegal nest collection, generate livelihood to the local people (especially nest collectors and farmers), and utilize this natural resource for developing the economy of the islands. Together, these steps will provide safety to the edible nest swiftlets, allowing the population to re-establish in the wild.

Conservation and Management Implications, and Future Research Needs

Conservation and Management Implications

The information about the species nest-site characters, their preferences and also their importance in nesting success can help in engineering the most innovative houses to attract glossy swiftlets and edible-nest swiftlets and also to modify the existing *ex-situ* conservation site. The availability of information on preferred nest-site characteristics and the microclimates inside the houses can lead to successful breeding of the edible-nest swiftlets in the future. Forests have proved to be very crucial for the foraging habitat of edible-nest swiftlets, and to some extent for the glossy swiftlets as well. It is very important to conserve the forest in these islands, prevent deforestation and also make efforts to recover lost forest patches. Since almost all swiftlet species depend on forests the present study could be applied to the conservation of the forests in the Western Ghats and the conservation of the endangered Indian edible-nest swiftlet *Aerodramus unicolor*. The understanding of breeding biology of the edible-nest swiftlets can help to decide the best possible protection periods and schedule the harvesting of edible nest. The information on the breeding biology of the glossy swiftlets in the wild can assist us to explore possibilities of transferring the eggs of the edible-nest swiftlets into the nests of the glossy swiftlets in the same cave for better hatching and fledging success during the second brood time of the edible-nest Swiftlets when the rains cause falling of the edible-nests.

The current *in-situ* protection system has proved viable. Care must be taken to minimize human interference or activities within and around the caves. The recommendations given by Sankaran and Manchi (2008) to expand the program and to remove the species from the schedules of the Wildlife Protection Act should be considered. People dependent on this natural resource should be involved in the conservation programme, motivating them to conserve and use it sustainable. Apart from the survival of the edible-nest swiftlet on the islands, the major advantage of the ongoing *in-situ* conservation programme is the protection of natural limestone caves. These caves hold unexplored diversity of flora and fauna, which can gain protection throught the swiftlet protection programme.

Future research needs

Edible-nest Swiftlet

There is a need to understand the breeding seasonality and the biology of the species in other colonies, especially in the Nicobar Islands. Studies should be conducted on the dispersal movement patterns of the edible-nest swiftlet chicks using radio telemetry and solving the mystery of their activities from the time they fledge to the time they return to their parent caves. Once the illegal collection of the nests is completely eradicated, it will be possible to study the breeding seasonality in colonies located on different islands for at least a complete year. The biology of the species after the breeding season should also be studied in detail. Research on nest composition is another important factor. Once the population of the edible-nest swiftlets is set up in the *ex-situ* houses, it will be crucial to keep them under continuous scientific observations and study the changes in their behaviour.

Glossy Swiftlet

Populations of the glossy swiftlets in colonies on different islands should be studied to know their breeding biology in greater details. Most importantly, colonies of the species should be studied in urban areas to learn about their adaptive change in habits and habitats.

References

Ali S. and Ripley S. D., 1970, *Handbook of Birds of India and Pakistan*. Vol - 4, Oxford University Press, Bombay.

Altmann J., 1974, *Observational study of behaviour: sampling methods.* Behaviour. 49: 227 – 265.

Alwany M. A., 2003, *Ecological Aspects of Some Coral Reef Fishes in the Egyptian Coasts of the Red Sea.* PhD thesis, Faculty of Science, University of Innsbruck Pg: 52.

Andrews H. V. and Vasumati S., 2002, *Sustainable Management of Protected Areas in the Andaman and Nicobar Islands*. Ultra Print Communication Press, New Delhi.

Anonymous, 2007, *Meteorological Data of Andaman and Nicobar Islands*, Meteorology Department, Andaman and Nicobar Islands, India.

Bernstein H. A., 1859, *Ueber die Nester der Salangana*. J. f. Ornithologie. 7: 110-119 In Nguyen Quang P., Yen Vo Q. and Voisin J., 2002, *The White-Nest Swiftlet and the Black-Nest Swiftlet*. Paris, Société Nouvelle des Éditions Boubée.

Brooke R. K., 1970, *Taxonomic and Evolutionary notes on the sub-families, tribes, genera and subgenera of the swifts (Aves: Apodidae)*. Durban Mus. Novit. 9(2): 13 – 24.

Burgess P. F., 1961, *Breeding of the White-bellied Swiftlet Collocalia Esculenta in North Borneo.* Sarawak Museum Journal. 10(17-18): 265-268.

Challinor J., 1967, *A Dictionary of Geology*. University Press, Oxford, Great Britain, pp. 39.

Chantler P. and Driessens G., 1995, *Swifts - A Guide to the Swifts and Treeswifts of the World*. Sussex Pica Press, UK.

Charles M. F., 1987, *The Management of Bird's Nest Caves in Sabah.* Wildlife Section, Sabah Forest Department, Sabah, Malaysia.

Clements R., Sodhi N. S., Schilthuizen M., Ng P. K. L., 2006, *Limestone karsts of Southeast Asia: imperiled arks of biodiversity*. Bioscience. 56: 733–742.

Cody M. L., 1983, *Habitat Selection in Birds*. London, Academic Press.

Collins C., 2000, *Foraging of Glossy and Pygmy Swiftlets in Palawan, Philipines.* Forkyail. 16: 53-55.

Cranbrook Earl of, 1984, *Report on the birds' nest industry in the Baram District and at Niah, Sarawak*. Sarawak Museum Journal. 33(54): 145-170.

Cranbrook Earl of, and Lim C. K., 1999, *Cave Swiftlets.* In: B.E. Smythies, revised by G.W.H. Davison. *The Birds of Borneo* (4th edition). Natural History Publications (Borneo) in association with The Sabah Society, Kota Kinabalu.

Fenton M. B., 1975, *Acuity of echolocation in Collocalia hirundinacea (Aves: Apodidae), with comments on the distribution of echolocating Swiftlets and Molossid bats.* Biotropica. 7: 1-7.

Fischer R. B., 1958, *The breeding biology of the Chimney Swift (Linnaeus).* New York State Museum Science Service Bulletin. pp 368.

Ford T. D. and Cullingford C. H. D., 1976, *The Science of Speleology.* New York, Academic Press.

Francis C. M., 1987, *The management of edible bird's nest caves in Sabah.* Wildlife Section, Sabah Forest Department, Sandakan.

Frank P. F., 1926, *Uber die Lebens- und Nistweisisen von Collocalia francica vestita (Lesson).* Orn. Monatsber. 34: 99-103. In Nguyen Quang, P., Yen Vo, Q. & Voisin, J. 2002. The White-Nest Swiftlet and the Black-Nest Swiftlet. Paris: Société Nouvelle des Éditions Boubée.

Gahalaut and Kalpna, 2005, *28 March 2005 Sumatra earthquake: expected, triggered or aftershock?* Current Science. 89(3): 452-454.

Gausset Q., 2004, *Chronicle of a Foreseeable Tragedy: Birds' Nests Management in the Niah Caves (Sarawak).* Human Ecology. 32(4): 487-507.

Hails C. J. and Amirrudin A. 1981. Food samples and selectivity of White-bellied Swiftlets (*Collocalia esculenta*). Ibis 123: 328-333.

Hails C. J. and Turner A. K., 1985, *The role of fat and protein during breeding in the White-bellies Swiftlet (Collocalia esculenta).* Journal of Zoology London. 206: 469-484.

Harrison T., 1959, *New archiological and ethological results from Niah caves*, *Sarawak.* Man 4: 1-8.

Harrison T., 1976, *The food of Collocalia Swiftlet (Aves, Apodidae) at Niha Great Cave in Borneo.* Journal of Bombay Natural History Society. 71(3): 376-392.

Holmgren J., 1998, *A parsimonious phylogenetic tree for the swifts, Apodi, compared with DNA analysis phylogenies:* Bulletin of the British Ornithologists' Club. 118: 238-249.

Holyoak and Thibault J. C., 1978, *Notes on the biology and systematics of Polynesian swiftlets, Aerodramus.* Bulletin of the British Ornithologists' Club. 98: 59–65.

Jafri S. H., Balaram V. and Govil P. K., 1993, *Depositional environments of Cretaceous radiolarian cherts from Andaman-Nicobar Islands, northeastern Indian Ocean.* Marine Geology. 112: 291-301.

Jain S. K., Murthy C. V. R., Rai D. C., Malik J. N., Sheth A. and Jaiswal A., 2005, *Effects of M 9 Sumatra earthquake and tsunami of 26 December 2004.* Current Science. 88(3): 357-359.

Jayaraj R. S. C. and Andrews H. V. (Eds), 2005, *Andaman and Nicobar Islands Union territory Biodiversity Strategy and Action Plan.*

Jehle G., Adams A. A. Y., Savidge J. A. and Skagen S. K., 2004, *Nest survival estimation: a review of alternatives to the Mayfield estimator.* Condor. 106: 472–484.

Johnson C. G., 1969, *Migration and dispersal of insects by flight.* London: Methuen.

Johnson T. H. and Stattersfield A. J., 1990, *A global review of island endemic birds.* lbis 132: 167-180.

Josep d. H., Andrew E., and Sargatal J., 1999, *Handbook of the Birds of the World. Vol-5, Barn Owls and Humming Birds.* Birdlife International.

Kang N., Hails C. J. and Sigurdsson J. B., 1991, *Nest construction and egg-laying in Edible-nest Swiftlets Aerodramus spp. and the implications for harvesting.* Ibis. 133:170-177.

Kong Y. C., Keung W. M., Yip T. T., Tsao S. W. and Ng M. H., 1987, *Evidence that epidermal growth factor is present in swiftlet's (Collocalia) nest.* Comp. Biochem. Physiol. 87(B): 221-226.

Koon L. C. and Cranbrook Earl of., 2002, *Swiftlets of Borneo: Builders of Edible Nests.* Kota Kinabalu, Malaysia: Natural History Publications (Borneo).

Kovach Computing Services. 2004, Oriana, Version 2.01c. Kovach Computing Services, Anglesey.

Kumar S., 1981, *Geodynamics of Burma and Andaman-Nicobar region, on the basis of tectonic stresses and regional seismicity*. Tectonophysics. 79: 75-95.

Kumar S., 1990, *Gravity Anomalies, Seismicity, Subducting Slab Folding and Surface Deformations in the Orogenic Belts---An Example from the Andaman-Nicobar Region.* Journal of Geodynamics. 12: 39-63.

Lack D., 1954, *The natural regulation of animal members.* Oxford University Press, Oxford.

Lack D., 1956. *A review of the genera and nesting habits of swifts*. Auk. 73: 1-32.

Langham N., 1980, *Breeding Biology of the Edible-nest Swiftlet (Aerodramus fuciphagus).* Ibis 122: 447-461.

Lau A. S. M. and Melville D. S., 1994, *International Trade in Swiftlet Nests.* Traffic International and World Wide Fund for Nature, Cambridge.

Laurie S. A. and Tompkins D. M., 2000, *The diets of Malaysian Swiftlets*. Ibis. 142: 596-602.

Lee P. G. and Kang N., 1994, *The reproductive strategies of edible-nest Swiftlets (Aerodramus spp.).* Bulletin of British Ornithological Club. 114: 106-113.

Lim C.K., 1999. *Sustainable Management and Conservation of the White-nest Swiftlets of Sarawak.* Hornbill. 3: 74-85.

MacArthur H., 1958, *Population ecology of some warblers of Northeastern coniferous forests*. Ecology. 39: 599-619.

MacKinnon K., Hatta G., Halim H. and Mangalik A., 1996, *The Ecology of Kalimantan.* The Ecology of Indonesia Series, vol. 3. Singapore: Periplus Editions.

Marshall A. J. and Folley S. J., 1956, *The origin of nest-cement in edible-nest swiftlets (Collocalia sp.).* Proceedings of Zoological Society London. 126: 383-389.

Martin T. E., 1995, *Avian life history evolution in relation to nest-sites, nest predation and food.* Ecological Monograph. 65: 101–127.

Medway L., 1957, *Birds' Nest Collecting*. Sarawak Museum Journal. 8(10): 252-260.

Medway L., 1959, *Echo-location among Collocalia.* Nature. 184: 1352-1353.

Medway L., 1962a, *The swiftlets (Collocalia) of Niah Cave, Sarawak. Part I. Breeding Biology.* Ibis. 104: 45-66.

Medway L., 1962b, *The swiftlets (Collocalia) of Niah Cave, Sarawak. Part II. Ecology and the regulation of breeding*. Ibis. 104: 228-245.

Medway L., 1963, *The antiquity of trade in edible birds'- nest.* Federal Museum Journal. 8: 36-47.

Medway L., 1966, *Field character as a guide to specific relations of Swiftlets.* Proceedings of Linnean Society of London. 177: 151-172.

Medway L., 1967, *The function of echonavigation among Swiftlets.* Animal Behaviour. 15: 416–420.

Medway L., 1969, *Studies on the biology of the edible-nest Swiftlets of South-east Asia.* Malayan Nature Journal. 22: 57-63.

Mitchell K., 2001, *Quantitative Analysis by the Point-Centered Quarter Method.* Department of Mathematics and Computer Science, Hobart and William Smith Colleges, Geneva, NY.

Moore P. and Cobby J., 1998, *Introductory Statistics for Environmentalists*. Prentice Hall Europe.

Moreau E., 1948, *Ecological isolation in a rich tropical avifauna.* Journal of Animal Ecology. 17: 113-126.

Nguyen Q. P. and Jean-Francois V., 1998, *Influence of cave structure, microclimate and nest harvesting on the breeding of the White-nest Swiftlet Collocalia fuciphaga germani in Vietnam.* Ibis. 140: 257-264.

Nguyen Q. P., 1983, *The food of edible-nest Swiftlets Collocalia fuciphaga germani Oust.* In Vietnam. Top Chi Sinh Vat Hoc 5(3): 5-8.

Nguyen Q. P., 1992, *Breeding biology and moult in the Edible-nest Swiftlet Collocalia fuciphaga germani Oustalet 1878 in Vietnam.* Oiseau et Revue francaise d'Ornithologie. 62: 149-161.

Nguyen Q. P., 1994, *Breeding and moult in the Edible-nest swiftlets Collocalia fuciphaga germani in Vietnam.* Alauda. 62(2): 107-115.

Nguyen Q. P., Yen Vo, Q. and Voisin J., 2002, *The White-Nest Swiftlet and the Black-Nest Swiftlet.* Paris: Société Nouvelle des Éditions Boubée.

Norusis M. J., 1996, SPSS/PC+: Advanced Statistics 10.0 SPSS Inc. Chicago.

Odum E. P., 1971, *Fundamentals of Ecology*. 3rd Ed, Philadelphia.

Osmaston B. B., 1906, *Notes on Andaman Birds with accounts of the nidification of several species where nest and eggs have been hitherto described.* Journal of Bombay Natural History Society. 17: 156-163.

Pande P., Kothari A. and Singh S. (Eds.), 1991, *Directory of National Parks and Sanctuaries in Andaman and Nicobar Islands.* Indian Institute of Public Administration, New Delhi.

Peters J. L., 1940, *Check-list of Birds of the World.* Vol. 4. Harvard University Press, Cambridge.

Pettingill O. S., 1970. *Ornithology in Laboratory and Field.*

Pimm S. L., Jones H. L. and Diamond J., 1988, *On the risk of extinction*. The American Naturalist. 132: 757–785.

Rao and Chary, 2005, *What caused the great Sumatran earthquakes of 26 December 2004 and 28 March 2005?* Current Science. 89(3): 449-451.

Saldanha C. J., 1989, *Andaman, Nicobar and Lakshadweep. An environmental Impact Assessment.* Oxford & IBH Publ. Co. New Delhi.

Salmonsen F., 1983, *Revision of the Melanesian swiftlets (Apodes, Aves) and their conspecific forms in the Indo-Australasian and Polynesian regions.* Biol. Skr. Dan. Vidensk. Selsk. 23(5): 1-112.

Sankaran R., 1995, *Impact assessment of nest collection on the Edible-nest Swiftlet (Collocalia fuciphaga) in the Nicobar Islands*. Sálim Ali Centre for Ornithology and Natural History, Occasional Report.

Sankaran R., 1998, *The impact of nest collection on the Edible-nest Swiftlet (Collocalia fuciphaga) in the Andaman and Nicobar Islands*. Sálim Ali Centre for Ornithology and Natural History, Report to IUCN.

Sankaran R., 2001, *The status and conservation of the Edible-nest Swiftlet (Collocalia fuciphaga) in the Andaman and Nicobar Islands.* Biological Conservation. 97: 283-294.

Sankaran R., Andrews H. and Vaughan A., 2005. *The Ground Beneath the Waves: Post-tsunami Impact Assessment of Wildlife and their Habitats in India*. Vol-2: The Islands.

Sankaran R. Manchi S., 2008, *Conservation of the Edible-nest Swiftlets in the Andaman and Nicobar Islands.* Sálim Ali Centre for Ornithology and Natural History, Report to the Department of Environment and Forest, Andaman and Nicobar Islands.

Sibley C. G. and Ahlquist J. E., 1990, *Phylogeny and Classification of Birds*. Yale University Press, New Haven and London.

Smith J., 1950, *Notes on the Alpine Swift.* British Birds. 43: 122-123.

Spennemann A. W., 1928, *Die eßbaren Vogelnester von Grissee*. Orn. Monatsb., Berlin: 111-112.

Spennemann A. W., Die ebaren Vogelnestre von Grissee. Orn. Monatsb, Berlin: 111-112. In Nguyen Q. P., Yen Vo Q. and Voisin J., 2002. *The White-Nest Swiftlet and the Black-Nest Swiftlet.* Paris: Société Nouvelle des Éditions Boubée.

Srinivasan M. S., 1979, *Geology and mineral resources of the Andaman-Nicobar islands Andaman-Nicobar information*, Govt. Press, Port Blair, India. 44-52.

Supaluck V., Kumthorn T., Art-Ong P. and Pilai P., 2002, *Nest-site Characteristics of the Edible-nest Swiftlet Aerodramus fuciphagus (Thunberg, 1812) at Si-ha Islands, Phattalung Province, Thailand.* The Natural History Journal of Chulalongkorn University. 2(2): 31-35.

Velando A. and Márquez J. C., 2002, Predation risk and nest-site selection in the Inca Tern. Canadian Journal of Zoology. 80: 1117–1123.

Wang C.C., 1921, *The composition of Chinese edible nest birds' nests and the nature of their proteins.* Journal of Biological Chemistry. 49: 429-439.

Waugh D. R. and Hails C. J., 1983, *Foraging ecology of a tropical aerial feeding guild.* Ibis. 125: 200-217.

Appendix 1 Number and types of caves in the A & N Islands (Sankaran 1998)

Island Name	Cave Type							
	Coastal				Inland			
	A	AB	B	BD	Ci	Cii	Ciii	D
Interview I.			13			21		
Point I.			2					
Reef I.						5		
White Cliff I.		1		3				
East I.			1					
Chalis-ek, N. Andaman						3		30
Ramnagar, N. Andaman			2					
Cuthbert Bay, M. Andaman			3					
Strait I.			2					
North Passage I.			1					
Wraffters Creek, Baratang						170		
Henry Lawrence I.			20					
Inglis I.			2					
Outram I.			2					
Neil I.			9					
South Button I.			14					
Middle Button I.			1					
Chidiya Tapu, S. Andaman			1					
North Cinque I.			1					
Rutland I.			6					
Passage I.			2					
Little Andaman I.			3					
Redsink I.			1					
Jarawa Territory								
Middle Andaman I.			1					
South Andaman I.			1					
Montgommery I.			3					
Patrie I.			1					
Great Nicobar I.	8	2	5					
Kondul I.	4	4	3					
Little Nicobar I.	15							
Pilo Milo I.	1							
Nancowry Group Is.	1	1	3	4	2	1	1	2
Car Nicobar I.			1			1		
Total	29	8	104	7	2	201	1	32

- Note: **A**= On coast, approachable on foot; **AB**= On coast, approachable on foot after swimming ashore; **B**= On coast, entrance partially submerged and access by swimming into cave; **BD**= Cave above sea level on cliff face ending in the sea; **Ci**= In the forest, at the origin of stream; **Cii**= In the forest, cavern bellow the ground; **Ciii**= In the forest, above ground; **D**= On inland cliff

Appendix 2 The extent of damage due to the earthquake during December 2004 in different type and size of caves in North and Middle Andaman Islands

Cave No.	Cave Size	Cave type	No. of openings pre earthquake	No of openings post earthquake	Extent of Damage
Caves At Chalis-ek, Pattilevel, North Andaman					
1	Small	Above ground	1	1	Nil
2	Medium	Above ground	2	2	Medium
4	Big	Above ground	3	3	High
5	Medium	Above ground	1	1	Low
6	Big	Above ground	3	3	Low
7	Medium	Above ground	1	1	High
8	Very big	Above ground	2	1	High
9	Medium	Above ground	2	2	Medium
10	Big	Above ground	2	2	Low
11	Small	Above ground	1	1	High
12	Small	Above ground	1	1	Nil
13	Small	Above ground	1	1	High
14	Small	Above ground	1	1	Nil
15	Small	Above ground	1	1	Nil
16	Medium	Above ground	2	2	Low
17	Very big	Above ground	2	2	High
18	Small	Above ground	1	1	High
19	Small	Above ground	1	1	Nil
20	Small	Above ground	1	1	Nil
21	Small	Above ground	1	1	Nil
22	Very big	Above ground	1	1	Low
23	Small	Above ground	1	1	Low
24	Very big	Above ground	2	2	High
25	Medium	Above ground	1	1	Nil
26	Small	Above ground	1	1	Nil
27	Small	Above ground	1	1	Nil
28	Small	Above ground	1	1	Nil
Caves at Interview Island Wildlife Sanctuary, Middle Andaman					
2	Very big	Below ground	1	1	Nil
3	Small	Below ground	1	1	Nil
4	Medium	Below ground	1	1	Nil
5	Medium	Below ground	1	1	Nil
7	Small	Below ground	1	1	Nil
8	Small	Below ground	1	1	Nil
9	Small	Below ground	1	1	Nil
10	Small	Below ground	1	1	Nil
11	Small	Below ground	1	1	Nil
12	Small	Below ground	1	1	Nil

13	Small	Below ground	1	1	Nil
14	Small	Below ground	1	1	Nil
15	Medium	Below ground	1	1	Nil
16	Small	Below ground	1	1	Nil
17	Big	Below ground	2	2	Nil
18	Small	Below ground	1	1	Nil

Appendix 3 Predators of swiftlets and their nests in the Andaman and Nicobar Islands (Plate 10).

Species	**Description**
Brown-Hawk Owl (*Ninox scutulata obscura)*	Individuals were observed hunting both species of swiftlet in the cave openings of Chalis-ek and Interview Island while the birds entered or exited from the caves at dusk and dawn, in North & Middle Andaman during May and June of each year from 2001 to 2008. In 2005 may an individual was also seen roosting just bellow the Edible-nest Swiftlet colony on the man made scaffolding inside the cave at Interview Island
*Besra (*Accipiter virgatus)*	According to the nest collectors, round the year the Besras were recorded hunting swiftlets near the cave openings and also in the dim-lit zones inside the cave in North & Middle Andaman and Baratang Island.
Large-billed Crow (*Corvus macrorhynchos)*	During morning hours on 19th March 2007, under Panighat bridge in North & Middle Andaman Island a Large-billed Crow while in flight was observed preying on the breeding colony of Glossy Swiftlet.
*Red-tailed Trinket Snake (*Gonyosoma oxycephalum)*	A known bird predator (Whitaker and Captain 2004), this species was found near cave openings and inside caves, close to the swiftlet breeding colonies, at Chalis-ek North Andaman and Interview Island, during the breeding season of the swiftlets in February 2002, May 2005, May 2007 and January 2009. We did not directly observe predation (Plate 10).
*Reticulated Python (*Python reticulatus)*	A common visitor to the caves, it is known to prey on swiftlets in other regions (Koon and Cranbrook 2002), but we did not observe predation. During the survey in 1997 an individual was encountered in a cave at Great Nicobar.
*King Cobra (*Ophiophagus hannah)*	The species was observed resting in the crevice inside the cave at Baratang Island. We believe that King Cobra can be a potential predator of the swiftlets or the bats inside the cave.
*Vipers (*Trimeresurus* spp?)	During the survey in 1997 inside the caves at Pambuka and Pagget Island vipers were seen resting near the swiftlet colony, most probably for hunting the adults approaching to the nests and also flying from the nests. These species were never observed predating on the swiftlets or their nests.
*Sea snake (unidentified sp)	During the survey in 1997, sea snakes were seen resting under the swiftlet colony in the coastal caves in Nicobar Islands. They were

	presumed to be predating on the fallen chicks or eggs. Predation was never observed.
*Lizard (unidentified spp)	Geckos from South-East Asia were recorded predating on the swiftlets eggs in the houses. In the cave at Interview Island we could record a lizard moving in the Edible-nest Swiftlet colony. We could not observe any type of predation of the swiftlets by the lizard.
Crabs (Unidentified spp)	Different species of Crabs were found predating on the fallen chicks and also scavenging on dead ones. During the survey in 1997 the individuals were observed inside most of the coastal caves in Andaman and Nicobar Islands. Under Mayabunder Jetty in February 2007 and individual was observed predating on the Glossy Swiftlet chick fallen from the nest.
Spider (Order: Arachinid)	At Great Nicobar the Glossy Swiftlet was caught in the spider's web; the spider took almost three days to finish sucking it dry (Manish Chandi, Per. comm.). In another instance, during June 2006 an adult Edible-nest Swiftlet was observed caught in a spider's web within 200 meters from the nearest cave on Interview Island (Plate 10).
Ants (Order: Hymenoptera)	Red ants are one of the major predators of eggs and chicks inside caves. In almost all the caves at Interview Island and Chalis-ek Ants were seen attacking newly-hatched chicks and also feeding on the material inside the eggs by making a hole in the egg (Plate 10).
Cockroach (unidentified spp)	Not a conventional predator, but cockroaches inside caves reduced breeding success of the Edible-nest Swiftlets by feeding on their nests. In the several caves on Interview Island this incidence was observed. There is a cave on Interview Island called Cockroach cave because of their high number and rate of nest predation rate.
*Crickets (unidentified spp)	Giant Crickets in South-East Asia are known as predators of the swiftlets. Crickets were also encountered in the caves at Baratang Islands during the survey in 2007, but were never observed predating on the swiftlets.
Domestic cat	During cyclonic weather of April, May and June in 2004, 2005 and 2006 in front of the police station at Mayabunder, North and Middle Andaman when Glossy Swiftlets forage close to the tar road a Domestic Cat was observed hunting by hitting them with its forelimb.
*Rat (unidentified spp)	The Rats are present in most caves of the Andaman and Nicobar Islands. Rats were recorded predating on swiftlets in South-East Asian countries but we could never observed them predating on swiftlets. Rats were observed feeding on the edible nests fallen on the ground, in the cave at Interview Island rats.
Note: * Potential predators of the swiftlets	