STUDY ON NEST TREE PREFERENCES BY CAVITY NESTING BIRDS IN THE RIVERINE FORESTS OF ATHIKADAVU VALLEY, WESTERN GHATS, INDIA

Thesis submitted to the

Bharathiar University, Coimbatore

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in

BOTANY

By

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Tamil Nadu, India

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CERTIFICATE

This is to certify that the thesis, entitled **"Study on nest tree preferences by cavity nesting birds in the riverine forests of Athikadavu Valley, Western Ghats, India"**, submitted to **Bharathiar University,** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy in Botany** is a record of original work done by **P. Manikandan** during September 2012 to August 2017 of his research in the Landscape Ecology Division at **Sálim Ali Centre for Ornithology and Natural History (SACON)**, Anaikatty, Coimbatore 641108, Tamil Nadu, India under my supervision and guidance and the thesis has not formed the basis for the award of any Degree / Diploma / Associateship / Fellowship or any other similar title of any candidate of any University.

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I, **P. Manikandan** hereby declare that the thesis entitled **"Study on nest tree preferences by cavity nesting birds in the riverine forests of Athikadavu Valley, Western Ghats, India"**, submitted to **the Bharathiar University** in partial fulfillment Degree of **Doctor of Philosophy in Botany** is a record of original work done by me during September 2012 to August 2017 under the research supervision and Guidance of **Dr. P. Balasubramanian,** Senior Principal Scientist, Landscape Ecology Division at **Sálim Ali Centre for Ornithology and Natural History (SACON)**, Anaikatty, Coimbatore - 641108, Tamil Nadu, India and it has not formed the basis for the award of any Degree / Diploma / Associateship / Fellowship or any other similar title of any candidate of any University.

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1 GENERAL INTRODUCTION

1.1 Riverine forest

Rivers are considered as the pillars of human civilization all over the world. Riparian zone or riparian area is the interface between land and river or stream or it generally encompasses the vegetative strip of land that extends along stream and rivers and therefore the interface between terrestrial and aquatic ecosystems (Gregory *et al*., 1991). The word ″RIPARIAN″ originated from the Latin word ″RIPA″, which means the bank of a river, lake or pond of the surrounding landscape (Tabacchi *et al*., 1990; Junk and Piedade 1997). Riparian forests are also known as gallery forests and stream side forest (Brinson, 1990). Riparian zones are habitats of critical conservation concern worldwide, as they are known to filter agricultural contaminants, buffer landscapes against soil erosion and provide suitable habitat for wild faunas (John *et al*., 2005). They are distinctly different from the surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Plant communities in large river flood plains are amongst the most productive and diverse in the world and frequently support higher number of plant species arranged in vegetation associations of greater complexity than surrounding landscaping units (Menges and Waller, 1983; Tockner and Stanford, 2002). The undisturbed stands of age old woody species in the riparian zone provide habitat for nesting birds. The riparian vegetation provides Non Wood Forest Products (NWFP) for the dependent communities especially tribals who use the riparian forest to make their huts (mainly Bamboo and Ochlandra), honey collections, timber, manure for farming and medicinal plants etc.

The lower reaches of the riparian forests acts as a buffer between the upland and the river. However due to anthropogenic activities such as expanding agricultural activities and deforestation, the riparian vegetation remains threatened. The riparian landscapes are highly threatened ecosystem as they are inherently rare habitats, occupying a mere 1000th of the earth surfaces (Hynes, 1970). Species richness, diversity and phytosociology of riparian vegetation have been studied in many rivers of America, Europe, Africa and Australia. In the Pacific coastal eco-region (USA), approximately 29% of wildlife species found in riparian forests are riparian obligates (Kelsey and West, 1998). It provides habitat for more species of breeding birds than any other vegetation association. For example, of all bird species breeding in Northern Colorado, 82% occur in riparian vegetation, and about half of South-Western species depend upon riparian vegetation (Knopf and Samson, 1994). In Europe, 30% of threatened bird species are inland wetland-dependent species and 69% of the important breeding areas for birds contain wetland habitats, primarily flood plains (Tiker and Evans, 1997). In Switzerland, 10% of the entire fauna is restricted in its occurrence to riverine flood plains, although flood plains only cover 0.26% of the country's surface.

1.1.1 Vegetation community in the riverine forests

The word "Riparian" itself means along the river margin. The plant communities seen along the river margins are commonly referred to as the riparian vegetation (Wissmar and Swanson, 1990; Gregory *et al.,* 1991; Décamps and Tabacchi, 1994; Pollock *et al.,* 1998). Riparian ecosystems have a greater species diversity compared to the adjacent upland habitats within the same geographic location (Naiman *et al.,* 1993). Structurally riparian vegetation as classified in three layers such as tree canopies, shrubs in middle stratum and woody stragglers and flora of herbaceous in ground level. The zonation of above ground vegetation of the riparian ecosystems depends on the regional climate and topography.

Tree layers: Trees are considered the most significant component, due to the keystone nature of riparian forests which controls the flood and soil erosion thereby maintaining the integrity of riparian ecosystems (Minore and Weatherly, 1994; Pettit and Froend, 2001). The canopy and stems of riparian vegetation above the ground provide shade, which controls temperature and in-stream photosynthetic productivity for fish and other aquatic organisms (Gregory *et al.,* 1991; Nakamura and Swanson, 1993, 1994).

Shrub layers: Shrubs provide shade and stream bank stabilization and compete strongly for the resources needed by tree seedlings. The competition indirectly influences production of large woody debris and habitat maintenance for other organisms. Shrub competition may prevent the regeneration of trees in some riparian environments, thereby resulting in gradual succession to a shrub community (Hibbs, 1987) and their root system contributing root strength that maintains stream bank integrity and prevent soil erosion (Gregory and Ashkenas, 1990; Cordes *et al.,* 1997).

Ground layer: Grass and herbaceous vegetation also helps to sustain high moisture levels in the upper layers during dry periods because of the sheltering of the sediment surface by the vegetation cover and the capillarity provided by the rhizosphere (Magette *et al.*, 1989). However in the tropical riparian floodplains, seasonal herbaceous annual vegetation dominates, where large flood disturbance prevents the recruitment of tree species.

Riparian vegetation functions as cover for wildlife and corridors for species migration, dispersal (Wegner and Merriam, 1979; Henderson *et al.*, 1985; Merriam and Lanoue, 1990; Cordes *et al.,* 1997), breeding ground for birds and small mammals (Blair, 1996; Rottenborn, 1999; Cockle and Richardson, 2003). The vegetation structure (e.g., percentage of plant cover, tree density, height and size of trees, or percent of snags) indicates the suitability of a territory for breeding, sheltering and feeding, and is a primary factor in habitat selection by wild animals and birds (Hildén, 1965; Sanchez *et al.*, 2012). Although vegetation structure has been traditionally considered as one of the most important factors affecting bird communities (MacArthur and MacArthur, 1961; Blondel *et al*., 1973), bird distribution is not only influenced by vegetation structure, but also by plant species composition (Holmes and Robinson, 1981; Rotenberry, 1985).

The riparian vegetation has been recognized as “keystone ecosystem”, because it harbours certain unique habitats which are highly influenced by water (Goebel *et al.*, 2003a). Wildlife researchers recognize the riverine forests as a critically and functionally dominant component of a terrestrial landscape (Tabacchi *et al.,* 1998). The riverine forests have been greatly exploited for meeting the increasing demand of the humans and are therefore, now considered to be among the most threatened ecosystem in the world (Richter *et al*., 1997; Malmqvist and Rundle, 2002). Most of the world's riparian zones have been altered because of human activities including dam construction, small-scale supporting construction and channeling with artificial banks (Kim *et al*., 2012). The vegetation of the riverine forests serves as food for herbivores (Goulber and Baker, 1991) and functions as egg laying sites and a refuge of birds (Kim *et al*., 2012).

The riparian vegetation in India has suffered greatly and is degraded in many parts due to accidental activities which caused severe irreversible damage to the riparian ecosystems of many rivers (Datta *et al.,* 2011). Although documentation of riparian vegetation is very essential for biodiversity management, only a few detailed studies have been made from India (Bachan, 2003; Joby Paul, 2012; Johnsingh and Joshua, 1989; Iqbal, 2012; Sunil *et al.,* 2016). In this context, the present study was carried out in the Bhavani River, Tamil Nadu state of India to assess the diversity and composition of woody vegetation.

1.2 Riverine bird community

Riparian forests are considered an important habitat for bird communities, because a gradient in the vegetation can be detected in relation to the surrounding areas, resulting in increased regional bird diversity (Pollock *et al.* 1998; Bub *et al*. 2004). It forms an important habitat for several species of birds (Knopf and Samson, 1994) including migratory birds. Further, varieties of birds use river and riparian vegetation as a habitat for feeding, roosting, nesting and breeding (Biju Kumar, 2006; Larue *et al.,* 1995; Inman *et al*., 2002; Sallabanks *et al*., 2000). In Northern Colorado, 82% of annually breeding species are present in riparian zones (Knopf *et al.,* 1988) and in South Western states, 51% of birds breed only within riparian corridors (Johnson *et al*., 1977).

Birds' nests are more or less elaborate structures built with reproductive aims. They form a receptacle which usually provides protection and an adequate microclimate for the development of eggs and nestlings (Collias and Collias, 1984). The size and structure of the nest might arise from an evolutionary trade-off between benefits as the insulation from unfavourable weather conditions or protection of eggs and chicks against predation (Skowron and Kern, 1980; Kern, 1984; Quader, 2006). Bird populations are usually limited by natural ultimate factors (limiting factors), including food-supplies, nest and refuge sites, competitors, natural enemies (predators, parasites and pathogens) and weather (Begon and Mortimer, 1986; Newton, 1994; Begon *et al.,* 2006; Brambilla *et al.,* 2010).

General ecological differences among nest types are relevant to an understanding of life history patterns of nesting organisms. Several types of bird nests are recognized in the wild, they are scrape, mound, burrow, cavity, cup, saucer or plate, platform, pendant and sphere. Some species nest is simply a shallow depression made of sand; some others, it is the knot-hole left by a broken branch, a burrow dug into the ground, a chamber drilled into a tree, an enormous rotting pile of vegetation and earth or a mud dome with an entrance tunnel. Two important tree strata, namely bole and canopy are heavily used by birds for nesting. The cavity nesters such as parakeets, owls, barbets, hornbills, woodpeckers, kingfishers, starlings and mynas use the cavities for their nesting.

1.3 Cavity Nesting Birds

Cavity nesting birds (CNBs) comprise a major component of many forest bird communities. Throughout the world, many bird species depend on tree cavities for reproduction and sometimes roosting: the percent proportion of cavity nesters constituted 14% for Europe, 10% for North America, 24% for New Zealand, 18% Australia and 9% for south Africa (Rhodes *et al.,* 2009). Tree cavities provide birds with a safe, dry environment to incubate eggs and raise a brood of nestlings, or to spend nights. Cavity nesting birds are able to increase their reproductive output by using a cavity with features that protect the young ones from predators and inclement weather (Wesołowski, 2002; Wesołowski and Rowinski, 2012). However, secondary cavity-nesters (which require but cannot produce a cavity) are constrained in nest placement to existing cavities (Newton, 1994). For their close association with trees and cavities, CNBs are one of the most sensitive groups to the alteration of forest structure (Imbeau *et al*., 1999, 2001). Thus they are suggested to be indicators suitable for detecting and monitoring impacts of forestry (Winkel, 1996; Hausner *et al.,* 2003). Among them, the habitat requirements of woodpeckers have been most studied.

Cavity nesters typically experience high rates of nest success, but predation remains the primary cause of failure (Li and Martin, 1991). Changes in forest structure induced by silviculture may influence the predator community (Simard and Fryxell, 2003) and therefore the nest success (Duguay *et al.,* 2000). Ornithologists generally agree that Cavity nesting birds have greater nesting success than open-nesting species, primarily because cavities provide better protection from nest predators (Bulmer, 1984; Milonoff, 1989; Gill, 1990). They had substantially shorter nestling period than cavity nesting birds in order to avoid nest predation (Ricklefs, 1969, 1977). Some non-excavating birds have shorter nesting period (e.g., Nuthatch groups, Martin and Li, 1992).

Cavity nesting birds are considered as one of the most susceptible groups to such impacts due to their strong dependence on trees (Angelstam and Mikusiński, 1994; Martin and Eadie, 1999; Imbeau *et al.,* 1999; 2001). It has been suggested that the availability of nesting cavities limits the population density of such birds in many managed forests (Newton, 1994; Semel and Sherman, 2001; Twedt and Henne-Kerr, 2001; Pöysa and Pöysa, 2002).

1.3.1 Tree selection, tree size and tree condition

Trees suitable for cavity excavation are an essential resource for wildlife species that require cavities in trees for breeding, roosting, and shelter from inclement weather and predators. The suitability of trees for cavity excavation is primarily determined by their size and the degree and pattern of decay present in the main stem or major branches of trees (Bull *et al.,* 1997). However, patterns of use may differ among cavity nester guilds (groups) such as strong excavators and weak excavators. In addition, both strong (large woodpeckers) and weak excavators (small woodpecker and barbets) commonly prefer trees with greater diameters in which to nest (Yahya, 1988; Li and Martin, 1991; Yamauchi *et al.,* 1997; Hooge *et al.,* 1999; Adkins Giese and Cuthbert, 2005; Kosiński *et al.,* 2006; King *et al.,* 2007), and the reproductive success of cavity nesting birds is linked to the diameter of the nesting tree (Christman and Dhondt, 1997).

Cavity-nesting birds (CNBs) often select nesting and foraging sites in large declining or decaying trees (Raphael and White, 1984). Cavity nesting birds (excavators) are known to rely principally on dead or decaying trees for cavity excavation (Drapeau *et al*., 2009). Larger diameter trees or snags are clearly preferred by cavity nesting birds. Nest tree diameters must be large enough to accommodate a cavity with room for an adult bird and nestlings. The tree bole where the nest is located must be wide enough to allow a cavity large enough to contain nestlings. These factors promote preference for large diameter trees, in which the stem is of suitable width well above the ground. Nest tree or nest site selections are very important for bird nesting and their ability to select nest tree with reduced predation risk should be favoured by natural forest.

Standing dead wood (snags) are especially important for many wild fauna species, especially birds species (Bull *et al.,* 1997; Parks *et al*., 1997), providing roosting, feeding, and nesting sites (Mannan *et al*., 1980; Raphael and White, 1984; Niemi *et al.,* 1998). The presence of dead or dying trees suitable for cavity excavation is the single most important factor limiting the numbers of CNBs (Thomas *et al.,* 1976; Thomas *et al*., 1979; Dickson *et al*., 1983). Some cavity nesters also require relatively mature forests and large trees to excavate cavities (Conner *et al*., 1975; McClelland *et al*., 1979; Conner, 1980).

The age and size of a tree have a primary role in defining the abundance and distribution of tree cavities. Older and larger trees possess more cavities than younger and smaller ones (Gibbons and Lindenmayer, 2002; Blakely *et al*., 2008; Spiering and Knight, 2005; Koch *et al*., 2008b). There is a close relationship between many species of cavity dependent vertebrates and the abundance of large trees (Lindenmayer *et al*., 1993, Martin and Eadie, 1999; Cockle *et al*., 2011a).

When selecting a nest tree or cavity, birds need to balance several requirements and risks. Minimally, a cavity must be sufficiently large to contain a brood of nearly-fledged nestlings (Martin *et al.,* 2004). Risks to nests of CNBs include flooding (Wesolowski *et al.,* 2002), usurpation (Deng and Gao, 2005) and predation (Wesolowski, 2002). If nest-site selection is adaptive, birds should choose nest sites to balance space for nestlings, ease of acquisition, thermal properties, risk of flooding or tree collapse and risk from terrestrial predators and competitors. Many birds choose cavities high above the ground to avoid terrestrial predators such as snakes, rodents and monkeys (Nilsson, 1984; Brightsmith, 2005; Fisher and Wiebe, 2006). Birds might choose cavities with good visibility to observe the approach of predators and competitors in time to defend or leave their cavity (White *et al.*, 2006).

1.3.2 Tree cavity formation

Generally, cavities are formed by two basic modes in forest trees. Excavating birds (woodpeckers and barbets) provide one source of cavities, available to secondary cavity-nesters (SCNs). Natural decay processes provide a second source of cavities formed by biotic factors such as fungal decay, insects and abiotic processes such as attack, fire, wind (Hooge *et al.,* 1999; Hart and Hart, 2001; Wormington *et al.,* 2003; Jackson and Jackson, 2004; Martin *et al.,* 2004; Adkins, 2006; Holloway *et al.,* 2007; Ojeda *et al*., 2007; Koch *et al*., 2008). Most of the cavities are excavated by primary cavity users as nesting sites. Their entrances are typically circular, with clean edges and surfaces. Cavities created by wounding or broken branches are often more irregular in shape. Typically primary users such as woodpeckers will nest in a cavity only once, prefer to excavate a new nest hole in the same or different tree, the following year.

Cavity nesting birds can be classified into different guilds according to their mode of cavity acquisition. Primary cavity nesters (PCNs) (woodpeckers and barbets) excavate cavities in trees for nesting and roosting. Secondary cavity nesters (SCNs) require cavities but cannot excavate by their own and thus relying on the cavities constructed by excavators or formed through decay process. In recent years, some studies suggested the division of a third group, weak primary cavity nesters (WPCNs). These birds may excavate their own cavities in decayed trees, use naturally occurring ones, or use cavities from other species. Due to their potential flexibility, they may have different relationships with birds in other guilds, or show different response to the changing availability of nest site resources. Therefore, some authors strongly suggested considering them as a separate group when studying the structure within CNB communities (Martin and Eadie, 1999; Martin *et al.*, 2004).

1.3.3 Primary Cavity Nesters (PCNs)

Primary cavity nesters (PCN) birds, best represented by woodpeckers, use the dead wood extensively. These species excavate hollow cavities in tree stems, usually in dead and decayed wood, as a part of regular nesting and courtship behavior. These cavities are critical for life history needs of other species of birds and mammals, known as secondary cavity users. Thus, PCN birds can be considered “keystone species” in forest ecosystems, because many other species of forest wildlife are dependent on them for cavities (Wilson, 1992; Dailey *et al.*, 1993; Gorman, 2004; Michalczuk *et al.*, 2011). Cavities are an important resource in forests for many birds and mammals which use them for nesting, roosting and escaping from predators (Mudappa and Kannan, 1997).

Primary cavity-nesting birds (PCNs) (woodpeckers and barbets) choose decayed trees to excavate their nest cavities. All self-excavated nests of these species were in dead trees or dead portions of live trees, which are likely to have both sapwood and heartwood softened by decay (Harestad and Keisker, 1989). Woodpeckers are more dependent on dead trees, which have a soft wood substrate facilitating cavity excavation (Schepps *et al.*, 1999; Kosinski and Winiecki, 2004). Nesting in live trees may also have advantages as protection from predators (Arsenault, 2004) and cavities in live trees are warmer (Hooge *et al.*, 1999). Birds rarely excavate their cavities in live trees because of the hard structural properties of the wood (Mannan *et al.*, 1980, Lundquist and Mariani, 1991) and because most insect wood sources are found in decayed trees compared with the hard wood (Neitro *et al.*, 1985).

Primary excavators show different abilities to excavate. Two groups are recognized viz., species that forage by drilling, boring, or hammering into wood or soil and species that probe or glean bark, branches, and leaves to acquire prey. The former group is termed strong excavators. It includes most woodpeckers, sapsuckers, and the northern flicker (*Colaptes auratus*). Woodpeckers (Picidae) are the strongest vertebrate excavators (Martin and Eadie, 1999), with morphological adaptations in their bills, reinforced skulls, neck musculature, ribs and legs that allow them to chisel out cavities in hard tree substrates (Spring, 1965; Kirby, 1980).

Woodpeckers commonly start more than one potential nest cavities early in the breeding season (Conner *et al.*, 1976; Short, 1979). Some researchers propose that potential cavity trees are abandoned if they are not suitably decayed (Conner *et al.*, 1976), but Short (1979) suggests that the excavation of partial holes may be adaptive, allowing pairs to re-nest quickly after the loss of their first nest due to predation or competition. For small woodpeckers, the availability of suitable trees is likely to be particularly limiting because of these birds' weak excavation ability (Martin, 1993). Thus, smaller woodpeckers are more dependent on dead trees, which have a soft wood substrate facilitating cavity excavation, than the larger woodpeckers (Hagvar *et al*., 1990; Schepps *et al*., 1999; Kosinski and Winiecki, 2004). In addition, both small and large woodpeckers commonly prefer trees with greater diameters in which to nest (Yamauchi *et al.*, 1997) and the reproductive success of CNBs is linked to the diameter of the nesting tree (Christman and Dhondt, 1997). Many woodpecker species depend on certain tree resources, e.g. large trees, decayed trees (snags) or deciduous trees and other trees (Gunn and Hagan, 2000; Rolstad *et al*., 2000; Bonar, 2000; Hartwig *et al*., 2004; Kosinski and Kempa, 2007; Matsuoka, 2008; Kozma, 2010; Charman *et al*., 2012; Dempsey, 2013; Ćiković *et al.*, 2014; Michalczuk and Michalczuk, 2016).

Weak excavators, which require soft decaying substrate, may be limited by the availability of dead or dying trees (Steeger and Hitchcock, 1998). These trees may be rare in some forests because they are susceptible to wind throw and are often removed or knocked down during logging operations (Thomas *et al.,* 1976; DeLong *et al*., 2004). Woodpeckers have unique ecological roles in forested ecosystems (Virkkala, 2006). The niche of woodpeckers is defined by their use of rare forest features such as snags for nesting and roosting and downed wood for foraging. The exploitation of these forest features by woodpeckers creates habitat for other cavity nesting species and a variety of other vertebrates (Aubry and Raley, 2002; Martin *et al*., 2004). Because of their important roles in forests, several woodpeckers are designated as indicator species, or considered species at-risk by state and federal agencies and overall forest health (Mikuskinski *et al.,* 2001; Remm *et al.,* 2006).

1.3.4 Secondary Cavity Nesters (SCNs)

Cavity nesters that rely on cavities excavated by primary cavity nesters or natural cavities are called ‘‘secondary cavity nesters’’ (e.g., birds, mammals, reptiles, amphibians and insects). These nesters lack the morphological adaptations necessary for excavating their own cavities. Most of them use natural cavities or cavities excavated by PCNs. SCNs (non-excavators) usually occupy old cavities abandoned by PCNs (Sonerud, 1989; Bunnell and Dupuis, 1995; Stelmock and Harestad, 1979). Trees with cavities are often used repeatedly over time, either by the same breeding pair, by different pairs of the same species, or by multiple species either sequentially or simultaneously (Daily, 1993; Sedgwick, 1997). The dependence of SCNs on the excavations of PCNs has been well established (Machmar and Steeger, 1995). The SCNs rely on the cavities created by PCNs and rarely depend on existing cavities which have been formed by decay, limb breakage or other injuries of trees (natural holes). SCNs and small mammals reuse nests excavated by PCNs (Daily *et al.*, 1993; Johnsson *et al.*, 1993; Kalcounis and Brigham, 1998; Simberloff, 1998; Bonar, 2000; McClelland and McClelland, 2000; Arsenault, 2004; Blanc and Walters, 2008a; Cooke and Hannon, 2011). These birds are chosen for study because they play a keystone role in forest ecosystems and are associated with stand structures typical of mature forests. In addition, cavity nesting birds are important predators of forest pests and play a critical role in the maintenance of forest health

(Holmes, 1990; Machmar and Steeger, 1995). Hence, one may conclude that PCNs are most important in natural forests, where the different species produce a diverse supply of cavities. Secondary users are relatively abundant compared to primary excavators and competition for cavities is often intense (Bock *et al*., 1992). Some secondary cavity nesters choose suitable natural cavities for nesting to avoid competition in managed forest.

In addition to excavated cavities, naturally occurring cavities provide nest and roost sites for secondary cavity nesting species. These cavities develop through a variety of mechanisms, including tree limb or top breakage, loosening of bark wound openings and a range of fungal and diseases processes. However, little is known about the relative abundance and importance of excavated and non-excavated holes for cavity nesters (Martin and Eadie, 1999; Aitken *et al.*, 2002). The value of excavators as cavity providers may depend on the abundance of naturally occurring non-excavated holes (Carlson *et al.*, 1998, Remm *et al.*, 2006; Wesolowski, 2002). However, if non-excavated cavities are scarce in the landscape then it may be difficult for secondary users to locate cavities with suitable characteristics. Some SCNs may select deep cavities with small entrances, which would restrict access by larger predators (Cockle *et al.*, 2008). In that case, excavated cavities may provide the most options for secondary users, particularly if the primary excavator assemblage in the community is diverse (McClelland and McClelland, 2000; Kotaka and Matsuoka, 2002; Martin *et al*., 2004; Blanc and Walters, 2008b; Cooke and Hannon, 2011).

1.3.5 Nest Web

Nest web is a newly emerged approach in structuring cavity nesting bird communities analogous to food webs (Martin and Eadie, 1999). It reveals direct and indirect interactions among species and may predict the response of the community to perturbations or change. Studies on nest web structure have been investigated in British Columbia (Martin and Eadie, 1999; Aitken *et al*., 2002; Blanc and Walters, 2007; Aitken and Martin, 2008). Some recent trends of study on cavity nesting birds within broader ecological context include studies of sequential cavity use and nest web analysis. Patterns of cavity reuse are central to understanding the population ecology and evolution of cavity nesting birds (Sedgwick, 1997; Bai *et al.*, 2005). Secondary cavity users do not excavate their own cavities, but instead use excavated cavities, and it include bird species, small mammal species like squirrels, rodents and bats (Bai *et al.* 2005; Politi *et al.*, 2010). These cavities are critical for life history requirements of secondary cavity users (Machmer and Steeger, 1995; Martin *et al.*, 2004) and such interdependencies have been identified in an emerging concept called 'nest webs' (Martin and Eadie, 1999; Martin *et al.*, 2004; Blanc and Walters, 2008b). It has been shown that a relatively few number of primary cavity excavators may produce the majority of cavities reused by secondary species (Cooke and Hannon, 2011; Martin *et al.*, 2004). In this sense, primary excavators can be considered 'keystone species' in forest ecosystems (Wilson, 1992).

Across the globe, nest-site selection of cavity nesting birds has been intensively investigated. However, majority of the studies focused only on single species (Belthoff and Ritchison, 1990; Rudolph and Conner, 1991; Daily, 1993; Steeger *et al*., 1997; LaHaye *et al*., 1997; Smith, 1997; Rolstad *et al.,* 2000; Conner *et al*., 2001; Monterrubio-Rico *et al.*, 2006; Hartwig *et al*., 2004; Mitrus and Socko, 2004; King *et al*., 2005; Saab *et al.*, 2009; Politi *et al.*, 2009; Newlon and Saab, 2011; Kozma, 2010; Dempsey, 2013). These efforts resulted in detailed information valuable for setting up individual conservation guidelines. However, analyses of nest-site selection and use at the community levels were few, and interspecific relationships were largely ignored (Waters *et al.*, 1990; Ingold, 1994; Dobkin *et al.*, 1995; Martin and Eadie, 1999; Steeger and Dulisse, 2002; Bednarz *et al*., 2004; Nielsen-Pincus and Garton, 2007; Saab *et al.*, 2009). Some studies filled the gap by surveying the nest sites of several sympatric PCNs or SCNs, which provided the information to investigate the relative preference of each species, extent of niche overlap and the potential for competition (Balen *et al.*, 1982; Stauffer and Best, 1982; Peterson and Gauthier, 1985; Wesolowski, 1989; Carlson *et al*., 1998; Aitken *et al.*, 2002; Bai *et al.*, 2003; Saab *et al.*, 2011). While CNBs were composed of PCNs and SCNs, which have different constraints but are intimately related, an overall consideration is critical for demonstrating ecological links among species and drawing up comprehensive conservation plans.

In southern India, although nest site selection of cavity nesting birds has been investigated, most studies focused only on single species or sympatric species (Santharam, 2006 on woodpeckers, Santhanakrishnan *et al*. (2011) on owls, Sivakumaran and Thiyagesan (2003) on Indian Roller; Gokula and Venkatraman (2003) on Blue-winged Parakeet, Mudappa and Kannan, (1997), Maheswaran and Balasubramanian (2003) on Malabar Grey Hornbill, Charde *et al*. (2011), Santhoshkumar and Balasubramanian (2010) on Indian Grey Hornbill; James and Kannan (2009) on Great Hornbill; Bhatt *et al*. (2014) on Oriental Magpie Robin; Asokan *et al*. (2009a,b) and Nithiyanandam and Asokan (2015) on Indian Roller and Common Myna; Shukla *et al.*, (2015) on sympatric hornbills; Datta and Rawat (2004) on sympatric hornbills. Community level study of cavity nesting birds such as those by Thiyagesan (1991) and Pandey and Mohan (1993) are rare.

Anthropogenic interventions such as tree felling, non-timber forest products collection, agricultural activities along the forest boundaries threatens birds nesting in cavities of tree trunks and canopies. Cavity nesting birds prefer diseased, dying or dead trees because it is easier to find or excavate cavities in such trees. Although the low elevation riverine forests that course through forests are exceptionally rich in tree diversity and birds, very little is known about the use of tree resources by the important guild of birds- the cavity nesters. To conserve cavity-nesting birds and the services they provide in tropical forests, it is important to understand their breeding ecology and dependence on cavity resources. Nevertheless, little is known about cavity availability, nest-site requirements and nest tree preference of cavity nesters, or cavity nester community structure in the riverine forest.

1.4 Aim of the study

The present study aims to assess and determine the conservation value of the cavity nesting birds, cavity-bearing trees in riverine forest, cavity utilization by cavity nesting birds and to identify high-quality nest sites (nest tree) for protection or restoration.

1.5 Objectives

The present study addresses how a cavity-nesting community in the riverine forest is structured around the cavity production, characteristics, uses and tree preferences. The objectives are as follows.

1. Quantify the vegetation diversity of woody plants and species composition of riverine forest.
2. Find out the nest trees utilized by cavity nesting birds and assess the preferred nest tree species of cavity nesting birds.
3. Ascertain the characteristics of nest trees and nest cavities used by cavity nesting birds and to identify key relationships among cavity producers and consumers.

2 REVIEW OF LITERATURE

2.1 Riparian forest vegetation

Species richness, diversity and Phytosociology of riparian vegetation have been studied in many riparian forests of America, Europe, Africa and Australia. Balian and Naimen (2005) studied the abundance and production of Riparian trees in the lowland floodplain of the Queets river, Washington. Burton and Samuelson (2008) studied tree diversity, composition and structure in the riparian forest of Georgia Piedmont, USA.

Burton *et al.* (2005) examined the forest structure and woody vegetation diversity of riparian communities in Chattahoochee river basin in West Georgia, USA. They measured the forest structure and diversity was compared to measures of urbanization and land cover. Although *Liquidambar styraciflua* and *Quercus nigra* were dominant species in the forest stand and regeneration layer for all riparian communities, the invasive, non-native shrub *Ligustrum sinense* was the most dominant species observed in the regeneration layer for urban, developing, and agriculture communities.

Distribution and abundance of riparian trees was assessed by Harper *et al.* (1997) in English lowland floodplains, Great Ouse, Central England. McLennan and Plumptre (2012) studied the composition, structure and diversity of riverine forest fragments in Hoima and Masindi, Uganda. Family Moraceae was dominant with 11 species in Bulindi riverine forest, Uganda. Metzger *et al*. (1997) quantified the tree species and diversity of riparian forest in Jacare-Pepira river, southeast Brazil. Nakamura, *et al.* (1997) analysed the tree structure and composition of riparian forests with special reference to geomorphic site conditions along the Tokachi River, northern Japan. Nilsson and Jansson (1995) compared the species richness of vascular plants in different rivers in northern Sweden. Zani *et al*. (2013) determined the diversity of tree species and composition in a primary tropical rainforest of Taman Negara Pahang and found family Meliaceae and Leguminosae were the most abundant in the riparian forest.

Uowolo *et al*. (2005) studied plant diversity of riparian forest in northwest Colorado and recorded 159 species in Yampa river and 93 species in Green river. Wittmann *et al.* (2008) estimated the tree species composition and structure a riparian forest of the Lower Miranda River, Brazil and reported that Fabaceae was the most dominant family. Pither and Kellman (2002) studied tree species diversity in tropical riparian forest in Belize, Central America and recorded family Melastomaceae and Leguminosae as dominant families.

Studies dealing with Indian riparian vegetation analysis are very few. Johnsingh and Joshua (1989) categorized the gallery forest of the River Tambiraparani, Mundanthurai Wildlife Sanctuary, southern India. Balasubramanian *et al*. (2011) analysed the species diversity, richness and composition of riverine forest in Sathyamangalam Wildlife Sanctuary, Tamil Nadu. They recorded 64 tree species belonging to 25 families with a tree diversity value of 3.40 ha^{-1}. Shanmugam *et al.* (2016) studied the floral diversity of Vaigai river in Thiruppuvanam region of Sivagangai, Tamil Nadu, Southern India. Sunil *et al.* (2016) examined tree species richness, and composition and diversity of riparian forests across forest and agro-ecosystem landscapes along river Cauvery of southern India. Cherullipadi and Paul (2016) studied the diversity of herbaceous riparian flora in the Bharathappuzha river. Species composition and diversity of plant species between the forest vegetation along the Pamba river was studied by Joby Paul (2012) in Kerala, Western Ghats. They concluded that tree species diversity was higher along the river and the same decreased as one moves away from the river. Manoj *et al.* (2012) analysed the phytosociology of riparian tree species in Alakyam stream at Pariyaram, Kannur district of Kerala. Shah *et al.* (2015) documented the floristic richness in the riparian zone of Mini River, Gujarat, India. Srivastava and Singh (2013) studied the plant communities in the riparian forest of Ganga river at Bharwari. Riparian vegetation of Kali river in Aligarh was studied by Prabodh and Shipra (2010). In Himalaya, Iabal *et al.* (2012) studied plant diversity, structure and composition of plant species in Khoh river. They recorded 124 plant species belonging to 84 families. Chauhan and Gopal (2005) studied the vegetation structure and dynamics of a floodplain wetland along in Yamuna river, Delhi.

2.2 Bird communities in the riparian forest

In Kenya, Owino *et al*. (2008) recorded 155 bird species belonging to 43 families in lower Tana river forest of coastal Kenya. Molina Martinez (2014) surveyed the birds of Totare river basin, Columbia and recorded 410 bird species. dos Anjos *et al.* (2007) stressed the importance of riparian forest for the maintenance of bird species richness in an Atlantic Forest, southern Brazil. They reported a total of 145 species. Of the 81 species recorded in the upland and riparian forests, 19 species were recorded only in upland forest and 45 species exclusively in riparian forest. Frugivore guild was associated in upland forest whereas insectivores exclusively in riparian forest.

Aynalem and Bekele (2008) evaluated species composition, relative abundance and distribution of the bird fauna of wetlands and riverine habitat at Infranz, Lake Tana, Ethiopia and recorded 129 bird species. Breeding bird communities in riparian forests along the central Platte river, Nebraska was surveyed by Davis (2005), who reported 56 bird species in the riparian forests. Avifaunal diversity and distribution were estimated by Hossain and Abdul Baki (2015) in Buriganga river, Dhaka, Bangladesh and they recorded 38 species of birds in the river bank.

Kumbar and Ghadage (2014) recorded 126 species of birds belonging to 30 families in Krishna river basin, Maharashtra, India. Chavan *et al*. (2015) recorded 168 species of birds belonging to 53 families birds from Godavari river basin in Nanded, Maharashtra. In Andhra Pradesh, Prasad *et al.* (2014) studied that avifaunal diversity of Manjeera Wildlife Sanctuary. He reported the occurrence of 164 species belonging to 53 families of avifauna in different habitats including part of Manjeera river basin. Balapure *et al*. (2012) studied that avian diversity in Barna wetland of Narmada basin in Central India and recorded that 63 bird species belonging to 12 families. Bashir *et al*. (2012) recorded 55 bird species along a section of the river and banks of upper Ganges, India. Dal and Vaghela (2015) surveyed the avifaunal diversity around the Shetrunji River, Dhari, India and recorded 18 species of birds belonging to 8 families.

Biju Kumar (2006) recorded 140 species of avifauna and 49 families in the river bank of Bharathapuzha river basin, Kerala. Vincy *et al*. (2016) analysed the bird species abundance and distribution in Meenachil river basin of Kerala and recorded 92 bird species.

In Tamil Nadu, Joshua and Johnsingh (1986) recorded 159 species of birds belonging to 40 families in Mundanthurai Plateau, South India.

2.3 Nest tree use by cavity nesting birds

World over, several authors have studied the nesting ecology and nest site characteristics of cavity nesters. Martin *et al.* (2004) studied the nest sites and nest webs for cavity-nesting bird communities in interior British Columbia, Canada. They found that both live and dead trees were used, but noticed a strong preference for live trees with decay (45% of nests) or dead trees (45% of nests). Steeger and Dulisse, (2002) assessed the nest tree characteristics in coniferous forests of southern British Columbia, Canada and recorded 602 nests of 16 cavity-nesting species in 420 trees. Predominant tree species with active nests were Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), trembling aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). They found that 30 percent of nest trees were reused by cavity nesters. Rendell and Robertson (1994) studied cavity entrance orientation and nest site use by secondary hole nesting birds in south western Ontario. Tree Swallows (*Tachycineta bicolor*) were found to show preference to cavity entrances facing south- south East. European Starlings (*Sturnus vulgaris*) did not show any preference for entrance.

Aitken and Martin (2007) studied the importance of excavators in cavity nesting communities in the old mixed forest of Canada. They examined the 1371 excavated and non-excavated cavities used by 22 bird species and 7 mammal species in central British Columbia and excavated cavities were much more abundant (85%) than non-excavated cavities (15%). Fifty two percent of excavated cavities were most predominantly created by two species such as Red-naped Sapsucker (*Sphyrapicus nuchalis*) and Northern Flicker (*Colaptes auratus*).

Kozma and Kroll (2010) examined the association of temporal and spatial factors with nest survival of Western Bluebirds (*Sialia mexicana*) nesting in tree cavities in ponderosa pine (*Pinus ponderosa*) forests along the east slope of the Cascade Mountains, Washington.

Buchanan and Irwin (1993) described Spotted Owl (*Strix occidentalis*) nests and nest tree use on the slopes of the Cascade Mountains in Washington, USA. They found that more nests (92%) were in Douglas-fir live trees (*Pseudotsuga menzeiesii*) with larger diameter.

Kozma (2012) described that nest-site characteristics of the White-headed Woodpecker (*Picoides albolarvatus*), Hairy Woodpecker (*Picodes villosus*), and Northern Flicker (*Colaptes auratus*) in burned and unburned logged Ponderosa Pine (*Pinus ponderosa*) stands of the eastern Cascade Range of Washington. These woodpecker species were found most frequently in the excavated cavities in well-decayed snags.

King *et al*. (2007) examined the nest-tree and nest cavity characteristics of Red-headed woodpeckers in restored Savannas, Wisconsin. Red-headed woodpeckers nested in areas with greater basal area, cavity density, snag density, limb-tree density, and total dead limb length. They concluded that mainly snags and trees with greater dead limb length were used by Red-headed woodpeckers.

Nielsen-Pincus and Garton (2007) studied 111 nests of three species (Black-backed Woodpeckers, Pileated Woodpeckers and Williamson's Sapsuckers) of cavity nesting birds in the coniferous forest of Upper Grande Ronde sub-basin in the Blue Mountains of northeastern Oregon. All the three species preferred more than 10 m tall snags (dead) for nesting. Pileated Woodpecker and Black-backed Woodpeckers preferred Ponderosa Pine and Western Larch. Williamson's Sapsuckers did not exhibit preference for tree species. Schreiber and deCalesta (1992) studied the relationship between cavity-nesting birds and snags in the western Oregon.

Dobkin *et al*. (1995) assessed the nest site and nest cavity characteristics for six species of cavity nesting birds in the montane riparian and Snow Pocket Aspen (*Populus tremuloides*) woodlands in the north western Great Basin, Oregon. Live trees and snags with DBH >24 cm were favored as nest sites by cavity nesting birds. Red-naped Sapsuckers (*Sphyapicus nuchalis*) and Northern Flickers (*Colaptes auratus*) excavated nest cavities for a suite of non-excavator species.

Nest-site preferences of Flammulated Owls (*Otus flammeolus*) was studied by (McCallum and Gehlbach, 1988) in the Zuni Mountains of western New Mexico who recorded nest tree, nest features and nest tree surrounding woody vegetation. Average nest height was 4.9 m (SD 1.6) from the ground; average size of the nest entrance was 15.9 cm (SD 0.9); cavity depth was 21.2 cm (SD 5.2). They suggested that Flammulated Owls have increased in abundance with increasing vegetative density.

Arsenault (2004) assessed nest-site characteristics of two cavity-excavating species, the Acorn Woodpecker (*Melanerpes formicivorus*) and Northern Flicker (*Colaptes auratus*) and two secondary cavity-nesting birds, the Flammulated Owl (*Otus flammeolus*) and Western Bluebird (*Sialia mexicana*) in a mixed coniferous-deciduous forest of New Mexico. He found that Acorn Woodpeckers nested in live Gambel Oak (*Quercus gambelii*) most frequently and Northern Flickers in Ponderosa Pine (*Pinus ponderosa*) snags and these differences may be attributed to the excavation ability of the relevant species. Secondary cavity-nesters showed no preference for trees of different conditions i.e., alive or dead.

Monterrubio-Rico and Enkerlin-Hoeflich (2004) studied the Thick-billed Parrot (*Rhynchopsitta pachyrhyncha*) nest sites in the Sierra Madre Occidental in Mexico and nests were found in 187 trees (snags and live) of seven species, which averaged 75.2 cm dbh. They found that most nests were in snags (59%) and only two nests occurred in trees under 40 cm dbh. Most nests occurred in Douglas Fir (*Pseudotsuga menziesii*; 32.6%), and Mexican White Pine (*Pinus ayacahuite*; 21.9%).

Conner and Saenz (1996) examined woodpecker excavation and use of artificial polystyrene snags in four forest types in eastern Texas and reported 50% of the artificial snags were used by Downy Woodpeckers (*Picoides pubescens*) for cavity excavation. They observed that abandoned cavities in artificial snags used by other wildlife species were Carolina Chickadees *(Parus carolinensis),* Prothonotary Warblers *(Protonoraria citrea)* and southern flying squirrels *(Glaucomys volans).*

Red-cockaded Woodpecker nest trees were discovered by Conner *et al*. (2001) in the Angelina National Forest, eastern Texas, who reported that successful Red-cockaded Woodpecker nests in Loblolly (*Pinus taeda*) Shortleaf (*P. echinata*) pine habitat on the Angelina National Forest.

Dempsey (2013) studied the nest-tree characteristic of Red-headed Woodpeckers (*Melanerpes erythrocephalus*) at Cedar Creek Ecosystem Science Reserve in East Bethel, Minnesota. Of the 50 nests, 82% were located in oak savannah and the remaining nests in low-woodlands and open areas. He recorded that Red-headed Woodpeckers' nest cavities were excavated in an average height of 7.3 m in East Bethel, Minnesota. Saab *et al.* (2009) studied nest-site selection by six species of cavity-nesting birds in burned forests of

Western Idaho. They found that nest-site selection for most species was consistently associated with higher snag densities and larger snag diameters, whereas wildfire location was secondarily important. Newlon and Saab (2011) monitored 76 Lewis's Woodpecker nests in Aspen riparian woodlands of south-central Idaho and described nest-site characteristics. They suggested that Aspen riparian woodlands also serve as valuable breeding habitat for this species.

Primary cavity nesters (woodpeckers) chose different nest-sites mainly on the basis of support-structure height, whereas secondary cavity nesters primarily segregated nest-sites on the basis of cavity height. Waters *et al.* (1990) assessed the lack of nest site limitation in a cavity-nesting bird community in the western foothills of the Sierra Nevada Fresno, California. They examined the relationships between nest site availability and density of secondary cavity nesting birds by blocking cavities in an oak-pine (*Quercus* spp.-*Pinus* sp.) woodland.

Rodriguez-Estrella *et al*. (1995) assessed the nest-site characteristics of the Socorro Green Parakeet in a tropical vegetation of Isla Socorro, California and found that nests were in *Bumelia socorrensis*. Parakeets used the natural holes in large branches as nest cavities. They recorded that the average tree height was 9.7 m, average nest height 3.1 m, diameter of nest entrance 16 cm and cavity depth 100 cm.

LaHaye *et al*. (1997) evaluated the quality of nesting habitat and nest-site selection of California Spotted Owls (*Strix occidentalis*) in southern California and estimated that nest stands were characterized by greater variation in tree size, higher canopy closure, and greater basal area of large trees compared with random points. They found that the average Spotted Owl nest was located 16.1 m above ground, average tree height 24.4 m and tree dbh 90.8 cm. Most nests (75; 34.7%) were placed in *Abies concolor*.

Hooge *et al*. (1999) assessed that nest site selection in the Acorn Woodpeckers (*Melanerpes formicivorus*) at Hastings Reservation in central California and they preferred dead limbs in large, dead valley oaks (*Quercus lobata*) and California sycamores (*Platanus racemoa*) were frequently used as acorn storage trees. They recorded that nest tree mean dbh was 98.3 m (SD 36.8), nest height 8.1m (SD 2.7) and all nest holes (95.4%) faced downwards.

Hudson and Bollinger (2013) examined the nest success and nest site selection of red-headed woodpeckers (*Melanerpes erythrocephalus*) in east-central Illinois and reported that cavities at greater height had greater nest success from predators. Nest cavities were located primarily in Oaks *Quercus* spp. (40.7%) and Maples *Acer* spp. (33.3%). Red-headed woodpeckers nested more frequently in snags and they recommended that maintenance of large diameter snags and snags high above the ground will likely improve nesting habitat and nest success of Red-headed woodpeckers.

Nest-site selection and nesting success of cavity nesting birds were examined by Li and Martin (1991) in Central Arizona. According to these authors, Red-naped Sapsuckers (*Sphyrapicus varius*) and Cordilleran Flycatchers nested primarily in snags. Several species had 30% or more of their nests in live trees, all of which were aspens, except 19 House Wren nests in Maple. House wrens nested mostly in cavities abandoned by excavators (n=100), but some of birds took advantage of natural cavities (e.g. cracks) in Can-yon maples (n=19). Cordilleran flycatchers placed 30% of their nests in other sites such as broken-off trees, stumps and in a depression among the roots of overturned trees.

Ingold (1994) assessed nest-site characteristics of Red-bellied and Red-headed woodpeckers and Northern Flickers in east-central Ohio. Dimensions of cavity entrances of Red-bellied woodpecker (23 cm), Flicker woodpecker (32 cm) and Red-headed woodpeckers (18 cm) nests were determined. He stated that the flicker nest cavities had larger entrances and were located lower in trees than the Red-bellied and Red-headed Woodpecker cavities.

Nest site selection, nest design and nest entrance orientation in Bachman's Sparrow (*Aimophila aestivalis*) were assessed by Haggerty (1995) in central Arkansas. He found that there is no significant relationship among the nest site selection, nest design, vegetation structure. Steeger *et al*. (1997) assessed the characteristics of nest trees and nest sites of California spotted owls in coniferous forests of the southern Sierra Nevada and found that nests were in found both in live trees (69) and snags (17). They found that average nest tree height was 46 m (±SD19) and average nest height 26 m (±SD11) for the California Spotted Owls.

Belthoff and Ritchison (1990) observed nest site selection by Eastern Screech-Owl (*Otus asio*) in Central Kentucky. They found that the mean nest tree height was 20.8 ± 1.97 m, nest tree DBH 44.2 ± 2.05 cm and nest hole location height 6.5 ± 0.44 m. The mean length, width and depth of nest cavities were 12.4 ± 0.82 cm, 11.0 ± 0.72 cm and 30.6 ±3.69 cm, respectively.

Losin *et al*. (2006) investigated that nest-hole excavation by the Red-naped Sapsucker (*Syphrapicus nuchalis*) in Aspen (*Populus tremuloides*) woodlands in Western Colorado. Sapsuckers excavate nest cavities primarily in aspens infected with a heartwood rot fungus (*Phellinus tremulae*), which softens the heartwood of infected trees. Cavity entrance orientations were significantly biased to the south and southeast, corresponding with the directional bias in heartwood rot. Ramirez and Ober (2014) examined nest site selection and reproductive success of Red-cockaded woodpeckers in Ocala National forest, in central Florida, USA. Hartwig *et al*. (2004) examined cavity trees and cavity patches used by Pileated woodpeckers in south-eastern Vancouver Island.

Lawler and Edwards Jr (2002) found a total of 40 nests belonging to eight species of cavity-nesting birds in natural cavities in the Montane Aspen woodland fragments of Wasatch National Forest, Jordan. Birds that nested in natural cavities selected nest trees that were greater than 23 cm dbh. Nest-tree heights ranged from 3.7 to 24.8 m (12.5 ± 4.9 m). Alice Boyle *et al.* (2008) studied cavity density and distribution in a wet lowland tropical forest in Costa Rica. They found that cavities occurred frequently in live trees, and were often formed by damage or decay rather than by woodpeckers. Most cavities had small openings and woodpecker- made cavities were non-randomly oriented. Sandoval (2008) recorded 39 nests of Hoffmann’s Wood pecker in Getsemani, Costa Rica and observed that 25 nests were built in *Erythrina* sp., three in *Lonchocarpus* sp., two in *Bursera simaruba*, one in *Zanthoxylum caribeum* and one in an unknown tree species. He stated that all nests were built in snags or dead branches of live trees.

Cockle *et al*. (2011b) assessed the nest tree selection by cavity nesting birds in the neo-tropical Atlantic Forest Argentina. They observed that excavators selected dead or unhealthy trees. Secondary cavity nesters mainly selected cavities that were deep and high on the tree, using live and dead cavity bearing trees. Non excavated cavities suitable for birds occurred primarily in live trees.

Cockle *et al*. (2012) studied a 'nest web' or interspecific hierarchical network of cavity producers and users in the Atlantic forest, a tropical biodiversity hotspot of high conservation concern in South America. They recorded 132 nests and 5 roosts of 35 species of cavity-nesting birds in 100 tree cavities. Seventeen percent of the 98 nests and roosts of non-excavators were in cavities produced by woodpeckers, and 83% were in non-excavated cavities. Non-excavators did not use any of the seven cavities produced by Trogons (Trogonidae). Nesting cavities occurred in at least 27 species of trees and one palm, from 25 genera in 15 families. The most common cavity-bearing tree was Grapia (*Apuleia leiocarpa*, Fabaceae) with 17 cavities (accounting for 20%) followed by Yellow Laurel (*Nectandra lanceolata*, Lauraceae) with 9 cavities (10%).

Cockle *et al.* (2015) studied influence of nest survival of cavity-nesting birds along a gradient of human impacted sites in the subtropical Atlantic Forest, south America. They monitored 157 nests of 27 species in 98 cavities to examine nest survival in relation to habitat condition, tree characteristics and cavity characteristics. They found that the small birds experienced higher nest survival in cavities with smaller entrance diameters, higher above the ground. Large birds showed higher nest survival in living trees than in dead trees. Cornelius (2008) examined the nest-site selection by secondary cavity-nesting birds in a human-altered landscape in a temperate rainforest of southern South America.

Nest tree use by primary cavity-nesting birds was assessed by (Harestad and Keisker, 1989) in south central British Columbia who recorded 243 active nests. Most were in Trembling Aspen (*Populus tremuloides*) and Paper Birch (*Betula papyrifera*). Strong excavators preferred to nest in live Trembling Aspen and weak excavators preferred to nest in dead trees or dead top of live trees. They found that strong excavators (Yellow-bellied Sapsucker, Pileated Woodpecker, and Hairy Woodpecker) preferred to nest in live Trembling Aspen with heartwood decay. Weak excavators (Red-breasted Nuthatch, Northern Flicker, and Downy Woodpecker) preferred to nest in dead trees or dead tops of live trees. They concluded that heartwood-decay trees were the most important for nest tree selection by primary cavity-nesting birds in British Columbia. Restrepo and Mondragon (1998) studied the co-operative breeding in the frugivorous Toucan Barbet

(*Semnornis ramphastinus*) in south-western Colombia. They reported that out of 31 cavities observed, 23 were built in snags and seven in dead standing trees; only one cavity was built in a dead branch of a living tree.

Joy (2000) quantified the nest-tree and cavity characteristics of 32 Red-breasted Sapsucker (*Sphyrapicus ruber*) nests in the high-elevation coastal forests of northern Vancouver Island, British Columbia. He found nests in Western White Pine (*Pinus monticola*), Hemlock (*Tsuga* sp.), and Douglas-fir (*Pseudotsuga menziesii*) snags. Dias and Lima (2015) evaluated the nest-site characteristics and nesting success of Tropical Screech-Owls (*Megascops choliba*) in an area of Cerrado interspersed with cultivated areas in central Brazil. They found that Tropical Screech-owls nested in cavities with different orientations and closer to the ground than unused cavities. Cockle *et al*. (2011b) assessed the nest tree selection by cavity nesting birds in the neo-tropical Atlantic Forest Argentina. They observed that excavators selected dead or unhealthy trees. Secondary cavity nesters mainly selected cavities that were deep and high on the tree, using live and dead cavity bearing trees. Non excavated cavities suitable for birds occurred primarily in live trees.

Africa

Nest site characteristics of the Black-casqued Hornbill *Ceratogymna atrata* and White-thighed Hornbill *Ceratogymna cylindricus* were studied by (Stauffer and Smith, 2004) in south-central Cameroon. Of the 38 active hornbill nests recorded in the site, 25 were Black-casqued Hornbill nests and 13 White-thighed Hornbill nests. They observed that most cavities were in the boles of trees, but three were in large branches. They recorded average nest height of 22.8 m for Black-casqued Hornbill and 21.4 m for White-thighed hornbills.

Sweden

Carlson *et al.* (1998) studied that availability and use of natural tree holes by cavity nesting birds in a deciduous forest in Sweden. Of the 130 occupied cavities in the study area, 92.3% contained bird nests and 4.6% social insects. They quantified the density of cavities, their characteristics, their origin and the implications these have on nest site choice by hole-nesting birds in a deciduous forest in south central Sweden. They determined that limb holes were the most abundant type found (53%) and were also frequently used by hole-nesting birds (64.8%). Penduncate Oak and Aspen trees had more cavities. Generally the cavities used by hole-nesters had narrower entrance and were situated at greater heights.

Iberian Peninsula

Availability and suitability of tree cavities for hole-nesting birds were surveyed (Camprodon *et al*., 2008) in three beech wood types (mature, cleared and coppice forests) in the North east of the Iberian Peninsula. They studied the occupation of cavities and the abundance of hole-nesting birds. They found that trunk and branch cavities (25.9%) were significantly more abundant in mature woods and are correlated with the density of secondary occupants. Stump and root cavities (74.1%) were more abundant in coppice forests. The results show that suitability of cavities rather than availability determines secondary hole-nesting bird abundance in managed forests.

Finland

Virkkala *et al*. (1994) studied 15 cavity nesting species in different Nature Reserves in southern Finland. Of the six species of cavity nesters (Three-toed woodpecker, great-spotted woodpecker, Redstart, Pied Flycatcher, Crested Tit and Treecreeper) standardized, nest density increased in old growth forests (over 100 years) of the nature reserves. Nests of these species nests occurred in dead and dying trees in natural forest. Based on their observations they recommended a ban on the removal of dead trees in old growth forests for conserving the nest trees and hole nesting birds in southern Finland.

England

Charman *et al*. (2012) recorded that foraging behaviour, attributes of foraging trees and nest site characteristics of Lesser-spotted woodpecker in mature woodland blocks in England and reported that small branches of live oaks at heights usually in the upper third of the tree were most frequently used for foraging. Smith (2007) studied the woodpeckers and dead wood in oak woods in southern England. He surveyed a total of 517 nest trees used by Great Spotted Woodpeckers, 16 by Lesser Spotted and 36 by Green woodpecker. Great and Lesser Spotted woodpecker showed strong selection for nesting in snags. They found that Green and Great Spotted woodpecker nests were in ‘mature/live’ trees and half in trees recorded as 'dead/ decaying', whereas for Lesser Spotted Woodpeckers 75% of nests were in 'dead/decaying' sites. He concluded that dead and decaying trees strongly resource for Great woodpecker and Lesser Spotted woodpecker.

Europe

Ćiković *et al*. (2014) assessed the nest site and nest characteristics of Great-spotted woodpecker (*Dendrocopos major*) in hill forest and riverine forest of Croatia, southern Europe and found most nest cavities were excavated in tree trunks (78%). They found that *Quercus robur* in riverine forest and *Prunus avium* in hill forest were mainly used by Great-spotted Woodpecker in Croatia.

Poland

Nest site choice of the starling *Sturnus vulgaris* in relation to cavity depth and the presence of old nests was studied by Mazgajski (2003) in the northern outskirts of Warsaw, Central Poland. He found that starlings chose nest sites according to the depth of the cavity.

In the coniferous and deciduous, Kosinski and Kempa (2007) studied breeding ecology of woodpeckers. They observed that except Lesser Spotted Woodpeckers, all other species used live trees as nest sites. Weaker excavators such as Middle Spotted and Lesser Spotted Woodpeckers nested more frequently in limbs and branches (31 and 25% of nests, respectively) compared to strong excavators, i.e., Great Spotted, Black and Grey-faced Woodpeckers. They concluded that weaker excavators more frequently selected dead tree fragments compared to strong excavators.

Kosiński *et al*. (2006) assessed the nest site characteristics of Great-spotted woodpeckers (*Dendrocopos major*) and Middle-spotted woodpeckers *(Dendrocopos medius)* in near natural and managed riverine forests of the Warta river valley, central Poland. They found that Great- Spotted Woodpecker strongly preferred oaks and Middle Spotted Woodpecker excavated in ashes. They recorded that average height of the nest entrance from the ground level was 10.0 ± 6.2 m for Greater Spotted Woodpecker and 11.3 ± 7.0 m for Middle Spotted Woodpecker. Greater and Middle Spotted Woodpecker nests were located in live trees (86.1% and 72.3%).

Great and Middle Spotted Woodpecker nest-hole dimensions and tree diameters at hole-entrance height were analysed by Kosiński and Ksit (2007) in the riverine forest of the Warta river valley, central Poland. They recorded that cavity entrance vertical diameter was 49.2 mm (±SD 4.9), horizontal diameter 46.0 mm (±SD 4.1) and chamber depth 240.4 mm (±SD 47.6) for Greater spotted woodpecker. In the case of Middle Spotted Woodpecker, the cavity entrance vertical diameter was 45.7 mm (±SD 3.8), horizontal diameter 44.9 mm (±SD 4.3) and chamber depth 244.5 mm (±SD 58.7). They opined that small entrance diameters of holes helps to prevent predation by Pine Marten *Martes martes.*

Kosiński and Kempa (2007) described that abundance, distribution and nest-site characteristics of woodpecker species i.e., Great Spotted Woodpecker (*Dendrocopos major*), Middle Spotted Woodpecker (*D. medius*), Lesser Spotted Woodpecker (*D. minor*), Black Woodpecker (*Dryocopus martius* L.), Grey-faced Woodpecker (*Picus canus*) and Wryneck (*Jynx torquilla*) in managed forest, central Poland. They analysed that Great and Middle Spotted Woodpecker excavated nest-holes most commonly in oaks (78 and 86% of nests, respectively), but Black- and Grey-faced Woodpeckers in beeches (71 and 100% of nests). Great Spotted- and Grey-faced woodpeckers nested three meters lower (9 m) compared to Middle Spotted and Black Woodpeckers (12 m). Great Spotted Woodpeckers, Middle Spotted Woodpeckers, Black Woodpeckers and Grey-faced Woodpeckers primarily used live trees, while Lesser Spotted Woodpeckers selected decaying trees. They concluded that Lesser Spotted Woodpeckers and Middle Spotted Woodpeckers, those attributes are related to the presence of older deciduous-dominated forests with dead or decaying trees as nesting and foraging-sites, but Grey-faced Woodpeckers and Black Woodpeckers are adapted to nesting in large trees and foraging in young forest stands.

Maziarz *et al.* (2015) studied the natural nest-sites of Great Tits (*Parus major*) in a primeval temperate forest in Białowieza National Park, Poland and reported that the nest cavities were situated from 0.3 to 28 m above ground level, at an average (8.9 m ±6.3) in plots. The compass orientation of all nest cavities was uniformly distributed among eight divisions and 11 % cavities facing south-east and north-west to 16 % facing north. They found majority of cavity entrances (69 %, n = 614) were in a vertical plane, 25 % directed upwards and 6 % facing downward from the horizontal.

Wesołowski and Rowiński (2012) studied the breeding performance of Blue Tits *Cyanistes caeruleus* in relation to the attributes of natural holes in a primeval forest, in Poland. They found that nest holes were situated mainly in trunks of live trees, non-excavated, with narrow slit-like openings, and had relatively small bottoms.

Research in Asian countries

Bai *et al*., (2003) surveyed natural tree holes and nest holes of hole-nesting birds in four forest types in the west Khentii Mountains of NE Mongolia. They investigated the utilization patterns of species, size and condition of trees, as well as hole types. The average density of tree holes in the study area approached 30 holes/ha, while that of hole-nesting birds was 2.4 nests/ha only. The riparian mixed forest had the greatest number of species and individuals of hole-nesting birds, while the spruce-fir forest had the lowest numbers. Excavating bird species preferred larger, deciduous trees, and snags. Non-excavators did not select holes according to tree species or size, but preferred holes in living trees and branch holes. They observed that the density of secondary hole-nesting birds is not limited by availability of holes in the study area.

Bai *et al*. (2005) mentioned that the utilization of live/dead trees varied among different primary cavity nesters and the density of secondary hole-nesting birds is not limited by availability of holes in the study area. Koh and Lu (2009) investigated the characteristics of nest trees and nest cavities of *M. nuchalis* in Taipei Botanical Garden and recorded that 27 nest holes in 12 trees, which included eight different tree species dominated by camphor (*Cinnamomum camphora*). They suggested that removal of dead trees and dead limbs from *M. nuchalis* habitats is disadvantageous during their breeding season of barbets.

Nesting habitats of two subspecies of Hill Mynah *Gracula religiosa* were studied by Archawaranon (2006) in Thailand. He recorded 76 nest trees and 310 neighbour trees of northern Hill Mynah (*G. r. intermedia)* and 25 nest trees and 136 neighbour trees of southern Hill Mynah (*G. r. religiosa)*. He studied the nest characteristics including nest height, nest size, nest depth, cavity entrance, angle of nest cavity and cavity entrances.

Leadprathom *et al*. (2009) studied the nesting ecology of the Collared Scops Owl *Otus lettia* in Thailand. He reported that the majority of nest sites were tree cavities with the cavity opening facing skyward.

Okahisa *et al.* (2012) assessed the nest sites and nest characteristics of Narcissus Flycatcher (*Ficedula narcissina*) in the Fuji primitive forest of Japan. Japanese Hemlocks were the most commonly chosen tree species for nesting. Narcissus Flycatcher prefer to nest in dead trees whose average nest height was 7.3 m. Nests were built in shallow cavities (mean depth± SD: 7.00±SD4.24 cm) with small bottom area (mean hole greatest diameter ± SD: 9.85±1.37, mean smallest diameter ±SD: 8.26±1.34). Most of the entrance holes were oriented either north or south.

Shiina *et al*. (2013) assessed the characteristics of trees excavated by the Japanese Pygmy Woodpeckers *Dendrocopos kizuki* in a natural mixed forest in Hokkaido, Japan. They recorded eight nests and 10 roosts of Japanese Pygmy Woodpecker whose nests were located in seven tree species. For trees used by the woodpeckers, tree mean height was 17.0±SD 8.0 m and mean DBH was 40.1±21.5 cm. Sixteen of the used trees were classed as dead, 12 as partly dead, and 22 as live. They discovered that nest cavities were freshly excavated in dead branches of live trees by Japanese Pygmy woodpecker during every breeding season. They concluded that Japanese Pygmy woodpeckers preferred large trees and small dead branches for nesting.

Nest sites and nest characteristics of Narcissus Flycatcher *Ficedula narcissina* were examined by (Okahisa *et al*., 2012) in a deciduous broadleaf forest and evergreen coniferous forest of Japan. Japanese Hemlocks were the most commonly chosen tree species for nesting. Nests were built at an average height of 7.3 m. Flycatcher tented to nest in dead trees or trees with trunks greater than 20 cm diameter. Most of the entrance holes were orientated either North or South.

Research in Indian subcontinent

Sarker *et al*. (2012) studied the breeding biology of the Coppersmith barbet (*Megalaima haemacephala*) in Dhaka district, Bangladesh. They recorded that the height of the nests from the ground ranged from 6- 13 m (average 9.7±1.59 m). Trounov and Vasilieva (2014) reported the nesting biology of the Red-vented Barbet (*Megalaima lagrandieri*) in a natural habitat in Loc Bac forest, southern Vietnam. *Megalaima lagrandieri* excavated nests in dead trees or in dead branches of living trees. Average nest tree diameter was 386.66 mm nest height 13.5 mm and cavity entrance diameter 62.33 mm.

Hussain *et al.* (2013) investigated the cavity-bearing trees, the attributes of their cavities and the associated vertebrate fauna in a Coniferous forest of Dhirkot, Jammu and Kashmir. They found 211 cavities (64% natural cavities and 36% excavated cavities) in 83 trees (41% live and 59% snags). It was reported that 74% of the cavities were recorded in trunks and 26% were in branches. Only 28% of the cavities showed signs of recent use by any vertebrate species. They observed that 19 cavities were used by vertebrate species (2 mammals, 13 birds and 4 reptiles). Height from the ground, entrance diameter, and depth of the cavities used by mammals were greater than the dimensions of the cavities occupied by birds and reptiles. Their studies showed that tree cavities have a critical role in providing nesting sites to many vertebrate species of Pakistan that require tree cavities in order to breed.

Shukla *et al*. (2015) examined the nest site characterization of sympatric hornbills include Indian Grey Hornbill (*Ocyceros birostris*) and Oriental Pied Hornbill (*Anthracoceros albirostris*) in a tropical dry forest in the Rajaji National Park, Himalayas, India. Cavity-width was marginally larger in Indian Grey Hornbill nests (9.54 ±0.81 cm) compared to Oriental Pied Hornbill (7.6 ±0.65 cm). Among the 14 tree species on which the two hornbill species nested, five were common to both hornbills (*Shorea robusta*, *Syzygium cumini*, *Terminalia bellerica*, *Bombax ceiba* and *Lagerstroemia parviflora*).

Nesting of Common Myna (*Acridotheres tristis*) was studied by Kaur and Khera, (2014) in the fields of Punjab Agricultural University, Ludhiana, India. In the breeding season, 35 nests of Common Myna were observed out of which 30 were on tree cavities and five were natural nests. They concluded that Common Myna mostly preferred Gulmohar followed by Silver Oak for nesting and the average nest height was 7.5 feet.

Nath (2009) observed that Jungle Myna *Acridotheres fuscus* occupied usurping the nest hole of Grey-headed Starling *Sturnus malabaricus* in the Bansbari range office campus in Manas National Park, Assam, India. He noticed that Jungle Myna nested at a height of 7 m from the ground in a dead *Melia dubia*.

Yahya (1988) studied that breeding biology of barbets, *Megalaima viridis* and *M. rubricapilla* in Periyar Tiger Reserve, Kerala. He reported that barbet species selected only dead and dry branches of live trees for excavating nests and *M. rubricapilla* prefers thinner branches at much higher levels than does *M. viridis*. According to Yahya (1988) both species usually excavate a new nests each breeding season they use old roost-holes for nesting.

Breeding biology of the Spotted Owlet (*Athene brama*) was studied by (Santhanakrishnan *et al*., 2011) in Madurai district, Tamil Nadu, India. Of the 32 nest-sites located, the Spotted Owlet largely preferred cavities in trees. Largest numbers of nests were located in *Ficus benghalensis.* They assessed that nest-site characters and reported a mean nest tree height 13.3 ± 5.44m above the ground, diameter at breast height 194.3 ± 22.49 cm and nest hole location height 6.9 ± 1.92 m above the ground. Mean height, width and depth of nest cavities were 34.5 ± 10.42 cm, 24.9 ± 9.24 cm and 80.9 ± 15.74 cm respectively.

Santharam (2003) reported 11 nest-trees of White-bellied woodpeckers (*Dryocopus javensis*) in 29 different sites of the Western Ghats, India and the nest trees were 18.5 (± 4.2) m tall, and 59.1 (± 14.5) cm diameter and the nest cavities were 11.7 (± 2.3) m high, and the diameter at nest height was 37.6 (± 11.5) cm. Seventy three percent nests were located on tree trunks, and twenty seven percent nests were located on branches. He opined that dead or dying trees are essential for the survival of White-bellied Woodpeckers.

Breeding biology of the Indian Roller, *Coracias benghalensis* was investigated by Asokan *et al.* (2009b) in the Cauvery river basin, Tamil Nadu, India. They studied that a total of 11 nest-sites and found the Indian Roller highly preferring Coconut trees *Cocos nucifera* (45.5%). Gokula and Venkatraman, (2003) studied the breeding biology of the Malabar Parakeet *Psittacula columboides* in the Siruvani foothills, Western Ghats, Tamil Nadu. They found that the common trees of the area being used for nesting and reported a mean tree height of 14.5 m (range; 13.1 to 16.9 m) and nest hole height was 7.9 m (range; 4.8 to 8.3 m).

Mudappa and Kannan (1997) quantified and characterized the nesting habitat of Malabar Grey hornbills *Ocyceros griseus* in the Anamalai Hills of southern Western Ghats, India. They reported that Malabar Grey hornbills selected nest trees of significantly larger diameter at breast height (DBH 60-89 cm). Santhoshkumar and Balasubramanian (2010) studied breeding behaviour and nest tree use by Indian Grey Hornbill *Ocyceros birostris* in the Eastern Ghats, India. They located 32 nests in live trees and all of them in stream/riverine habitats. Maheswaran and Balasubramanian (2003) studied the nest tree preferences of Malabar Grey Hornbill *Ocyceros griseus* in Western Ghats and stated that most of the nests were placed on live trees. Datta and Rawat (2004) also found the nests of hornbill on live trees in Arunachal Pradesh, India.

3 STUDY AREA

3.1 Western Ghats

The study area Athikadavu Valley is located in the Nilgiri hills of southern Western Ghats. The Western Ghats, also known as the "Sahyadri Mountains", is a majestic mountain range along the west coast of India. It runs north to south along the western edge of Deccan Plateau, and separates the plateau from a narrow coastal plain along the Arabian Sea. This chain of mountains runs parallel to the West coast of Peninsular India. The range starts from the mouth of river Tapti and extends southwards up to the southern most tip of the Peninsula, Kanyakumari in Tamil Nadu through the states of Gujarat, Maharashtra, Goa, Karnataka and Kerala (Rodgers *et al.*, 2002). The continuous chain of mountains has a major discontinuity in the Palghat gap thus separating the Nilgiris from the Anamalais. Western Ghats lie between 8° 20'- 20° 40' N and 73°-77° E and is approximately 1,600 km long (Nair and Daniel, 1986) and covers an area of 1,60,000 km^2. The average elevation is around 900 m and the highest mountain peak is Anaimudi (2695m).

This unique biogeographic Malabar province of the Oriental Kingdom (Mani, 1974; Rodgers *et al.*, 2002) has pronounced north-south, east-west elevation gradients. The Western Ghats is internationally recognized as an important eco-region (Olson and Dinerstein, 1998). Because of rich floral and faunal diversity (Raman, 2001), it has been recognized as one among the 36 biodiversity hotspots of the world (Noss, 2016) and also the most thickly populated hotspot of all. The major soil types found in the Western Ghats are red soil, laterite, black and humid (Subramanyan and Nayar, 1974; Nair and Daniel, 1986). The Western Ghats is further divided into Northern and Southern Western Ghats.

3.1.1 Climate

The Western Ghats sector receives rains from the southwest monsoon. The southern parts receive rains all through the year while the areas in the north remain dry for 8 to 9 months. The average annual rainfall in the Western Ghats region is 2500 mm (Padhye *et al.*, 2012). There are 38 east flowing and 27 west flowing major rivers in the Western Ghats. The rivers which originate in the west in the Western Ghats drain into the Arabian Sea while the three major rivers in the Western Ghats - Cauvery, Krishna and Godavari flows eastwards into the Bay of Bengal. The temperature gradient is related mostly to increase in altitude. However, it is not uniform throughout the Ghats because of the variability in relief from south to north. Mean temperature ranges between 20° to 24°C, frequently shooting beyond 30°C during summer (April–May) and sometimes falling to almost 0°C during winter in the high altitude hilly regions (Dahanukar *et al.,* 2011).

3.1.2 Vegetation types

The vegetation of the Western Ghats is classified into seven major types such as 1) montane wet temperate grasslands, 2) montane wet temperate (shola) forests, 3) tropical wet evergreen forests, 4) tropical semi-evergreen forests, 5) tropical moist deciduous forests, 6) dry deciduous forests, and 7) scrub forests (Champion and Seth, 1968).

3.1.3 Floral diversity

A compilation of the floral biodiversity of Western Ghats shows that it has 7402 species of flowering plants (Nayar *et al.,* 2014) and 608 species are aquatic plant species (Kumar *et al.,* 2011). Of the 7,402 species of flowering plants occurring in the Western Ghats 5,588 species are native or indigenous and 376 are exotics naturalised and 1,438 species are cultivated or planted as ornamentals.

Apart from these, 750 species fungi were also reported (Lakhanpal, 1994). Out of the 4303 angiosperm endemic species reported in India, 2116 species are endemic to the Western Ghats (Singh *et al.,* 2015). The validity of endemism at generic and higher taxonomic levels is however subject to systematic revisions. It is interesting to note that nearly 38% of all species of flowering plants in the Western Ghats are endemic. Further, 63% of evergreen woody plants of India (Johnsingh, 2001) and of the nearly 650 tree species found in the Western Ghats, 352 (54%) are endemic to the Western Ghats (Daniels, 2001).

3.1.4 Faunal diversity

The Western Ghats supports rich and diverse faunal wealth. Among the vertebrates, birds were represented by the largest number of birds (508 species), followed by fishes (290 species), reptiles (227 species), mammals (137 species), and amphibians (181 species) (Radhakrishnan and Rajmohana, 2012). A total of 137 species of mammals are known from Western Ghats. Notable species include Lion-tailed Macaque (*Macaca silenus*), Nilgiri Tahr (*Nilgritragushylocrius*), Asian Elephant (*Elephas maximus*), Tiger (*Panthera tigris*), and Indian Leopard (*Panthera pardus*). Among the vertebrates of Western Ghats, the highest levels of endemism are exhibited by Amphibians. Among the Amphibias, the family Rhachophoridae popularly known as 'the old world tree frogs' are the most diverse in Western Ghats. Of the 181 species identified, 159 are endemic to Western Ghats (Molur, 2008). One of the interesting recent discoveries from Western Ghats pertains to that of a new species of frog of the Indo-Madagascan line, namely the purple frog *Nasikabatrachus sahyadrensis*. The streams and rivers in the southern parts of the Western Ghats support a greater aquatic faunal diversity. The east flowing streams and rivers have richer fish fauna than in west flowing river. Currently, 320 species of freshwater fishes belonging 35 families and 112 genera are recognized from the Western Ghats (Dahanukar and Raghavan 2013). The Western Ghats harbours 189 species of endemic fishes (Dahanukar *et al.,* 2011). Molluscs are an important group for freshwater biodiversity, and where abundant, play an important role in ecosystem functioning (Vaughn *et al.* 2004). A total of 77 molluscs species were reported and which includes 52 gastropod and 25 bivalve species. Of these 27 species are endemic to Western Ghats (Aravind *et al.,* 2011). Of the 270 species of snails identified 207 were endemic to the region (Aravind *et al.,* 2005).

The vast majority of the reptiles in Western Ghats are the snakes. A total of 227 species of reptiles belonging to 20 families have been recorded from the assessment region of which 107 species (47.13%) are endemic to Western Ghats (Srinivasulu *et al.,* 2014). Lizards also exhibit rich diversity with the families Gekkonidae and Scincidae being most species rich. Of these 124 endemic species are known in this region. The primitive burrowing snakes of the family Uropeltidae are mostly restricted to the Western Ghats

(Mirza and Pal, 2010). Butterfly fauna of the Western Ghats comprises of 334 species belonging to 164 genera under 6 families. Of the 334 species, 38 were endemic to the Western Ghats (Padhye *et al.*, 2012).

The Western Ghats supports around 508 species of birds out of which 144 are aquatic birds including those which are found in the coastal regions (Daniels, 2001). Sixteen species of birds were endemic to Western Ghats (Radhakrishnan and Rajmohana, 2012). The avian fauna of the Western Ghats includes endangered Rufous-breasted Laughingthrush (*Garrulax cachinnans*), the vulnerable Nilgiri Woodpigeon (*Columba elphinstonii*), White-bellied Shortwing (*Brachypteryx major*) and Broad-tailed Grassbird (*Schoenicola platyurus*), the near threatened Grey-breasted Laughingthrush (*Garrulax jerdoni*), Black and Rufous Flycatcher (*Ficedula nigrorufa*), Nilgiri Flycatcher (*Eumyias albicaudata*), Nilgiri Pipit (*Anthus nilghiriensis*) and Malabar Parakeet (*Psittacula columboides*), Malabar Grey Hornbill (*Ocyceros griseus*), White-bellied Treepie (*Dentrocitta leucogastra*), Grey-headed Bulbul (*Pycnonotus priocephalus*), Rufus Babbler (*Turdoides subrufa*), Wynaad Laughingthrush (*Garrulax delesserti*), White-bellied Blue Flycatcher (*Cyornis pallipes*) and the Crimson-backed Sunbird (*Leptocoma minima*).

3.2 Location of study area

The study was carried out in Athikadavu valley along the river Bhavani in the south-eastern Nilgiri slopes, Western Ghats. The Valley is situated between 11°11'26.06" to 11°16'26.46" N & 76°43'49.58" to 76°50'25.83" E in the Western Ghats (Figure 3.1). Average elevation of the valley is 500m. The vegetation of the river bank is classified as tropical semi-evergreen forest type, which is flanked by dry mixed deciduous forests. Bhavani, the second largest river in Tamil Nadu, originates in Kerala's Silent Valley and flows into western Tamil Nadu, covering a distance of 217 km before merging with the Cauvery near Erode. (Figure 3.2). The basin drains an area of 0.62 million ha, spread over Kerala (9 per cent), Karnataka (4 per cent) and Tamil Nadu (87 per cent). The main river courses through Coimbatore and Erode districts of Tamil Nadu, before reaching the Cauvery at Bhavani town. About 90 per cent of the river’s water is used for agriculture, even as industries dot the sub-basin at every point.

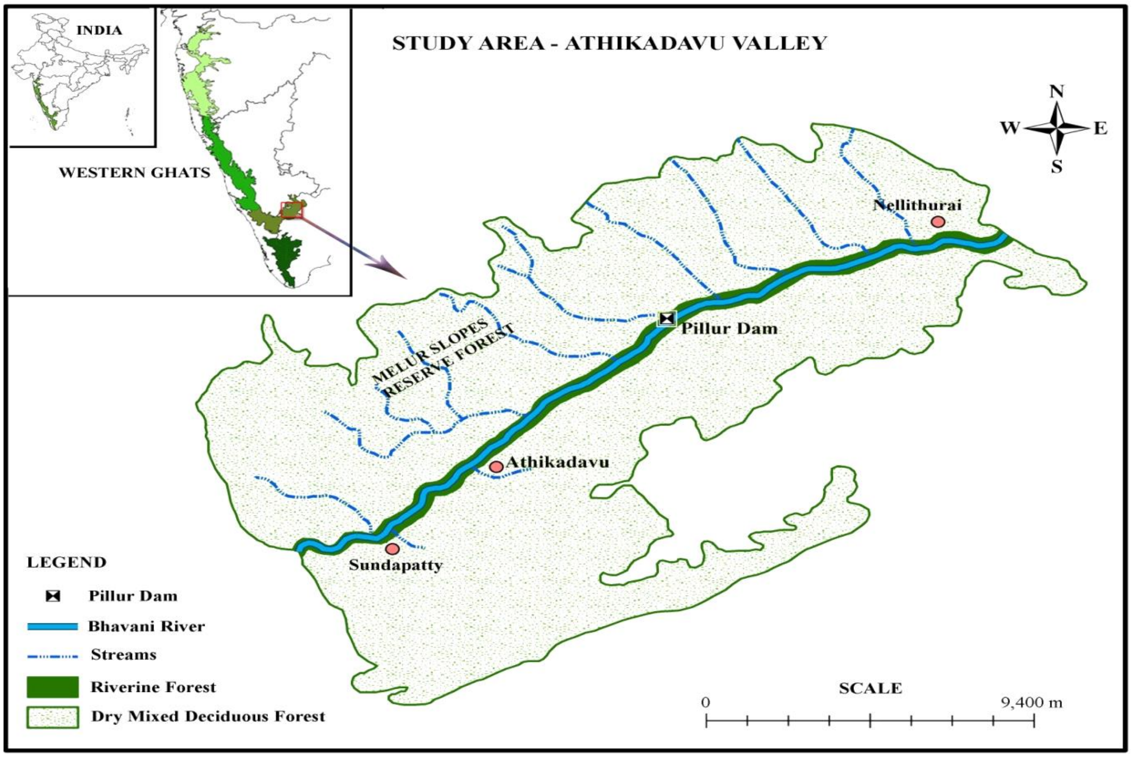


Figure 3.1 Map showing the study area-Athikadavu Valley

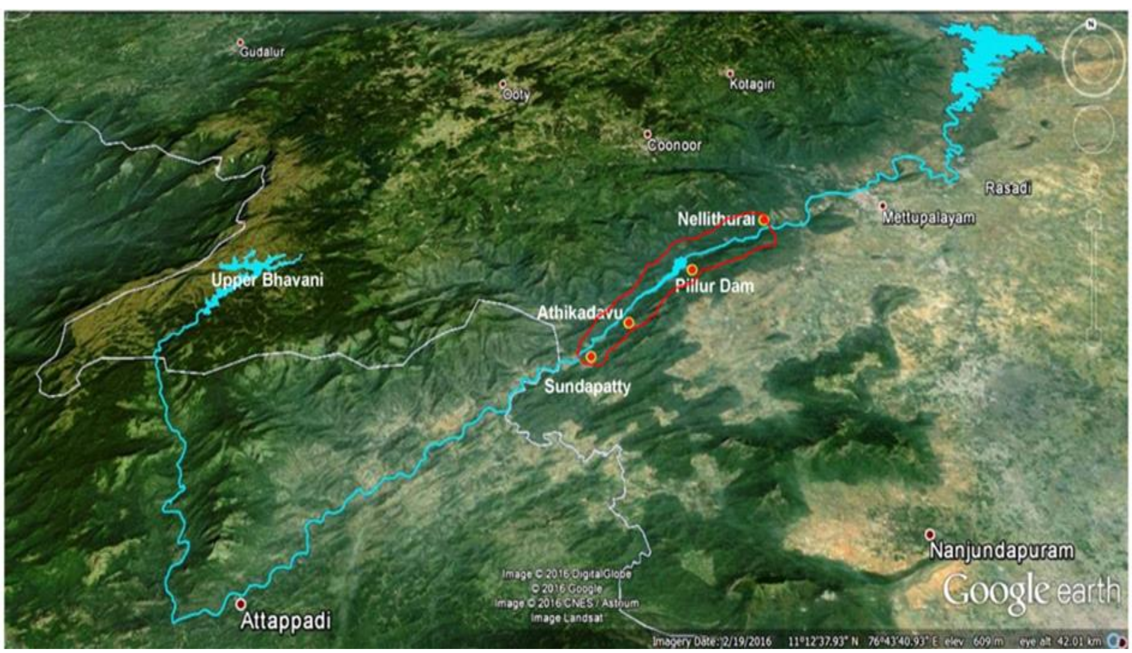
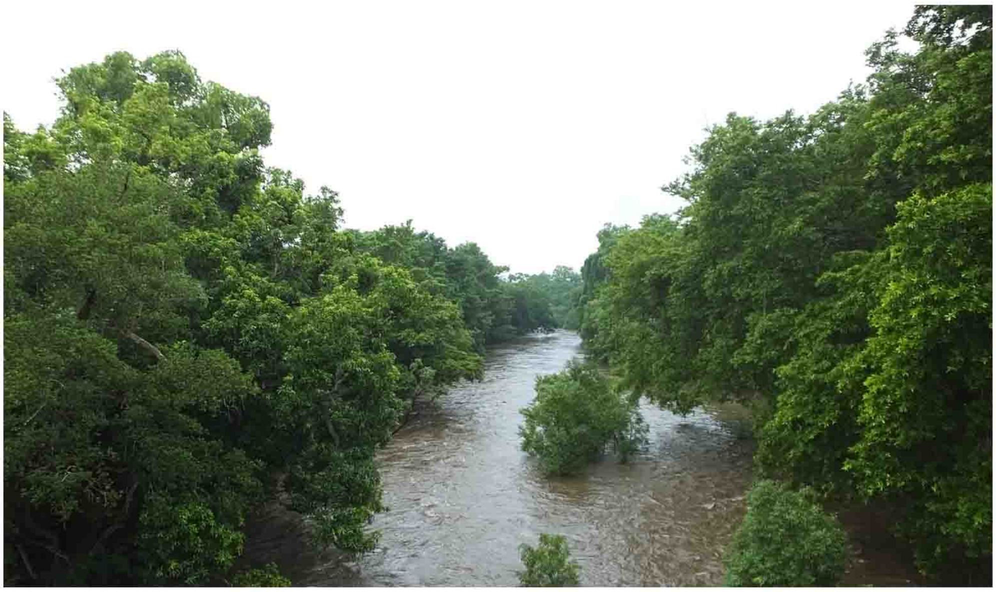
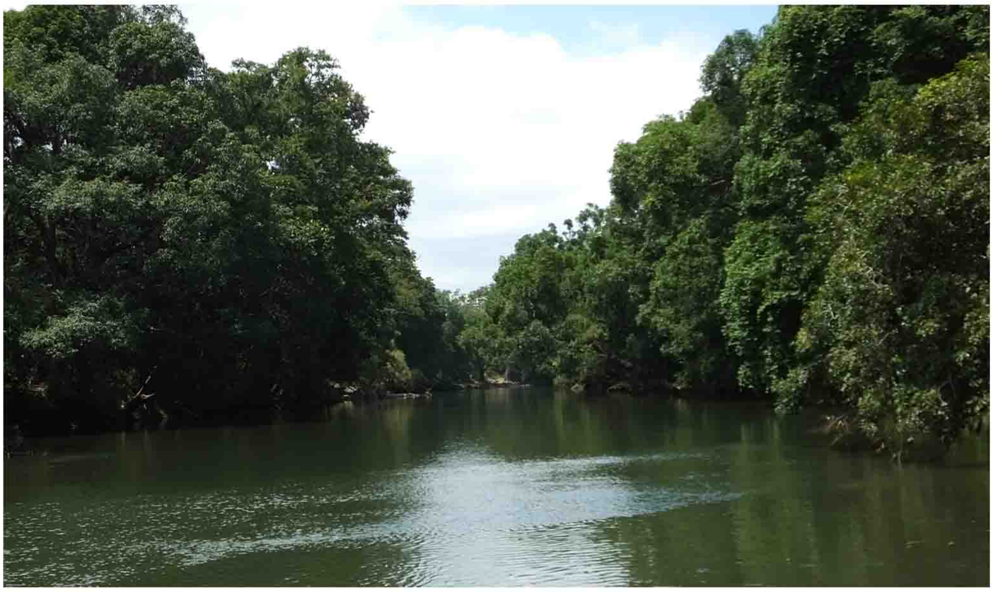
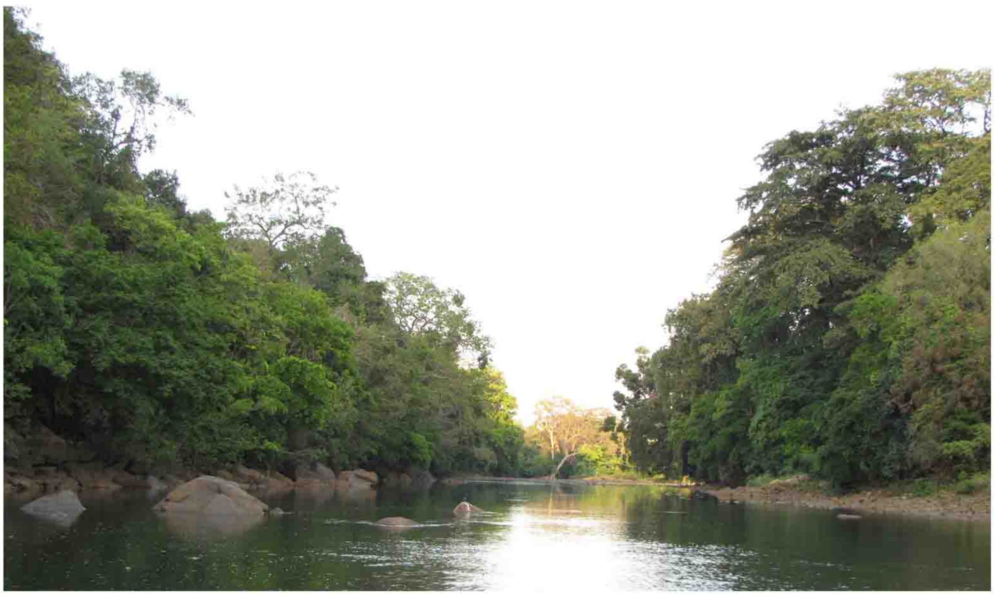


Figure 3.2 Satellite image showing Bhavani river course through the study area

Riverine Forests - Athikadavu Valley







3.2.1 Climate and Rainfall

The atmospheric temperature varies from a maximum of 35.6° C in the summer months to a minimum of 18.5° C in winter months. Summer commences from February and continues upto May. Temperature decreases with south-west monsoon which sets in June. The hottest months are April-May and the coldest December and January. The study area receives rain fall from both the monsoons. The south-west monsoon sets in June and the north-west monsoon sets in October. Average annual rainfall is about 556 mm.

3.2.2 Soil type

Basically two type of soils namely red soil with sandy loam which contains gravel mixed with red soil are recognised (Palanisami, 2008) in the study area.. The sandy loamy soils deposited in river bed have a moderate deep, moist, fertile, loamy upper covered with humus. Red soils are having sandy loam and silt content occur in the mixed dry deciduous forest with underlying rocks and boulders.

3.2.3 Vegetation

Athikadavu Valley is an ecologically important region owing to the presence of pristine semi-evergreen forest alongside the Bhavani River. The semi-evergreen forest, mainly seen on the fringes of river Bhavani is dominated by tree species such as *Terminalia arjuna, Terminalia bellirica* (Combretaceae), *Mangifera indica* (Anacardiaceae) *Madhuca longifolia*, (Sapotaceae) and *Syzygium cumini* (Myrtaceae). Flanking the riverbanks is the southern dry mixed deciduous forest, dominated by species such as *Anogeissus latifolia*, *Azadirachta indica*, *Bauhinia racemosa*, *Cassine glauca*, *Chloroxylon swietenia* and *Drypetes sepiaria* (Balasubramanian *et al.*, 2004; Balasubramanian and Manikandan, 2015).

3.2.4 Fauna

Athikadavu Valley harbours a wide variety of wildlife including aquatic species. A total of 158 species of birds were reported by Manikandan and Balasubramanian (2016). Notable bird species include the vulnerable Nilgiri Woodpigeon (*Columba elphinstonii*), the near threatened Malabar Pied Hornbill (*Ocyceros birostris*), Great Hornbill (*Buceros bicornis*), Indian Darter (*Anhinga melanogaster*), Lesser Fish-eagle (*Icthyophaga humilis*) the endemic Nilgiri Flycatcher (*Eumyias albicaudata*), Malabar Parakeet (*Psittacula columboides*) and

Rufus Babbler (*Turdoides subrufa*). The area is rich in mammal life. The Asian Elephant (*Elephas maximus*), Indian Gaur (*Bos gaurus*), Spotted Deer (*Axis axis*), Sambar Deer (*Rusa unicolour*), Barking Deer (*Muntiacus muntjak*), Sloth Bear (*Melursus ursinus*), Wild Boar (*Sus scrofa*), Bonnet Macaque (*Macaca radiata*), Common Langur (*Semnopithecus priam*) and Nilgiri Langur (*Trachypithecus johnii*) are the herbivorous mammals of this area. Carnivores such as Leopard (*Panthera pardus*), Indian Wild Dog (*Cuon alpinus*) and Indian Civet (*Viverricula indica*) and Indian Grey Mongoose (*Herpestes edwardsii*) also occur here. The Short-nosed fruit bat (*Cynopterus sphinx*) and insectivorous bats are also common. Seed predators such as Large Brown Flying Squirrel (*Petaurista philippensis*) and Indian Giant Squirrel (*Ratufa indica*) and Indian Palm Squirrel (*Funambulus palmarum*) are very common here. Indian Smooth Indian Otter (*Lutrogale perspicillata*) inhabit the streams. Herpetofauna such as Indian Rock Python, Monitor Lizard, Pit vipers, Cobra and Green Forest Lizard, Garden Lizard are recorded.

3.2.5 Eco-tourism

Eco-tourism program is being organized by the Tamil Nadu Forest Department in Athikadavu. This Jungle Eco-tourism initiative has been initiated to create an eco-tourism spot in Coimbatore region for the public to have a feel of forest and appreciate the flora and fauna as well as to create employment and income generation avenues for the tribals. Tourism activities such as coracle ride in backwater of Pillur dam, field trekking in the jungle have become popular in the recent time. Tourists enjoy the backwaters of Pillur dam taking a coracle ride and also treat themselves with the tribal cuisine. Tourists walk for two km watching birds and wild animals.

3.2.6 Tribal settlements in the riverine forests

Several tribal settlements are situated along the Bhavani river course in the Coimbatore Forest Division. Twenty settlements are located in the study ara namely Gethekaadu, Kodiyur, Korapathi, Koravankandy, Maannar, Mulli, Neeradi, Nellimarathur, Nellithurai, Parali kadu, Poochimarathur, Puthukaadu, Sengalpallam, Sirukinaru, Sorandi, Sundapatty, Surukki, Thondai, Veppamarathur, Veerakkal (Figure 3.3). Irulars are the most predominant tribal inhabitants of these settlements. They mainly depend on forest produce for their income, though agriculture is also practiced by some of them. Most of them have lost interest in traditional agriculture and hence, lease out their little lands under their possession to the settlers who employ modern techniques to raise various crops. Hundreds of hectares of riverine habitats are cleared for cultivation. Major crops cultivated include banana and maize. Vegetables such as onion, chilly, brinjal and tomato are also grown in many locations. Extensive fishing activities are noticed near the Pillur dam and along the Bhavani river. All cultivated lands and settlements along the river bank mainly depend on the river for water source. Approximately 2000 domestic cattle are maintained in the settlement area. Goats and Sheep are also found in large numbers. These cattle freely graze in riverine patches often competing with the wild herbivores such as gaur, sambar and deer.

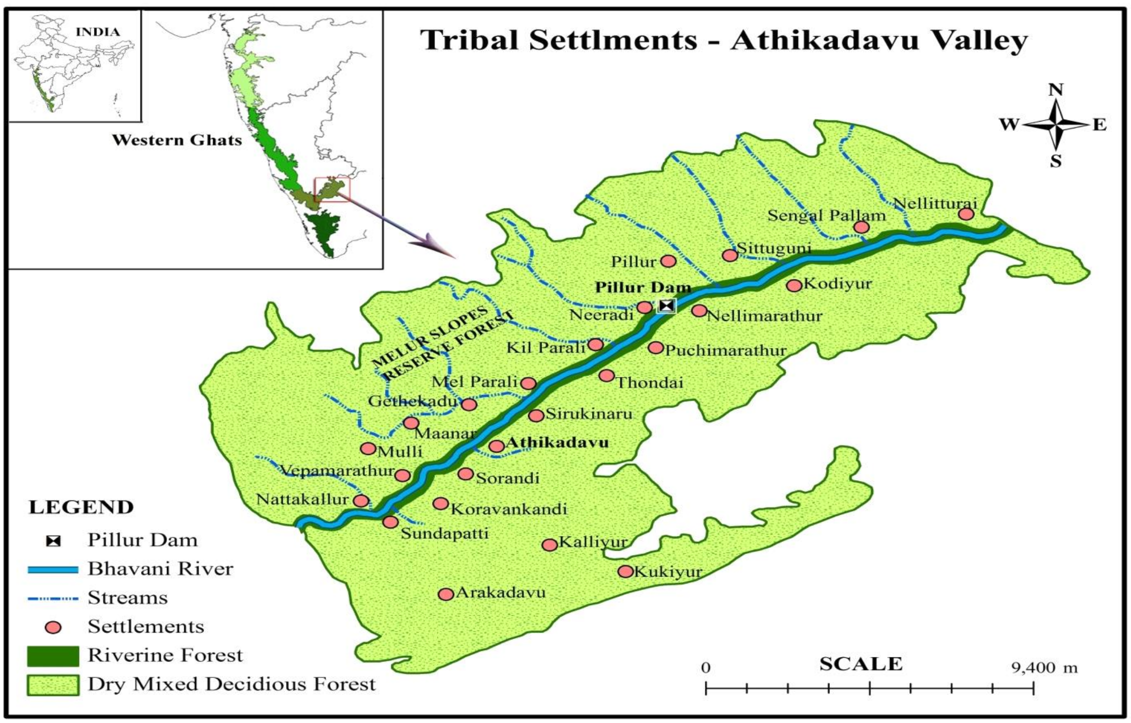


Figure 3.3 Study area map showing tribal settlement locations

Tribal Settlements in the riverine forests

4 VEGETATION ECOLOGY OF ATHIKADAVU

4.1 Introduction

Riparian forests are the interface between aquatic and terrestrial ecosystems. They are affected by fluvial processes such as flooding and deposition of alluvial soil, and typically support a distinctive flora that differs in structure and function from adjacent terrestrial vegetation (Gregory *et al*., 1991; Naiman *et al*., 1993, 2005; Tang and Montgomery, 1995; Naiman and Décamps, 1997). Riparian vegetation influences ecologically major important functions in relation to aquatic habitats, including the provision of food, moderation of stream water temperature via evapotranspiration and shading, providing a buffer zone that filters sediments and controls nutrients and stabilization of stream banks (Barling and Moore, 1994; Hood and Naiman, 2000). It also provides a corridor for the movement of biota (Naiman and Décamps, 1997) and serves many important roles for humans (Kemper, 2001). The riparian forest has been recognized as "keystone ecosystem", because it harbours certain unique habitats which are highly influenced by water (Goebel *et al.* 2003b). Wildlife biologists recognize the riparian forests as a critically and functionally dominant component of a terrestrial landscape (Tabacchi *et al.*, 1998). However, riparian forests have been subjected to progressive alteration in the last centuries, mainly due to human pressures that have greatly degraded their ecological structure and function (Naiman *et al*., 1993; Hughes, 2003).

Significant researches on diversity and phytosociology of riparian vegetation have been carried out in many rivers in America eg. Sacramento River (Micheli *et al.*, 2004), Jacare-Pepira river (Metzger *et al*., 1997), La Plata river (Heartsill-Scalley and Aide, 2003), Colorado River (Tiegs *et al*., 2005), Willamette river (Fierke and Kauffman, 2005), Missouri river (Johnson, 2002), Miranda river (Wittaman *et al*., 2008), Animas river (Baker, 1990), Queets river (Balian and Naiman, 2005); in Europe, Danube river (Molder and Schneider, 2011), Biebrza River (Wassen *et al*., 2002), Adour River (Decamps *et al*., 1995), Andarax River (Salinas *et al*., 2000); in Africa, Caura river (Rosales *et al*., 2001), Letaba and Olifants rivers (Hood and Naiman, 2000); in Australia, Murray River (Roberts and Ludwig, 1991) and Boyer river (Boutin *et al*., 2003) in Canada.

There are only a few studies in the Indian subcontinent dealing with riparian vegetation analysis. Studies on riparian vegetation in India were carried out in Chalakkudy (Bachan, 2002; 2003), Pamba (Joby Paul, 2012), Alakyam river (Manoj *et al.,* 2012) in Kerala, Tambiraparani (Johnsingh and Joshua, 1989) and Vagai river (Shanmugam *et al.,* 2016) in Tamil Nadu, Cauvery (Sunil *et al.,* 2010, 2016) in Karnataka, Mini river in Gujarat and Khoh river in Uttarakhand.

Johnsingh and Joshua (1989) described the vegetation of a gallery forest of the River Tambiraparani, Mundanthurai Wildlife Sanctuary, Southern India. Jayaram (2000) and Sunil *et al.* (2010) point out that the Cauvery river basin in Southern India has floristic wealth which is large enough to constitute a separate phytogeographic unit. Bachan (2002, 2003) recorded 329 flowering plants of 260 genera and 97 families from the Vazhachal region of the Chalakkudy river basin, Western Ghats. The impact of river valley projects on this endemic riparian vegetation was analyzed and it was found that alterations in the ecosystem would destroy the entire riparian habitats and vegetation (Bachan, 2005). A study on the status of Valappatanam river with special reference to its ecology and socio-cultural aspects was carried out by Sreedharan (2005) in Kerala. Joby Paul (2012) studied richness, diversity, distribution, ecology, phenology, and disturbances of riparian vegetation along the elevation gradient of the Pamba river basin of Kerala. In this context, the present study was conducted to assess the tree species diversity and composition of vegetation along river Bhavani, Tamil Nadu. This is perhaps the first attempt to discern the river bank vegetation of this river system.

4.2 Methodology

4.2.1 Vegetation Sampling

Woody vegetation of the riverine forest was quantified by using belt-transect method. Sampling was done in two belt transects, each measuring 1 ha (1000x10m). The belt transect was divided into 10x10 m subplots and the trees measuring >20 cm gbh (girth at breast height) were recorded. To quantify the vegetation composition in the adjoining mixed dry deciduous forests, 2 ha was sampled. Tree species were identified using regional floras (Gamble and Fischer, 1915-1936; Chandrabose and Nair, 1988). Snags found inside the sampling plots were identified to species level and enumerated.

4.2.2 Data analysis

The important quantitative analysis of tree species (abundance, density and frequency) was determined as per Curtis and McIntosh (1950). A species based rarefaction curve was generated to compare the species variation between the two landscapes using Biodiversity Pro software (McAleece *et al.,* 1997).

Density of a species is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied. It is calculated by the following equation:

$$\text{Density} = \frac{\text{Total number of individuals of a species in the quadrats}}{\text{Total number of quadrats studied}}$$

Frequency of single species refers to the degree of dispersion of individual species in an area and usually expressed in terms of percentage of occurrence. It is calculated by the following equation:

$$\text{Frequency} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats sampled}} \times 100$$

Abundance of single species is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats in which the species occurred. It is calculated by the following equation:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in the quadrats studied}}{\text{Total number of quadrats in which the species occurred}}$$

The role of individual species in the totality was quantified by estimating the Relative density, Relative frequency, Relative dominance and Importance value index.

4.2.2.1 Relative density

Relative density is the expression of numerical strength of a species in relation to the total number of individuals of all the species and it is calculated by the following equation:

$$\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Total number of all individual species}} \text{ X100}$$

4.2.2.2 Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurring in the given area of study is called relative frequency. It is estimated by the following formula:

$$\text{Relative frequency} = \frac{\text{Frequency of one species}}{\text{Total frequency of all species}} \text{ X100}$$

4.2.2.3 Relative dominance

Dominance of a species is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

$$\text{Relative dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \text{ X100}$$

The total basal area was calculated from the sum of the total girth of woody stems. In trees and woody stems, the basal area was measured at breast height (1.3 m) and by using the formula πr^2.

4.2.2.4 Importance Value Index

This index is used to determine the overall importance of each species in the community structure. In calculating this Index, the percentage values of the relative frequency, relative density and relative dominance are summed up together and this value is designated as the Importance Value Index or IVI of the species (Curtis, 1959).

Vascular plants form the dominant component of any forest ecosystem. Species richness, species diversity and dominance index are the important values of this assemblage to be determined.

4.2.2.5 Species richness, diversity and dominance indices

The species richness of the vascular plants was calculated by using the method

'Margalef's index of richness' (D_{mg}) (Magurran, 1988)

$$D_{mg} = (S-1)/ \text{In } N$$

Where, S = Total number of species.

N = Total number of individuals.

Species diversity and dominance were evaluated by using the following methods.

Shannon's diversity index and Simpson's index of dominance were calculated using important value index (IVI) of species.

4.2.2.6 Shannon – Wiener (1963) index of diversity

The formula for calculating the Shannon diversity index is

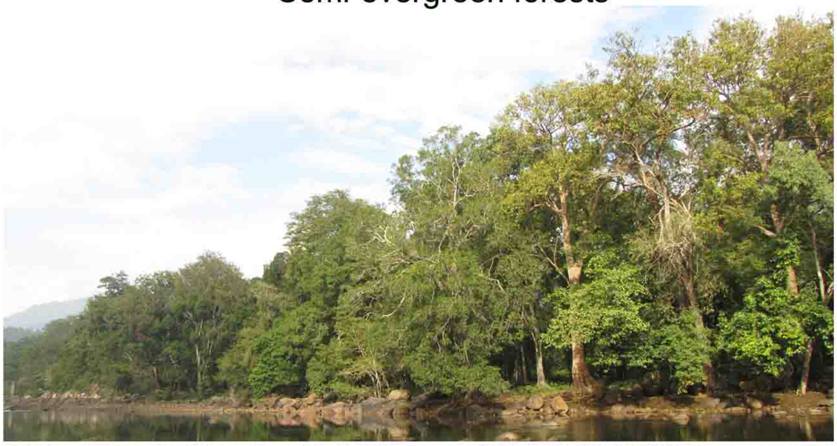
$$H' = -\Sigma\, p_i \text{ In } p_i$$

Where, H' = Shannon index of diversity

p_i = the proportion of important value of the i^{th} species ($p_i = n_i / N$, n_i is the important value index of i^{th} species and N is the important value index of all the species).

Forest Types - Athikadavu Valley

Semi-evergreen forests



Mixed dry deciduous forests

4.2.2.7 Simpson (1949) index of Dominance

The equation used to calculate Simpson's index was

$$D = 1-\Sigma (p_i)^2$$

Where, D = Simpson index of dominance p_i = the proportion of important value of the i^th^ species ($p_i = n_i / N$, n_i is the important value index of i^th^ species and N is the important value index of all the species).

As D increases, diversity decreases and Simpson's index was therefore usually expressed as 1 – D or 1/ D.

4.3 Results

4.3.1 Woody species composition in the riverine forests

In the riverine forests of Athikadavu valley, a total of 70 woody species belonging to 60 genera and 34 families were recorded (Appendix 1). Woody species included 65 tree, three species woody lianas and two species shrubs. A total of 1039 trees were recorded in the 2 ha sampling plots and the total basal area was 280.25 m^2. Tree layer consisted of species such as *Aglaia roxburghiana*, *Albizia chinensis*, *Alphonsea sclerocarpa*, *Diospyros peregrina*, *Calophyllum apetalum* etc. In the sample plots, highest number of individuals were recorded for *Pongamia pinnata* (n=280) followed by *Diospyros peregrina* (n=151) and *Mangifera indica* (n=80). The maximum value for relative density, relative dominance, and relative frequency were recorded for *Pongamia pinnata* and the values were 26.95, 30.65 and 17.64 respectively. The dominant tree species included *Pongamia pinnata* (IVI-74.64) *Diospyros peregrina* (41.75) and *Mangifera indica* (41.16). The plant community of the riverine forests in Athikadavu valley can be described as *Pongamia pinnata-Diospyros peregrina* - *Mangifera indica* community (Table 4.1 & Figure 4.1).

Table 4.1 Ecological values of woody plants enumerated in the riparian forest

Sl. No.	Name of the species	No. of Individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
1	*Pongamia pinnata*	280	26.95	8.93	17.64	53.52
2	*Terminalia arjuna*	65	6.26	29.69	6.96	42.90
3	*Mangifera indica*	80	7.70	20.92	9.69	38.31
4	*Diospyros peregrina*	151	14.53	7.38	13.66	35.58
5	*Syzygium cumini*	71	6.83	7.65	7.58	22.06
6	*Madhuca longifolia*	42	4.04	7.74	4.84	16.63
7	*Drypetes roxburghii*	25	2.41	1.11	2.86	6.37
8	*Hopea ponga*	17	1.64	1.05	1.74	4.42
9	*Salix tetrasperma*	17	1.64	1.10	1.61	4.35
10	*Calophyllum apetalum*	12	1.15	1.20	1.49	3.84
11	*Aglaia roxburghiana*	16	1.54	0.26	1.86	3.66
12	*Terminalia bellirica*	5	0.48	2.42	0.62	3.53
13	*Ixora pavetta*	15	1.44	0.16	1.74	3.34
14	*Ficus drupacea*	6	0.58	1.98	0.75	3.30
15	*Pleurostylia opposita*	13	1.25	0.46	1.49	3.21
16	*Crataeva magna*	12	1.15	0.31	1.12	2.58
17	*Atalantia racemosa*	11	1.06	0.04	1.37	2.46

Sl. No.	Name of the species	No. of Individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
18	*Ligustrum perrottetii*	10	0.96	0.15	1.24	2.35
19	*Homonoia riparia*	13	1.25	0.44	0.62	2.31
20	*Memecylon edule*	9	0.87	0.28	0.99	2.14
21	*Hydnocarpus pentandra*	8	0.77	0.48	0.87	2.12
22	*Pterocarpus marsupium*	4	0.38	1.15	0.50	2.03
23	*Strychnos nux-vomica*	9	0.87	0.05	0.99	1.91
24	*Olea dioica*	8	0.77	0.12	0.99	1.89
25	*Manilkara hexandra*	7	0.67	0.34	0.87	1.88
26	*Vitex altissima*	7	0.67	0.32	0.87	1.86
27	*Celtis philippinensis*	7	0.67	0.05	0.87	1.60
28	*Alseodaphne semecarpifolia*	6	0.58	0.25	0.62	1.45
29	*Ficus microcarpa*	5	0.48	0.31	0.62	1.41
30	*Shorea roxburghii*	5	0.48	0.29	0.62	1.39
31	*Mimusops elengi*	5	0.48	0.24	0.62	1.34
32	*Phyllanthus polyphyllus*	6	0.58	0.01	0.75	1.33
33	*Trewia polycarpa*	6	0.58	0.12	0.62	1.32
34	*Chionanthus mala-elengi*	6	0.58	0.09	0.62	1.29
35	*Dalbergia latifolia*	5	0.48	0.30	0.50	1.27

Sl. No.	Name of the species	No. of Individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
36	*Psydrax dicoccos*	5	0.48	0.12	0.62	1.22
37	*Alphonsea sclerocarpa*	5	0.48	0.11	0.62	1.21
38	*Schleichera oleosa*	5	0.48	0.19	0.50	1.17
39	*Ficus amplissima*	4	0.38	0.19	0.50	1.07
40	*Nothopegia beddomei*	4	0.38	0.05	0.50	0.93
41	*Melia dubia*	2	0.19	0.34	0.25	0.78
42	*Diospyros ovalifolia*	3	0.29	0.08	0.37	0.74
43	*Litsea deccanensis*	3	0.29	0.05	0.37	0.71
44	*Diospyros ferrea*	3	0.29	0.02	0.37	0.68
45	*Garcinia gummi-gutta*	3	0.29	0.02	0.37	0.68
46	*Ficus virens*	3	0.29	0.01	0.37	0.67
47	*Ficus racemosa*	2	0.19	0.17	0.25	0.62
48	*Streospermum personatum*	2	0.19	0.15	0.25	0.59
49	*Tamarindus indica*	2	0.19	0.08	0.25	0.52
50	*Albizia lebbeck*	1	0.10	0.29	0.12	0.51
51	*Gmelina arborea*	2	0.19	0.07	0.25	0.51
52	*Erythrina stricta*	2	0.19	0.04	0.25	0.48
53	*Ficus benghalensis*	2	0.19	0.04	0.25	0.48

Sl. No.	Name of the species	No. of Individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
54	*Ficus religiosa*	1	0.10	0.26	0.12	0.48
55	*Cassine glauca*	2	0.19	0.01	0.25	0.46
56	*Mallotus philippensis*	2	0.19	0.02	0.25	0.46
57	*Celtis tetrandra*	2	0.19	0.01	0.25	0.45
58	*Streblus asper*	2	0.19	0.01	0.25	0.45
59	*Pleiospermum alatum*	2	0.19	0.00	0.25	0.44
60	*Albizia chinensis*	1	0.10	0.08	0.12	0.30
61	*Gyrocarpus asiaticus*	1	0.10	0.06	0.12	0.28
62	*Acacia polyacantha*	1	0.10	0.05	0.12	0.27
63	*Butea parviflora*	1	0.10	0.05	0.12	0.27
64	*Sterculia guttata*	1	0.10	0.03	0.12	0.25
65	*Hiptage benghalensis*	1	0.10	0.01	0.12	0.23
66	*Premna tomentosa*	1	0.10	0.01	0.12	0.23
67	*Anamirta cocculus*	1	0.10	0.00	0.12	0.22
68	*Ardisia solanacea*	1	0.10	0.00	0.12	0.22
69	*Murraya paniculata*	1	0.10	0.00	0.12	0.22
70	*Scleropyrum pentandrum*	1	0.10	0.00	0.12	0.22

Some Woody plants in the riverine forests

Alphonsea sclerocarpa

Alseodaphne semecarpifolia

Diospyros peregrina

Ficus drupacea

Ficus amplissima

Hopea ponga

Madhuca longifolia

Terminalia arjuna

4.3.2 Family-wise composition of tree species in the riverine forests

Family Moraceae was represented by the highest number of species (n=8) followed by Euphorbiaceae and Fabaceae being represented by 5 species each (Figure 4.2). Sixteen families were represented by single species each. At the generic level, *Ficus* had the highest number of species (n=7). The most dominant tree families were Fabaceae, Ebenaceae, Anacardiaceae and Combretaceae (Table 4.2). In the riverine forest, Fabaceae was the most important family with FIV of 45.71. This elevated value resulted from the fact that many Fabaceae individuals were large statured. A greater proportion of relative density was Fabaceae (28.10 %) followed by Ebenaceae (15.11%) and Anacardiaceae (8.08%). The family Fabaceae had highest number of individuals of trees (292) in the riverine forest. The highest total basal area of Combretaceae (90 m^2) and lowest values (0.01 m^2) were exhibited by families such as Malpighiaceae, Menispermaceae, Santalaceae and Solanaceae (Table 4.2).

Table 4.2 Family-wise distribution of woody species in the riparian forest

Sl. No.	Families	NG	NS	NI	BA	RDi	RDe	RBA	FIV
1	Fabaceae	5	5	292	29.3	7.14	28.10	10.47	45.71
2	Ebenaceae	1	3	157	21	4.29	15.11	7.48	26.88
3	Anacardiaceae	2	2	84	58.8	2.86	8.08	20.97	31.91
4	Myrtaceae	1	1	71	21.4	1.43	6.83	7.65	15.91
5	Combretaceae	1	2	70	90	2.86	6.74	32.11	41.71
6	Sapotaceae	3	3	54	23.3	4.29	5.20	8.32	17.80
7	Euphorbiaceae	5	5	52	4.79	7.14	5.00	1.71	13.86
8	Moraceae	2	8	25	8.32	11.43	2.41	2.97	16.80
9	Oleaceae	3	3	24	1	4.29	2.31	0.36	6.95
10	Dipterocarpaceae	2	2	22	3.74	2.86	2.12	1.33	6.31
11	Rubiaceae	2	2	20	0.78	2.86	1.92	0.28	5.06
12	Meliaceae	2	2	18	1.68	2.86	1.73	0.60	5.19

Sl. No.	Families	NG	NS	NI	BA	RDi	RDe	RBA	FIV
13	Salicaceae	1	1	17	3.09	1.43	1.64	1.10	4.17
14	Celastraceae	2	2	15	1.34	2.86	1.44	0.48	4.78
15	Clusiaceae	2	2	15	3.41	2.86	1.44	1.22	5.52
16	Rutaceae	3	3	14	0.12	4.29	1.35	0.04	5.68
17	Capparaceae	1	1	12	0.87	1.43	1.15	0.31	2.89
18	Verbenaceae	3	3	10	1.11	4.29	0.96	0.40	5.64
19	Lauraceae	2	2	9	0.84	2.86	0.87	0.30	4.02
20	Ulmaceae	1	2	9	0.17	2.86	0.87	0.06	3.78
21	Loganiaceae	1	1	9	0.14	1.43	0.87	0.05	2.34
22	Melastomataceae	1	1	9	0.78	1.43	0.87	0.28	2.57
23	Achariaceae	1	1	8	1.34	1.43	0.77	0.48	2.68
24	Annonaceae	1	1	5	0.3	1.43	0.48	0.11	2.02
25	Sapindaceae	1	1	5	0.53	1.43	0.48	0.19	2.10
26	Mimosaceae	2	3	3	1.17	4.29	0.29	0.42	4.99
27	Bignoniaceae	1	1	2	0.41	1.43	0.19	0.15	1.77
28	Caesalpiniaceae	1	1	2	0.22	1.43	0.19	0.08	1.70
29	Hernandiaceae	1	1	1	0.16	1.43	0.10	0.06	1.58
30	Malpighiaceae	1	1	1	0.02	1.43	0.10	0.01	1.53
31	Menispermaceae	1	1	1	0.01	1.43	0.10	0.00	1.53
32	Santalaceae	1	1	1	0.01	1.43	0.10	0.00	1.53
33	Solanaceae	1	1	1	0.01	1.43	0.10	0.00	1.53
34	Sterculiaceae	1	1	1	0.09	1.43	0.10	0.03	1.56

NG = number of genera; NS = number of species; NI = number of individuals; BA = basal area (m^2); RDi = relative diversity; RDe = relative density; RBA = relative basal area; FIV = family importance value.

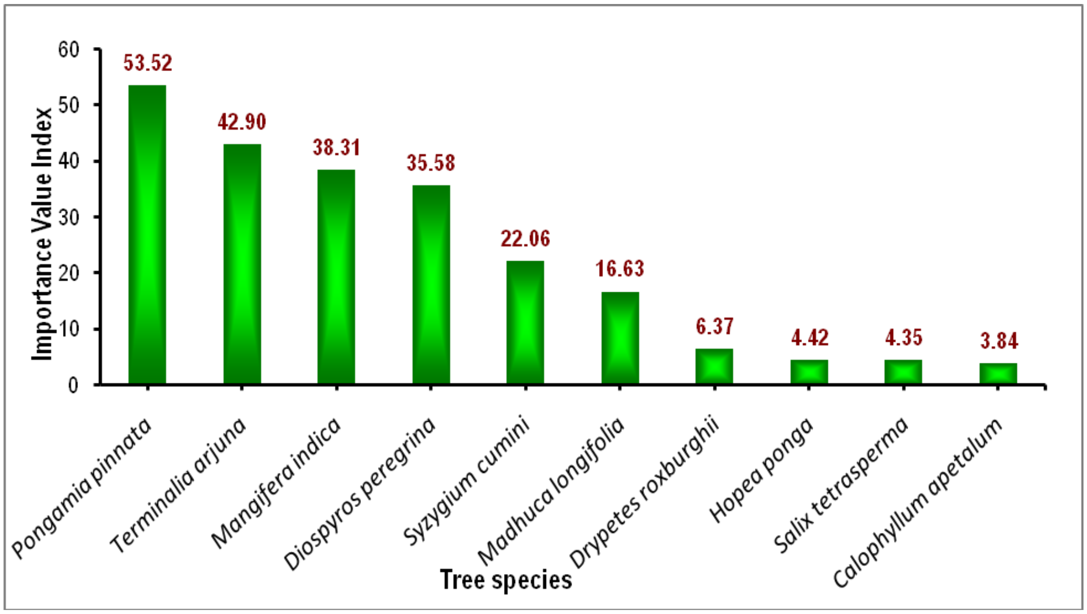


Figure 4.1 Predominant tree species based on the IVI values in the riverine forests

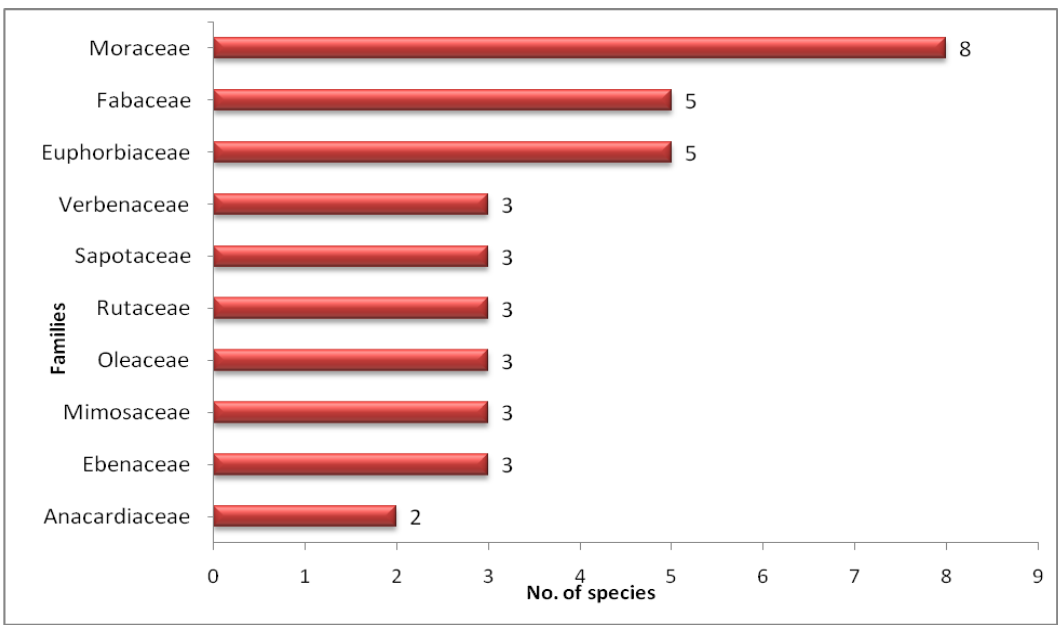


Figure 4.2 Predominant plant families represented in the riverine forests

The lowest girth class harboured more species richness and abundance. But the highest girth class had comparatively less species richness and abundance. The basal area was low in lowest girth class, very high in intermediate girth classes (101-200 and 401-500 cm) and normal in remaining girth classes (Figure 4.3).

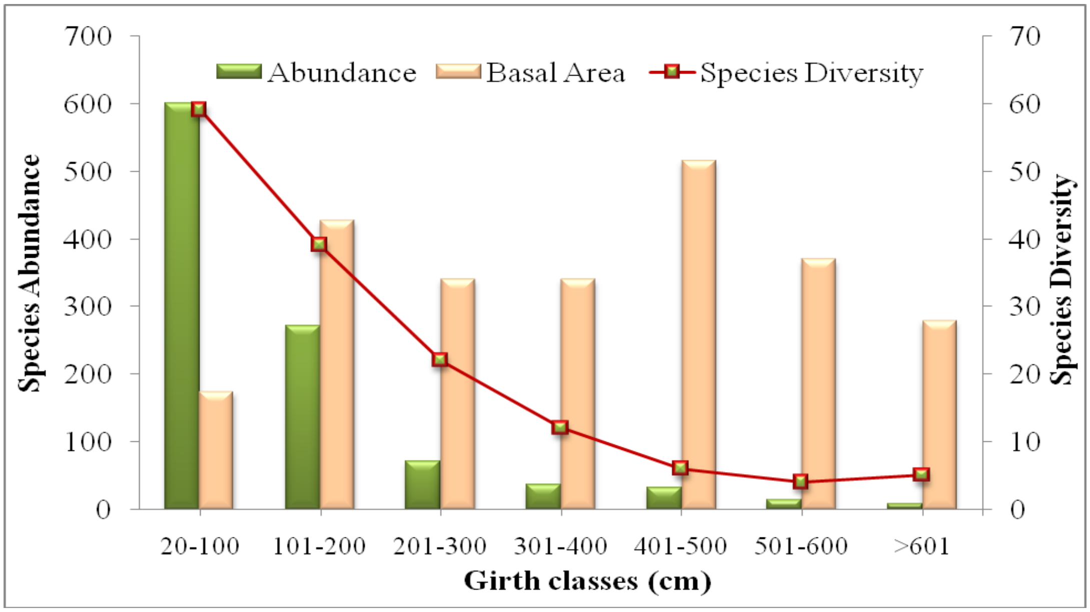


Figure 4.3 Girth classes distribution, species abundance and density in the riverine forests

4.3.3 Woody species composition in the southern mixed dry deciduous forests

In the mixed dry deciduous forests of Athikadavu Valley, a total of 63 woody plant species belonging 50 genera and 26 families were recorded (Appendix 1). The woody species included 53 trees, six shrubs and four stragglers / lianas. A total of 1615 trees belonging to 63 woody species were recorded in the 2 ha sampling plot and the total basal area was 94.97 m^2. Tree layer consisted of species such as *Atalantia racemosa*, *Chloroxylon swietenia*, *Psydrax dicoccos*, *Drypetes sepiaria*, *Erythroxylum monogynum*, *Ixora pavetta*, *Strychnos potatorum* etc. Highest number of individuals were observed for *Chloroxylon swietenia* (n=233) followed by *Drypetes sepiaria* (n=219), *Pleiospermium alatum* (n=124) and *Atalantia racemosa* (n=115). Maximum values for relative density, relative dominance and relative frequency were recorded for *Chloroxylon swietenia* and the values are 14.43, 23.36 and 11.49 respectively (Table 4.3). The dominant tree species included *Chloroxylon swietenia* (IVI-52.31), *Drypetes sepiaria*

(IVI-51.23), and *Pleiospermium alatum* (IVI-22.0). The vegetation community of mixed dry deciduous forests can be described as *Drypetes sepiaria – Chloroxylon swietenia – Pleiospermium alatum* community (Figure 4.4).

Table 4.3 Ecological value of woody plants in the mixed dry deciduous forests

Sl. No.	Name of the species	No. of individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
1	*Chloroxylon swietenia*	233	14.43	10.34	11.49	36.26
2	*Drypetes sepiaria*	219	13.56	10.86	9.20	33.61
3	*Pleiospermium alatum*	124	7.68	4.14	8.22	20.04
4	*Hardwickia binata*	47	2.91	13.74	3.18	19.83
5	*Erythroxylum monogynum*	99	6.13	2.63	6.72	15.48
6	*Gyrocarpus asiaticus*	62	3.84	5.23	4.95	14.02
7	*Atalantia racemosa*	115	7.12	2.76	3.63	13.50
8	*Psydrax dicoccos*	57	3.53	4.13	4.33	11.99
9	*Ixora pavetta*	68	4.21	2.95	4.42	11.58
10	*Strychnos potatorum*	44	2.72	3.37	3.18	9.28
11	*Ziziphus oenoplia*	67	4.15	0.63	4.42	9.20
12	*Cassine glauca*	25	1.55	3.37	2.03	6.95
13	*Premna tomentosa*	28	1.73	2.48	2.21	6.43

Sl. No.	Name of the species	No. of individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
14	*Diospyros montana*	26	1.61	2.20	2.30	6.11
15	*Sapindus emarginatus*	32	1.98	1.64	2.12	5.75
16	*Dalbergia lanceolaria*	27	1.67	1.87	2.03	5.58
17	*Gardenia resinifera*	32	1.98	1.30	2.21	5.49
18	*Walsura trifolia*	24	1.49	2.07	1.77	5.33
19	*Bauhinia racemosa*	19	1.18	2.04	1.33	4.55
20	*Bombax ceiba*	12	0.74	2.72	1.06	4.52
21	*Albizia amara*	16	0.99	1.22	1.50	3.72
22	*Pleurostylia opposita*	21	1.30	0.94	1.41	3.65
23	*Diospyros ovalifolia*	20	1.24	0.88	1.41	3.54
24	*Acacia nilotica*	22	1.36	0.47	1.41	3.25
25	*Madhuca longifolia*	3	0.19	2.72	0.27	3.17
26	*Cordia monoica*	18	1.11	0.37	1.06	2.54
27	*Phyllanthus polyphyllus*	20	1.24	0.41	0.88	2.53
28	*Ficus bengalensis*	4	0.25	1.84	0.35	2.44
29	*Alphonsea sclerocarpa*	8	0.50	1.10	0.53	2.12
30	*Givotia moluccana*	4	0.25	1.17	0.35	1.77

Sl. No.	Name of the species	No. of individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
31	*Mimusops elengi*	8	0.50	0.54	0.71	1.74
32	*Euphorbia antiquorum*	10	0.62	0.26	0.71	1.59
33	*Hiptage benghalensis*	4	0.25	0.91	0.27	1.42
34	*Holoptelea integrifolia*	4	0.25	0.72	0.35	1.32
35	*Acacia planifrons*	5	0.31	0.54	0.44	1.29
36	*Vitex altissima*	2	0.12	0.81	0.18	1.11
37	*Ficus tomentosa*	4	0.25	0.49	0.35	1.10
38	*Ehretia ovalifolia*	6	0.37	0.09	0.53	1.00
39	*Azadirachta indica*	5	0.31	0.22	0.44	0.97
40	*Pongamia pinnata*	4	0.25	0.55	0.18	0.97
41	*Drypetes roxburghii*	4	0.25	0.36	0.35	0.96
42	*Ziziphus mauritiana*	5	0.31	0.21	0.44	0.96
43	*Ailanthus excelsa*	4	0.25	0.32	0.35	0.92
44	*Capparis grandis*	4	0.25	0.28	0.35	0.89
45	*Streblus asper*	4	0.25	0.31	0.27	0.82
46	*Santalum album*	5	0.31	0.03	0.44	0.78
47	*Butea parviflora*	6	0.37	0.04	0.35	0.77

Sl. No.	Name of the species	No. of individuals	Relative Density	Relative Dominance	Relative Frequency	IVI
48	*Dalbergia paniculata*	3	0.19	0.27	0.27	0.72
49	*Acacia leucopholea*	3	0.19	0.24	0.27	0.69
50	*Schleichera oleosa*	2	0.12	0.39	0.18	0.69
51	*Gmelina asiatica*	4	0.25	0.05	0.35	0.65
52	*Diospyros ferrea*	4	0.25	0.03	0.35	0.63
53	*Dichrostachys cinerea*	2	0.12	0.02	0.35	0.50
54	*Pterocarpus marsupium*	2	0.12	0.15	0.18	0.45
55	*Alseodaphnae semecarpifolia*	2	0.12	0.09	0.18	0.40
56	*Catunaregam spinosa*	2	0.12	0.05	0.18	0.35
57	*Diospyros melanoxylon*	2	0.12	0.05	0.18	0.35
58	*Prosopis juliflora*	2	0.12	0.05	0.18	0.35
59	*Strychnos nux-vomica*	2	0.12	0.05	0.18	0.35
60	*Scutia myrtina*	2	0.12	0.01	0.18	0.31
61	*Albizia lebbeck*	1	0.06	0.15	0.09	0.30
62	*Acacia cineria*	1	0.06	0.09	0.09	0.25
63	*Manilkara hexandra*	1	0.06	0.01	0.09	0.16

Some Woody plants in the mixed dry deciduous forests

Atalantia racemosa

Drypetes sepiaria

Hardwickia binata

Erythroxylum monogynum

Ixora pavetta

Pleiospermium alatum

Psydrax dicoccos

Strychnos potatorum

4.3.4 Family-wise composition of tree species in the mixed dry deciduous forests

Family Mimosaceae constituted the largest family with eight species followed by Fabaceae and Euphorbiaceae represented by five species each. Ebenaceae and Rubiaceae had four species each (Figure 4.5). Ten families were represented by single species each. The most dominant tree families were Rutaceae, Euphorbiaceae, Rubiaceae and Erythroxylaceae (Table 4.4). In the mixed dry deciduous forest, Rutaceae was the most important family with FIV of 51.22. This elevated value resulted from the fact that many Rutaceae individuals were large statured. A greater proportion of relative density was Rutaceae (29.23 %) followed by Ebenaceae (15.91%) and Rubiaceae (9.85 %). The family Rutaceae had highest number of individuals of trees (472) in the mixed dry deciduous forest. The highest total basal area of Rutaceae (16.37m^2) and lowest values were exhibited by families Lauraceae and Santalaceae (0.09 m^2 and 0.03 m^2) respectively (Table 4.4).

Table 4.4 Family-wise distribution of woody species in the mixed dry deciduous forest

Sl. No.	Family Name	NG	NS	NI	BA	RDi	RDe	RBA	FIV
1	Rutaceae	3	3	472	16.37	4.76	29.23	17.24	51.22
2	Euphorbiaceae	4	5	257	12.4	7.94	15.91	13.06	36.91
3	Rubiaceae	4	4	159	8	6.35	9.85	8.42	24.62
4	Erythroxylaceae	1	1	99	2.5	1.59	6.13	2.63	10.35
5	Rhamnaceae	3	3	74	0.81	4.76	4.58	0.85	10.20
6	Caesalpiniaceae	2	2	66	14.99	3.17	4.09	15.78	23.05
7	Hernandiaceae	1	1	62	4.97	1.59	3.84	5.23	10.66
8	Ebenaceae	1	4	52	3.01	6.35	3.22	3.17	12.74
9	Mimosaceae	4	8	52	2.65	12.70	3.22	2.79	18.71
10	Celastraceae	2	2	46	4.09	3.17	2.85	4.31	10.33
11	Loganiaceae	1	2	46	3.25	3.17	2.85	3.42	9.45

Sl. No.	Family Name	NG	NS	NI	BA	RDi	RDe	RBA	FIV
12	Fabaceae	4	5	42	2.74	7.94	2.60	2.89	13.42
13	Sapindaceae	2	2	34	1.93	3.17	2.11	2.03	7.31
14	Verbenaceae	3	3	34	3.18	4.76	2.11	3.35	10.22
15	Meliaceae	2	2	29	2.18	3.17	1.80	2.30	7.27
16	Cordiaceae	2	2	24	0.44	3.17	1.49	0.46	5.12
17	Bombacaceae	1	1	12	2.58	1.59	0.74	2.72	5.05
18	Moraceae	1	3	12	2.51	4.76	0.74	2.64	8.15
19	Sapotaceae	3	3	12	3.1	4.76	0.74	3.26	8.77
20	Annonaceae	1	1	8	1.04	1.59	0.50	1.10	3.18
21	Santalaceae	1	1	5	0.03	1.59	0.31	0.03	1.93
22	Capparaceae	1	1	4	0.27	1.59	0.25	0.28	2.12
23	Malpighiaceae	1	1	4	0.86	1.59	0.25	0.91	2.74
24	Simaroubaceae	1	1	4	0.3	1.59	0.25	0.32	2.15
25	Ulmaceae	1	1	4	0.68	1.59	0.25	0.72	2.55
26	Lauraceae	1	1	2	0.09	1.59	0.12	0.09	1.81

NG = number of genera; NS = number of species; NI = number of individuals; RDi = relative diversity; RDe = relative density; RBA = relative basal area; FIV = family importance value.

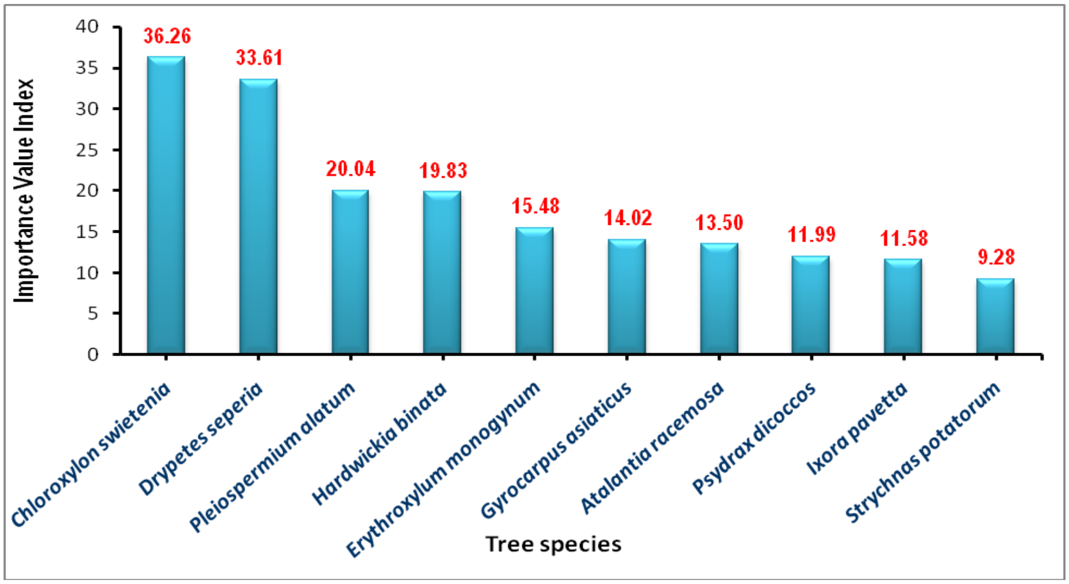


Figure 4.4 Predominant tree species represented by their IVI values in the mixed dry deciduous forests

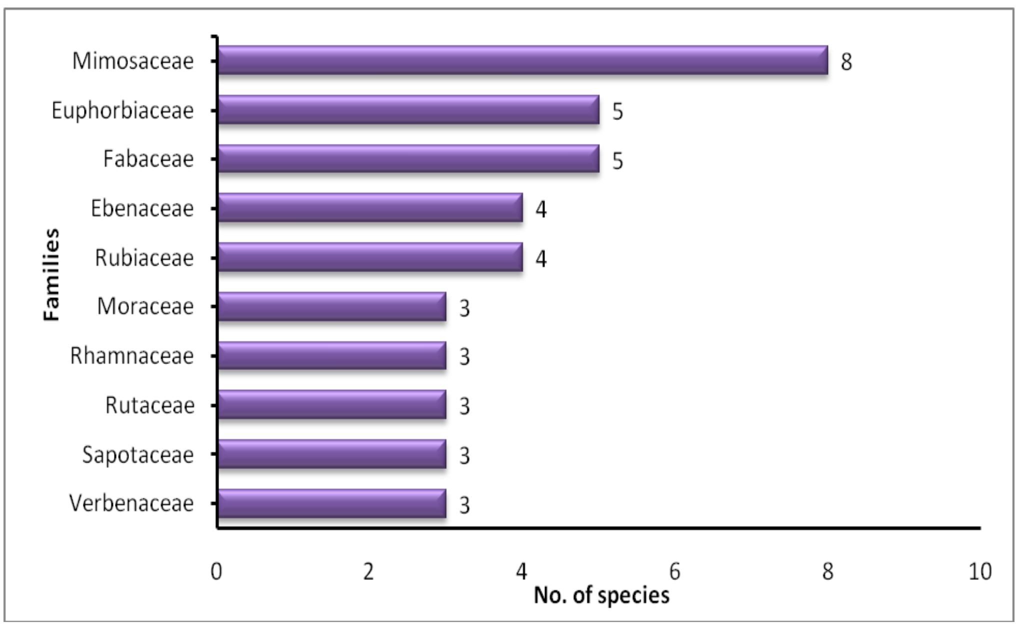


Figure 4.5 Predominant plant families represented in the mixed dry deciduous forests

4.3.5 *Girth class distribution of woody species in the mixed dry deciduous forests*

The lowest girth class encountered a greater species richness and abundance but, low basal area. The remaining girth classes showed the same trend, except girth class 61-120 cm which show higher values for basal area (Figure 4.6).

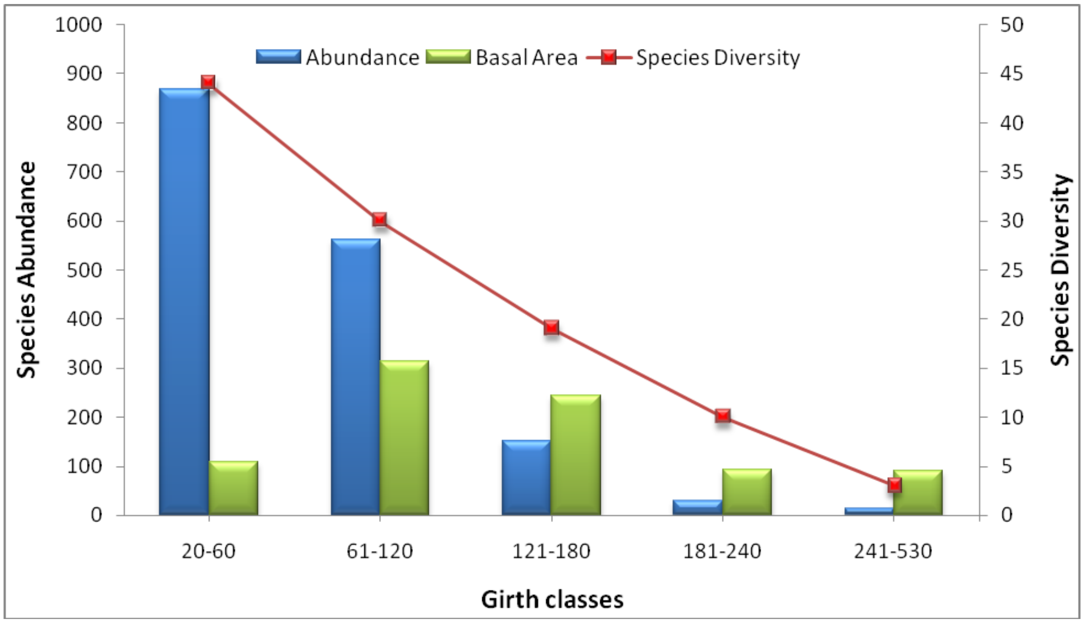


Figure 4.6 Girth class distribution, species abundance and density in the mixed dry deciduous forest

4.3.6 Comparison of vegetation parameters between riverine and mixed dry deciduous forests

Comparison of vegetation features between the two forest types revealed that the riverine forest showed significantly higher number of species than the mixed dry deciduous forests. The rarefaction curve showed high species diversity in riverine forests than mixed dry deciduous forests (Figure 4.7). A total of 70 tree species that belonged to 38 families and 60 genera were recorded in the riverine forests, whereas in the mixed dry deciduous forests, 63 tree species belonging to 26 families and 51 genera were recorded (Table 4.5). The basal area values of woody individuals were 94.97 m^2 for the mixed dry deciduous forests, whereas 280.25 m^2 for the riverine forests. Tree height and tree girth values were higher in the riverine forests than in the mixed dry deciduous forests. Shannon and Simpson's Index was one fold high in dry deciduous forest than in the riverine forests.

Table 4.5 Comparison of plant diversity in the two major forest types in Athikadavu Valley

S. No.	Vegetation Parameters	Riverine forest (2 ha)	Mixed dry deciduous forest (2 ha)
1	Number of Species	70	63
2	Number of Genera	60	51
3	Number of Families	34	26
4	Total abundance	1039	1615
5	Species richness ha^{-1}	35	31.5
6	Species abundance ha^{-1}	519.5	807.5
7	Basal area (m^2)	280.25	94.97
8	Tree height (Mean±SD) (m)	20.2±4.3	14.2±2.2
9	GBH (Mean±SD) (cm)	152.4±84.9	87.5±39.6
10	Shannon-Weiner Index (H')	2.965	3.219
11	Simpson's Index (1/D)	8.839	15.350
12	Margalef's Index (M)	9.934	8.393

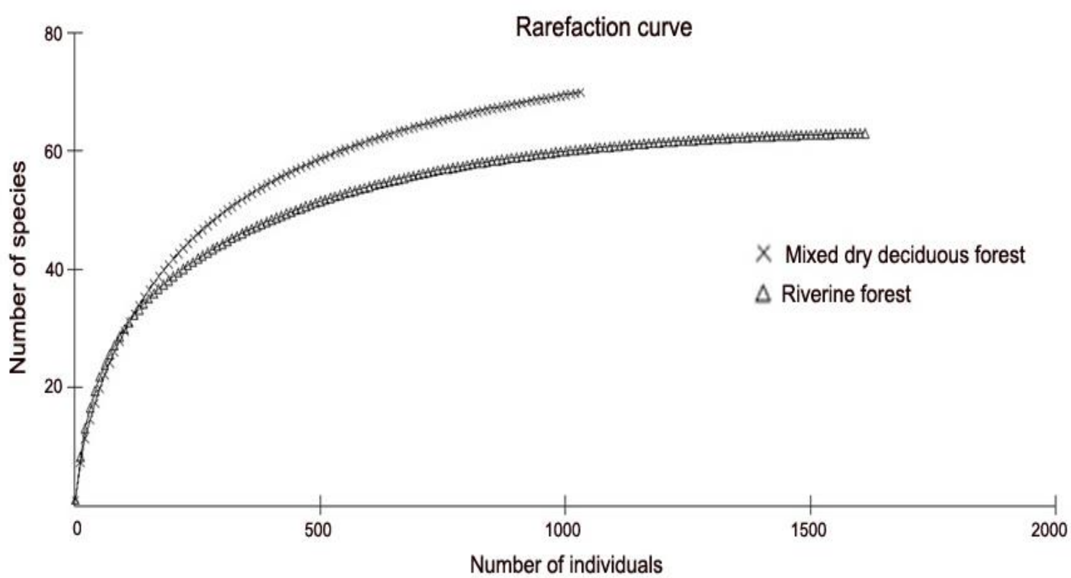


Figure 4.7 Rarefaction curve shows the number of species and their abundance for two major forest types in Athikadavu valley.

4.3.7 Assessment of threats

There are several human settlements in Athikadavu valley. They mainly depend on forest and forest products such as honey, amla, queen sago, medicinal plants and other plant materials. Out of 70 woody species recorded in riverine forest 36 woody species was exploited by tribals for various purposes. It included fruits for dyeing, leaves for cattle feed, wood for house construction, support poles for fencing and fuel wood etc. (Table 4.6). About five plant species were heavily exploited, six species were moderately used and remaining species less exploited. Heavily exploited species included *Diospyros peregrina, Mangifera indica, Madhuca longifolia, Pongamia pinnata* and *Atalantia racemosa.* Among the different kinds of utilisations, cutting for timber (18 species and 48 individuals) and feed for livestock (17 species and 102 individuals) contributed more when compared to other utilisations (Figure 4.8). In addition, other anthropogenic activities such as agricultural activities along the river banks and livestock grazing were also noted.

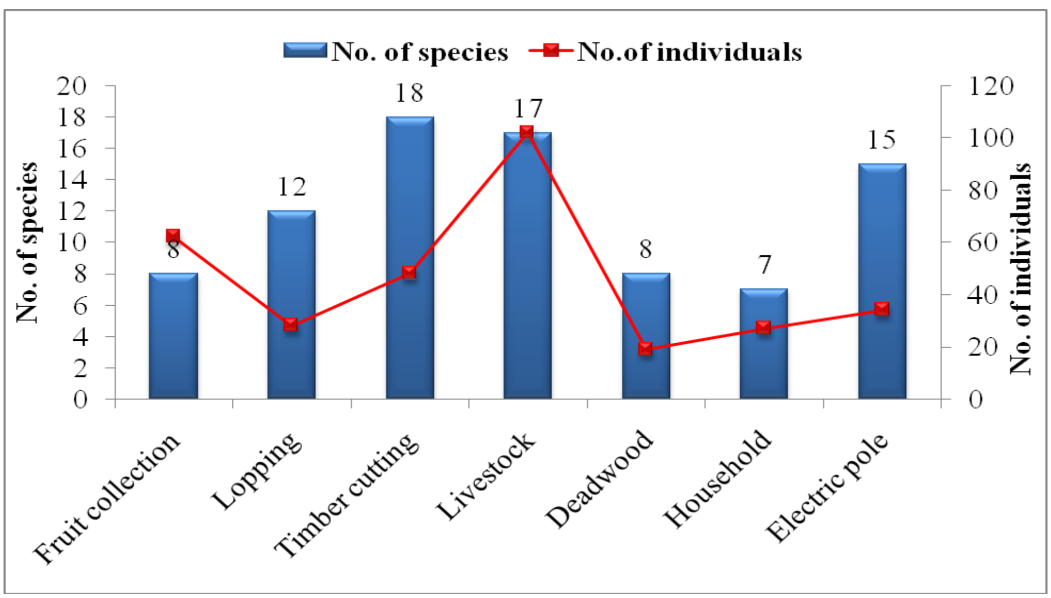


Figure 4.8 Various purpose of species utilisation by local people in riverine forests of Athikadavu valley.

Anthropogenic activities in the riverine forests

Livestock fodder collection

Fuelwood collection

Timber cutting

Fencing pole

Fig collection

Cattle grazing

Land clearance for cultivation

Banana cultivation

Table 4.6 Woody plant species exploited by local communities in the riverine forests of Athikadavu valley (Values indicate the number of trees observed with disturbance signs in the 2 ha sampling plots)

Sl. No.	Botanical Name	Fruit/ seed collection	Lopping	Cutting for Timber value	Livestock feed	Dead wood gathering	House Construction	Support Poles for Electric fence	Total no. of purposes for which used
1	*Diospyros peregrina**	16	-	5	-	1	2	3	5
2	*Mangifera indica**	10	6	4	-	3	-	1	5
3	*Madhuca longifolia**	4	2	1	-	-	-	1	4
4	*Pongamia pinnata**	3	8	11				7	4
5	*Atalantia racemosa*	-	-	1	17	-	1	1	4
6	*Aglaia roxburghiana*	-	-	1	15	-	-	2	3
7	*Terminalia arjuna**	-	-	4	-	-	1	1	3
8	*Trewia polycarpa*	-	-	3	-	-	1	1	3

Sl. No.	Botanical Name	Fruit/ seed collection	Lopping	Cutting for Timber value	Livestock feed	Dead wood gathering	House Construction	Support Poles for Electric fence	Total no. of purposes for which used
9	*Pleurostylia opposita**	-	1	-	5	-	-	2	3
10	*Syzygium cumini**	-	3	5	2	-	-	-	3
11	*Ligustrum perrottetii*	-	-	3	4	-	-	1	3
12	*Dalbergia latifolia**	-	1	2	-	-	-	-	2
13	*Ixora pavetta*	-	1	-	2	-	-	-	2
14	*Murraya paniculata*	-	1	-	2	-	-	-	2
15	*Strychnos nux-vomica**	1	2	-	-	-	-	-	2
16	*Calophyllum apetalum**	-	1	1	-	-	-	-	2
17	*Terminalia bellirica**	1	1						2
18	*Alphonsea sclerocarpa**	-	1	-	1	-	-	-	2

Sl. No.	Botanical Name	Fruit/ seed collection	Lopping	Cutting for Timber value	Livestock feed	Dead wood gathering	House Construction	Support Poles for Electric fence	Total no. of purposes for which used
19	*Pleiospermium alatum*	-	-	-	14	-	-	-	1
20	*Phyllanthus polyphyllus*	-	-	-	6	-	-	-	1
21	*Hiptage benghalensis*	-	-	-	4	-	-	-	1
22	*Celtis philippensis**	-	-	-	3	-	-	-	1
23	*Drypetes roxburghii**	-	-	-	2	-	-	-	1
24	*Salix tetrasperma**	-	-	2	-	-	-	-	1
25	*Annona reticulatta*	1							1
26	*Carissa carandas*	-	-	-	1	-	-	-	1
27	*Cassine glauca**	-	-	-	1	-	-	-	1
28	*Glycosmis mauritiana*	-	-	-	1	-	-	-	1

Sl. No.	Botanical Name	Fruit/ seed collection	Lopping	Cutting for Timber value	Livestock feed	Dead wood gathering	House Construction	Support Poles for Electric fence	Total no. of purposes for which used
29	*Hopea ponga*	-	-	1	-	-	-	-	1
30	*Mimusops elengi*	-	-	-	1	-	-	-	1
31	*Olea dioica*	-	-	1	-	-	-	-	1
32	*Pterocarpus marsupium**	-	-	1	-	-	-	-	1
33	*Schleichera oleosa**	-	-	1	-	-	-	-	1
34	*Shorea roxburghii*	-	-	1	-	-	-	-	1
35	*Tarenna asiatica*	-	-	-	1	-	-	-	1
36	*Vitex altissima**	-	-	-	-	-	-	1	1

* Species used by cavity nesting birds for nesting.

4.4 Discussion

Riverine forests of Athikadavu Valley, in Western Ghats harboured 70 woody species comprising 65 tree species. In a similar ecosystem of river Cauvery in the Karnataka state of India, Sunil *et al.* (2010) recorded 84 species exclusively in riparian zone. Johnsingh and Joshua (1994) recorded 47 tree species in the riverine forests of Mundanthurai Plateau, Western Ghats, southern India. In Sathyamangalam Wildlife Sanctuary, Eastern Ghats, Tamil Nadu (Balasubramanian *et al.,* 2011) recorded 64 tree species in a riverine forest. In the Pampa river, Western Ghats, Kerala (Joby Paul, 2012) recorded 79 tree species. In the Alakyam river, Kerala Manoj *et al.* (2012) recorded 63 tree species. Iqbal *et al.* (2012) recorded 23 tree species in Khoh river, Himalayan region, India.

Tree species diversity recorded in the riverine forests of Athikadavu Valley is relatively less when compared with Chalakkudy river basin, (Bachan, 2003) and Cauvery river basin (Sunil *et al.,* 2010) and higher than the values recorded for Mini river, Vadodara, Gujarat (Shah *et al.,* 2015) and Khoh river, Himalayas (Iqbal *et al.,* 2012). The tree density of riverine forest in Athikadavu valley is found to be higher (519.5 ha^{-1}) than the riverine forests of Cauvery (118.6 ha^{-1}; Sunil *et al*., 2016) and in Khoh river (66 ha^{-1}). Basal area of trees in the riparian forest of Athikadavu valley was observed to be 140.12 m^2 ha^{-1} and it is very similar to that of Cauvery river 143.43 m^2 ha^{-1} (Sunil *et al.,* 2016). However Iqbal *et al*. (2012) reported higher values for the Khoh river of the Himalayas.

Vegetation parameter of woody plant species in different riverine forests of India tabulated in Table 4.7. In Athikadavu Valley, Moraceae constituted the largest family with eight species followed by Fabaceae and Euphorbiaceae. Mimosaceae (6 species) constituted the largest family in Cauvary river basin (Sunil *et al*., 2016). Euphorbiaceae constituted largest family in Khoh river in the Himalayas (Iqbal *et al.* (2012). In Kerala, riparian forest of Pampa river was dominated by Fabaceae and Moraceae (Joby Paul, 2012). Family Euphorbiaceae (Manoj *et al.,* 2012) was dominant in Alakyam river, Kerala. Leguminaceae constituted the largest family (Jhonsingh and Joshua, 1994) in the riparian forest of Tambiraparani. It is to be noted that a plant families such as Moraceae, Euphorbiaceae, Leguminaceae (Fabaceae, Caesalpiniaceae, Mimosaceae) constituted the dominant families in the riverine forest of India.

Table 4.7 Comparison of tree community structure and composition in different riverine forests of India

Sl. No.	Name of the river	No. of Species	No. of Genera	No. of Family	Shannon's Index	Tree density (ha^{-1})	Basal Area (ha^{-1})	Reference source
1	Bhavani river, Athikadavu Valley	65	53	31	2.91	511	278.82	Present study
2	Sathyamangalam Wildlife Sanctuary, Tamil Nadu	64	49	25	3.40	588	--	Balasubramanian *et al*. (2011)
3	Tamirabarani, Mundanthurai, Tamil Nadu	47	40	20	2.92	812	--	Johnsingh and Joshua (1994)
4	Cauvery river, Karnataka	84	50	36	5.6	--	143.43	Sunil *et al*. (2016)
5	Pampa river, Kerala	79	71	39	2.46	--	--	Joby Paul (2012)
6	Alakyam river, Kerala	63	55	37	--	--	--	Manoj *et al*. (2012)
7	Khoh river, Himalayas	23	20	13	3.06	66	206.23	Iqbal *et al*. (2012)

The riparian vegetation of the study area is commonly in predominated by *Pongamia pinnata*, *Terminalia arjuna* and *Mangifera indica*. Similar composition was reported by Balasubramanian *et al.* (2011) in Sathyamangalam Wildlife Sanctuary, Southern India. As in the present study, *Terminalia arjuna* constituted the most dominant species followed by *Pongamia pinnata* and *Mangifera indica* in Sathyamangalam, Eastern Ghats. In the Cauvery river, Karnataka, Sunil (2016) reported the predominant occurrence of *Terminalaia arjuna* and *Pongamia pinnata.* In the Tamirabarani river of Mundanthurai Plateau *Hopea parviflora*, *Aglaia roxburghiana* and *Pongamia pinnata* predominance was recorded by Johnsingh and Joshua (1994). In Kerala, dominant tree species of the riverine forest are *Humboldtia vahliana*, and *Neolamarckia cadamba* (Joby Paul, 2012) in Pampa river and *Hopea ponga* and *Hopea parviflora* (Manoj *et al.*, 2012) in Alakyam riverine forest.

Majority of the riverine forests of southern India showed similar tree community composition. It is inferred that the predominant tree species of riverine forests is *Pongamia pinnata, Terminalia arjuna, Mangifera indica* and *Diospyros peregrina* in the present study site. A close similarity of vegetation composition of riparian forest was observed in Tambiraparani (Jhonsingh and Joshua, 1989), Chalakkudy river (Bachan, 2003), Cauvery river (Sunil *et al.,* 2010, 2016) and in Sathyamangalam (Balasubramanian *et al.,* 2011).

The species diversity (Shannon's) values of riverine forest in the present study (2.91) was more or less similar to the values reported by Johnsingh and Joshua (1994) (2.92) in Tambiraparani river and Cauvery river basin (Sunil *et al.*, 2016) in Karanataka. The Sathyamangalam Wildlife Sanctuary (Balasubramanian *et al.*, 2011) appears to present a comparatively higher tree species diversity value (3.40).

Anthropogenic activities such as agriculture, livestock, grazing, mining, industrialization and urbanization have caused alteration and degradation of many riparian environments (Apan *et al.*, 2002; Robertson and Rowling, 2000; Merritt and Cooper, 2000; Gurnell, 1997). The riparian vegetation of Athikadavu valley is disturbed by grazing of domestic animals, cultivation and timber and wood collection. Impact of anthropogenic disturbances on riverine vegetation was reported in Bhavani river (Balasubramanian *et al*., 2004) and Sathyamangalam Wildlife Sanctuary (Balasubramanian *et al.*, 2011). Native species exploitation by human was reported in Cauvery river (Mittemeier *et al*., 2003).

Consequences of different anthropogenic disturbances influence species diversity (Pickett and White, 1985; van der Maarel, 1993; Biswas and Mallik, 2010). Regular or frequent disturbance by livestock may result in abnormally small tree sizes along the riverine systems. This further retards regeneration of the trees, woody lianas and woody shrubs. Tiver and Andrew (1997) found that cattle were the most significant vertebrates affecting regeneration of woody species in Australia. In the present study goat and sheep were found mainly feeding on saplings of riparian species contributing to habitat degradation.

5 AVIFAUNAL DIVERSITY IN THE RIVERINE FOREST OF BHAVANI RIVER

5.1 Introduction

Birds play a useful role in the control of insect of pests, as predators of rodents, scavengers, seed dispersers and as pollinating agents and thus form an important component in natural ecosystem (Manjunath and Joshi, 2012). The Indian subcontinent has diverse avian fauna with above 1,300 bird species (Rasmussen and Anderton, 2012). Avifaunal diversity has been decreasing due to the destruction of natural habitat by human activities (Bhadja and Vaghela, 2013). Protection and maintenance of avifaunal diversity is important in maintaining species diversity of plants and animals (Simeone *et al.*, 2002). Birds inhabit a variety of ecosystems such as forest, grassland, wetland etc. (Blair, 1999). Riparian habitats have been shown to be important in maintaining biodiversity (Naiman *et al.*, 1993) and considered as topical forest refugia (Farooqui *et al*., 2010). Although riparian forests have been known for the high bird species richness (Knopf *et al*., 1994; Darveau *et al*., 1995) very little information is available from India (Johnsingh and Joshua, 1994; Balasubramanian, 2004). Hence, with the objective of assessing avian diversity and richness of a riparian forest in the Nilgiri Biosphere Reserve, the present study was carried out in the riparian forests Bhavani river, Western Ghats.

5.2 Material and Methods

The study was carried out from August 2012 to March 2014. Bird census was done by using Line transect method as given in Bibby *et al.* (1992). Censuses were carried out once in a month during morning hrs (between 0700 and 0900 hrs) on the Bhavani River bank in Athikadavu valley along the riparian forest strip. Two, 1 km long transects with a width of 10 m either side of the census route were used for the census. Birds sighted were identified using binoculars (8X40). Photographs of birds were taken by a Canon (12 mp with x 20 optical zoom lenses) camera. Birds were identified by their characteristic features in accordance with the standard identification manuals and field guides (Ali and Ripley, 1983; Grimmett *et al.*, 2001; Ali, 2002; Rasmussen and Anderton, 2012). Common (English) names and scientific nomenclature of bird has been adopted from (Del Hoyo and Collar, 2014). The threat status of the birds given in the check list is as per IUCN list of Threatened Taxa (Birdlife International, 2001). Birds recorded in the study area were classified as residents (seen throughout the year), winter migrants (seen during September-February) and summer migrants (March-May). Birds were classified into various feeding guilds based on Ali and Ripley (1983). Species diversity was calculated by using Shannon-Wiener Index H' = -∑ *Pi* In *Pi* where the *Pi* = the proportion of individuals of species *i*.

5.3 Results

The study revealed the occurrence of 158 species (51.26% Passeriformes and 48.74% Non-Passeriformes) of birds belonging to 18 orders of 52 families and 121 genera in Athikadavu Valley. White-browed Bulbul (26.45) followed by Little Cormorant (24.35) and Grey-fronted Green Pigeon (24.35) were found to be the most abundant species in the area (Table 5.1). Among the 18 orders, Passeriformes with 81 species formed the most predominant followed by Piciformes with 10 species and each nine species Coraciiformes and Falconiformes. Of the 3 orders contained one species each of Upupiformes, Trogoniformes and Gruciformes   Majority of the families are represented by a fewer species (Appendix 2).

Table 5.1 Birds recorded in the riverine forests of Athikadavu Valley

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
1	**Phasianidae** Indian Peafowl	*Pavo cristatus*	R	3.00	O	LC
2	Grey Junglefowl	*Gallus sonneratii*	R	4.80	O	LC
3	Common Quail	*Coturnix coturnix*	R	0.65	G	LC
4	Jungle Bush-quail	*Perdicula asiatica*	R	0.40	G	LC
5	Painted Bush-quail	*Perdicula erythrorhyncha*	R	0.85	G	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
6	**Picidae** Common Flameback	*Dinopium javanense*	R	5.05	I	LC
7	Rufous Woodpecker	*Micropternus brachyurus*	R	0.25	I	LC
8	Brown-capped Pygmy Woodpecker	*Picoides nanus*	R	0.30	I	LC
9	Greater Golden-backed Woodpecker	*Chrysocolaptes guttacristatus*	R	0.50	I	LC
10	Yellow-fronted Pied Woodpecker	*Dendrocopos mahrattensis*	R	0.50	I	LC
11	White-naped Woodpecker	*Chrysocolaptes festivus*	R	0.45	I	LC
12	**Capitonidae** White-cheeked Barbet	*Psilopogon viridis*	R	4.85	F	LC
13	Brown-headed Barbet	*Psilopogon zeylanicus*	R	5.25	F	LC
14	Malabar Barbet	*Psilopogon malabaricus*	WM, E	0.15	F	LC
15	Coppersmith Barbet	*Psilopogon haemacephalus*	R	15.75	F	LC
16	**Bucerotidae** Malabar Pied Hornbill	*Anthracoceros coronatus*	R	3.90	F	NT
17	Great Hornbill	*Buceros bicornis*	R	0.70	F	NT
18	Indian Grey Hornbill	*Ocyceros birostris*	WM	0.10	F	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
19	**Upupidae** Common Hoopoe	*Upupa epops*	R	0.90	I	LC
20	**Trogonidae** Malabar Trogon	*Harpactes fasciatus*	SM	0.35	I	LC
21	**Coraciidae** Indian Roller	*Coracias benghalensis*	R	0.90	I	LC
22	**Alcedinidae** Common Kingfisher	*Alcedo atthis*	R	3.05	P	LC
23	Pied Kingfisher	*Ceryle rudis*	SM	0.20	P	LC
24	Black-capped Kingfisher	*Halcyon pileata*	SM	0.10	P	LC
25	Stork-billed Kingfisher	*Pelargopsis capensis*	R	3.90	P	LC
26	White-throated Kingfisher	*Halcyon smyrnensis*	R	4.40	I	LC
27	**Meropidae** Little Green Bee-eater	*Merops orientalis*	R	6.00	I	LC
28	Chestnut-headed Bee-eater	*Merops leschenaultia*	WM	3.70	I	LC
29	Blue-bearded Bee-eater	*Nyctyornis athertoni*	SM	0.45	I	LC
30	**Cuculidae** Chestnut-winged Cuckoo	*Clamator coromandus*	WM	0.25	I	LC
31	Jacobin Cuckoo	*Clamator jacobinus*	R	0.40	I	LC
32	Common Hawk-cuckoo	*Hierococcyx varius*	SM	0.25	I	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
33	Grey-bellied Cuckoo	*Cacomantis passerines*	R	0.40	I	LC
34	Asian Koel	*Eudynamys scolopaceus*	R		F	LC
35	Blue-faced Malkoha	*Phaenicophaeus viridirostris*	R	3.80	I	LC
36	Sirkeer Malkoha	*Taccocua leschenaultia*	R	0.15	I	LC
37	Greater Coucal	*Centropus sinensis*	R	1.60	I	LC
38	**Psittacidae** Vernal Hanging-parrot	*Loriculus vernalis*	R	1.25	F	LC
39	Rose-ringed Parakeet	*Psittacula krameri*	R	4.80	F	LC
40	Malabar Parakeet	*Psittacula columboides*	R, E	11.65	F	LC
41	Plum-headed Parakeet	*Psittacula cyanocephala*	R	1.20	F	LC
42	**Apodidae** Little Swift	*Apus affinis*	R	2.35	I	LC
43	**Strigidae** Indian Scops Owl	*Otus lettia*	R	0.40	Cr	LC
44	Brown Fish Owl	*Ketupa zeylonensis*	SM	0.15	Cr	LC
45	Rock Eagle Owl	*Bubo bengalensis*	R	0.20	Cr	LC
46	Jungle Owlet	*Glaucidium radiatum*	R	0.85	Cr	LC
47	Brown Hawk Owl	*Ninox scutulata*	WM	0.25	Cr	LC
48	Spotted Owlet	*Athene brama*	R	0.25	Cr	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
49	**Columbidae** Grey-fronted Green Pigeon	*Treron affinis*	R	23.45	F	LC
50	Nilgiri Woodpigeon	*Columba elphinstonii*	WM, E	0.15	F	V
51	Rock Pigeon	*Columba livia*	R	4.00	G	LC
52	Emerald Dove	*Chalcophaps indica*	R	1.85	G	LC
53	Spotted Dove	*Streptopelia chinensis*	R	9.20	G	LC
54	Red Collared-dove	*Streptopelia tranquebarica*	R	0.45	G	LC
55	**Rallidae** White-breasted Waterhen	*Amaurornis phoenicurus*	R	0.20	I	LC
56	**Charadriidae** Red-wattled Lapwing	*Vanellus indicus*	R	2.40	I	LC
57	**Ardeidae** Little Egret	*Egretta garzetta*	R	0.95	P	LC
58	Intermediate Egret	*Egretta intermedia*	WM	3.00	P	LC
59	Cattle Egret	*Bubulcus ibis*	R	0.75	I	LC
60	Indian Pond Heron	*Ardeola grayii*	R	2.50	P	LC
61	Grey Heron	*Ardea cinerea*	WM	0.40	P	LC
62	Green-backed Heron	*Butorides striata*	R	0.35	P	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
63	**Scolopacidae** Common Sandpiper	*Actitis hypoleucos*	WM	0.65	I	LC
64	**Ciconiidae** Asian Openbill	*Anastomus oscitans*	WM	0.85	P	LC
65	**Accipitridae** Jerdon's Baza	*Aviceda jerdoni*	WM	0.20	Cr	LC
66	Black Kite	*Milvus migrans*	R	0.55	Cr	LC
67	Lesser Fish-eagle	*Ichthyophaga humilis*	R	3.30	P	NT
68	Crested Serpent-Eagle	*Spilornis cheela*	R	0.70	Cr	LC
69	Changeable Hawk-eagle	*Nisaetus cirrhatus*	R	0.50	Cr	LC
70	Bonelli's Eagle	*Aquila fasciata*	R	0.35	Cr	LC
71	Brahminy Kite	*Haliastur indus*	R	0.95	Cr	LC
72	Black Eagle	*Ictinaetus malayensis*	R	0.40	Cr	LC
73	Shikra	*Accipiter badius*	R	1.25	Cr	LC
74	**Podicipedidae** Little Grebe	*Tachybaptus ruficollis*	R	0.20	I	LC
75	**Anhingidae** Oriental Darter	*Anhinga melanogaster*	R	0.30	P	NT
76	**Phalacrocoracidae** Little Cormorant	*Microcarbo niger*	R	24.35	P	LC
77	Great Cormorant	*Phalacrocorax carbo*	R	0.15	P	LC
78	**Pittidae** Indian Pitta	*Pitta brachyuran*	WM	0.15	I	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
79	**Irenidae** Asian Fairy-bluebird	*Irena puella*	R	6.40	F	LC
80	Golden-fronted Leafbird	*Chloropsis aurifrons*	R	7.60	I	LC
81	**Laniidae** Bay-backed Shrike	*Lanius vittatus*	R	0.65	I	LC
82	**Corvidae** Rufous Treepie	*Dendrocitta vagabunda*	R	4.30	F	LC
83	House Crow	*Corvus splendens*	R	2.30	O	LC
84	Indian Jungle Crow	*Corvus culminates*	R	3.35	O	LC
85	**Artamidae** Ashy Woodswallow	*Artamus fuscus*	R	1.00	I	LC
86	**Oriolidae** Black-hooded Oriole	*Oriolus xanthornus*	R	4.45	F	LC
87	Eurasian Golden Oriole	*Oriolus oriolus*	WM	1.40	F	LC
88	Black-naped Oriole	*Oriolus chinensis*	WM	0.35	F	LC
89	**Campephagidae** Large Cuckooshrike	*Coracina macei*	SM	0.30	I	LC
90	Black-headed Cuckooshrike	*Coracina melanoptera*	SM	0.40	I	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
91	Orange Minivet	*Pericrocotus flammeus*	R	6.85	I	LC
92	Small Minivet	*Pericrocotus cinnamomeus*	R	8.20	I	LC
93	**Dicruridae** Black Drongo	*Edolius macrocercus*	R	10.40	I	LC
94	White-bellied Drongo	*Edolius caerulescens*	R	3.05	I	LC
95	Ashy Drongo	*Edolius leucophaeus*	SM	0.65	I	LC
96	Bronzed Drongo	*Chaptia aeneus*	WM	0.50	I	LC
97	Spangled Drongo	*Dicrurus hottentottus*	WM	0.40	I	LC
98	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	R	5.60	I	LC
99	**Monarchidae** Asian Paradise-flycatcher	*Terpsiphone paradise*	WM	1.95	I	LC
100	**Aegithinidae** Common Iora	*Aegithina tiphia*	R	6.30	I	LC
101	**Malconotinae** Common Woodshrike	*Tephrodornis pondicerianus*	R	1.40	I	LC
102	Malabar Woodshrike	*Tephrodornis virgatus*	R	0.30	I	LC
103	**Turdidae** Malabar Whistling-thrush	*Myophonus horsfieldii*	SM	0.20	I	LC
104	Eurasian Blackbird	*Turdus simillimus*	WM	1.50	I	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
105	**Muscicapidae** Indian Robin	*Saxicoloides fulicatus*	R	3.90	I	LC
106	Oriental Magpie-robin	*Copsychus saularis*	R	7.75	I	LC
107	White-rumped Shama	*Copsychus malabaricus*	R	1.70	I	LC
108	Pied Bushchat	*Saxicola caprata*	R	1.40	I	LC
109	Tickell's Blue-flycatcher	*Cyornis tickelliae*	R	8.20	I	LC
110	Asian Brown Flycatcher	*Muscicapa latirostris*	WM	0.25	I	LC
111	Verditer Flycatcher	*Eumyias thalassinus*	WM	0.60	I	LC
112	Brown-breasted Flycatcher	*Muscicapa dauurica*	WM	0.45	I	LC
113	Nilgiri Flycatcher	*Eumyias albicaudatus*	WM, E	0.25	I	NT
114	**Sturnidae** Common Myna	*Acridotheres tristis*	R	16.10	O	LC
115	Jungle Myna	*Acridotheres fuscus*	R	9.05	O	LC
116	Hill Myna	*Gracula religiosa*	WM	1.65	F	LC
117	Brahminy Starling	*Sturnia pagodarum*	R	0.85	F	LC
118	Chestnut-tailed Starling	*Sturnia malabaricus*	WM	3.65	F	LC
119	Rosy Starling	*Pastor roseus*	SM	0.30	F	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
120	**Sittidae** Velvet-fronted Nuthatch	*Sitta frontalis*	R	0.25	I	LC
121	**Paridae** Great Tit	*Parus nuchalis*	R	3.60	I	LC
122	**Hirundinidae** Pacific Swallow	*Hirundo tahitica*	R	7.30	I	LC
123	**Pycnonotidae** Red-vented Bulbul	*Pycnonotus cafer*	R	20.65	F	LC
124	Red-whiskered Bulbul	*Pycnonotus jocosus*	R	17.30	F	LC
125	White-browed Bulbul	*Pycnonotus luteolus*	R	26.45	F	LC
126	Asian Black Bulbul	*Hypsipetes leucocephalus*	WM	0.75	F	LC
127	Yellow-browed Bulbul	*Acritillas indica*	R	4.25	F	LC
128	**Cisticolidae** Ashy Prinia	*Prinia socialis*	R	1.50	I	LC
129	Plain Prinia	*Prinia inornata*	R	0.45	I	LC
130	Grey-breasted Prinia	*Prinia hodgsonii*	R	0.25	I	LC
131	Common Tailorbird	*Orthotomus sutorius*	R	4.35	I	LC
132	**Zosteropidae** Oriental White-eye	*Zosterops palpebrosus*	SM	0.45	F	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
133	**Sylviidae** Greenish Warbler	*Phylloscopus trochiloides*	WM	0.45	I	LC
134	Paddyfield Warbler	*Acrocephalus agricola*	R	1.30	I	LC
135	Blyth's Reed-Warbler	*Acrocephalus dumetorum*	SM	1.10	I	LC
136	Booted Warbler	*Hippolais caligata*	WM	1.30	I	LC
137	**Timaliidae** Tawny-bellied Babbler	*Dumetia hyperythra*	R	2.60	I	LC
138	Jungle Babbler	*Turdoides striata*	R	9.60	I	LC
139	Yellow-eyed Babbler	*Chrysomma sinense*	R	0.70	I	LC
140	Common Babbler	*Turdoides caudata*	R	21.00	I	LC
141	**Alaudidae** Indian Bushlark	*Mirafra erythroptera*	WM	0.40	G	LC
142	Singing Bushlark	*Mirafra cantillans*	R	0.65	G	LC
143	**Dicaeidae** Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	R	4.55	F	LC
144	Thick-billed Flowerpecker	*Pachyglossa agile*	R	0.75	F	LC
145	**Nectarinidae** Purple Sunbird	*Cinnyris asiatica*	R	4.60	N	LC
146	Purple-rumped Sunbird	*Leptocoma zeylonica*	R	11.60	N	LC
147	Loten's Sunbird	*Cinnyris lotenia*	R	1.10	N	LC

S. No	Family/ Common Name	Scientific Name	Status	Abundance	Feeding guild	IUCN Status
148	**Passeridae** House Sparrow	*Passer domesticus*	R	1.65	G	LC
149	**Motacillidae** White Wagtail	*Motacilla alba*	WM	0.30	I	LC
150	White-browed Wagtail	*Motacilla maderaspatensis*	R	8.75	I	LC
151	Yellow Wagtail	*Motacilla flava*	WM	1.55	I	LC
152	Grey Wagtail	*Motacilla cinerea*	WM	0.55	I	LC
153	Forest Wagtail	*Dendronanthus indicus*	R	1.50	I	LC
154	**Estrididae** Tricoloured Munia	*Lonchura malacca*	R	2.35	G	LC
155	Scaly-breasted Munia	*Lonchura punctulata*	R	0.80	G	LC
156	White-rumped Munia	*Lonchura striata*	R	0.65	G	LC
157	Indian Silverbill	*Lonchura malabarica*	R	0.55	G	LC
158	**Fringillidae** Common Rosefinch	*Carpodacus erythrinus*	WM	0.55	G	LC

NT = Near Threatened; VU = Vulnerable; EN = Endemic; R = Resident; SM = Summer Migrant; WM = Winter Migrant; I = Insectivore; F = Frugivore; P = Piscivore; G = Granivore; Cr = Carnivore; O = Omnivore; N = Nectarivore

Some common birds in the riverine forest

Chestnut-headed Bee-eater

Orange Minivet

Stork-billed Kingfisher

Common Kingfisher

Yellow-footed Green Pigeon

Emerald Dove

Asian Brown Flycatcher

Purple-rumped Sunbird

Some common birds in the riverine forest


Black-hooded Oriole


Eurasian Golden Oriole


Malabar Parakeet


Vernal Hanging-parrot


Lesser Fish-eagle


Bonelli's Eagle


Brown Fish-owl


Brown Hawk-owl

Family Accipitridae and Muscicapidae was represented by the highest number of species (n=9) followed by Cuculidae (eight species) constituted the most prominent avian families. Most of the families contained 1-2 species (Appendix 2). Maximum percent occurrence was found in the families: Accipitridae and Muscicapidae each were 5.70% and Cuculidae (5.06%) (Table 5.2). Of the 158 species, 70% were residents and 30% migrants.

5.3.1 Species richness and diversity

Species richness showed highest values in February (127 species) and lowest (75) in July. Highest diversity value (4.23) was observed in December and lowest (3.69) in July (Table 5.3). In general, bird species richness and diversity was found to be high during north-east monsoon and winter months and low in summer and southwest monsoon months. Most abundant bird species of the riparian forests included Grey-fronted Green Pigeon (31.27) followed by White-browed Bulbul (26.45) and Little Cormorant (24.35).

*5.3.2 Avian guild*s

Among the different avian feeding guilds, insectivores (47%; 74 species) comprised the highest proportion followed by frugivores (20%; 31 species), piscivores (9.5%; 15 species) etc (Figure 5.1).

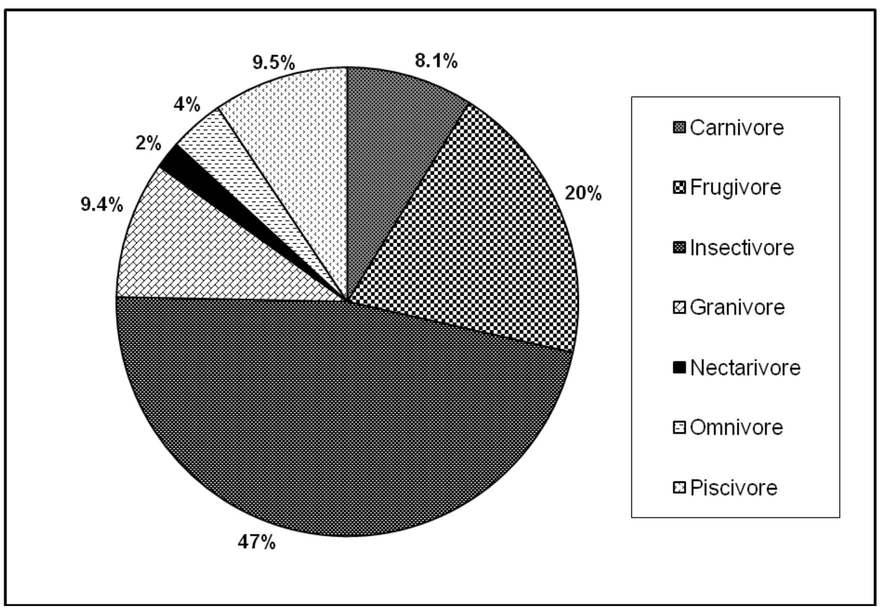


Figure 5.1 Distribution of birds feeding habits in the study area

The avifauna of this locality included a Vulnerable species, Nilgiri Woodpigeon (*Columba elphinstonii*) (IUCN, 2012) and five Near Threatened species namely, Oriental Darter (*Anhinga melanogaster*) (BirdLife International, IUCN, 2012), Great Hornbill (*Buceros bicornis*) (BirdLife International, IUCN, 2013), Malabar Pied Hornbill (*Anthracoceros coronatus*) (BirdLife International, IUCN, 2012), Nilgiri Flycatcher (*Eumyias albicaudata*) and Lesser Fish-eagle (*Ichthyophaga humilis*) (BirdLife International, IUCN, 2012). Nilgiri Flycatcher (*Eumyias albicaudata*), Nilgiri Woodpigeon (*Columba elphinstonii*), Malabar Parakeet (*Psittacula columboides*) White-cheeked Barbet (*Psilopogon viridis*) and Malabar Barbet (*Psilopogon malabaricus*) Endemic to the Western Ghats (Rasmussen and Anderton, 2012) were also reported here.

Table 5.2 Percent occurrence of bird family in the study area

Families	**Bird species**		**Families**	**Bird species**	
	#	**%**		**#**	**%**
Accipitridae	9	5.70	Meropidae	3	1.90
Aegithinidae	1	0.63	Monarchidae	1	0.63
Alaudidae	2	1.27	Motacillidae	5	3.16
Alcedinidae	5	3.16	Muscicapidae	9	5.70
Anhingidae	1	0.63	Nectarinidae	3	1.90
Apodidae	1	0.63	Oriolidae	3	1.90
Ardeidae	6	3.80	Paridae	1	0.63
Artamidae	1	0.63	Passeridae	1	0.63
Bucerotidae	3	1.90	Phalacrocoracidae	2	1.27
Campephagidae	4	2.53	Phasianidae	5	3.16
Capitonidae	4	2.53	Picidae	6	3.80
Charadriidae	1	0.63	Pittidae	1	0.63
Ciconiidae	1	0.63	Podicipedidae	1	0.63

Families	Bird species		Families	Bird species	
	#	%		#	%
Cisticolidae	4	2.53	Psittacidae	4	2.53
Columbidae	6	3.80	Pycnonotidae	5	3.16
Coraciidae	1	0.63	Rallidae	1	0.63
Corvidae	3	1.90	Scolopacidae	1	0.63
Cuculidae	8	5.06	Sittidae	1	0.63
Dicaeidae	2	1.27	Strigidae	6	3.80
Dicruridae	6	3.80	Sturnidae	6	3.80
Estrididae	4	2.53	Sylviidae	4	2.53
Fringillidae	1	0.63	Timaliidae	4	2.53
Hirundinidae	1	0.63	Trogonidae	1	0.63
Irenidae	2	1.27	Turdidae	2	1.27
Laniidae	1	0.63	Upupidae	1	0.63
Malconotinae	2	1.27	Zosteropidae	1	0.63

Table 5.3 Mean monthly diversity and richness of bird species (2012-2014)

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Species Richness	84	109	111	101	112	113	127	98	92	95	78	75
Shannon's Diversity Index	3.97	4.05	4.18	4.15	4.23	4.13	4.18	4.12	4.07	3.97	3.98	3.69

5.4 Discussion

The riparian ecosystem harbours both aquatic and land birds including several important species (Farooqui *et al.,* 2010). In Western Ghats, Joshua and Johnsingh (1986) assessed the 159 bird communities of the Mundanthurai plateau in the three vegetation types including the riverine forests, Tamil Nadu. In Kerala, Biju Kumar (2006) recorded 140 species of Bharathapuzha river basin and Vincy *et al*. (2016) analysed the bird species abundance and distribution in Meenachil river basin and recorded 92 bird species. In Maharashtra, Chavan *et al.* (2015) recorded 168 bird communities from Godavari river basin and 126 species of bird species from Krishna river basin (Kumbar and Ghadage, 2014). In Andhra Pradesh, Prasad *et al.* (2014) studied avifaunal diversity of Manjeera Wildlife Sanctuary. He reported the occurrence of 164 species of avifauna in different habitats including part of Manjeera river basin. Balabure *et al.* (2012) reported that 63 bird species in Narmada river basin, Central India. The present study recorded 158 species belonging to 52 families in the riverine forests exclusively, thus highlighting the significance of riverine forests as an important bird habitat in the Western Ghats. A variety of birds including endemic and threatened species occur here. Notable water birds include Oriental Darter, Asian Openbill Stork, Cormorants, Egrets, Herons and Kingfishers. The occurrence of near threatened species such as Great Hornbill, Malabar Pied Hornbill, Lesser Fish-eagle, Nilgiri Flycatcher, Oriental Darter and the Vulnerable Nilgiri Woodpigeon (Birdlife International, 2001) is interesting. Of these five species, both the hornbill species and Lesser Fish-eagle breed in the riparian forests (personal observations). The Lesser Fish-eagle and Malabar Pied Hornbill are habitat specialists mainly inhabiting the lowland riparian forests (Ali and Ripley, 1983; Balasubramanian *et al.,* 2004; Balasubramanian and Manikandan, 2015). Presence of tall trees with large canopy makes it an ideal nesting site of these large birds. The sighting of altitudinal migrants such as Malabar Whistling Thrush, Malabar Trogon, Malabar Barbet, Nilgiri Flycatcher, Eurasian Blackbird, Hill Myna and Nilgiri Woodpigeon indicates that these species use the riparian forests during their migration from high altitude evergreen forests to foothill forests for foraging. The occurrence of nine species of raptors further signifies the importance of this bird-habitat. Notable among the raptors include Bonelli's Eagle and Jerdon's Baza. Jerdon's Baza is disjunctly distributed and only rarely sighted in Peninsular India (Ali and Ripley, 1983). The occurrence of six species of owls indicates that the lowland riparian forests are favoured home for these nocturnal species.

In the study area, bird species richness and diversity were found higher during December, January and February. Similar findings were reported in a foot hill forest of the Nilgiris, Western Ghats (Peter *et al.*, 2015) and in a tropical evergreen forest in the Silent Valley National Park, Nilgiri Biosphere Reserve (Jayson and Mathew, 2000; Sanalkumar *et al.,* 2012). Johnsingh and Joshua (1994) reported maximum species richness in November-December in three different vegetation types of the Mundanthurai Plateau, Western Ghats.

6 NEST TREE SELECTION AND PREFERENCES BY CAVITY NESTING BIRDS IN THE RIVERINE FOREST

6.1 Introduction

Trees are important ecological resources for a diverse range of wildlife species throughout the world (Greeney, 2001; Gibbons and Lindenmayer, 2002; Ranius, 2002; Taylor and Ewers, 2003; Fan *et al.*, 2003) for breeding, roosting and shelter (Steeger and Dulisse, 2002; Walker *et al.*, 2005; Remm *et al.*, 2006). Trees with cavities play a significant role in maintaining forest biodiversity, and the abundance of cavity trees has become an important parameter in wildlife conservation and forest management (Gibbons and Lindenmayer, 1996; Whitford and Williams, 2002; McElhinny *et al.*, 2006). Many forest vertebrates depend on tree cavities for their reproduction including mammals, birds and reptiles. Cavity formation is vital to nest site selection for cavity nesting birds (CNBs), whether formation is through natural sources or facilitated by primary cavity nesters (PCNs). Cavity selection has historically served as a basis for dividing CNBs, as some species (e.g. woodpeckers) possess the capacity to excavate their own nest sites (PCNs), while SCNs cannot excavate their own nest cavity and depend on existing cavities. Selection of nest-cavity maximize the potential for finding cover and protection from direct sun light, competition, predators risk and territorial defence (Burger, 1985; Clark and Shutler, 1999; Purcell and Verner, 1999; Pöysa and Pöysa, 2002). Cavity users are divided into two main categories: primary cavity excavators, mainly woodpeckers (Picidae) and barbets (Capitonidae), which usually excavate one cavity per year, and secondary cavity nesters [(e.g. hornbills (Bucerotidae), owls (Strigidae), parakeets (Psittacidae), mynas (Sturnidae), tits (Paridae) and bats (Chiroptera)] which are dependent on tree cavities for roosting or nesting but cannot excavate themselves. Consequently, secondary cavity nesters rely on cavities created by excavators and decay processes (Martin and Eadie, 1999; Martin *et al.*, 2004; Robles *et al.*, 2011).

Primary cavity nesters such as woodpeckers constitute key-stone species in forest ecosystem (Johnsson, 1993; Miller *et al.*, 1998; Simberloff, 1998). The unique ability of primary cavity nesters is to excavate cavities in large trees for nesting and which form habitat for many other species of cavity nesting birds (Adkins Giese and Cuthbert, 2005). Those excavators chose certain trees that are suitable for cavity excavation which has certain features such as girth size and health condition (live and dead) (Schepps *et al.*, 1999; Kosinski and Winiecki, 2004). Excavators, nesting in live trees may also have advantages as protection from predators (Arsenault, 2004) and cavities in live trees are warmer (Hooge *et al.,* 1999; Fisher and Wiebe, 2006). Some excavators (barbets) depend to varying degrees of dead branches and decaying trees (snags) for nesting (Yahya, 1988; Kler, 1994; Koh and Lu, 2009; Lin *et al.*, 2010; Trounov and Vasilieva, 2014). The dead woods or decaying trees are essential for the survival of excavators (Kler, 1994; Koh and Lu, 2009). Snags form an important source of cavities, and hence snag management has been considered an effective means of enhancing habitat for cavity nesters (Franklin *et al.,* 1987; Sandstrom, 1992).

Secondary cavity nesters mainly use excavated cavities (PCNs created; Arsenault, 2004; Martin *et al.,* 2004; Aitken and Martin, 2007; Blanc and Walters, 2008b) or otherwise they nests in suitable natural cavities (natural formation), select trees that trees of greater diameter for successful reproduction (Johnson and Kermott, 1994; Lawler and Edwards Jr, 2002). The secondary cavity nesting birds prefer large trees which have more suitable cavities and deeper cavities (excavated or non-excavated) to avoid predators (Nilsson, 1984; Purcell and Verner, 1999; Willson *et al.*, 2001; Wesolowski *et al.*, 2002; Mitrus, 2003; Brightsmith, 2005; Mahon and Martin, 2006). Those cavities were highly distributed in mature or large trees than small girth trees (Blakely *et al.*, 2008; Koch *et al.*, 2008b). Many cavities in live limbs were warmer and experience lower overall variance in temperature than cavities in dead limbs (Hooge *et al.*, 1999).

In general, trees larger in girth and height are used compared to small trees (Zarnowitz and Manuwal 1985). Old and large trees have more cavities than younger and smaller trees (Gibbons and Lindenmayer, 2002; Blakely *et al.,* 2008; Koch *et al.,* 2008b). There is a close relationship between many species of cavity users and the abundance of large trees (Lindenmayer *et al.*, 1991). A high number of animal species depend on large trees which had more suitable cavities for cavity nesting or roosting (Onodi and Winkler, 2016).

Many cavity nesting birds select large size trees or snags for nesting (Adkins Giese and Cuthbert, 2005). Nest tree diameters must be large enough to accommodate a cavity with room for an adult bird and nestlings, but sizes usually exceed that requirement (Conner *et al.,* 1975). The selection of trees were larger than the size of cavity require reflects age and the size at which heart rot develops. Cavity-nesting birds benefit from the protection from predators that cavities provide their young, as well as shelter and insulation of the nest or roost (Miller and Miller, 1980; Purcell and Verner, 1999). The ideal cavity nest also should be high in a tree to avoid nest predators (Brightsmith, 2005; Fisher and Wiebe, 2006). Consequently, characteristics of nest trees that influence nest success are usually important in determining nest-tree preferences. For example, nest predation is the primary cause of nest failure in birds (Martin, 1993); therefore, predation is an important selective force in nest-tree selection for cavity nesting species (Nilsson, 1984; Martin and Li, 1992; Martin, 1993; Brightsmith, 2005; Fontaine and Martin, 2006).

A high number of animal species depend on large trees for cavity nesting or roosting (Onodi and Winkler, 2016). Distribution of resources important for cavity nesting birds naturally varied across the landscape or forest ecosystem. However, human activities such as logging and deforestation reduce the abundance of tree cavities and their associated wildlife by altering the forest structure (Wardle, 1984; Blakely and Didham, 2008). Practically, large trees are targeted in selective logging, deforestation processes and anthropogenic activity (Robertson and Rowling, 2000; Biswas and Mallik, 2010), which reduces the roosting and nesting sites of obligate cavity-dwelling species (Mackowski, 1984; Lindenmayer *et al.,* 1991). Despite their having high importance in providing foraging, nesting, roosting and breeding sites, the information available about characteristics of the trees, their cavities, and associated wildlife species is insufficient, especially for tropical forest (Marsden and Jones, 1997; Law and Andersen, 2000; Lumsden *et al.,* 2002; Courtney and Debus, 2006; Murphy and Legge, 2007; Cornelius *et al.,* 2008; Remm and Lohmus, 2011).

Studies of cavity-nesting birds have occurred in temperate forests of Europe, North America, and Australia (Fan *et al.*, 2003; Harper *et al.*, 2005; Kenefic and Nyland, 2007; Goldingay, 2009; Remm and Lohmus, 2011). Many studies have examined attributes of trees and cavity trees preferred by various cavity nesting birds, as reported by Raphael and White (1984) in the mixed evergreen forest, California; Harestad and Keisker (1989) in coniferous forest, British Columbia; Bate (1995) in the central Oregon Cascades; Bull *et al.*, (1997) in riverine basin, Columbia; Goodburn and Lorimer, (1998) in Northern hardwood forests, Wisconsin and Michigan; Schepps *et al.* (1999) in mixed coniferous forest, central Arizona; Fan *et al.,* (2003) in Midwestern old-growth and second-growth forests, Missouri, USA. Arsenault (2004) in mixed coniferous-deciduous forests, New Mexico; Kosinski *et al.* (2006) in the riverine forest of central Poland; Remm *et al.* (2006) in riverine forest, in central Estonia; Kenefic and Nyland (2007) in a Northern hardwood stand in Central New York; Cornelius (2008) in a temperate rainforest, southern Chile; Kozma (2010) in a pine forest of Washington.

Certain studies concentrated on distribution of cavities and their utilization by cavity nesting birds and other fauna *viz.*, Bai *et al.* (2003) in a Primeval Boreal forest of Mongolia; Remm *et al.* (2006) in a riverine forest in Central Estonia; Zheng *et al.* (2009) in subtropical evergreen broad-leaved forest in the Ailao Mountains in southwestern China; Alice Boyle *et al.* (2008) in a tropical rain forest at Costa Rica; Robles *et al.* (2011) in the oak forests of southern Cantabrian Mountains; Warakai *et al.* (2013) in the mixed evergreen forest, Guinea. In India, studies on breeding ecology of cavity nesting birds mostly focused on single species namely, Malabar Parakeet (Gokula and Venkatraman, 2003); Great Hornbill (James and Kannan, 2009); Indian Roller (Sivakumaran and Thiyagesan, 2003; Asokan *et al.*, 2009b); Spotted Owlet (Santhanakrishnan *et al*., 2011); Oriental Magpie Robin (Bhatt *et al*., 2014); Indian Roller and Common Myna (Nithiyanandam and Asokan, 2015); *Megalaima* species (Yahya, 1988). Information on nest tree characteristics of some cavity nesting birds namely, Great Hornbill (Mudappa and Kannan, 1997); Malabar Grey Hornbill (Maheswaran and Balasubramanian, 2003); Indian Grey Hornbill (Santhoshkumar and Balasubramanian, 2010); sympatric woodpeckers (Santharam, 2006) were available. However, community-wide study on nest-site selection and nest tree preferences of cavity nesting birds was lacking. Hence, in order to investigate and understand the tree preferences of the entire community of cavity nesting birds in a riparian habitat, the present study was undertaken.

6.2 Methodology

6.2.1 Nest searches

Nests of cavity nesting birds were searched in trunks of all trees >50 cm girth along the river bank. Each tree was observed from at least three directions with the help of binoculars. Trees found with cavities were referred to as cavity trees. Cavity trees were defined as trees with a nest cavity, den, or hollow that might shelter a cavity nesting species (Healy *et al.* 1989). Cavities were classified into the following different types: 1) bird excavated cavities (woodpecker, barbets) for nesting, 2) non excavated (natural) cavities, which formed from fallen branches and natural damages of tree trunk. Bird excavated cavities were cavity entrances round or oval and regular interior of cavity, and the others were natural cavities (irregular entrances and interiors of cavity). Nest trees were located by making repeated walks along river banks and monitor the tree holes. Excavators (woodpeckers and barbets) were located at the beginning of the breeding season either by the sound of excavation or signs of wood-boring, e.g. wood chips on the ground, as well as by observations of adults and begging-calls of the young birds during breeding period. The occupancy of cavities was recorded from the ground by adults' behaviour (carrying nest material and food items) or observations of chicks' behaviour in nest cavity.

Active nest cavities were checked for the presence or absence of birds, on a regular basis twice or more times in a week. Sightings of adult bird repeatedly visiting the same tree, flying out of a tree suddenly, birds clinging to cavity entrances, perch near cavities, and enter and exit actions near cavities helped in confirmation of active nests. Parental birds' behaviour was observed from a hideout made on the ground near the nest tree. Cavities were considered active nests if they contained chicks, or if the activities of adult birds indicated nesting (e.g., parent bird carrying food into cavity nest) and young calling from nest cavity. The tree species on which bird nests are placed were identified and nest tree name and features were recorded. These observations were made from the ground by using a pair of binoculars. The cavities were observed to find out if it is occupied by any bird species, evidence of use (e.g., eggs, hatchlings, or chick callings), and direct sighting of the occupant bird species entering or exiting the cavity.

6.2.2 Nest tree features

After confirmation of active nest, the following parameters were recorded for each cavity-bearing tree: 1) tree species, 2) number of cavities in the tree, 3) tree health condition (live, partially dead or dead), 4) girth at breast height (height at 1.3 m from ground), 5) nest tree height, 6) tree canopy height measured with Laser Range Finder (Nikon Forestry Pro), 7) Origin of the cavity (excavated or non-excavated cavities).

6.2.3 Nest site plots

Neighbour trees were surveyed in 5 m radius in circular plots (0.04ha) keeping the nest tree as centre point. “Neighbour Trees” (NBT) are trees that were nearest and closest to the focal nest tree. In each circular plot, data on neighbour tree characteristics were gathered: girth at breast height (height at 1.3 m from ground) measured with tape, tree heights measured with Laser Range Finder (Nikon Forestry Pro). Nest trees compared to neighbour trees were tested by different variable characters such as tree height and tree girth size. Tree height was grouped into six classes in the analysis, i.e. 5 – 10 m, 11 – 15 m, 16 – 20 m, 21 – 25 m, 26 – 30 m and >30 m. For the tree GBH was grouped into seven classes in the analysis, i.e. < 100 cm, 101 – 200 cm, 201 – 300 cm, 301 – 400 cm, 401 – 500 cm, 501 – 600 cm and > 601 cm.

6.2.4 Quantification of trees

The tree vegetation of the riverine forest was quantified by using belt-transect method. Sampling was done in two belt transects, each measuring 1 ha (1000x10m). The belt transect was sub-divided into 10x10 subplots and all live trees and snags (>20 cm at breast height (gbh) were measured, identified to species and each stem was categorized as live or dead. The data collected were analysed to obtain quantitative values such as frequency, density and abundance. The frequency of individual species is the number of times the species occurs in the sampling quadrats. Abundance of a species is determined as the number of individuals per quadrat. Density is defined as the number of individuals of a species in a quadrat. The definition of 'cavity' is any excavated cavity or non-excavated cavity (naturally formed) in tree trunk or limbs having a cavity entrance diameter of more than 5 cm and depth of more than 10 cm (Blakely and Didham, 2008; Blakely *et al.*, 2008). These cavities were surveyed in the tree trunks of all trees >50 cm girth at breast height in 1 ha sampling plot. Parameters such as tree density, structure, availability of suitable cavities, cavity bearing trees and total number of trees with in sample plot were assessed.

Nest trees and available trees (potential trees) were compared and tested by different variable characters such as tree height and tree girth size. Tree height was grouped into six classes in the analysis, i.e. 5 – 10 m, 11 – 15 m, 16 – 20 m, 21 – 25 m, 26 – 30 m and >30 m. For the tree GBH was grouped into seven classes in the analysis, i.e. < 100 cm, 101 – 200 cm, 201 – 300 cm, 301 – 400cm, 401 – 500 cm, 501 – 600 cm and > 601 cm. Nest-tree preferences were evaluated by comparing the number of trees used for nesting with the number of trees available within predefined categories. In addition, use and availability were compared among the group species to evaluate preference for tree size and tree species.

6.2.5 Statistical Analysis

Nest tree preferences of cavity nesting birds were assessed by using Ivlev's Index (Ivlev, 1961). Preference Index (PI) was calculated using Ivlev's Index of Selectivity, (PI= U-A/U+A, where U denotes utilization of the tree species and A denotes availability of corresponding species). Availability of the nest tree species was estimated from the vegetation sampling data. Utilization of the species was obtained from the number of nests occupied. Values of PI range between -1 and +1, where -1 indicates avoidance, while +1 indicates +1 highest preference. Data were analyzed using SPSS for Windows version 16. 2010. I presented descriptive statistical test for nest tree characters (tree height and tree girth) compared with available trees and neighbour trees (Mean ± SD). Student independent *t*-test was applied to nest tree characters (height and tree girth) compared with available trees and neighbour trees for primary and secondary cavity nesting birds. Non-parametric Chi-square test was applied to compare nest tree health condition (live, partially dead, snag) of excavated and non-excavated cavity trees.

6.3 Results

6.3.1 Cavity nesting birds community

Of the 158 bird species belonging to 52 families found in the riparian forests of the study site, 32 species were found to use tree cavities for nesting. Of the 32 species, nine species comprising five woodpeckers (*Celeus brachyurus, Dendrocopos nanus, Dinopium javanense Picus chlorolophus* and *Chrysocolaptes festivus*) and four barbets (*Psilopogon haemacephala, Psilopogon rubricapila, Psilopogon viridis* and *Psilopogon zeylanica*) are primary cavity nesters (PCNs) and 23 species are secondary cavity nesters (SCNs). The SCNs included parakeets (*Psittacula* spp and *Loriculus vernalis*), mynas (*Acridotheres tristis, Acridotheres fuscus, Gracula religiosa* and *Sturnus pagodarum*), hornbills (*Anthracoceros coronatus, Buceros bicornis* and *Ocyceros birostris*), owls (*Athene brama, Glaucidium radiatum, Ketupa zeylonensis, Ninox scutulata* and *Otus bakkamoena*), Common Hoopoe (*Upupa epops*), Oriental Magpie Robin (*Copsychus saularis*), White-rumped Shama (*Copsychus malabaricus*), Tickell's Blue-flycatcher (*Cyornis tickelliae*), Indian Roller (*Coracias benghalensis*), Great Tit (*Parus major*) and Chestnut-bellied Nuthatch (*Sitta castanea*) (*Appendix 2). Major proportion of cavity nesting birds comprised woodpeckers and owls (20.83%), mynas, parakeets and barbets represented by 16.66% each, and hornbills (12.5%). A lesser proportion of cavity nesting birds included Oriental Magpie Robin, Great Tit, Chestnut-bellied Nuthatch, White-rumped Shama and Tickell's Blue-flycatcher, Common Hoopoe and Indian Roller 4.16% each.

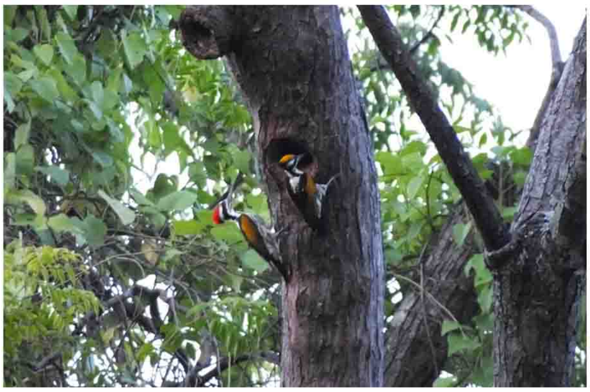
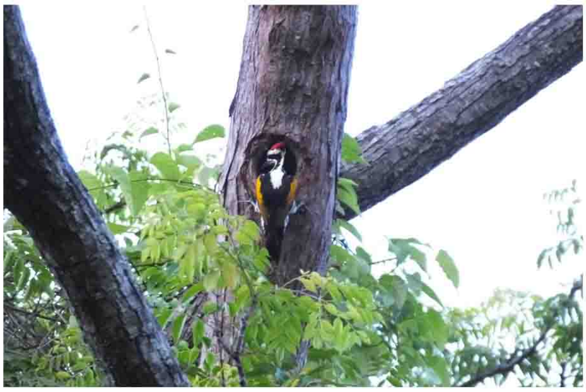
A total of 376 active nests of various bird species were indentified in the riparian forests. Out of 376 nests, 116 (30.85%) belonged to primary cavity nesters and 260 (69.14%) belonged to secondary cavity nesters. Highest proportion of cavities was used by Common Myna (18.88%) followed by White-cheeked Barbet (12.5%) and Brown-headed Barbet (8.51%) (Table 6.1). Highest number of tree species was used by Common Myna (n=22) followed by Brown-headed Barbet (n=20) and White-cheeked Barbet (n=18) (Figure 6.1). In all, tree species such as *Terminalia arjuna*, *Mangifera indica*, *Ceiba pentandra* and *Melia dubia* were favoured by several cavity nesting species.

Table 6.1 Percentage proportion of various cavity nesters in the riverine forests

S. No	Birds species	Cavity nests	
		Number	Percent
1	**Primary Cavity Nesters (PCNs)** White-napped Woodpecker	5	1.32
2	Greater Golden-backed Woodpecker	12	3.19
3	Brown-capped Pygmy Woodpecker	5	1.32
4	Brown-headed Barbet	32	8.51
5	Coppersmith Barbet	15	3.98
6	White-cheeked Barbet	47	12.5
7	**Secondary Cavity Nesters (SCNs)** Common Myna	71	18.88
8	Jungle Myna	35	9.30
9	Great Hornbill	3	0.79
10	Malabar Pied Hornbill	11	2.92
11	Malabar Parakeet	22	5.85
12	Rose-ringed Parakeet	12	3.19
13	Jungle Owlet	6	1.59
14	Indian Scops Owl	9	2.39
15	Common Hoopoe	11	2.92
16	Indian Roller	11	2.92
17	Great Tit	8	2.12
18	Tickell's Blue-flycatcher	27	7.18
19	Oriental Magpie Robin	26	6.91
20	White-rumped Shama	8	2.12

Primary cavity nesting birds in the riverine forests
(Woodpeckers)


Golden-backed Woodpecker

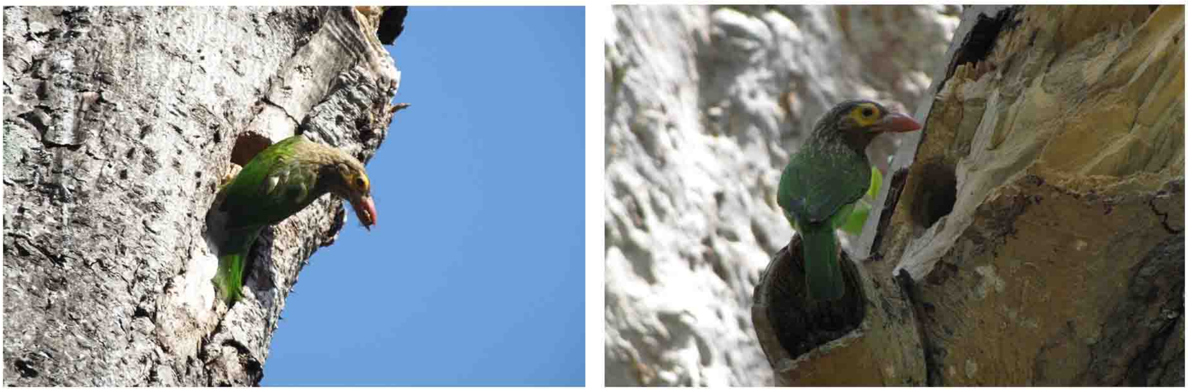



White-naped Woodpecker


Brown-capped Pygmy Woodpecker

Primary cavity nesting birds in the riverine forests

(Barbets)



Brown-headed Barbet

White-cheeked Barbet

Coppersmith Barbet

Secondary cavity nesting birds in the riverine forests

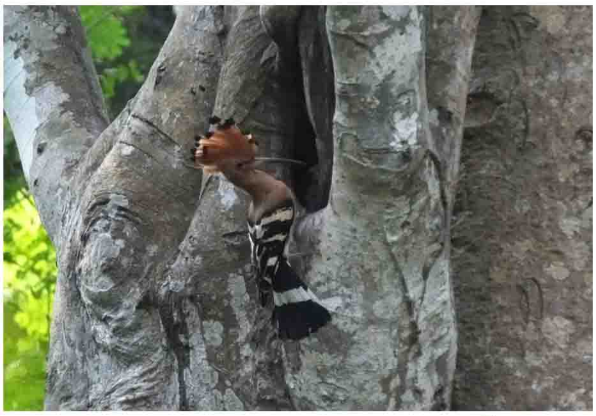
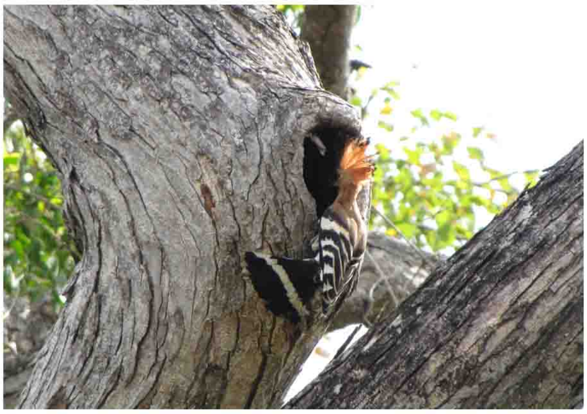

Great Hornbill


Malabar Pied Hornbill


Common Myna


Rose-ringed Parakeet

Secondary cavity nesting birds in the riverine forests

Common Hoopoe

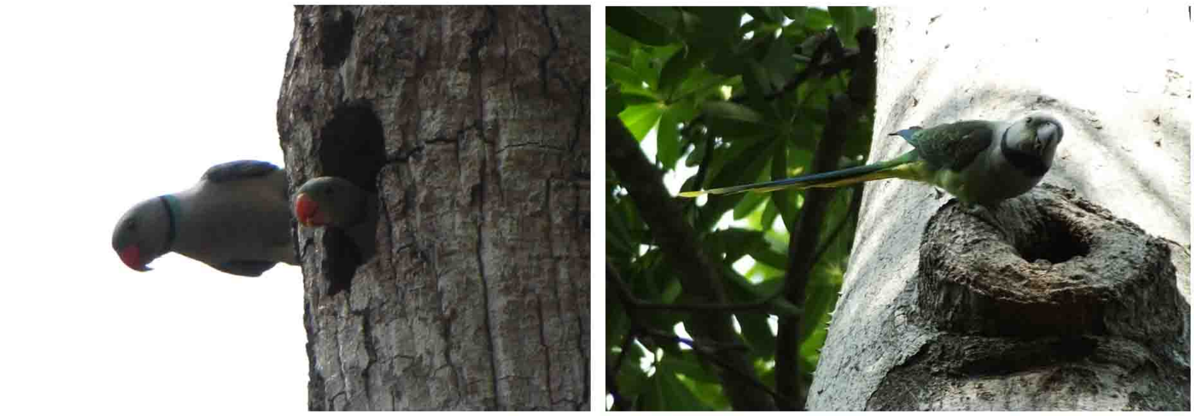

Indian Roller


White-rumped Shama

Jungle Owlet

Indian Scops Owl

Secondary cavity nesting birds in the riverine forests



Malabar Parakeet

Jungle Myna

Oriental Magpie Robin

Tickell's Blue Flycatcher

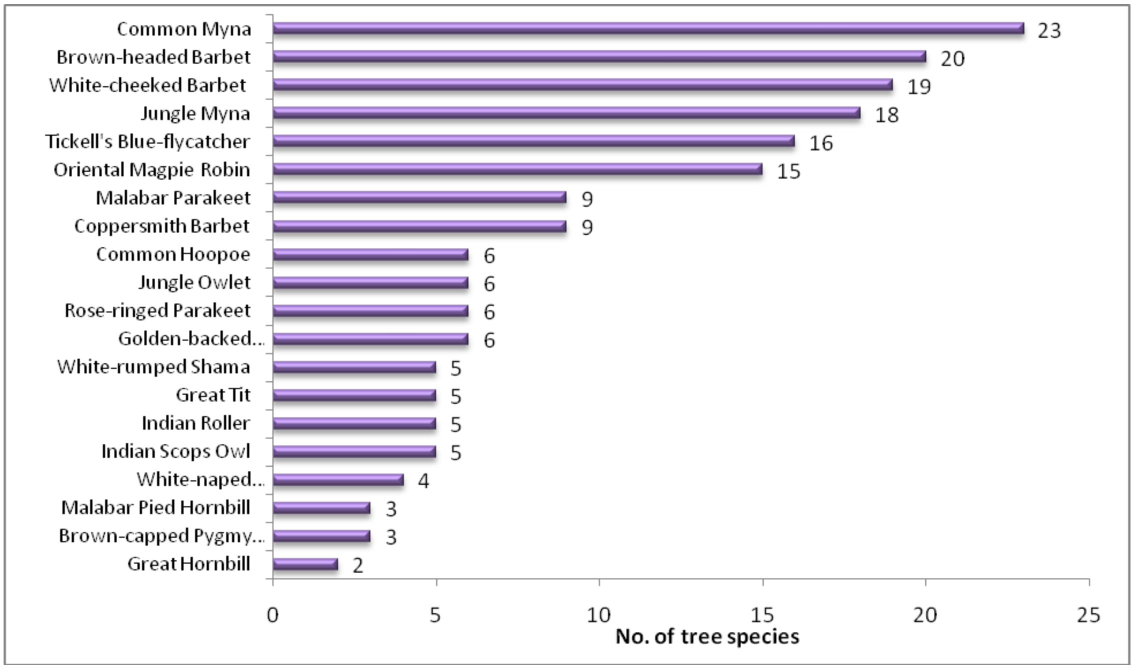


Figure 6.1 Number of nest tree species used by various cavity nesting birds

6.3.2 Tree species utilization by cavity nesting birds (CNBs)

A total of 257 nest trees belonging to 54 species of 23 families were located in the study site. Of the 257 nest trees, 226 were live trees and 31 dead trees (snags) which were used by 20 different cavity nesting birds. Fifteen out of 20 cavity nesting bird species utilized *Mangifera indica. Terminalia arjuna* was the second important nest tree species, utilized by 14 bird species. Tree species such as *Gmelina arborea, Pleurostylia opposita, Pterocarpus marsupium, Salix tetrasperma, Sapindus emarginatus* and *Sterculia guttata* were used by only one bird species (Table 6.2).

Table 6.2 List of tree species utilized by various cavity nesting birds (CNBs)

S. No.	Name of the Tree species	Family name	# of species (CNBs)
1	*Mangifera indica*	Anacardiaceae	15
2	*Terminalia arjuna*	Combretaceae	14
3	*Melia dubia*	Meliaceae	8
4	*Syzygium cumini*	Myrtaceae	8
5	*Albizia lebbeck*	Mimosaceae	7
6	*Ceiba pentandra*	Bombacaceae	7
7	*Madhuca longifolia*	Sapotaceae	7
8	*Acacia polyacantha*	Mimosaceae	6
9	*Gyrocarpus asiaticus*	Hernandiaceae	5
10	*Hopea ponga*	Dipterocarpaceae	5
11	*Pongamia pinnata*	Fabaceae	5
12	*Tamarindus indica*	Caesalpiniaceae	5
13	*Ficus amplissima*	Moraceae	4
14	*Ficus religiosa*	Moraceae	4
15	*Manilkara hexandra*	Sapotaceae	4
16	*Diospyros peregrina*	Ebenaceae	3
17	*Ficus benghalensis*	Moraceae	3
18	*Ficus microcarpa*	Moraceae	3
19	*Ficus racemosa*	Moraceae	3
20	*Ficus virens*	Moraceae	3
21	*Givotia moluccana*	Euphorbiaceae	3
22	*Hardwickia binata*	Caesalpiniaceae	3
23	*Holoptelea integrifolia*	Ulmaceae	3
24	*Strychnos nux-vomica*	Loganiaceae	3
25	*Vitex altissima*	Verbenaceae	3
26	*Albizia chinensis*	Mimosaceae	2

S. No.	Name of the Tree species	Family name	# of species (CNBs)
27	*Alseodaphne semecarpifolia*	Lauraceae	2
28	*Bombax ceiba*	Bombacaceae	2
29	*Celtis philippensis*	Ulmaceae	2
30	*Celtis tetrandra*	Ulmaceae	2
31	*Delonix regia*	Caesalpiniaceae	2
32	*Drypetes roxburghii*	Euphorbiaceae	2
33	*Streospermum personatum*	Bignoniaceae	2
34	*Sweitenia macrophylla*	Meliaceae	2
35	*Ailanthus excelsa*	Simaroubaceae	1
36	*Albizia amara*	Mimosaceae	1
37	*Alphonsea sclerocarpa*	Annonaceae	1
38	*Butea parviflora*	Fabaceae	1
39	*Calophyllum apetalum*	Clusiaceae	1
40	*Cassine glauca*	Selastraceae	1
41	*Cordia monoica*	Cordiaceae	1
42	*Dalbergia latifolia*	Fabaceae	1
43	*Ficus drupacea*	Moraceae	1
44	*Gmelina arborea*	Verbenaceae	1
45	*Pleurostylia opposita*	Celastraceae	1
46	*Psidium guajava*	Myrtaceae	1
47	*Pterocarpus marsupium*	Fabaceae	1
48	*Salix tetrasperma*	Salicaceae	1
49	*Sapindus emarginatus*	Sapindaceae	1
50	*Schleichera oleosa*	Sapindaceae	1
51	*Sterculia guttata*	Sterculiaceae	1
52	*Strychnos potatorum*	Loganiaceae	1
53	*Terminalia bellirica*	Combretaceae	1
54	*Terminalia catapa*	Combretaceae	1

Out of 376 nests found, 116 nests belonged to primary cavity nesters (PCN), placed in 115 trees. A total of 260 nests belonged to secondary cavity nesters (SCN), which were found in 215 trees. Highest proportion of PCN's nest cavities were located in *Terminalia arjuna* (17; 14.66%) followed by *Mangifera indica* (16; 13.79%). Interestingly, highest proportions of SCN nests were also found in *Terminalia arjuna* (35; 13.46%) and *Mangifera indica* (23; 8.85%). Both *Terminalia arjuna* and *Mangifera indica* served most often as the nest tree species preferred by both primary and secondary cavity nesting birds in the riverine forest. Details of tree species utilized by primary and secondary cavity nesters are given in Table 6.3.

Table 6.3 Proportion of nest cavities in different tree species utilized by primary and secondary cavity nesters (n=376 nests)

S. No.	Name of the Tree species	Primary cavity nester nests		Secondary cavity nester nests		Total # of nests
		#	%	#	%	
1	*Terminalia arjuna*	17	14.66	35	13.46	52
2	*Mangifera indica*	16	13.79	23	8.85	39
3	*Melia dubia*	11	9.48	21	8.08	32
4	*Ceiba pentandra*	9	7.76	9	3.46	18
5	*Madhuca longifolia*	1	0.86	17	6.54	18
6	*Syzygium cumini*	3	2.59	14	5.38	17
7	*Streospermum personatum*	6	5.17	11	4.23	17
8	*Gyrocarpus asiaticus*	3	2.59	13	5.00	16
9	*Albizia lebbeck*	5	4.31	9	3.46	14
10	*Strychnos nux-vomica*	4	3.45	7	2.69	11
11	*Hardwickia binata*	0	-	11	4.23	11
12	*Ficus benghalensis*	9	7.76	1	0.38	10
13	*Vitex altissima*	1	0.86	7	2.69	8
14	*Diospyros peregrina*	1	0.86	6	2.31	7
15	*Tamarindus indica*	2	1.72	5	1.92	7

S. No.	Name of the Tree species	Primary cavity nester nests		Secondary cavity nester nests		Total # of nests
		#	%	#	%	
16	*Acacia polyacantha*	4	3.45	2	0.77	6
17	*Pongamia pinnata*	4	3.45	2	0.77	6
18	*Ficus religiosa*	1	0.86	4	1.54	5
19	*Drypetes roxburghii*	0	-	5	1.92	5
20	*Hopea ponga*	1	0.86	4	1.54	5
21	*Manilkara hexandra*	1	0.86	4	1.54	5
22	*Ficus microcarpa*	0	-	4	1.54	4
23	*Ficus racemosa*	3	2.59	1	0.38	4
24	*Ficus amplissima*	3	2.59	1	0.38	4
25	*Albizia chinensis*	2	1.72	2	0.77	4
26	*Alphonsea sclerocarpa*	0	-	3	1.15	3
27	*Alseodaphne semecarpifolia*	0	-	3	1.15	3
28	*Celtis philippensis*	0	-	3	1.15	3
29	*Givotia moluccana*	2	1.72	1	0.38	3
30	*Holoptelea integrifolia*	1	0.86	2	0.77	3
31	*Bombax ceiba*	1	0.86	2	0.77	3
32	*Ficus virens*	2	1.72	1	0.38	3
33	*Schleichera oleosa*	0	-	3	1.15	3
34	*Ailanthus excelsa*	0	-	2	0.77	2
35	*Calophyllum apetalum*	0	-	2	0.77	2
36	*Delonix regia*	0	-	2	0.77	2
37	*Terminalia bellirica*	0	-	2	0.77	2
38	*Celtis tetrandra*	0	-	2	0.77	2
39	*Sweitenia macrophylla*	1	0.86	1	0.38	2
40	*Albizia amara*	0	-	1	0.38	1
41	*Butea parvifolia*	0	-	1	0.38	1

S. No.	Name of the Tree species	Primary cavity nester nests		Secondary cavity nester nests		Total # of nests
		#	%	#	%	
42	*Cassine glauca*	0	-	1	0.38	1
43	*Cordia monoica*	0	-	1	0.38	1
44	*Dalbergia latifolia*	0	-	1	0.38	1
45	*Ficus drupacea*	1	0.86	0	-	1
46	*Gmelina arborea*	0	-	1	0.38	1
47	*Pleurostylia opposita*	0	-	1	0.38	1
48	*Psidium guajava*	0	-	1	0.38	1
49	*Pterocarpus marsupium*	0	-	1	0.38	1
50	*Salix tetrasperma*	0	-	1	0.38	1
51	*Sapindus emarginatus*	0	-	1	0.38	1
52	*Sterculia guttata*	0	-	1	0.38	1
53	*Strychnos potatorum*	0	-	1	0.38	1
54	*Terminalia catapa*	1	0.86	0	-	1

6.3.2.1 Utilization of bird excavated and natural cavities

Primary cavity nesting birds mainly used cavities excavated by them and these nesters did not use other bird excavated cavities for nesting. Secondary cavity nesting bird nest cavities were found both in the bird excavated cavities (woodpecker, barbet) and natural cavities. Per cent proportion of bird excavated and natural cavities (non-excavated) used by birds is given in (Table 6.4). Largest proportion of bird excavated nests were found in *Terminalia arjuna* (11.99%) followed by *Melia dubia* (11.24%), *Mangifera indica* (10.49%) and *Ceiba pentandra* (6.37%), whereas non-excavated cavity nests were higher in *Terminalia arjuna* (19.27%) and each 11.01 % nests were in *Madhuca longifolia* and *Mangifera indica*. Cavities occurred more frequently in large trees. *Terminalia arjuna* and *Mangifera indica* were favoured by both primary cavity and secondary cavity nesters.

Table 6.4 Proportion of excavated cavities and natural cavities used by birds

S. No.	Name of the tree species	Bird excavated cavities		Non-excavated cavities	
		#	%	#	%
1	*Terminalia arjuna*	32	11.99	21	19.27
2	*Acacia polyacantha*	6	2.25	-	-
3	*Ailanthus excelsa*	2	0.75	-	-
4	*Albizia amara*	1	0.37	-	-
5	*Albizia chinensis*	4	1.50	-	-
6	*Albizia lebbeck*	9	3.37	5	4.59
7	*Alphonsea sclerocarpa*	-	0.00	3	2.75
8	*Alseodaphne semecarpifolia*	2	0.75	1	0.92
9	*Bombax ceiba*	3	1.12	-	-
10	*Butea parvifolia*	-	0.00	1	0.92
11	*Calophyllum apetalum*	-	0.00	2	1.83
12	*Cassine glauca*	1	0.37	-	-
13	*Ceiba pentandra*	17	6.37	1	0.92
14	*Celtis philippensis*	-	0.00	3	2.75
15	*Celtis tetrandra*	2	0.75	-	-
16	*Cordia monoica*	-	0.00	1	0.92
17	*Dalbergia latifolia*	-	0.00	1	0.92
18	*Delonix regia*	1	0.37	1	0.92
19	*Diospyros peregrina*	2	0.75	5	4.59
20	*Drypetes roxburghii*	-	0.00	5	4.59
21	*Ficus amplissima*	4	1.50	-	-
22	*Ficus benghalensis*	9	3.37	1	0.92
23	*Ficus drupacea*	1	0.37	-	-
24	*Ficus microcarpa*	2	0.75	2	1.83
25	*Ficus racemosa*	4	1.50	-	-
26	*Ficus religiosa*	2	0.75	3	2.75
27	*Ficus virens*	3	1.12	-	-

S. No.	Name of the tree species	Bird excavated cavities		Non-excavated cavities	
		#	%	#	%
28	*Givotia moluccana*	3	1.12	-	-
29	*Gmelina arborea*	-	0.00	1	0.92
30	*Gyrocarpus asiaticus*	16	5.99	-	-
31	*Hardwickia binata*	9	3.37	2	1.83
32	*Holoptelea integrifolia*	2	0.75	1	0.92
33	*Hopea ponga*	4	1.50	1	0.92
34	*Madhuca longifolia*	6	2.25	12	11.01
35	*Mangifera indica*	28	10.49	12	11.01
36	*Manilkara hexandra*	4	1.50	1	0.92
37	*Melia dubia*	30	11.24	-	-
38	*Pleurostylia opposita*	-	0.00	1	0.92
39	*Pongamia pinnata*	5	1.87	1	0.92
40	*Psidium guajava*	-	0.00	1	0.92
41	*Pterocarpus marsupium*	-	0.00	1	0.92
42	*Salix tetrasperma*	1	0.37	-	-
43	*Sapindus emarginatus*	1	0.37	-	-
44	*Schleichera oleosa*	-	0.00	3	2.75
45	*Sterculia gutteta*	1	0.37	-	-
46	*Streospermum personatum*	15	5.62	2	1.83
47	*Strychnos nux-vomica*	6	2.25	5	4.59
48	*Strychnos potatorum*	-	0.00	1	0.92
49	*Sweitenia macrophylla*	2	0.75	-	-
50	*Syzygium cumini*	13	4.87	4	3.67
51	*Tamarindus indica*	3	1.12	4	3.67
52	*Terminalia bellirica*	2	0.75	-	-
53	*Terminalia catapa*	1	0.37	-	-
54	*Vitex altissima*	8	3.00	-	-

6.3.2.2 Cavity distribution of different girth classes of nest trees

Majority of the nest cavities were found in 201-300 cm girth class category of nest trees. Of the cavities found in this girth class, bird excavated cavities were 28.94% and non-excavated (natural) cavities 42.11%. Less than 5% of nest cavities (excavated, non-excavated) were found in <100 cm of tree girth (Figure 6.2). Trees with large girth classes were favoured by majority of the cavity nesting birds.

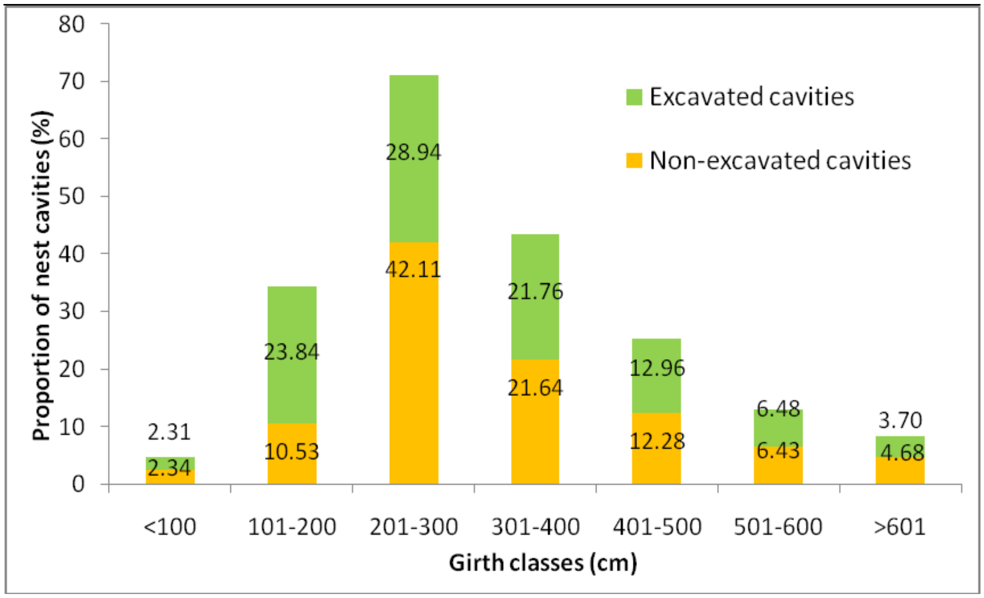


Figure 6.2 Nest cavities distribution in different size categories of nest trees

6.3.2.3 Potential cavities in different predominant trees species

The total tree population of 1ha in the study site was 520 trees of 65 species, among which *Terminalia arjuna* and *Mangifera indica* were the dominant canopy and large-sized of tree species in the riverine forest. Out of the 520 trees found in the sample plots, 274 (52.69%) contained potential cavities. Cavities occurred most frequently in *Mangifera indica* (34.74% excavated; 26.28% non-excavated) followed by *Terminalia arjuna* (29.47% excavated; 23.46% non-excavated) (Figure 6.3).

Various Types of Nest cavities in the riverine forest

Woodpecker excavted cavities

Barbet excavted cavities

Natural cavities

Natural cavities

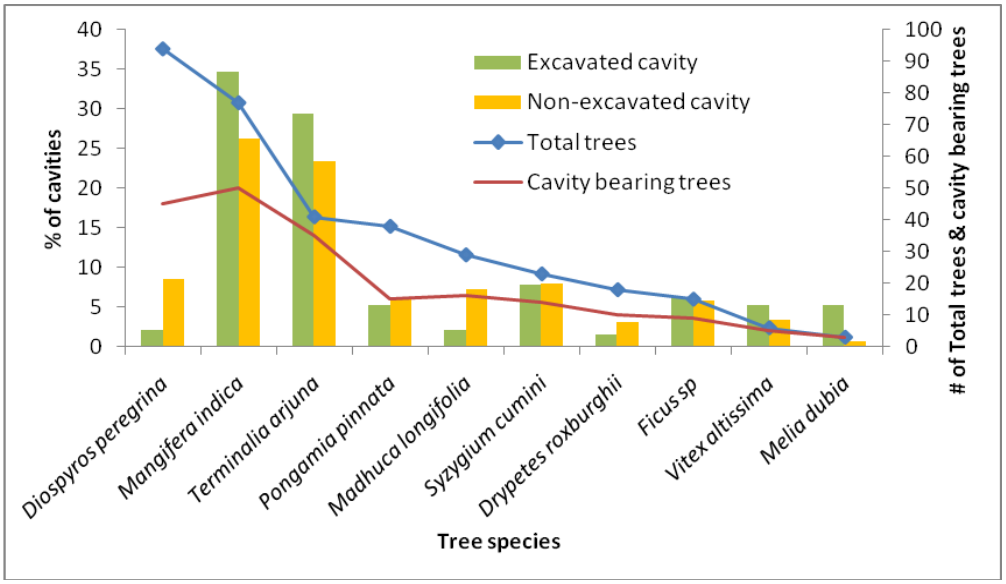


Figure 6.3 Distribution of cavities in 10 cavity-bearing tree species

6.3.3 Nest tree conditions

Nest tree conditions, namely live tree, dead tree, live top, dead top were assessed. A total of 376 nests belonging to 20 cavity nesting bird species were examined. Of the 116 nest cavities excavated by primary cavity nesting birds (barbets and woodpeckers) 89.21% were found in dead branches of live trees/dead trees and 10.79 % were in live branches of live trees.

Secondary cavity nesters used suitable cavities that were excavated by primary cavity nesters and natural decaying cavities for nesting. SCNs mainly used excavated cavities (woodpeckers and barbets) 152 (58.46%) of the 260 nest cavities. Of the 152 nests used by SCNs, 134 (88.74%) were in live trees and 18 (12.68%) in snags. Of the 108 (41.53%) natural cavities of which 86 (79.62%) were in live trees, 19 (17.59%) were in partially dead and 3 (2.77%) in snags. Hornbill used nests found in live trees only.

Nest cavity occurrence and distribution in different condition of trees used by cavity nesters

Excavated and natural cavities distribution showed that across the different tree condition (χ^2 = 3.24, df = 2, p < 0.000) most nest cavities occurred in healthy living trees in relation to the abundance of trees (Figure 6.4). Bird excavated cavities were higher in live trees than the natural cavities (χ^2 = 43.25, df = 1, p < 0.000). In live trees, about 70% of the cavities were excavated while 30% were natural cavities. In large snags, excavated cavities were frequent (χ^2 = 11.30, df = 1, p < 0.001) than non-excavated cavities. The trees accounted 76.92% of excavated cavities and 23.07 % of natural cavities. Excavated cavities (54.05 %) were relatively more frequent in partially dead trees (dead top and broken, more dead branches with live trees) than non-excavated (natural) cavities (45.94%) (χ^2= 3.56, df = 1, p < 0.05). Overall, live trees were highly used as nest sites by cavity nesters than expected compared to dead trees.

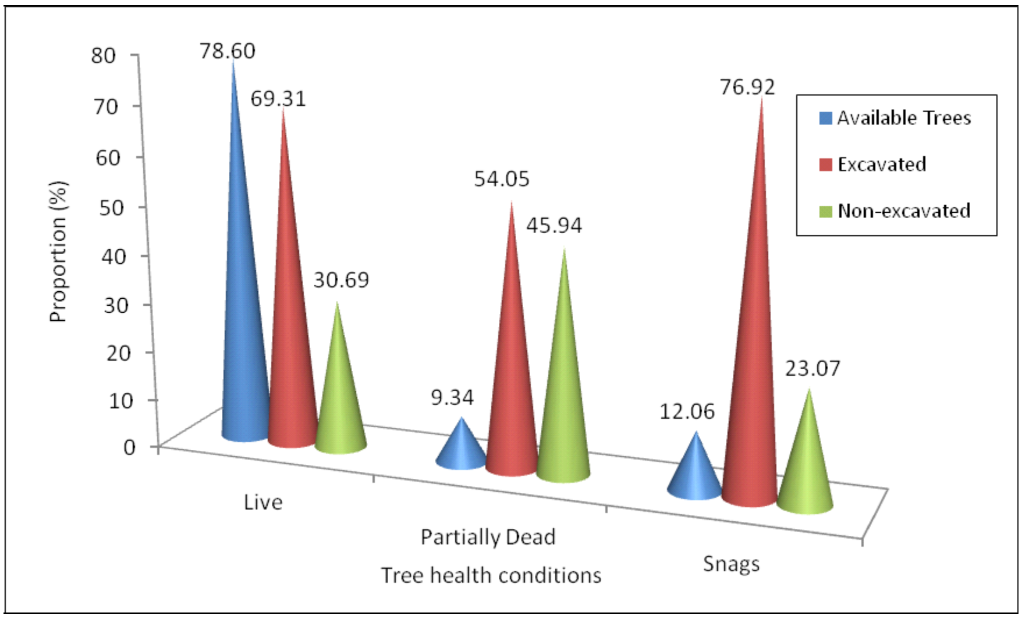


Figure 6.4 Proportion of cavities in different tree condition used (excavated, non-excavated) by cavity nesting birds

6.3.4 Nest tree preference

A total of 54 tree species were utilized for nesting by cavity nesting birds. Of the 54 species, 30 different species were preferred by primary cavity nesters. Cavity nesting birds exhibited preference towards certain tree species. Ivlev's index of selectivity was used to estimate species preference for various nest trees. Nest tree species preferences were assessed and summarized in Table 6.5. Primary cavity nesting birds showed preference to *Mangifera indica* (PI=0.87), followed by *Terminalia arjuna* (PI=0.87) and *Melia dubia* (PI=0.80). These three tree species formed the most preferred species for the cavity nesting birds. Secondary cavity nesters used 48 different tree species for nesting.

A large proportion of nests were found on *Terminalia arjuna* and *Mangifera indica*. Secondary cavity nesting birds showed preference to *Terminalia arjuna* (PI=0.91) followed by *Mangifera indica* (PI=0.88) and *Gyrocarpus asiaticus* (PI=0.83).

Table 6.5 Preference Index of nest tree use by primary and secondary cavity nesting birds

S. No.	Name of the trees	Preference Index (PI)	
		Primary Cavity Nesters	**Secondary Cavity Nesters**
1	*Acacia polyacantha*	0.50	0.33
2	*Ailanthus excelsa*	0.33	0.33
3	*Albizia amara*	-	-0.09
4	*Albizia chinensis*	0.33	-
5	*Albizia lebbeck*	0.50	0.80
6	*Alphonsea sclerocarpa*	-	0.50
7	*Alseodaphne semecarpifolia*	-	0.43
8	*Bombax ceiba*	-0.33	-
9	*Butea parviflora*	-	-0.09
10	*Calophyllum apetalum*	-	0.33
11	*Cassine glauca*	-	-0.09
12	*Ceiba pentandra*	0.75	0.80
13	*Celtis philippensis*	-	0.50
14	*Celtis tetrandra*	-	0.00
15	*Cordia monoica*	-	-0.09
16	*Dalbergia latifolia*	-	-0.11
17	*Delonix regia*	-	0.33
18	*Diospyros peregrina*	-0.16	0.63
19	*Drypetes roxburghii*	-	0.57
20	*Ficus amplissima*	0.50	-0.50

S. No.	Name of the trees	Preference Index (PI)	
		Primary Cavity Nesters	Secondary Cavity Nesters
21	*Ficus benghalensis*	0.71	-0.30
22	*Ficus drupacea*	-.033	-
23	*Ficus microcarpa*	-	0.60
24	*Ficus racemosa*	0.50	0.00
25	*Ficus religiosa*	-0.09	0.50
26	*Ficus virens*	0.33	0.00
27	*Givotia moluccana*	0.33	-0.33
28	*Gmelina arborea*	-	-0.33
29	*Gyrocarpus asiaticus*	0.50	0.83
30	*Hardwickia binata*	-	0.60
31	*Holoptelea integrifolia*	0.01	0.33
32	*Hopea ponga*	-0.10	0.43
33	*Madhuca longifolia*	-0.04	0.76
34	*Mangifera indica*	0.87	0.88
35	*Manilkara hexandra*	-0.33	0.50
36	*Melia dubia*	0.80	0.80
37	*Pleurostylia opposita*	-	-0.04
38	*Pongamia pinnata*	0.34	0.01
39	*Psidium guajava*	-	-0.09
40	*Pterocarpus marsupium*	-	-0.33
41	*Salix tetrasperma*	-	-0.13
42	*Sapindus emarginatus*	-	0.00
43	*Schleichera oleosa*	-	-0.11
44	*Sterculia guttata*	-	0.00

S. No.	Name of the trees	Preference Index (PI)	
		Primary Cavity Nesters	Secondary Cavity Nesters
45	*Streospermum personatum*	0.67	0.75
46	*Strychnos nux-vomica*	0.45	0.72
47	*Strychnos potatorum*	-	0.00
48	*Sweitenia macrophylla*	-0.04	0.00
49	*Syzygium cuminii*	0.44	0.81
50	*Tamarindus indica*	0.33	0.67
51	*Terminalia arjuna*	0.86	0.91
52	*Terminalia bellirica*	-	0.33
53	*Terminalia catapa*	0.00	-
54	*Vitex altissima*	-0.09	0.50

6.3.5. Tree characteristics of nest trees and available trees

Tree height classes of Nest Trees and Available Trees

Mean height of nest trees was 19.70 ± 5.04$_{SD}$ m (range 10.8-30.6 m; n=113) whereas mean height of available trees 17.79 ±5.46$_{SD}$ m (range 5.8-36.2 m; n=552) of primary cavity nesting birds. The PCNs nest tree height was significantly taller than the available trees height. (t = 3.43, df = 663, P < 0.001; n=665). Higher proportions of nest trees (34.48 %) were in 16-20 m tree height category while less than 2% nest trees were in <10 m of tree height. Comparison of use and availability, with all bird species of PCNs pooled, indicate that trees below the 16-20 m height category were used less in proportion to their availability (Figure 6.5). The tree height category >20 m was strongly preferred by PCNs for cavity excavation.

Mean height of nest trees of secondary cavity nesting birds was 19.18 ± 6.26$_{SD}$ m (range 7.2 – 33.4 m; n=223) whereas mean height of available trees was 17.79 ±5.46$_{SD}$ m (range 5.8 – 36.2 m; n=552). The SCNs nest tree heights were significantly (t = 3.08, df = 773, P = 0.002; n=775) higher than available trees height. Higher proportions of nest trees (33.46 %) were in 16-20 m tree height class while less than 10 % nest trees were in

<10 m height class (Figure 6.6). The availability and utilization of nest trees of all secondary cavity nesting birds were pooled for comparison. It indicated that trees below the 16-20 m height class was used less in proportion to their availability (Figure 6.5). Above 20 m tree height class was strongly preferred by SCNs.

Figure 6.5 Percentages of trees (by height classes) comparing PCN nest trees with available trees

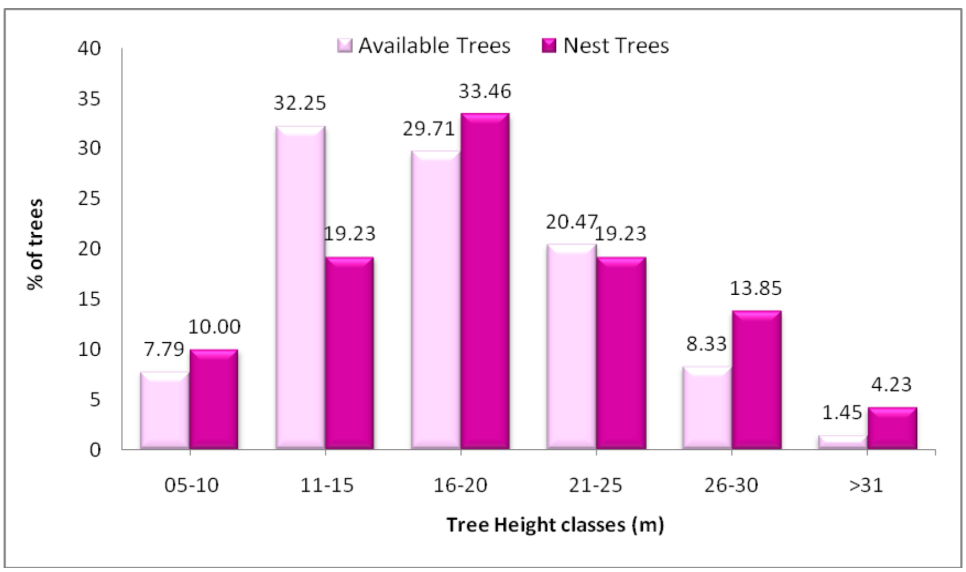


Figure 6.6 Percentages of trees (by height classes) comparing SCN nest trees with available trees

Tree girth size classes of Nest Trees and Available Trees

Mean girth at breast height of nest trees was 283.75 ±126.21$_{SD}$ cm (range 146 - 625 cm; n=113) whereas mean girth at breast height of available trees 127.37 ±111.39$_{SD}$ cm (range 35-701 cm; n=552) of primary cavity nesting birds. The PCNs nest tree girth size was significantly greater than available trees girth size (t = 13.56, df = 663, p < 0.000; n=665). Higher proportions of nest trees (40.52 %) were in 201-300 cm tree girth category while less than 1 % nest trees were in <100 cm (Figure 6.7).

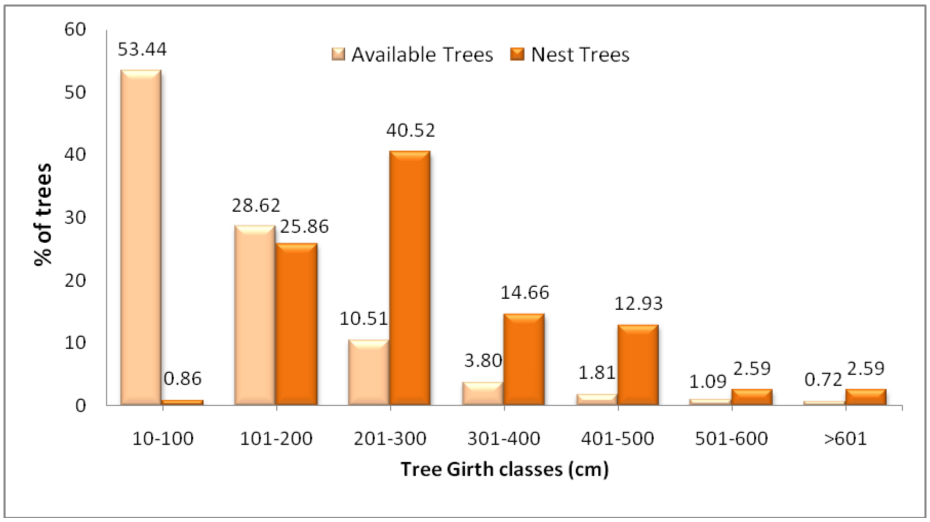


Figure 6.7 Percentages of trees (by girth classes) comparing PCN nest trees with available trees

Mean girth at breast height of nest trees of secondary cavity nesters was 289.98 cm±141.52$_{SD}$ cm (range 80 - 640 cm; n=223) whereas mean girth at breast height of available trees worked out to 127.37 cm±111.39$_{SD}$ cm (range 35-701 cm; n=552). The SCNs nest tree girth size was significantly (t =16.96, df = 773, p < 0.000; n=775) greater than the available trees. Higher proportions of nest trees (31.92 %) were 201-300 cm tree girth class, while less than 2.3 % of nest trees were in <100 cm class. This girth class was represented by higher proportion of nest trees (31.92 %) compared to available trees (Figure 6.8). Larger girth classes were highly preferred by birds for nesting.

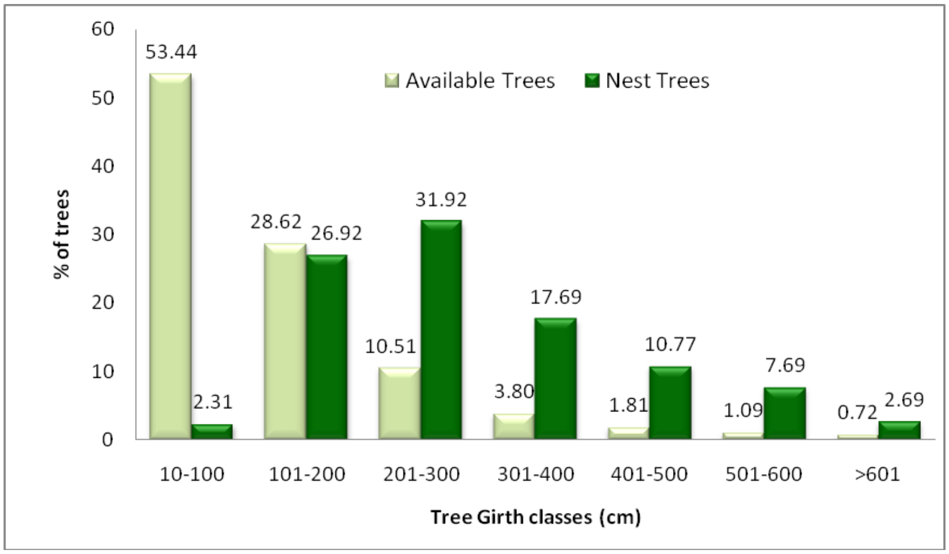


Figure 6.8 Percentages of trees (by girth classes) comparing SCN nest trees with available trees

6.3.6 Characteristics of Nest Trees (NT) and Neighbour Trees (NBT) of cavity nesting birds

A total of 376 nest cavities were located in the study site. Of the 376 cavities, 116 nest cavities in 113 different trees were excavated by PCNs. A total of 260 nest cavities of SCNs were found in 223 trees.

Height of Nest Trees (NT) and Neighbour Trees (NBT) of cavity nesting birds

The PCNs nest trees have 305 neighbour trees and SCNs nest trees 502 neighbour trees. Primary cavity nesting birds' mean values of nest tree height was 19.71 ± 4.99_{SD} m (range 10.8 – 30.6 m) whereas neighbour tree height was 10.84 ± 4.31_{SD} m (range 4.2 – 22.8 m). Mean values of height of nest tree and neighbour trees are given in table (Table 6.6 & Figure 6.9). The PCNs of nest tree height was significantly higher than the height of neighbour trees for the Greater Golden-backed Woodpecker (t = 5.73, df = 32, p < 0.000; n=34), Brown-capped Pygmy Woodpecker (t = 7.61, df = 19, p < 0.000; n=21), White-naped Woodpecker (t = 8.12, df = 15, p < 0.000; n=17), Brown-headed Barbet (t = 7.54, df = 122, p < 0.000; n=124), Coppersmith Barbet (t = 5.76, df = 53, p < 0.000; n=55) and White-cheeked Barbet (t = 12.38, df = 168, p < 0.000; n=170). These bird species preferred tall trees to prevent the predators.

Secondary cavity nesting birds' mean values of nest tree height was 19.18 ± 6.26_{SD} m (range 7.2 – 33.4 m; n=215) whereas neighbour tree height was 11.28 ± 5.62_{SD} m (range 4.5 – 33.5 m; n= 502). Mean height values of nest trees and neighbour trees are given in Table 6.7 and Figure 6.10. The SCNs nest tree height was significantly higher than the height of neighbour trees for Common Myna (t =7.02, df = 178, p < 0.000; n=180), Jungle Myna (t = 4.93, df = 121, p < 0.000; n=123), Malabar Parakeet (t = 6.18, df = 57, p < 0.000; n=59), Rose-ringed Parakeet (t = 4.70, df = 21, p < 0.000; n=23), Indian Roller (t = 1.92, df = 15, p < 0.07; n=17), Jungle Owlet (t = 4.34, df = 19, p < 0.000; n=21), Malabar Pied Hornbill (t = 8.99, df = 22, p < 0.000; n=24), Common Hoopoe (t = 5.81, df = 33, p < 0.000; n=35), Great Tit (t = 4.73, df = 20, p < 0.000; n=22), Oriental Magpie Robin (t = 5.02, df = 57, p < 0.000; n=59), Tickell's Blue-flycatcher (t = 7.64, df = 105, p < 0.000; n=107) and White-rumped Shama (t = 3.20, df = 20, p < 0.004; n=22). These bird species preferred tall trees to prevent the predators.

Table 6.6 Mean height values of nest trees (NT) and neighbour trees (NBT) of primary cavity nesting birds

Name of the birds	**Nest tree height (m)**		**Neighbour tree height (m)**	
	Mean±SD	Range	Mean±SD	Range
White-naped Woodpecker	24.92±2.7	22.3 – 28.6	12.05±2.94	7.8 – 17.8
Greater Golden-backed Woodpecker	23±4.36	18.6 – 31.2	11.88±5.88	5.8 – 24.2
Brown-capped Pygmy Woodpecker	21.26±4.12	14.2 – 24.5	9.84±2.51	6.8 – 14.8
Brown-headed Barbet	18.79±5.65	10.8 – 30.2	11.58±4.27	5.2 – 21.4
Coppersmith Barbet	18.51±4.82	14.5 – 26.4	9.87±4.99	4.2 – 22.8
White-cheeked Barbet	19.17±4.44	14.8 – 27.4	10.43±3.97	5.6 – 17.8

Table 6.7 Mean height values of nest trees (NT) and neighbour trees (NBT) of secondary cavity nesting birds

Name of the birds	**Nest tree height (m)**		**Neighbour tree height (m)**	
	Mean±SD	Range	Mean±SD	Range
Common Myna	19.62±5.98	7.2 – 30.4	12.62±6.92	4.7 – 32.5
Jungle Myna	19.66±5.27	11.8 – 29.4	12.79±7.5	4.5 – 33.5
Common Hoopoe	24.65±8.93	12.4 -35.2	10.95±4.5	4.8 – 14.5
Indian Roller	16.15±10.14	8.6 – 33.4	9.29±4.62	3.4 – 17.6
Great Tit	21.43±6.95	10.8 – 30	9.79±3.85	3.2 – 16.2
Great Hornbill	23.73±4.21	21.3 – 28.6	7.58±1.5	5.4 – 10.8
Malabar Pied Hornbill	24.65±6.44	18.4 – 34.8	9.27±2.92	5.8 – 13.4
Indian Scops Owl	13.68±4.15	8.6 – 18.2	12.98±6	5.7 – 17.3
Jungle Owlet	18.61±3.84	13.2 – 23.4	12.14±2.76	7.8 – 17.6
Malabar Parakeet	19.16±2.92	13.8 – 29.4	10.66±4.45	4.8 – 26.4
Rose-ringed Parakeet	20.7±4.55	12.4 – 30.4	10.88±4.29	4.8 – 17.4
Tickell’s Blue-flycatcher	16.51±4.73	9.2 – 26.4	10.28±3.23	7 – 17.6
White-rumped Shama	15.86±5.51	9.6 – 25.4	10.34±3.48	4.8 – 16.7
Oriental Magpie Robin	27.4±7.63	9 – 31.4	10.31±5.34	5.2 – 27.4

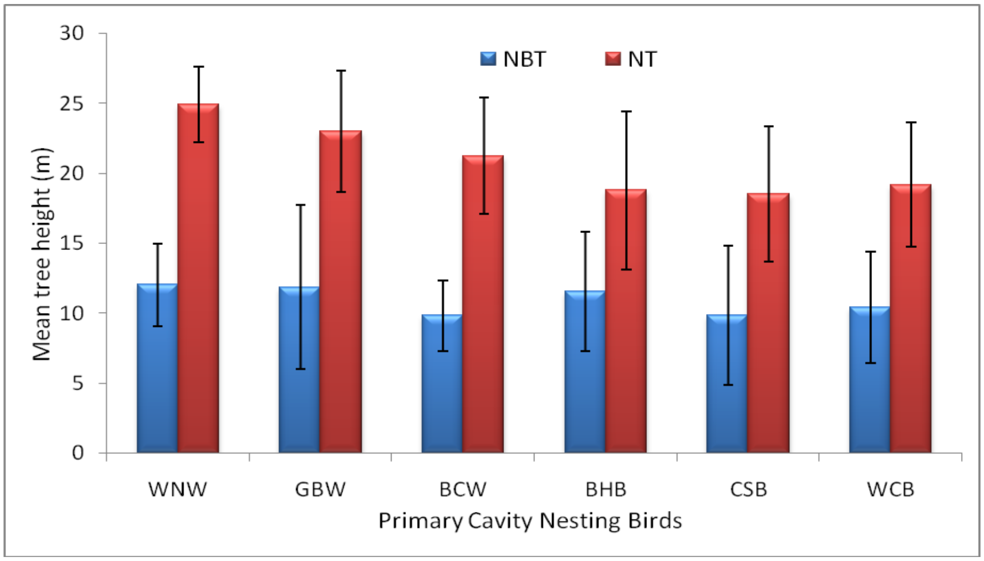


Figure 6.9 Mean height of nest trees (NT) and neighbour trees (NBT) of primary cavity nesters

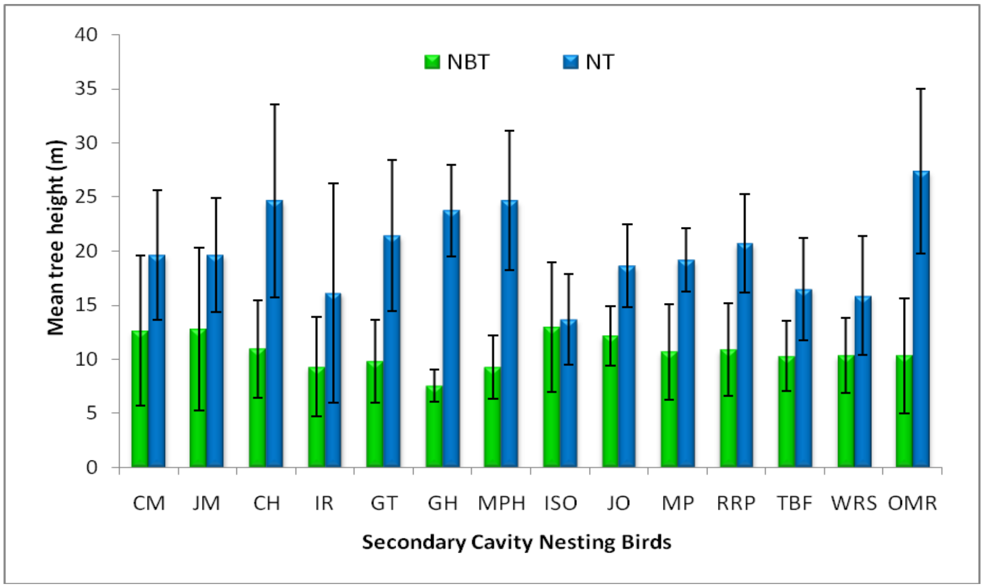


Figure 6.10 Mean height of nest trees (NT) and neighbour trees (NBT) of secondary cavity nesters

Girth at breast height of Nest Trees (NT) and Neighbour Trees (NBT) of cavity nesting birds

Primary cavity nesting birds' mean values of nest tree girth size was 283.75 ± 126.21_{SD} cm (range 146 – 625 cm) while neighbour tree girth size was 119.27 ± 67.94_{SD} cm (range 21 – 342 cm). Mean values of tree girth sizes of nest tree and neighbour trees are given in Table 6.8 and Figure 6.11. Mean girth of nest trees was significantly higher than the girth of neighbour trees surrounding the nest trees of Greater Golden-backed Woodpecker (t = 3.48, df = 32, p < 0.001; n=34), Brown- capped Pygmy Woodpecker (t = 9.12, df = 19, p < 0.000; n=21), White-naped Woodpecker (t = 4.36, df = 15, p < 0.001; n=17), Brown-headed Barbet (t = 9.12, df = 122, p < 0.000; n=124), Coppersmith Barbet (t = 7.71, df = 53, p < 0.000; n=55) and White-cheeked Barbet (t = 10.50, df = 168, p < 0.000; n=170).

Secondary cavity nesting birds nest tree mean girth size was 289.98 ± 141.52 cm (range 80 – 640 cm) whereas neighbour tree mean girth size was 132.26 ± 84.08 cm (range 40 – 472 cm). Mean girth values of nest trees and neighbour trees are given in Table 6.9 and Figure 6.12.

The mean girth of nest trees was significantly higher than the mean girth of neighbour trees for Common Myna (t = 7.54, df = 178, p < 0.000; n=180), Jungle Myna (t = 6.07, df = 121, p < 0.000; n=123), Malabar Parakeet (t = 6.07, df = 57, p < 0.000; n=59), Rose-ringed Parakeet (t = 3.29, df = 21, p < 0.003; n=23), Indian Roller (t = 2.57, df = 15, p < 0.07; n=17), Jungle Owlet (t = 2.08, df = 19, p < 0.05; n=21), Great Hornbill (t =-11.69, df = 10, p < 0.000; n=12), Malabar Pied Hornbill (t = 13.17, df = 22, p < 0.000; n=24), Common Hoopoe (t = 6.51, df = 33, p < 0.000; n=35), Great Tit (t = 7.80, df = 20, p < 0.000; n=22), Oriental Magpie Robin (t = 5.25, df = 57, p < 0.000; n=59), Tickell's Blue-flycatcher (t = 8.78, df = 105, p < 0.000; n=107) and White-rumped Shama (t = 5.01, df = 20, p < 0.004; n=22).

Table 6.8 Mean girth values of nest trees (NT) and neighbour trees (NBT) of primary cavity nesting birds

Name of the birds	**Nest tree girth (cm)**		**Neighbour tree girth (cm)**	
	Mean±SD	Range	Mean±SD	Range
White-naped Woodpecker	299.2±109.13	194 – 484	148.91±37.17	86 – 212
Greater Golden-backed Woodpecker	241.75±60.3	166 – 347	137.59±59.0	59 – 327
Brown-capped Pygmy Woodpecker	256.6±40.86	212 – 298	111.25±27.91	84 – 172
Brown-headed Barbet	302.28±137.8	148 – 579	131.43±69.0	47 – 342
Coppersmith Barbet	314.42±141.5	142 – 575	97.57±67.22	21 – 292
White-cheeked Barbet	273±132.8	162 – 625	112.11±65.77	27 – 342

Table 6.9 Girth at breast height of nest trees (NT) and neighbour trees (NBT) of secondary cavity nesting birds

Name of the birds	**Nest tree (GBH) (cm)**		**Neighbour tree (GBH) (cm)**	
	Mean±SD	Range	Mean±SD	Range
Common Myna	286.69±139.63	102 – 576	145.84±106.58	31 – 472
Jungle Myna	293.05±136.84	71 – 640	151.45±107.62	28 – 423
Common Hoopoe	336.12±131.27	146 – 547	115.62±65.92	36 – 296
Indian Roller	249.28±91.93	154 – 428	140.7±81.24	24 – 287
Great Tit	432.14±154.86	220 – 640	102.4±43.47	21 – 164
Great Hornbill	460.66±70.43	420 – 542	94.33±38.98	44 – 150
Malabar Pied Hornbill	451.66±93.46	320 – 542	119.38±33.69	68 – 192
Indian Scops Owl	228.16±154.04	80 – 482	135.13±89.48	65 – 312
Jungle Owlet	221.5±107.74	109 – 376	146.93±57.7	80 – 286
Malabar Parakeet	248.66±81.53	134 – 475	110.63±79.91	27 – 432
Rose-ringed Parakeet	314.71±155.82	165 – 171	147.06±88.85	32 – 278
Tickell’s Blue-flycatcher	239.77±97.57	97 – 485	122.75±40.29	68 – 216
White-rumped Shama	251.5±54.48	184 – 324	117.56±56.46	32 – 248
Oriental Magpie Robin	308.96±154.2	72 – 942	117.14±62.66	42 – 321

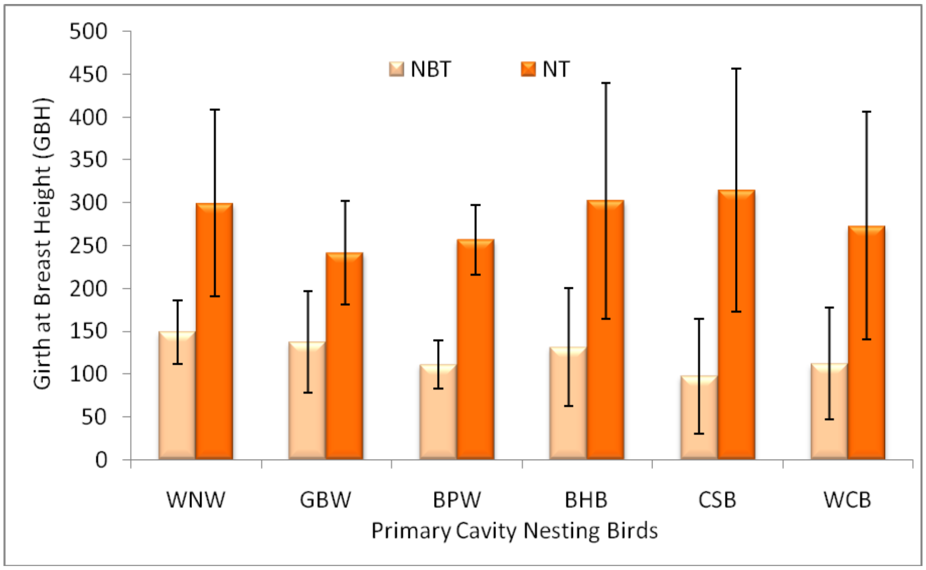


Figure 6.11 Mean girth values of nest trees (NT) and neighbour trees (NBT) of primary cavity nesting birds

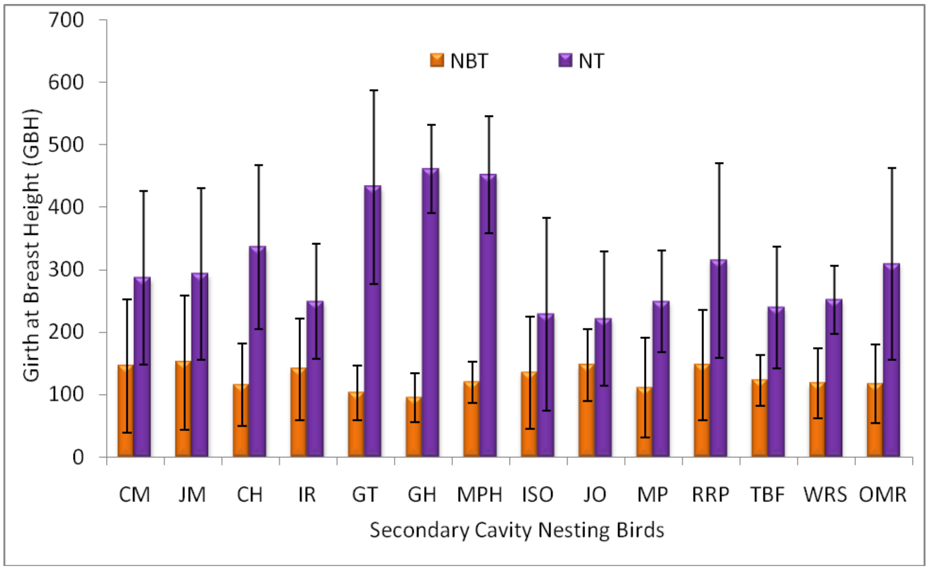


Figure 6.12 Mean girth values of nest trees (NT) and neighbour trees (NBT) of secondary cavity nesting birds

6.3.7 Nest cavities in different height categories used by cavity nesting birds

The PCN's excavated nest cavity above 10 m of tree height and higher proportion of nests was found in 16-20 m and 21-25 m class. These height categories were chosen by barbets. No nests were found in low categories <10 m of tree height (Figure 6.13). The secondary cavity nesters used either the cavities excavated by primary cavities or naturally formed cavities. These nest cavities were located on higher position of the tall trees, probably to reduce the risk of predators. Higher proportion of the nest cavities (41.54%) were found in 16-20 m and 21-30 m height classes. These tree height classes were used by Mynas, Parakeets, Hornbills, Common Hoopoe, Oriental Magpie Robin etc. There were no nests in the lower height class (<5 m) (Figure 6.14).

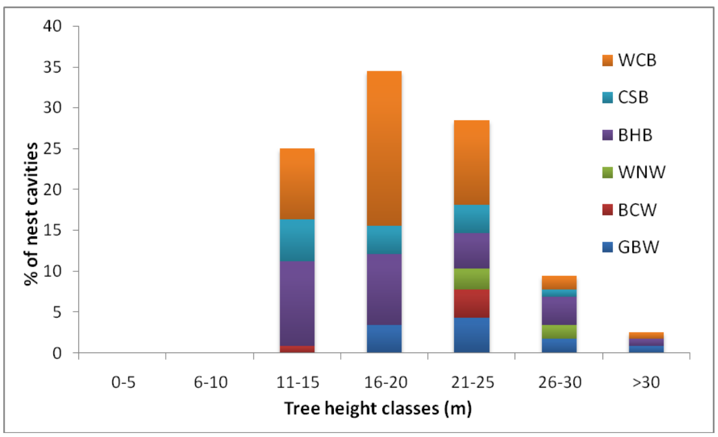


Figure 6.13 Proportion of nest cavities across height classes of nest trees used by different primary cavity nesters

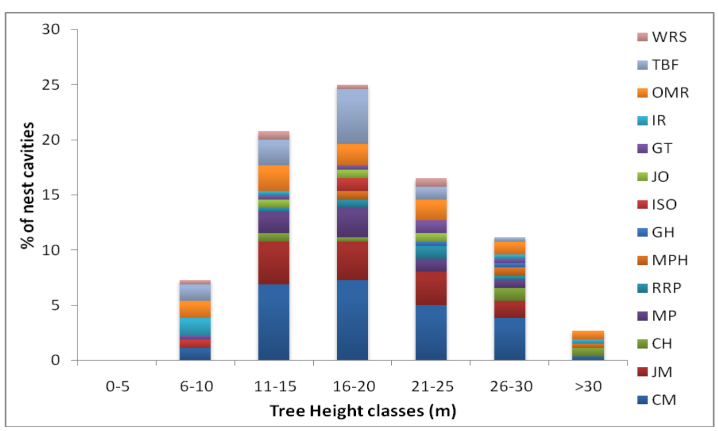


Figure 6.14 Proportion of nest cavities across height classes of nest trees used by different secondary cavity nesters

6.3.8 Nest cavity distribution across nest tree girth classes of cavity nesting birds

The PCN's mainly excavated nest cavities above 100 cm girth size and higher proportion of nests was found in 201-300 cm girth class. Less than 1% of nest cavities were found in <100 m of tree girth size (Figure 6.15). Maximum proportion of the secondary cavity nesting birds nest cavities was found in 101-200 cm and 201-300 cm of girth classes of nest trees (26.92 % and 31.92 %). These girth classes were highly used by mynas, parakeets, hornbills and owls. Less than 2% of nest cavities were in <100 m of tree girth size (Figure 6.16). Larger girth sizes of trees were mostly used by secondary cavity nesting birds.

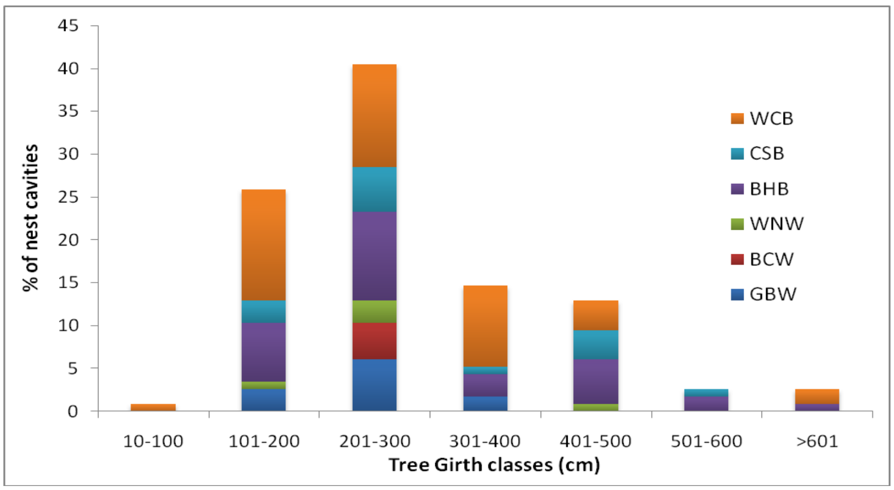


Figure 6.15 Proportion of nest cavities across girth classes of nest trees used by different primary cavity nesters

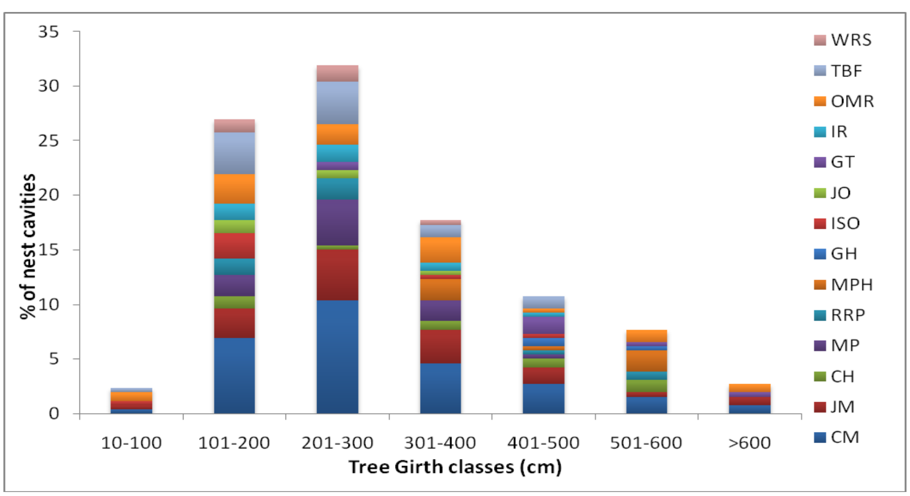


Figure 6.16 Proportion of nest cavities across girth classes of nest trees used by different secondary cavity nesters

6.4 Discussion

6.4.1 Nest tree features and tree selection

Woodpeckers that constituted the major primary cavity nesters of the study area which choose tall trees with huge girth for nest excavation. The possible advantages of nesting in huge, tall trees are avoidance of predators and competitors (Christman and Dhondt, 1997; Wesolowski, 2002; Kosinski and Winiecki, 2004; Pasinelli, 2007). In Iberian Peninsula, Camprodon *et al.,* (2008) reported that woodpeckers created nest cavities on trunk or main branches and those cavity locations were on higher position of trees. Several other studies reported that woodpeckers chose tall and large trees (Joy, 2000; Santharam, 2006; Fauvel *et al.*, 2001; Kosiński *et al.,* 2006; Shiina *et al.,* 2013; Cicovic *et al.,* 2014). When taller trees are selected and nest heights also higher, it is very hard to be detected and reached by the predators (Miller and Miller, 1980; Santharam, 2006).

Barbets constituted second important primary cavity nesters (weak excavators) of the study area, they mainly selected tall and huge-girthed trees. Similar findings were reported for Taiwan Barbet in a Broadleaved forest in Taiwan (Koh and Lu, 2009); Coppersmith Barbet in a garden site at Bangalore, India (Vergese and Govindakrishnan, 1975); and three species of *Megalaima* in the Periyar Tiger Reserve, Western Ghats, India (Yahya, 1988).

As observed in the primary cavity nesters, the secondary cavity nesting birds also mainly choose tall and huge trees for nesting. Similar findings were reported by Blakely *et al.* (2008) in Southern temperate mixed-beech forest, New Zealand. In China, Zheng *et al.* (2009) reported that large tree species of *Castanopsis wattii*, *Lithocarpus xylocarpus* and *L. hancei* had a higher proportion of cavity bearing tree stems than small tree species in the subtropical montane evergreen broad-leaved forest. Larger trees, which are usually older are more often in a decaying stage, at least partly dead. With increasing tree girth size, nest cavities can usually be excavated in higher tree positions (Wiesner, 2001). Many other studies *viz.* (Whitford and Williams, 2002; Bonar, 2000; Hartwig *et al*., 2004; Kosiński *et al.,* 2006; Kosinski and Kempa, 2007; Matsuoka, 2008; Kozma, 2010) have reported the use of taller trees by secondary cavity nesting birds.

Another important cavity nester of the present study, the hornbills choose live trees of tall and large girth size. Malabar Pied and Great Hornbill used natural cavities in live trees which are tall and large. Several other studies reported similar results *viz*., Poonswad (1995) in Khao Yai National Park, Thailand; Mudappa and Kannan (1997) in the tropical wet evergreen forest of Western Ghats; Maheswaran and Balasubramanian (2003) in a semi-evergreen forest, Western Ghats, India; Datta and Rawat (2004) in Pakke Tiger Reserve, Arunachal Pradesh; James and Kannan (2009) in the Indira Gandhi Wildlife Sanctuary, Southern Western Ghats; Santhoshkumar and Balasubramanian (2010) in the dry deciduous forest, Eastern Ghats, southern India.

Mynas mainly depend on bird excavated cavities though a small proportion of nests are placed in natural cavities. Cavities in tall and huge trees such as *Terminalia arjuna* and *Mangifera indica* were used by mynas. In Thailand, tall trees with large diameter were preferred by hill mynas (Archawarnanon, 2006). Kaur and Khera (2014) observed that mynas prefer large trees of Gulmohar (*Delonix regia*) and Silver Oak (*Grevillea robusta*) in Punjab Agricultural University, Ludhiana, India.

Parakeets generally nest in live trees which are huge and tall. Rose-ringed Parakeet in central Punjab, Pakistan (Khan, 1999); Eclectus Parrot in the rain forests of Australia (Heinsohn and Legge, 2003); Malabar Parakeet in Southern Western Ghats, India (Gokula and Venkatraman, 2003); Tucuman Parrot in Argentina (Rivera *et al*., 2011) and Socorro Green Parakeet in Isla Socorro, Baja California (Rodriguz-Estrella *et al.*, 1995) used tall trees.

Grey Tit mostly used cavities excavated by barbets. Those nest cavities were often located in tall trees of *Terminalia arjuna* whose cavity entrance was smaller. In Poland, Great Tits were reported to place nests on tall and large girth size of trees in the riverine stands (Maziarz *et al.*, 2015) and in primeval temperate forest (Wesolowski, 2002; Morozov, 2009; Wesolowski and Rowinski, 2012; Maziarz and Wesolowski, 2014).

Majority of the cavity nesting birds prefer huge, tall trees because, those trees are likely to have structural stability. These trees may also contain more places to excavate. Construction of cavities in large and tall trees offers protection from predators.

Mature and large trees are expected to have more suitable cavities (excavated or non-excavated) than younger and smaller trees (Newton, 1994; Gibbons and Lindenmayer, 2002; Blakely *et al.*, 2008; Koch *et al.*, 2008b). In the present study, higher proportion of suitable deep cavities such as bird excavated or natural cavities were found in large, mature trees than younger trees. These cavities constitute most important resource for secondary cavity nesting birds.

6.4.2 Nest tree condition of cavity nesting birds

Woodpeckers are the strongest excavators (Martin and Eadie, 1999), which have morphological adaptations in their sharp strong bills, skulls, musculature neck and ribs that allow them to chisel out cavities in live substrates of hard wood or live trees (Spring, 1965; Kirby, 1980; Aulén and Lundberg, 1991; Martin and Eadie, 1999; Gorman, 2004). Large woodpeckers (Greater Golden-backed woodpecker and White-naped woodpecker) are grouped as strong excavators and they select live and healthy trees to make their nest cavities. The sharp and strong bill appeared to be more efficient for excavating nesting cavities in hard, living trees (Aulén and Lundberg 1991; Gorman, 2004). Woodpecker species in the study area, *Chrysocolaptes guttacristatus* and *Chrysocolaptes festivus* are most often built their nest cavity in living trees, which were much more abundant than dead trees and their preferred hard wood live trees that have thicker wall cavities for nesting (Kirby, 1980). The wood hardness may be a good defence mechanism against nest predation (Kilham, 1971; Albano, 1992; Martin *et al.*, 2004).

In New Mexico, Arsenault (2004) reported that Acron woodpeckers (*Melanerpes formicivorus*) excavated most nests in live trees. Majority of the nest cavities of Great (*Dendrocoptes major*) and Middle-spotted woodpecker (*Dendrocoptes medius*) were excavated in live trees in the riverine forests of central Poland (Kosinski *et al.*, 2006; Kosinski and Kempa, 2007; Matsuoka, 2008) and in the deciduous and coniferous forest of North-Eastern Swiss (Pasinelli, 2007). In Japan, Matsuoka (2008) reported that Great-spotted woodpecker *Dendrocopos major* most excavated cavities on live trees in south eastern Sapporo. In Mongolia, Bai *et al.* (2003) found that Great-spotted woodpecker (*Dendrocopos major*) excavated mainly used live trees in a Boreal forest. The finding of the present study is in correspondence with the results reported in above-mentioned studies. However, Santharam (1995) observed that Woodpeckers relied mainly on dead wood in the tropical moist forests of Western Ghats India. He stated that they mainly excavate nest cavities in tree stems, usually in snags and unhealthy trees.

Small woodpeckers which are weak excavators prefer dead substrate in live trees rather than live substrate. Small woodpeckers such as White-bellied woodpecker (Santharam, 2003); Lesser-spotted woodpecker (Smith, 2007); Pileated woodpecker (Hartwig *et al.,* 2004; Raley and Aubry, 2006); Middle-spotted woodpecker (Kosinski *et al.,* 2006; Pasinelli, 2007); Red-headed woodpecker (Vierling and Lentile, 2006; King *et al.,* 2007; Hudson and Bollinger, 2013; Berl *et al.,* 2014); Japanese Pygmy Woodpecker (Shiina *et al.,* 2013) mainly nested in snags or dead branches of live trees. Excavation of cavities in dead branches of live trees by the Brown-capped Pygmy Woodpecker in the present study area is in correspondence with other studies quoted above.

Barbets (*Megalaima* spp) prefer dead trees (snags) for nesting (Yahya, 1988; Kler, 2003; Koh and Lu, 2009). The present study observed that *Psilopogon* spp. (*Psilopogon haemacephala*, *Psilopogon viridis* and *Psilopogon zeylanica*) excavated cavities only in dead trees or dead branches in live trees. This finding is similar to that of other studies on Coppersmith Barbet (Vergese and Govindakrishnan, 1975) in Bangalore, Karnataka; *Megalaima* species (Yahya, 1988) in Periyar Tiger Reserve, Western Ghats, Kerala; White-cheeked Barbet (Jayson and Mathew, 2002) mixed deciduous forest, Western Ghats; Coppersmith Barbet (Shorts and Horne, 2002) in Singapore; Taiwan Barbet (Kou and Lu, 2009) in the Taipei Botanical Garden in Taiwan. Barbets favour dead trees or dead branches of live trees for easy excavation. Compared to woodpeckers, barbets do not have sharp bill and hence appear to favour dead tree trunks or dead branches for nest excavation as it is easier to excavate cavities in dead branch (Ali and Ripley, 1978; Yahya, 1988).

Secondary cavity nesters such as Hornbills, Mynas, Parakeets, Hoopoe, Indian Roller, Oriental magpie Robin, White-rumped Shama utilize both live and dead trees for nesting. In the present study, majority of the nest cavities of secondary cavity nesting birds were found on live trees. This is in correspondence with the findings reported in the riparian forest of North-Western Great Basin, north America (Dobkin *et al.* (1995), in the mixed forests of Western Canada (Aitken and Martin, 2007), in mixed coniferous forest and deciduous forest of British Columbia (Martin *et al.,* 2004) in a Boreal forest of Mongolia (Bai *et al.,* 2003). In contrast, secondary cavity nesting birds mainly used dead trees in tropical moist forests of USA (Gibbs *et al.,* 1993) and in the Coniferous forests of British Columbia (Steeger and Dulisse, 2002). In India, hornbills were reported to use mainly live trees (Maheswaran and Balasubramnaian, 2003; Santhoshkumar and Balasubramanian, 2010; Datta and Rawat, 2004).

Parakeet nests were mostly found in live trees which were excavated by primary cavity nesters. Gokula and Venkatraman (2003) reported that parakeet nests were found in live trees in the mixed deciduous forest of Southern Western Ghats, India. Similar findings were reported for Blue-fronted parrot and Tucuman Parrot respectively in Argentina (Rivera *et al.,* 2011; Berkunsky and Reboreda (2009).

Nesting in live trees are known to have several advantages. Live trees have higher structural stability and are less prone to tree fall and nest cavities located on living part of large trees suffer less predation (Albano, 1992; Christman and Dhondt, 1997; Wiebe, 2001; Wesolowski, 2002; Remm *et al.,* 2006). Larger predators that could not reach the nest through cavity entrance usually destroy the cavity wall, which is less likely to happen when the cavity is surrounded by solid living wood. Therefore, security could be an important advantage of nesting in a live tree. According to (Hooge *et al.,* 1999; Wiebe, 2001; Remm *et al.,* 2006) microclimate inside cavities in living substrates has also been suggested to be more stable.

7 NEST TREE AND NEST CAVITY CHARACTERISTICS OF CAVITY NESTING BIRDS IN THE RIVERINE

7.1 Introduction

Tree cavities are an essential resource for wildlife species that require cavities for breeding, roosting and sheltering (Steeger and Dulisse, 2002; Cockle *et al.,* 2011a) and protection from unfavourable weather and predators (Newton, 1994; Nowak, 1999; Kunz and Lumseden, 2003). Generally, the formation of cavities in forest trees is attributed to fungal decay, insect attack, fire, wind or made by primary cavity nesters such as woodpeckers, barbets (Yahya, 1988; Hooge *et al.,* 1999; Jackson and Jackson, 2004; Adkins, 2006; Ojeda *et al*., 2007; Pasinelli, 2007). Among the cavity nesting birds, primary cavity nesters (PCN) excavate cavities of their own, while the secondary cavity nesters (SCN) rely on cavities excavated by excavators (primary cavity nesters) (Steeger and Machmer, 1995; Martin *et al.,* 2004) or utilize the naturally formed cavities (McClelland *et al*., 1979; Newton 1994; Martin and Eadie, 1999). The primary cavity nesters play a key role in forest communities. The unique ability of primary cavity nesters to excavate cavities in large trees for nesting and roosting creates habitat for many other species of cavity nesting birds (Adkins Giese and Cuthbert, 2005). These excavators choose certain tree characters for cavity excavation such as trees size, tree health condition, nest substrate condition (live and dead) (Yamauchi *et al.,* 1997; Schepps *et al.,* 1999; Kosinski and Winiecki, 2004). The tree must be large enough to support a nest, but selected tree size depends on excavator's body size (Conner *et al.,* 1975). Primary cavity-nesting birds (woodpeckers and barbets) mainly use decayed trees to excavate their nest holes. Woodpeckers are more dependent on dead trees, which have a soft wood substrate facilitating cavity excavation (Schepps *et al.,* 1999; Kosinski and Winiecki, 2004). PCNs rarely excavate their cavities in live trees because of the hard structural properties of the wood (Mannan *et al.,* 1980, Lundquist and Mariani, 1991) and because most insect wood sources are found in decayed trees compared with the hard wood (Neitro *et al.,* 1985). Nesting in live trees may also have advantages as protection from predators (Arsenault, 2004) and cavities in live trees are warmer (Hooge *et al.*, 1999). Primary and secondary cavity nesting birds might choose cavities high above the ground to avoid terrestrial or scansorial predators and competitors (Nilsson, 1984; Fisher and Wiebe, 2006). Many of the cavity nesting birds favoured riparian habitats where trees are old with the girth of the trunk large enough to allow for the production of cavities within them (Conner *et al.,* 1975; Gorman, 2004; Adkins Giese and Cuthbert, 2005; Kim *et al.,* 2012). Most cavity nesting birds depend heavily on excavated cavities created by primary cavity nesting birds (Aitken *et al.*, 2002; Arsenault, 2004; Bai *et al.*, 2005; Cockle *et al.,* 2011a).

The cavity nesting birds are severely affected by the reduced availability of cavities (Haapanen, 1965; Sandstrom, 1992), competition by other animals and predators (Brightsmith, 2005; White *et al.,* 2006; Wan *et al.,* 2008; Hebda, 2009) and anthropogenic disturbances e.g., forest degradation, logging, tree felling, agricultural activities. As a result, the populations of primary cavity nesting bird species have been decreasing in the forest ecosystem (Mackowski, 1984; Lindenmayer *et al.,* 1991; Mikusinski and Angelstam, 1997; Santharam, 2003; Angelstam, 2004; Koh and Lu, 2009).

Globally, tree and nest cavity characteristics are a critical component of forest ecosystems and are well studied in temperate Europe, North America and Australia (Goldingay, 2009; Remm and Lohmus, 2011). Nothing much is known about nest tree characteristics and occupancy rates in Asia. As for India, only a few researchers have investigated the breeding ecology of cavity nesting bird community. Most of the studies on cavity nesting birds in India focussed on single species *viz.,* Gokula and Venkatraman (2003) on Malabar Parakeet, Sivakumaran and Thiyagesan (2003) on Indian Roller, Maheswaran and Balasubramanian (2003) on Malabar Grey Hornbill, James and Kannan (2009) on Great Hornbill, Asokan *et al.* (2009b) on Indian Roller, Santhoshkumar and Balasubramanian (2010) on Indian Grey Hornbill; Santhanakrishnan *et al*. (2011) on Barn Owl, Bhatt *et al*. (2014) on Oriental Magpie Robin, Nithiyanandam and Asokan (2015) on Indian Roller and Common Myna, Yahya (1988) on barbets, Santharam (2006) on woodpeckers. There are only two studies on the cavity nesting bird communities in India and they are Thiyagesan (1991) in the agricultural landscape, southern India, and Pandey and Mohan (1993) in Tons river Valley, northern India.

7.2 Methodology

7.2.1 Nest Searching

Bird nests were searched in trunks of all trees measuring >50 cm girth at breast height in two study sites namely, Athikadavu and Pillur, along the river bank. Nest trees were located by making repeated walks along river banks. Nest cavities were located by examining from the ground with help of a binocular, and each tree was observed from at least three directions. Trees with cavities were referred as cavity trees. Primary cavity nesters usually excavate fresh nest cavities every breeding season. Their nests were located mainly by inspecting the ground around every nest tree for presence of fresh woodchips and by examining the tree trunks for cavity nester activities (cavity creating, pecking and drilling on trunk or branches). If fresh woodchips were available under a tree, it is confirmed as an active nest tree of a primary cavity nester. Some primary cavity nesters (barbets) typically excavate new cavities each year which cavities are round shape and smooth cavity entrance surface. This type of cavity is easily identified and confirmed as an active nest cavity. Sighting of an adult bird bringing in nesting material and entering the cavity helped in locating nest cavities. Observations of an adult bird repeatedly visiting the same tree, flying out of a tree suddenly, birds clinging to cavity entrances, perching near cavities and entering and exiting actions near cavities helped in confirming the active nests. Adult bird frequently entering a cavity was taken as the evidence of an active nest. A hide out made on the ground near the nest tree helped me to observe the behaviour of the parental birds without frightening or disturbing them. Cavities were considered active nests, if the activities of adult birds indicated nesting (e.g., parent bird carrying food into cavity nest) and young ones calling from nest cavity or if they contained eggs or chicks. In the case of shallow cavities, eggs or chicks can be seen. Active nest cavities were checked for the presence or absence of birds on a regular basis once a week. Nest cavities were also located by observing breeding behaviour, listening for begging chicks and scratching or knocking cavity trees.

After confirming the active nest, the tree was numbered and marked by using paint. For each of the tree that has an active nest cavity, geo-coordinates were noted by using Garmin GPS. A nest tree distribution map was prepared (Figure 7.1) using the geo-coordinates. The tree species on which bird nests are placed were identified and nest tree name and tree characters were recorded.

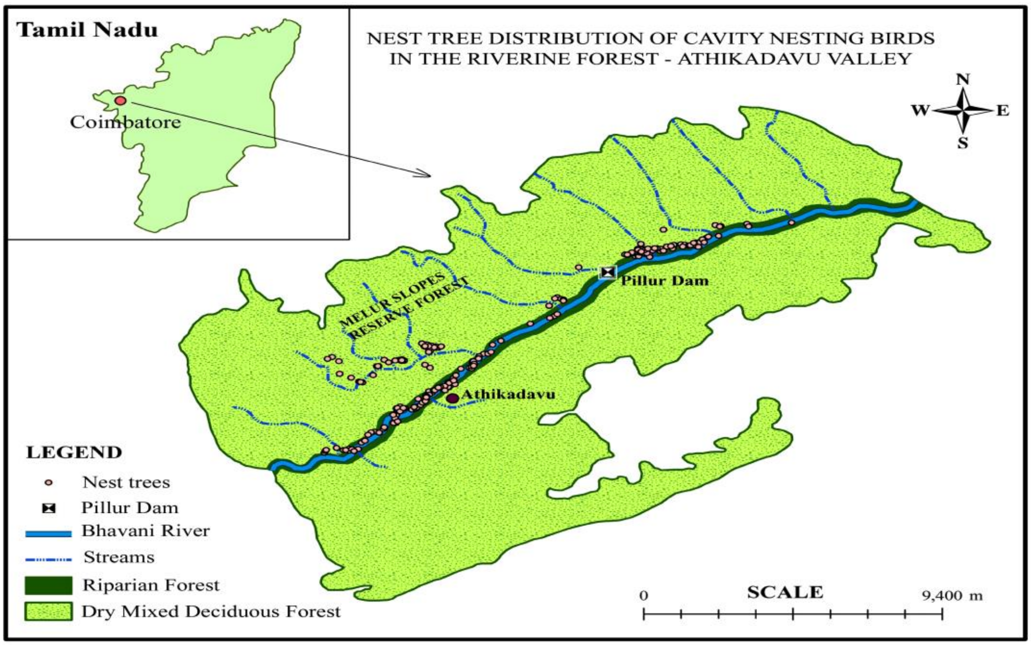


Figure 7.1 Nest tree distribution of cavity nesting bird in Athikadavu Valley

Cavity nesting birds were classified into two groups namely, i) primary cavity nesters (PCNs) and ii) secondary cavity nesters (SCNs). Although 32 species of cavity nesting birds were found in the study area, nest characteristics of 20 bird species alone were studied as the active nests of remaining 12 species (Appendix 3) could not be located by the present author during the study period. I measured three different types of variables describing the characteristics of the stand within a 0.04 ha circular plot centred at each nest. These were 1) nest site variables, 2) nest tree variables, and 3) nest cavity variables.

7.2.2 Nest tree features

The following parameters of nest trees were gathered:

1. Girth at breast height (height at 1.3 m) measured with a measuring tape,
2. Nest tree height (m),
3. Nest height (m),
4. Girth at nest height (cm),
5. Nest tree's 1st branch height (m),
6. Tree canopy height (m),
7. Percent of tree foliage (%),
8. Crown class (low, intermediate, dominant) (%),
9. Crown radius (m),

The tree height, nest cavity height and canopy height were measured with Laser Range Finder (Nikon Forestry Pro). Nest tree surface of tree bark textures were visually identified and were classified into four types namely, i) smooth, ii) rough, iii) segmented and iv) flagged bark. Nest tree health was visually examined and were categorized into three classes *viz* i) 'live' consisting of tree in which all branches had green leaves, ii) 'partially dead' consisting of live trees with some dead branches and iii) 'dead' including trees or snags that were completely dead. Wood condition of nest tree was recorded as hard wood/sapwood. Presences of fungal fruit body on nest trees were also recorded.

7.2.3 Nest site features

Nest site features were recorded within a 0.04 ha circular plot (nest site plot). Feature such as density of neighbour trees (NBTs) with tree condition (live or dead) and density of shrubs. In each circular plot, data on neighbour tree characteristics were gathered: girth at breast height (height at 1.3 m from ground) measured with tape, tree heights measured with Laser Range Finder (Nikon Forestry Pro).

7.2.4 Nest cavity features

Nest features were recorded after the female and chicks had vacated it. A nylon rope of 20 m length was used to obtain measurements of nest cavity. The following data on nest cavities, namely nest cavity height, location of nest cavity (main trunk or branches like as primary, secondary, tertiary and fourth branch), cavity type (excavated/natural), nest substrate condition (live/dead), substrate size (girth at nest height) measured with tailor tap (cm), shape of the nest cavity (round, oval, elongate etc.), cavity orientation using a compass direction of cavity entrance (degrees, measured from centre of nest tree), vertical and horizontal diameter of cavity entrance, cavity circumference and cavity depth were gathered.

7.2.5 Statistical Analysis

Data obtained from the observations were analysed using SPSS for Windows version 20. 2015. I presented descriptive statistical test for nest trees and nest cavity characters (Mean ± SD). The relationship between nest cavity height and nest tree height of primary and secondary cavity nesters were examined by applying Pearson Correlation. Cavity nesters' (PCNs, SCNs) nest tree variables (nest tree height, tree girth at breast height, 1st branch height, nest height and girth at nest height) and nest cavity variables

Data gathering on Nest tree & Nest cavity features

Measuring the tree size & substrate size

Measuring the nest cavity features

were tested by One-Way ANOVA. Mann-Whitney *U* test was applied to test the difference in bird species variables nest tree height, nest height and girth at nest height. Non-parametric chi-square test was applied to compare nest tree health condition (live, partially dead, snag) and substrate condition (live or dead) of cavity nesting birds (PCNs, SCNs). SCNs cavity selection (excavated cavity, natural cavity) was tested by non-parametric Chi-square test. Among the various PCNs (woodpeckers and barbets) nest height and nest substrate sizes were tested by Kruskal-Wallis ANOVA (*H*).

A linear discriminant analysis was performed on all 40 variables (percentages analyzed using an arcsine transformation) using the SPSS (version 20.0) and R (version 3.4.1). The null hypothesis was that nest sites of all species are equal, that is, the mean discriminate scores do not differ between members of any possible pair of species. The maximum number of functions derived in a multi-group discriminant analysis is either one less than the number of groups (in this case, bird species) or equal to the number variables entered in to the analysis, whichever is smaller. The first function derived explains the greatest proportion of the total variance, and each additional function explains successively less. There are two approaches in deciding how many of the possible functions to consider. First, one can test the statistical significance of each function by comparing the additional variance explained by that function to an expected value (Morrison, 1976). Alternatively, one can arbitrarily define a minimum proportion of explained variance and accept only those functions that explain more than that minimum. In this study, I considered only those functions explaining 5% or more of the total variance. This alternative allows more powerful planned comparisons of mean discriminant scores among the groups.

To interpret the biological meaning of each discriminant function. I computed the correlation of each variable with the discriminant score derived for each function (structure matrix). Variables with the highest and significant correlations ($p<0.05$) were used to interpret functions. All binary variables were coded as 0 or 1 for subsequent analysis. Tree species was converted to four dummy binary variables. If the tree was of a given species, it was assigned as 1. The fifth group other was left out of the analysis to avoid redundancy. In total, then 40 variables were included in the analysis. Nest orientation of PCNs and SCNs' cavity entrances using Rayleigh (*Z*) test, one-sample

Watson's (U^2) tests for circular distributions, and mean angular vector (μ) together with the confidence interval of 95%. PCN and SCN cavities were compared using two-sample Watson's (U^2) test using statistical program Oriana (Kovach, 2013).

7.3 Results

7.3.1 Cavity nesting birds' guild

A total of 158 bird species belonging to 52 families were recorded in the study area, out of which 32 species were cavity nesting birds. The 32 species comprised nine primary cavity nesters (PCNs) that included woodpeckers, barbets and 23 secondary cavity nesters (SCNs) which included parakeets, mynas, hornbills, owls, Common Hoopoe, Oriental Magpie Robin, White-rumped Shama and Great Tit (Appendix 3). Large proportion of cavity nesting birds comprised of woodpeckers and owls (20.83%), mynas, parakeets and barbets represented by 16.66% each and hornbills (12.5%). Lesser proportion of cavity nesting birds comprised of Oriental Magpie Robin, Great Tit, Chestnut-bellied Nuthatch, White-rumped Shama and Tickell's Blue-flycatcher, Common Hoopoe and Indian Roller formed a lesser proportion constituting 4.16% each of the nesting birds.

7.3.2 Nest Tree utilization by cavity nesting birds

Of the 376 nests found in the study area, 116 belonged to PCNs and 260 to SCNs. A total of 257 nest trees belonging to 54 species and 23 families were used by cavity nesting birds. Of the 257 nest trees, 226 were live trees and 31 dead trees (snags). Highest proportion of PCN nests were located in *Terminalia arjuna* (17; 14.66%) followed by *Mangifera indica* (16; 13.79%). Interestingly, highest proportions of SCN nests were also found in *Terminalia arjuna* (35; 13.46%) and *Mangifera indica* (23; 8.85%). Both PCN and SCN most frequently nested in *Terminalia arjuna* (Table 7.1). Highest number of tree species was used by Common Myna (n=23) followed by Brown-headed Barbet (n=20) and White-cheeked Barbet (n=19). Tree species such as *Terminalia arjuna, Mangifera indica, Melia dubia* and *Ceiba pentandra* were favoured by several cavity nesting birds.

Table 7.1 Major nest tree species of primary and secondary cavity nesting birds

S. No.	Name of the trees	PCNs		SCNs		Total
		#	%	#	%	
1	*Terminalia arjuna*	17	14.66	35	13.46	52
2	*Mangifera indica*	16	13.79	23	8.85	39
3	*Melia dubia*	11	9.48	21	8.08	32
4	*Ceiba pentandra*	9	7.76	9	3.46	18
5	*Madhuca longifolia*	1	0.86	17	6.54	18
6	*Stereospermum personatum*	6	5.17	11	4.23	17
7	*Syzygium cumini*	3	2.59	14	5.38	17
8	*Gyrocarpus asiaticus*	3	2.59	13	5.00	16
9	*Albizia lebbeck*	5	4.31	9	3.46	14
10	*Hardwickia binata*	0	0.00	11	4.23	11
11	*Strychnos nux-vomica*	4	3.45	7	2.69	11
12	*Ficus benghalensis*	9	7.76	1	0.38	10
13	*Vitex altissima*	1	0.86	7	2.69	8
14	*Diospyros peregrina*	1	0.86	6	2.31	7
15	*Tamarindus indica*	2	1.72	5	1.92	7
16	*Acacia polyacantha*	4	3.45	2	0.77	6
17	*Pongamia pinnata*	4	3.45	2	0.77	6
18	*Drypetes roxburghii*	0	0.00	5	1.92	5
19	*Ficus religiosa*	1	0.86	4	1.54	5
20	*Hopea ponga*	1	0.86	4	1.54	5
21	*Manilkara hexandra*	1	0.86	4	1.54	5
22	*Albizia chinensis*	2	1.72	2	0.77	4
23	*Ficus amplissima*	3	2.59	1	0.38	4
24	*Ficus macrocarpa*	0	0.00	4	1.54	4
25	*Ficus racemosa*	3	2.59	1	0.38	4
26	*Alphonsea sclerocarpa*	0	0.00	3	1.15	3
27	*Alseodaphne semecarpifolia*	0	0.00	3	1.15	3

S. No.	Name of the trees	PCNs		SCNs		Total
		#	%	#	%	
28	*Bombax ceiba*	1	0.86	2	0.77	3
29	*Celtis philippensis*	0	0.00	3	1.15	3
30	*Ficus virens*	2	1.72	1	0.38	3
31	*Givotia moluccana*	2	1.72	1	0.38	3
32	*Holoptelea integrifolia*	1	0.86	2	0.77	3
33	*Schleichera oleosa*	0	0.00	3	1.15	3
34	*Ailanthus excelsa*	0	0.00	2	0.77	2
35	*Calophyllum apetalum*	0	0.00	2	0.77	2
36	*Celtis tetrandra*	0	0.00	2	0.77	2
37	*Delonix regia*	0	0.00	2	0.77	2
38	*Sweitenia macrophylla*	1	0.86	1	0.38	2
39	*Terminalia bellirica*	0	0.00	2	0.77	2
40	*Albizia amara*	0	0.00	1	0.38	1
41	*Butea parviflora*	0	0.00	1	0.38	1
42	*Cassine glauca*	0	0.00	1	0.38	1
43	*Cordia monoica*	0	0.00	1	0.38	1
44	*Dalbergia latifolia*	0	0.00	1	0.38	1
45	*Ficus drupacea*	1	0.86	0	0.00	1
46	*Gmelina arborea*	0	0.00	1	0.38	1
47	*Pleurostylia opposita*	0	0.00	1	0.38	1
48	*Psidium guajava*	0	0.00	1	0.38	1
49	*Pterocarpus marsupium*	0	0.00	1	0.38	1
50	*Salix tetrasperma*	0	0.00	1	0.38	1
51	*Sapindus emarginatus*	0	0.00	1	0.38	1
52	*Sterculia guttata*	0	0.00	1	0.38	1
53	*Strychnos potatorum*	0	0.00	1	0.38	1
54	*Terminalia catapa*	1	0.86	0	0.00	1

7.3.3 Characteristics of nest trees utilized by birds

7.3.3.1 Primary cavity nesting birds

Mean values of nest tree height, nest tree girth at breast height, nest height and girth at nest height of the PCN birds were 19.71 ± 4.99_{SD} m, 283.75 ± 126.21_{SD} cm, 11.16 ± 3.20_{SD} m and 68.08 ± 37.86_{SD} cm respectively (Table 7.2). For the woodpeckers, the mean values of nest tree height, nest tree girth at breast height, nest height and girth at nest height were 23.04 ± 4.02_{SD} m, 258.18 ± 71.04_{SD} cm, 12.66 ± 2.92_{SD} m and 83.54 ± 48.79_{SD} cm. For the barbets, mean nest tree height was 18.93 ± 4.89_{SD} m, nest tree girth at breast height 289.73 ± 135.52_{SD} cm, nest height 10.81 ± 3.17_{SD} m and girth at nest height 64.46 ± 34.14_{SD} cm. PCNs nest height positively correlated with tree height (r = 0.569, p < 0.000), Girth at breast height of the nest trees was positively correlated with nest hieght (r = 0.204, p = 0.02). Nest tree characters (nest tree height, 1st branch height of nest tree, nest height, and girth at nest height) were significantly different among the PCN but tree girth at breast height did not differ significantly (Table 7.3).

Nest tree height

Nest tree height significantly varied among the different primary cavity nesters ($F_{5, 113}$ = 3.89, p< 0.000). Among the PCNs, woodpecker nest tree height was greater than barbet nest tree height (t = 3.53, df = 89, p <0.001). The mean nest tree heights of woodpeckers were 24.92 m for White-naped woodpecker 23.0 m for Greater Golden-backed woodpecker and 21.26 m for the Brown-capped Pygmy woodpecker. Nest tree height and girth at breast height of nest tree values did not vary much among the different barbet species (*Psilopogon* spp) and barbet species chose trees with similar features. White-cheeked Barbet's nest tree height was 19.16 ± 4.44_{SD} m, Brown-headed Barbet 18.79 ± 5.65_{SD} m, Coppersmith Barbet 18.51 ± 4.82_{SD} m. Mean nest tree girth of White-cheeked Barbet was 3.73 ± 132.80_{SD} m, Brown-headed Barbet 3.02 ± 137.8_{SD} m and Coppersmith Barbet 3.14 ± 141.5_{SD} m. There was correlation between nest tree height and girth at breast height of nest tree in three barbet species, Brown-headed barbet (r = 0.39), Coppersmith Barbet (r = 0.51) and White-cheeked Barbet (r = 0.18).

Nest height

Nest height significantly varied among the various PCNs (Figure 7.2). All the woodpecker species used tall trees with huge girth for nesting with strong woodpeckers (White-naped woodpecker and Greater Golden-backed woodpecker) exhibiting a mean nest height that was higher than that exhibited by weak woodpecker Brown-capped Pygmy woodpecker as well as the barbets.

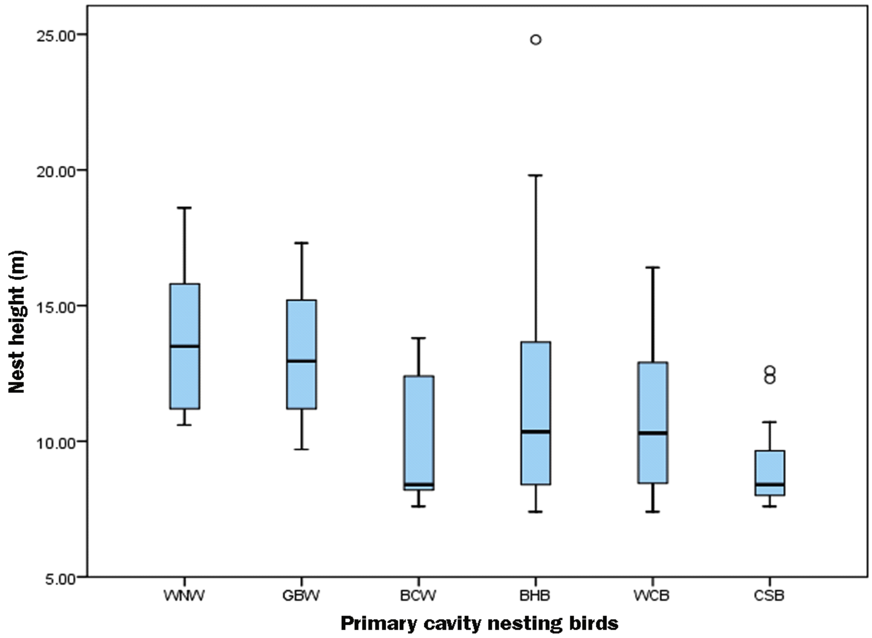


Figure 7.2 Nest height variations among the various primary cavity nesting birds. [The box plots present the median (horizontal line), 25% and 75% of box, and range (whiskers)].

Strong woodpeckers excavated their nest cavities at 3 m higher than the weak excavator, the Pygmy woodpecker. Mean nest height did not vary significantly across the woodpeckers species of the present study (Kruskal-Wallis *H* test, $\chi^2 = 4.08$, $df = 2$; $p = 0.13$). Greater Golden-backed Woodpecker excavated cavities at locations significantly higher than did the Brown-capped Pygmy Woodpecker nests (Mann-Whitney *U* test, $Z = -1.89$, $p < 0.05$). Nest height of woodpeckers showed correlation with their tree height in all the three species studied *viz* White-naped Woodpecker ($r = 0.62$), Greater Golden-backed Woodpecker ($r = 0.43$) and Brown-capped Pygmy Woodpecker ($r = 0.37$).

Mean nest height of barbets varied significantly across the three barbet species (Kruskal-Wallis *H* test, $\chi^2 = 6.60$, $df = 2$; $p < 0.03$). Brown-headed Barbet and White-cheeked Barbet excavated nest cavities location at approximately 2 m higher than Coppersmith Barbet nest cavities (Mann-Whitney *U* test, Z = -2.11, $p = 0.03$; and Z = -2.56, $p < 0.001$). Nest height values positively correlated with tree height in Brown-headed Barbet ($r = 0.78$, $p < 0.000$), Coppersmith Barbet ($r = 0.42$, $p < 0.01$) and White-cheeked Barbet ($r = 0.35$, $p < 0.01$). These birds chose tall trees and nests were found in the upper portion of the nest tree.

7.3.3.2 Secondary cavity nesting birds

Mean values of nest tree features of different species of secondary cavity nesting birds are given in Table 2. Mean nest tree height, nest tree girth at breast height, nest height and girth at nest height of secondary cavity nesting birds were $19.31 \pm 6.42_{SD}$ m, $292.26 \pm 141.27_{SD}$ cm, $10.42 \pm 4.39_{SD}$ m, $96.51 \pm 44.79_{SD}$ cm respectively (Table 8.2). For the mynas, the mean values of nest tree height, nest tree girth at breast height, nest height and girth at nest height were $19.63 \pm 5.73_{SD}$ m, $289.62 \pm 136.68_{SD}$ cm, $10.27 \pm 3.35_{SD}$ m and $100.75 \pm 40.84_{SD}$ cm respectively. For the hornbills, mean nest tree height was $24.72 \pm 5.91_{SD}$ m, nest tree girth at breast height $439.28 \pm 88.96_{SD}$ cm, nest height $14.47 \pm 4.59_{SD}$ m and girth at nest height $170.92 \pm 45.37_{SD}$ cm respectively. The mean nest tree height, nest tree girth at breast height, nest height and girth at nest height of the parakeets were $19.72 \pm 4.48_{SD}$ m, $272.61 \pm 112.85_{SD}$ cm, $11.85 \pm 2.59_{SD}$ m, $99.41 \pm 40.28_{SD}$ cm respectively.

Table 7.2 Nest tree characteristics of the cavity nesting birds in the riverine forest

S.No.	Bird Name	Sample size	Nest tree Height (m)	Girth at Breast Height (cm)	Nest Height (m)	Girth at Nest Height (cm)
			Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**
	Primary Cavity Nesters					
1	White-naped Woodpecker	5	24.92±2.70	299.2±109.13	13.94±3.31	83±19.13
2	Greater Golden-backed Woodpecker	12	23±4.36	241.75±60.30	13.20±2.31	108.08±46.34
3	Brown-capped Pygmy Woodpecker	5	21.26±4.12	256.6±40.86	10.08±2.81	25.2±3.49
4	Brown-headed Barbet	32	18.79±5.65	302.81±137.8	11.41±4.02	68.21±29.41
5	Coppersmith Barbet	15	18.51±4.82	314.26±141.5	9.04±1.63	19.6±2.69
6	White-cheeked Barbet	47	19.17±4.44	373±132.80	10.97±2.72	76.23±31.04
	Mean±SD	**116**	**19.71± 14.99**	**283.75±126.21**	**11.16±3.20**	**68.08±37.86**
	Secondary Cavity Nesters					
7	Common Myna	71	19.62±5.98	287.92±137.5	10.07±3.49	108.47±44.23
8	Jungle Myna	35	19.66±5.27	293.05±136.8	10.68±3.07	85.08±27.33
9	Great Hornbill	3	23.73±4.21	460.66±70.43	14.3±2.59	223.33±2.88

S.No.	Bird Name	Sample size	Nest tree Height (m)	Girth at Breast Height (cm)	Nest Height (m)	Girth at Nest Height (cm)
			Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**
10	Malabar Pied Hornbill	11	24.65±6.44	433.45±95.51	14.52±5.11	156.63±40.32
11	Malabar Parakeet	22	19.16±2.92	253.63±83.3	15.94±3.22	101.36±37.68
12	Rose-ringed Parakeet	12	20.74±4.55	307.41±151.3	12.41±2.08	95.83±46.21
13	Jungle Owlet	6	18.61±3.84	221.5±107.74	7.36±3.0	92.33±38.20
14	Indian Scops Owl	9	13.68±4.15	196.22±132.2	6.4±2.03	108.22±57.22
15	Common Hoopoe	11	24.65±8.93	360.81±150.1	13.45±5.31	85±27.98
16	Indian Roller	11	16.15±10.1	241.54±78.64	7.47±4.03	104.09±45.03
17	Great Tit	8	21.43±6.95	429.12±143.6	11.45±2.56	67.25±25.33
18	Tickell's Blue-flycatcher	27	16.51±4.73	239.77±97.57	7.44±2.38	88.96±42.65
19	Oriental Magpie Robin	26	19.09±7.63	318.03±201.9	12.77±7.54	56.61±22.33
20	White-rumped Shama	8	15.86±5.51	246.75±53.57	7.31±1.11	77.5±19.08
	Mean±SD	**260**	**19.31±6.42**	**292.26±141.27**	**10.48±4.39**	**96.51±44.79**

Nest tree height

The nest tree height of SCNs significantly varied among the different species ($F_{13, 223} = 7.20$, $p < 0.000$). Hornbills selected tall trees with large size for nesting compared to other secondary cavity nesting birds such as mynas (Mann-Whitney *U* test, $Z = -4.61$, $p < 0.000$) parakeets (Mann-Whitney *U* test, $Z = -3.38$, $p < 0.001$) and owls (Mann-Whitney *U* test, $Z = -2.91$, $p < 0.004$).

Nest height

Among the different species of SCNs, nest height varied highly among different species namely Oriental magpie Robin (ranges between 3.8-28.1 m) followed by Common Myna (ranges between 4.8-23.2 m) and Jungle Myna (ranges between 5.8-17.6 m) (Figure 7.3).

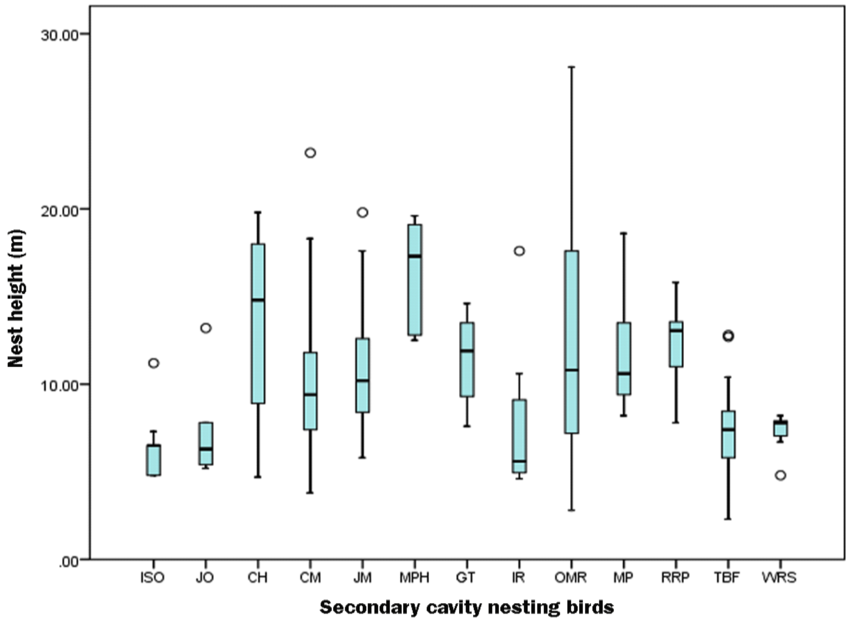


Figure 7.3 Nest height variations among the various secondary cavity nesting birds. [The box plots present the median (horizontal line), 25% and 75% of box, and range (whiskers)].

Secondary cavity nesters' nest height values positively correlated with tree height ($r = 0.73$, $p < 0.000$, n=260). The nest height is positively correlated with tree height for various species *viz.* Malabar Parakeet ($r = 0.77$, $p < 0.000$), Common Hoopoe ($r = 0.89$, $p < 0.000$), Common Myna ($r = 0.61$, $p < 0.001$), Jungle Myna ($r = 0.58$, $p < 0.001$), Malabar Pied Hornbill ($r = 0.89$, $p = 0.03$), Oriental Magpie Robin ($r = 0.84$, $p < 0.000$) and Tickell's Blue-flycatcher ($r = 0.54$, $p = 0.003$). Girth at breast height of the nest trees were positively correlated with nest height ($r = 0.55$, $p < 0.000$).

Nest tree characters (nest tree height, tree girth at breast height, 1st branch height of nest tree, nest height above the ground, and girth at nest height) statistically varied among the various groups of secondary cavity nesters (Table 7.3).

Table 7.3 F-Statistics from One-way ANOVA showing differences among the two group of cavity nesters and among groups for the variables measured at cavity nests

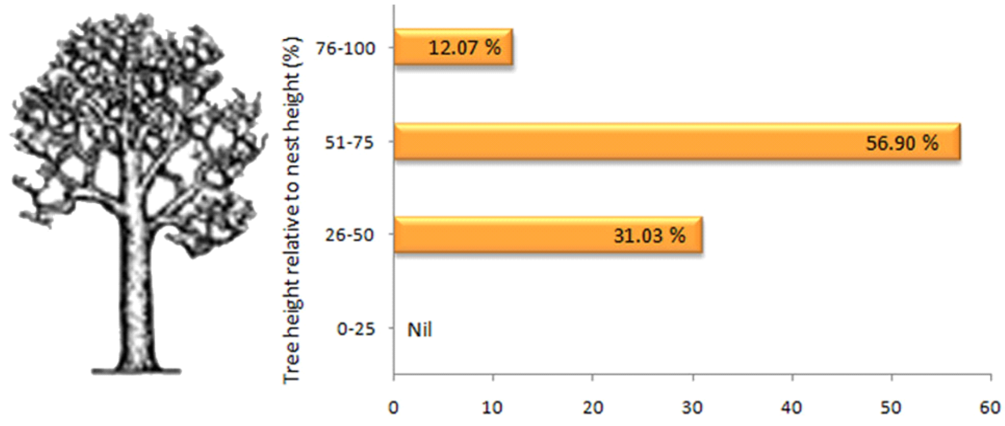
Variable	**All cavity nesters (20 bird species) (*df*= 19, nests=376)**	**PCNs (*df*=5, nests=116) (6 bird species)**	**SCNs (*df*= 13, nests=260)**
Nest tree height (m)	6.24***	3.89***	7.20***
Tree girth at breast height (cm)	6.69***	1.62	9.37***
1st branch height (m)	4.09***	3.63***	4.37***
Nest height (m)	6.15***	5.16***	6.44***
Girth at nest height (cm)	4.27***	2.13*	2.44***

*P < 0.05; **P < 0.01; and ***P < 0.001.

7.3.4 Distribution of nest cavities of primary and secondary cavity nesters

The nest height of PCNs relative to tree height showed a strong tendency for to be high with 69 percent (56.90+12.07%) of nests in the upper height class (51-100%) of the tree while 31.03 % of nests in the middle height class (26-50%) (Figure 7.4a). Secondary cavity nesters nest height relative to tree height showed a strong tendency for to be high with 59.23 percent (50.77+8.46%) of nests in the upper height class (51-100%) of the tree while 38.85 % of nests in the middle height class (26-50 %) of the tree (Figure 7.4b). Most cavity nesters' nest height was upper height class of the tree, probably to reduce nest predation.

a)



b)

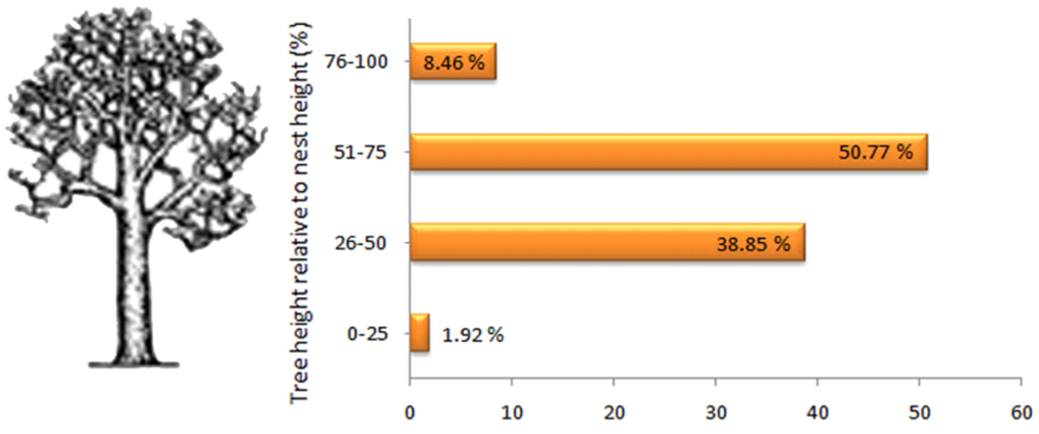


Figure 7.4 Distribution of nest height of primary cavity nesting birds (a) and secondary cavity nesting birds (b).

Nest substrate size

The substrate girth of primary cavity nesting birds ranged from 18 cm for Coppersmith Barbet to 207 cm for Greater Golden-backed woodpecker which nested in thicker part of tree than was for other species. Nest substrate size significantly varied among the three woodpecker species (Kruskal-Wallis *H* test, χ^2 = 11.28, df = 2, p < 0.001). Brown-caped Pygmy woodpecker chose small sized nest substrate than did the other woodpecker species (Mann-Whitney *U* test, Z =-3.16, p <0.001 for Greater Golden-backed woodpecker and Z = -2.61, p <0.001 for White-naped woodpecker). Strong woodpeckers (White-naped woodpecker and Greater Golden-backed woodpecker) nest substrate size was significantly larger than those of the barbet species (Figure 5a). The mean nest substrate size significantly varied across the three barbet species (Kruskal-Wallis *H* test, χ^2 = 37.96, df = 2, p < 0.000). The coppersmith barbet substrate girth size was smaller than that of other barbet species (Mann-Whitney *U* test, *Z* =-5.65, p<0.000 for Brown-headed Barbet; *Z* =-6.07, p<0.000 for White-cheeked barbet). Small-sized excavator species namely Brown-caped Pygmy Woodpecker and Coppersmith Barbets excavated on small sized dead branches to reduce the large predator risk.

The substrate girth for secondary cavity nesting birds ranged from 63 cm for Great Tit to 225 cm for Great Hornbills that nested in thicker part of tree than for other species. The nest substrate size significantly varied among the SCNs (Kruskal-Wallis *H* test, $\chi^2 = 68.79$, $df = 13$, $p < 0.000$). Hornbills selected substrate size of significantly large circumference than did other secondary cavity nesting birds which chose substrates of small size namely, Common myna (Mann-Whitney *U* test, *Z* = -4.23, *p* <0.000), Jungle Myna (Mann-Whitney *U* test, *Z* = -5.39, *p* < 0.000), Malabar Parakeets (Mann-Whitney *U* test, *Z* = -4.36, *p* < 0.000), Rose-ringed Parakeets (Mann-Whitney *U* test, *Z* = -4.13, *p* < 0.000), Indian Scops Owl (Mann-Whitney *U* test, *Z* = -3.40, *p* < 0.001), Jungle Owlet (Mann-Whitney *U* test, Z=-3.81, *p* < 0.000), Indian Roller (Mann-Whitney *U* test, *Z* = -3.51, *p* <0.000) and small bird as (Mann-Whitney *U* test, *Z* =-4.27, *p* <0.000) (Figure 7.5b).

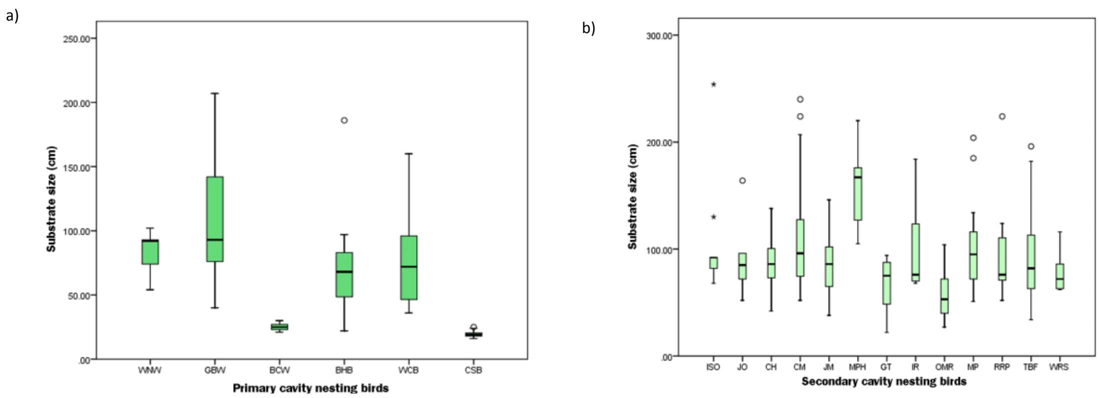


Figure 7.5 Nest substrate size (girth at nest height) variations among the various primary cavity nesting birds (a) and secondary cavity nesting birds (b) in the riverine forest. [The box plots present the median (horizontal line), 25% and 75% of box, and range (whiskers)].

Nest tree condition

Nest tree condition such as live, partially dead, dead were assessed for 376 nests located in 257 different trees. Of the 376 total nests found, 116 nests belonged to PCNs which were located on 115 different trees. Higher proportion of PCNs nest cavities were located live trees (71.55 %) followed by partially dead trees (15.52 %) and the remaining 12.93 % cavities were in snags. PCNs highly preferred live trees than partially dead and snag (PCNs = χ^2 = 74.7, df = 2, p < 0.000).

Majority of the primary cavity nester nest cavities higher in live trees (Figure 7.6). Majority of the barbets excavated nest cavities (56.90%) in dead branches of live trees whereas woodpeckers (12.07 %) chose nest cavities in live trees (Table 7.4). The barbet species are more dependent on dead branches of live trees and snags, which have a soft wood substrate facilitating easy cavity excavation. A total of 260 secondary cavity nesting bird nest cavities were located in 215 different trees. Among the SCNs, majority of the nests were placed in live trees (75.38 %) followed by dead trees (16.53 %) and snags (8.07 %) (Table 7.4). SCNs preferred live trees than partially dead trees and snags (SCN =χ^2 = 195.9, df = 2, p < 0.000). Among the various SCNs, nest cavities higher in live trees than few nest cavities were in partially dead and snag (Figure 7.7). Majority of the mynas and parakeet nests were found in bird excavated cavities. A lesser proportion of SCNs nests were found in natural cavities.

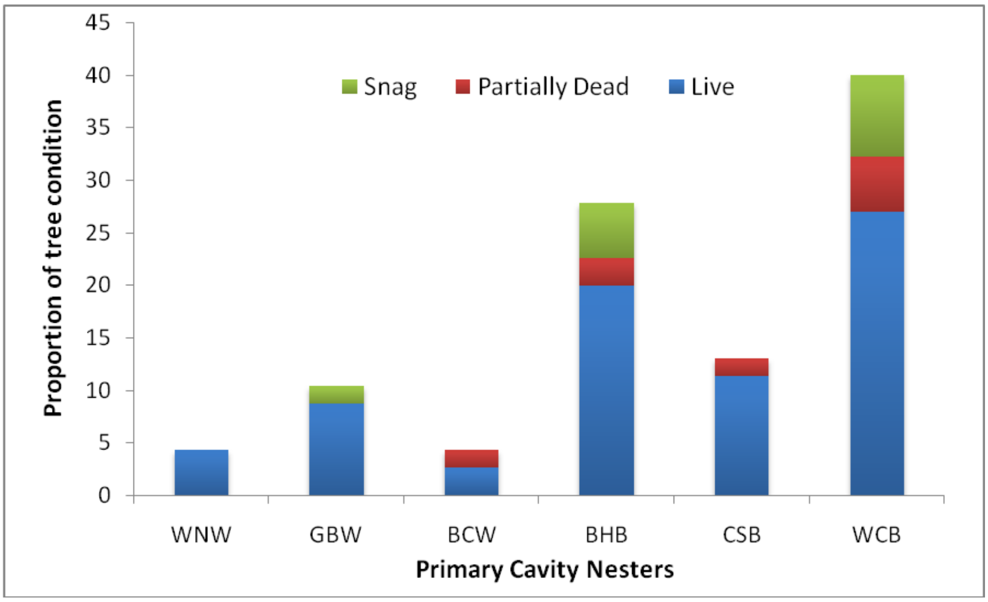


Figure 7.6 Primary cavity nesting birds nest cavities occurrence in different health condition of trees (live, partially dead, snag).

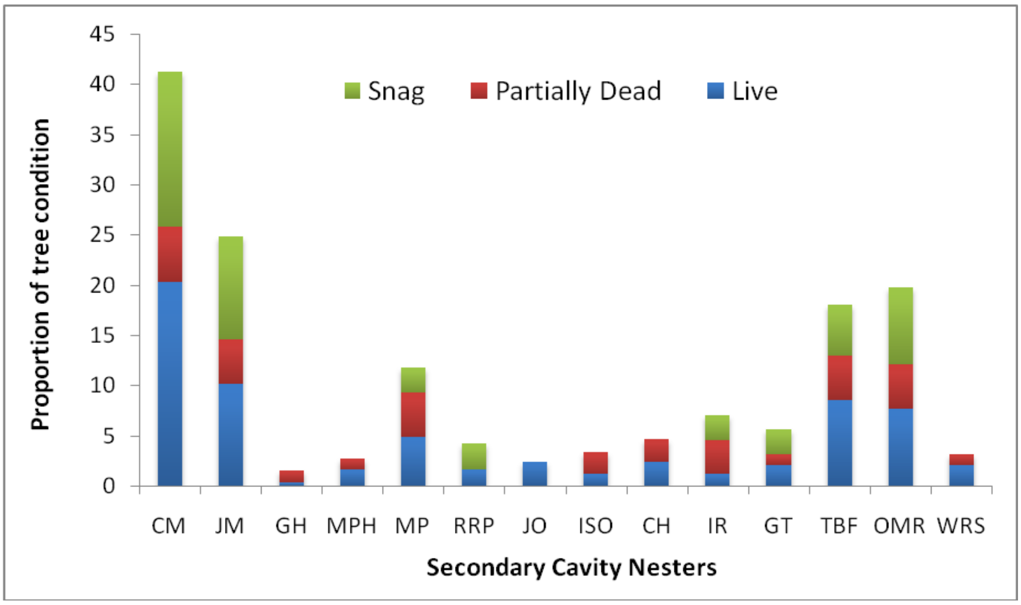


Figure 7.7 Secondary cavity nesting birds nest cavities occurrence in different health condition of trees (live, partially dead, snag).

Table 7.4 Different health conditions of nest trees (live, partially dead, dead) used by cavity nesting birds (n=376 nests)

Birds species	Total # nests	Live		Partially Dead		Dead	
		#	%	#	%	#	%
Primary Cavity Nesters							
White-naped Woodpecker	5	4	3.45	1	0.86	0	0.00
Greater Golden-backed Woodpecker	12	10	8.62	0	0.00	2	1.72
Brown-capped Pygmy Woodpecker	5	3	2.59	2	1.72	0	0.00
Brown-headed Barbet	32	22	18.97	4	3.45	6	5.17
Coppersmith Barbet	15	13	11.21	2	1.72	0	0.00
White-cheeked Barbet	47	31	26.72	6	5.17	10	8.62
Total	**116**	**83**	**71.55**	**15**	**12.93**	**18**	**15.52**
Secondary Cavity Nesters							
Common Myna	71	59	22.69	6	2.31	6	2.31
Jungle Myna	35	27	10.38	4	1.54	4	1.54
Great Hornbill	3	1	0.38	2	0.77	0	0.00

Birds species	Total # nests	Live		Partially Dead		Dead	
		#	%	#	%	#	%
Malabar Pied Hornbill	11	9	3.46	2	0.77	0	0.00
Malabar Parakeet	22	16	6.15	4	1.54	2	0.77
Rose-ringed Parakeet	12	10	3.85	0	0.00	2	0.77
Jungle Owlet	6	6	2.31	0	0.00	0	0.00
Indian Scops Owl	9	5	1.92	4	1.54	0	0.00
Common Hoopoe	11	8	3.08	3	1.15	0	0.00
Indian Roller	11	4	1.54	6	2.31	1	0.38
Great Tit	8	5	1.92	2	0.77	1	0.38
Tickell's Blue-flycatcher	27	21	8.08	4	1.54	3	1.15
Oriental Magpie Robin	26	19	7.31	4	1.54	4	1.54
White-rumped Shama	8	6	2.31	2	0.77	0	0.00
Total	**260**	**196**	**75.38**	**43**	**16.54**	**23**	**8.85**

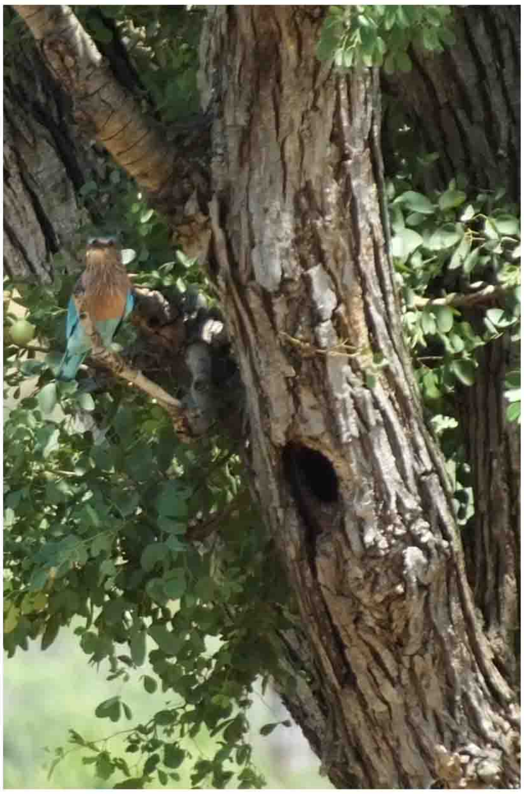
Bark types

Bark types of tree species used by cavity nesters were assessed. Four different types based on bark shape and texture was recognized *viz.* smooth, rough, flagged and segmented. Majority of the cavity nesting birds nested in smooth bark trees (52.59 % of the PCNs and 41.54 % of SCNs) (Figure 7.8). Significant preference was shown to smooth bark trees (χ^2 = 57.86, df = 3, p <0.000 for PCNs; χ^2 = 73.66, df = 3, p <0.000 for SCNs). In the study area, species such as *Terminalia arjuna, Pongamia pinnata, Diospyros peregrina, Celtis philippensis, Ceiba pendantra* and *Ficus* spp tree species had smooth bark.

Bark types of nest trees in the riverine forests

Smooth Bark

Rough Bark



Fissured Bark

Segmented Bark

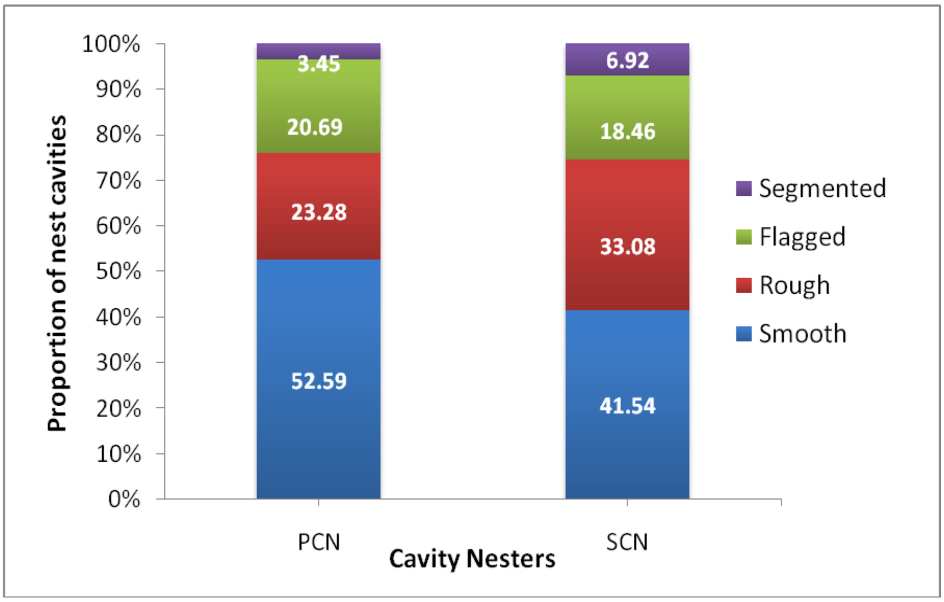


Figure 7.8 Proportion of different bark textures of nest trees used by cavity nesting birds

Cavity type

PCNs used cavities excavated by themselves only and they did not use natural cavities. SCNs used both excavated cavities (58.07%) and natural cavities (41.92%). The utilization of excavated and natural cavities by secondary cavity nesters varied significantly (χ^2 = 6.78, *df* = 1, *p* = 0.009).

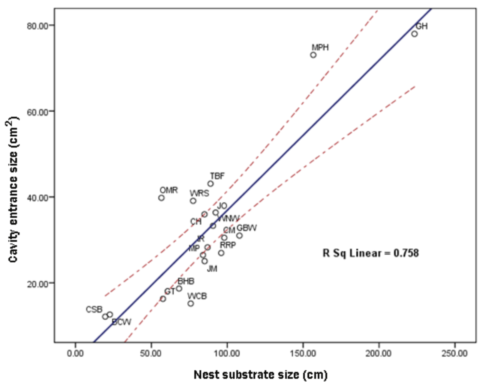
Cavity shape

Generally, primary cavity nesting birds' cavities are round or oval in shape. Among the excavated cavities, higher proportion of cavities was of oval shape (77.27 %) and the remaining was round. SCNs used PCN excavated cavities as well as natural cavities while a majority of them used bird excavated cavities. The natural cavity in general is irregular in shape with varying entrance shapes and size. Majority of the woodpecker excavated cavities' entrance were oval (77.27%) while a smaller proportion was round shaped (22.72%). In the case of barbets, the cavity entrance was only round. Also, barbet excavated cavities had narrow and smooth entrance compared to the woodpeckers.

Nest substrate

A higher proportion of PCNs excavated cavities were found on dead substrate (88.79%) and remaining nest cavities were in live substrate. The PCNs had significantly higher preference to dead substrate (χ^2 = 69.82, *df* = 1, *p* < 0.001) than to the live substrate. A large proportion of woodpecker excavated cavities was found on live substrate (59.09%). Barbets and Brown-capped Pygmy woodpecker choose only the dead portion of live trees for nesting. A large proportion of SCN nest cavities were found on live substrate (65.76%) (Table 7.5). The SCNs showed significantly higher preference to live substrate (χ^2 = 18.84, df = 1, p < 0.001) than the to the dead substrate. A strong correlation was found between the mean nest substrate size (girth) and mean nest cavity dimensions (cavity entrance circumference and mean cavity depth (Figure 7.9a & b). Overall, mean nest substrate size (girth) showed significant relationship with mean cavity entrance size (r^2 = 0.75, $F_{1, 18}$ = 53.28, P <0.000), and cavity depth (r^2 = 0.74, $F_{1, 18}$ = 48.99, P <0.000). A weak excavator such as Coppersmith barbet and Brown-capped pygmy woodpecker cavities were excavated in small limp of nest substrate while large cavity nesting birds such as Hornbills nested in large substrate with large cavity entrance.

a)



b)

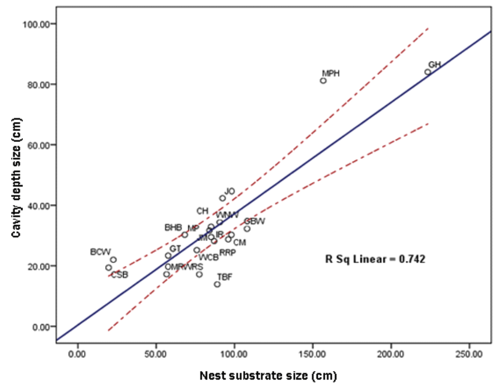


Figure 7.9 Preliminary examinations of mean nest substrate size relationships with mean cavity entrance area (a) and mean cavity depth size (b) of cavity nesting birds.

Nest location

Majority of the PCNs cavities were located on branches (83.62 %) and a smaller proportion (16.38 %) on main trunk. Similar trend was observed for SCNs in which 71.15 % nests were located on branches and a lesser proportion (28.85%) on main trunk (Table 7.5). Both the cavity nesters showed significant preference to tree branches than to the main trunk for nesting (χ^2 = 60.82, df = 1, p < 0.001 for PCNs; χ^2 = 40.01, df = 1, p < 0.001 for SCNs).

Table 7.5 Cavity nesting birds' nest position (trunk, branch) and nest substrate (live, dead) (n=376 nests)

Bird species Code	Total # nests	Nest Trees #	Nest Location				Nest Substrate condition			
			Main		Branch		Live		Dead	
			#	%	#	%	#	%	#	%
Primary Cavity Nesters										
WNW	5	5	3	60	2	40	4	80	1	20
GGBW	12	12	9	75	3	25	9	75	3	25
BCPW	5	5	-	-	5	100	-	-	5	100
BHB	32	32	2	6.25	30	93.75	-	-	32	100
CSB	15	15	-	-	15	100	-	-	15	100
WCB	47	46	5	10.64	42	89.36	-	-	47	100
Secondary Cavity Nesters										
CM	71	61	26	36.62	45	63.38	55	77.46	16	22.54
JM	35	33	5	14.29	30	85.71	17	48.57	18	51.43
GH	3	2	1	33.33	2	66.67	3	100	-	-
MPH	11	5	2	18.18	9	81.82	11	100	-	-
MP	22	17	6	27.27	16	72.73	19	86.36	3	13.64
RRP	12	5	8	66.67	4	33.33	8	66.67	4	33.33
JO	6	6	4	66.67	2	33.33	5	83.33	1	16.67
ISO	9	5	9	100	-	-	9	100	-	-
CH	11	8	1	9.09	10	90.91	9	81.82	2	18.18
IR	11	4	3	27.27	8	72.73	10	90.91	1	9.09
GT	8	7	3	37.50	5	62.50	-	-	8	100
TBF	27	21	6	22.22	21	77.78	16	59.26	11	40.74
OMR	26	26	1	3.85	25	96.15	7	26.92	19	73.08
WRS	8	6	-	-	8	100	2	25	6	75

Among the PCNs, Greater Golden-backed woodpecker and White-naped woodpecker excavated nest cavities mostly on tree trunks (75% and 60% respectively). A smaller proportion of nest cavities were created on branches. Brown-capped Pygmy woodpeckers chose small dead branches only for cavity excavation. A large proportion of barbet excavated cavities (92.55%) were located on branches (Figure 7.10). Among the SCNs, higher proportion of nests was located on branches *viz.* Common Myna (63.38%), Jungle Myna (85.71%), Malabar Parakeet (72.73%), Malabar Pied Hornbill (81.82%), Common Hoopoe (90.91%) and Indian Roller (72.73). Indian Scops Owl's nest cavities were mainly located on main trunk. These cavities were naturally formed ones. Oriental Magpie Robin selected shallow cavities on tree branches (Figure 7.11).

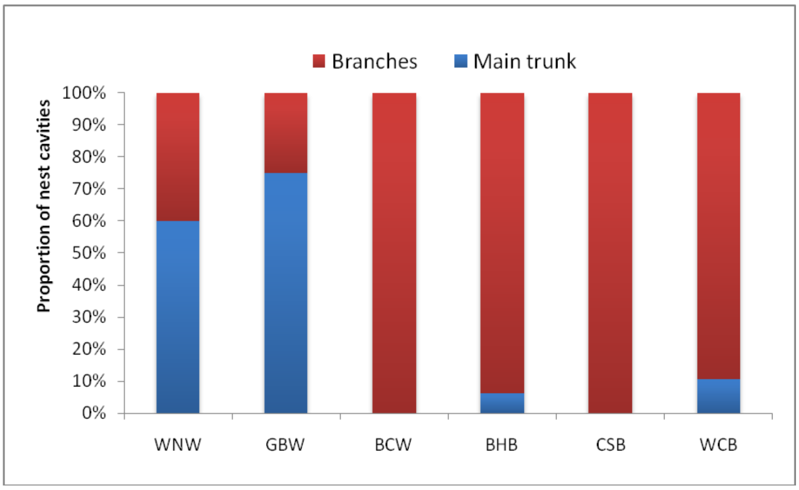


Figure 7.10 Nest cavity location (trunks, branches) of primary cavity nesting birds (n=116).

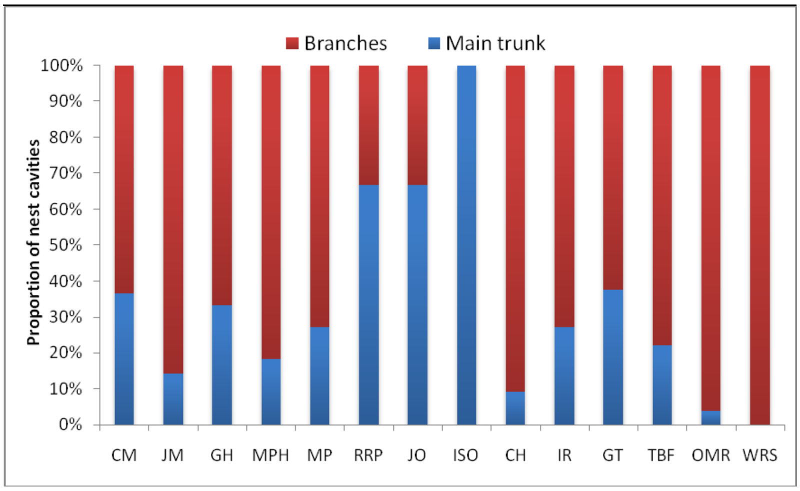


Figure 7.11 Nest cavity location (trunks, branches) of secondary cavity nesting birds (n=260)

7.3.5 Nest cavity features of cavity nesting birds

Nest cavity features of primary cavity nesting birds

Nest cavity features such as cavity entrance horizontal length (cm), vertical length (cm) and cavity depth (cm) are given in Table 7.6. Nest cavity dimensions of the PCNs were, mean cavity entrance horizontal length $5.94 \pm 2.42_{SD}$ cm, mean cavity entrance vertical length $5.56 \pm 1.79_{SD}$ cm, mean cavity circumference $18.06 \pm 6.52_{SD}$ cm and mean cavity depth $26.82 \pm 5.21_{SD}$ cm. For the woodpeckers, the mean value of nest cavity entrance horizontal length was 9.45 ± 3.49 cm, cavity entrance vertical length was $7.98 \pm 2.54_{SD}$ cm, cavity circumference $27.38 \pm 9.26_{SD}$ cm and cavity depth $30.40 \pm 5.23_{SD}$ cm respectively.

Cavity dimensions of the White-naped Woodpecker and Golden-backed Woodpecker differed from those of the Brown-capped Pygmy Woodpecker. The entrance size of the cavity excavated by the Brown-capped Pygmy Woodpecker was smaller than those excavated by the other woodpeckers namely, White-naped Woodpecker and Golden-backed Woodpecker. The mean values of barbets' cavity entrance horizontal length, cavity entrance vertical length, cavity circumference and cavity depth were $5.12 \pm 0.96_{SD}$ cm, $4.99 \pm 0.89_{SD}$ cm, $15.88 \pm 2.81_{SD}$ cm and $25.98 \pm 4.87_{SD}$ cm respectively. The Brown-headed Barbet, Coppersmith Barbet and White-cheeked Barbet excavated smaller cavities, while White-naped Woodpecker, Greater Golden-backed Woodpecker excavated larger cavities (Table 7.6). The PCNs' cavity entrance diameter significantly correlated with cavity inner depth ($r = 0.627$, $p < 0.001$). Nest cavity characters such as cavity entrance length, cavity entrance width and cavity depth significantly varied among the PCNs' (Table 7.7). Among the barbet species, cavity entrance size of vertical and horizontal length were almost similar because cavity entrance area was circular shaped. The large woodpeckers' cavity entrance vertical length and horizontal length significantly varied (Paired *t* test, $t = 3.20$, $df = 4$, $p = 0.03$ for White-naped woodpecker; $t = 3.95$, $df = 11$, $p = 0.02$ for Greater Golden-backed woodpecker). The cavity entrance of large woodpeckers (White-naped and Golden-backed) was oval in shape while Brown-capped woodpecker's (small woodpecker) cavity entrance round shape. Large woodpeckers' (White-naped Woodpecker and Greater Golden-backed Woodpecker) mean cavity entrance size and cavity depth were significantly larger than other primary cavity nesting species (Figure 7.12a & b).

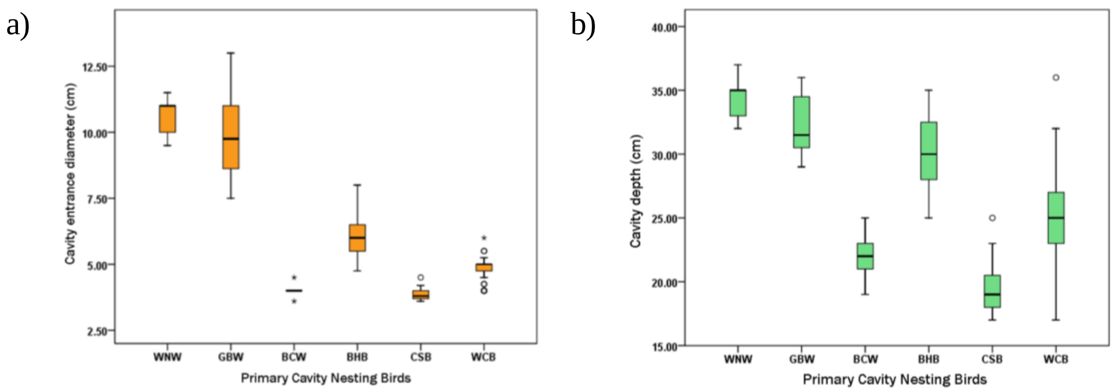


Figure 7.12 Nest cavity entrance diameter (a), cavity depth (b) variations among the various primary cavity nesting birds. [The box plots present the median (horizontal line), 25% and 75% of box, and range (whiskers)].

Nest cavity features of secondary cavity nesting birds

SCNs' mean values for cavity entrance horizontal length, cavity vertical length, cavity circumference and cavity depth were 12.31±7.03$_{SD}$ cm, 10.10±4.47$_{SD}$ cm, 35.19±17.14 $_{SD}$ cm and 31.15±16.76$_{SD}$ cm respectively. For mynas, mean value for cavity entrance horizontal length was 9.73±4.07$_{SD}$ cm, cavity entrance vertical length 8.54±3.06$_{SD}$ cm, cavity circumference 28.69±10.95 cm and cavity depth was 30±3.75 cm. For the parakeets mean cavity entrance horizontal length was 9.02±2.65$_{SD}$ cm, cavity entrance vertical length 7.94±1.87$_{SD}$ cm, cavity circumference 26.64±7.02$_{SD}$ cm and cavity depth 30.64±4.88$_{SD}$ cm. For the hornbills, mean cavity entrance horizontal length, cavity entrance vertical length, cavity circumference and cavity depth were 26.0±2.60$_{SD}$ cm, 21.21±3.86$_{SD}$ cm, 74.12±9.77$_{SD}$ cm and 76.92±8.41$_{SD}$ cm respectively (Table 7.6).

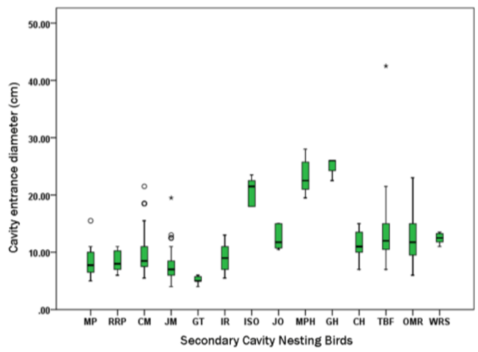
For the SCNs' nest characters such as cavity entrance length, cavity entrance width, Cavity entrance circumference and cavity depth statistically differed ($p < 0.001$) among the various species (Table 7.7). The SCNs cavity entrance length of vertical and horizontal size values significantly varied in Malabar Parakeet (Paired *t*-test, $t = 5.69$, $df = 21$, $p < 0.000$), Malabar Pied Hornbill (Paired *t*-test, $t = 6.78$, $df = 10$, p < 0.000), Common Hoopoe (Paired *t* test, $t = 2.67$, $df = 10$, $p < 0.02$), Tickell's Blue-flycatcher (Paired *t*-test, $t = 3.01$, $df = 26$, $p < 0.001$), Oriental Magpie Robin (Paired *t* test, $t = 3.16$, $df = 25$, $p < 0.004$) Jungle Myna (Paired *t*-test, $t = 4.07$, $df = 34$, $p < 0.000$), Common Myna (Paired *t*-test, $t = 5.46$, $df = 70$, $p < 0.000$) and Indian Scops Owl (Paired *t*-test, $t = 6.26$, $df = 8$, $p < 0.000$). Mynas, Parakeets, Indian Roller and Great Tits mostly used nest cavities excavated by PCNs which were small in size. Hornbills and Indian Scops Owl used non-excavated cavities by naturally formed cavities. Hornbill nest cavity characters such as cavity entrance length and cavity depth also significantly greater from other secondary cavity nesting birds (Figure 7.13a & b).

Table 7.6 Nest cavity features of the cavity nesting birds in the riverine forest (Mean±SD)

S. No.	Name of the birds	Sample size	Cavity Entrance (cm)		Cavity entrance circumference (cm^2)	Cavity Depth (cm)
			Vertical length	Horizontal length		
Primary Cavity Nesters (PCNs)						
1	White-naped Woodpecker	5	11.2±1.09	10±0.70	33.28±2.57	34.4±1.94
2	Greater Golden-backed Woodpecker	12	10.45±1.75	9±1.41	30.54±4.75	32.25±2.45
3	Brown-capped Pygmy Woodpecker	5	4.1±0.54	3.9±0.22	12.65±1.11	22±2.23
4	Brown-headed Barbet	32	6.12±0.70	5.76±0.85	18.66±2.27	30.25±2.56
5	Coppersmith Barbet	15	4.02±0.42	3.74±0.21	12.19±2.32	19.40±2.32
6	White-cheeked Barbet	47	4.80±0.49	4.86±0.45	15.18±1.35	25.19±3.80
Secondary Cavity Nesters (SCNs)						
7	Common Myna	71	10.33±4.17	9.08±3.11	30.49±1.11	30.23±3.64
8	Jungle Myna	35	8.50±3.61	7.45±2.68	25.05±9.69	29.51±3.98
9	Great Hornbill	3	27±1.73	22.66±2.36	77.97±6.34	84.0±3.46
10	Malabar Pied Hornbill	11	25.72±2.79	20.81±4.19	73.07±10.51	81.18±4.55
11	Malabar Parakeet	22	9.09±2.92	7.77±2.11	26.47±7.83	31.68±5.16
12	Rose-ringed Parakeet	12	8.91±2.19	8.25±1.35	26.95±5.55	28.75±3.81

S. No.	Name of the birds	Sample size	Cavity Entrance (cm)		Cavity entrance circumference (cm^2)	Cavity Depth (cm)
			Vertical length	Horizontal length		
13	Indian Scops Owl	9	22.88±2.57	18.44±2.45	64.89±7.15	45.77±3.96
14	Jungle Owlet	6	12.33±3.38	10.83±2.99	36.37±9.99	42.33±4.84
15	Common Hoopoe	11	12.81±3.37	10.09±2.30	35.96±7.34	32.90±2.42
16	Indian Roller	11	9.63±2.37	8.36±2.50	28.26±7.33	28.18±2.71
17	Great Tit	8	5.25±0.70	5.12±0.64	16.28±2.04	23.37±1.40
18	Tickell's Blue-flycatcher	27	16.92±11.96	10.51±2.67	43.08±20.97	13.88±4.31
19	Oriental Magpie Robin	26	14.03±6.10	11.30±4.05	39.79±14.73	17.23±2.19
20	White-rumped Shama	5	13.08±1.61	11.81±1.73	39.09±2.81	17.18±2.56

a)



b)

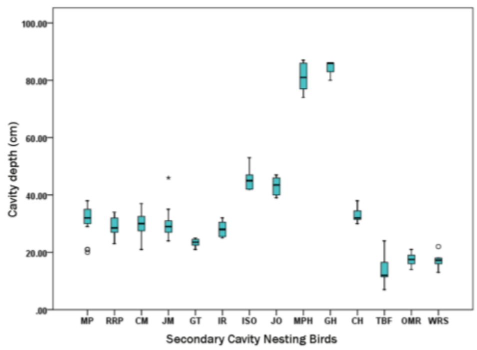


Figure 7.13 Nest cavity entrance diameter (a), cavity depth (b) variations among the various secondary cavity nesting birds. [The box plots present the median (horizontal line), 25% and 75% of box, and range (whiskers)].

Table 7.7 F-Statistics from One-way ANOVA differences among species and between groups of species in the variables measured at nest cavities

S. No.	Variables	Primary cavity nesters (6 bird species) (*df* = 5; n=116 nests)	Secondary cavity nesters (14 bird species) (*df*=13; n=260 nests)
1	Cavity entrance length (cm)	124.04***	16.43***
2	Cavity entrance width (cm)	122.24***	20.10***
3	Cavity circumference (cm)	148.56***	21.34***
4	Cavity depth (cm)	43.82***	138.33***

***$P < 0.001$.

Discriminant function analysis

The first 3 functions explained 57.5 %, 9.2 % and 5.7 % (totalling 72.4 %) of the total variance. The correlations between these first 3 discriminant function and the variables are given in table 7.8. and the mean discriminant scores were compared in Tables 7.9, 7.10 and 7.11. Box plots of discriminant scores for different bird species in the three discriminant functions are given Figures 7.14 a, b and c.

Table 7.8 Correlations between discriminant function and discriminating variables

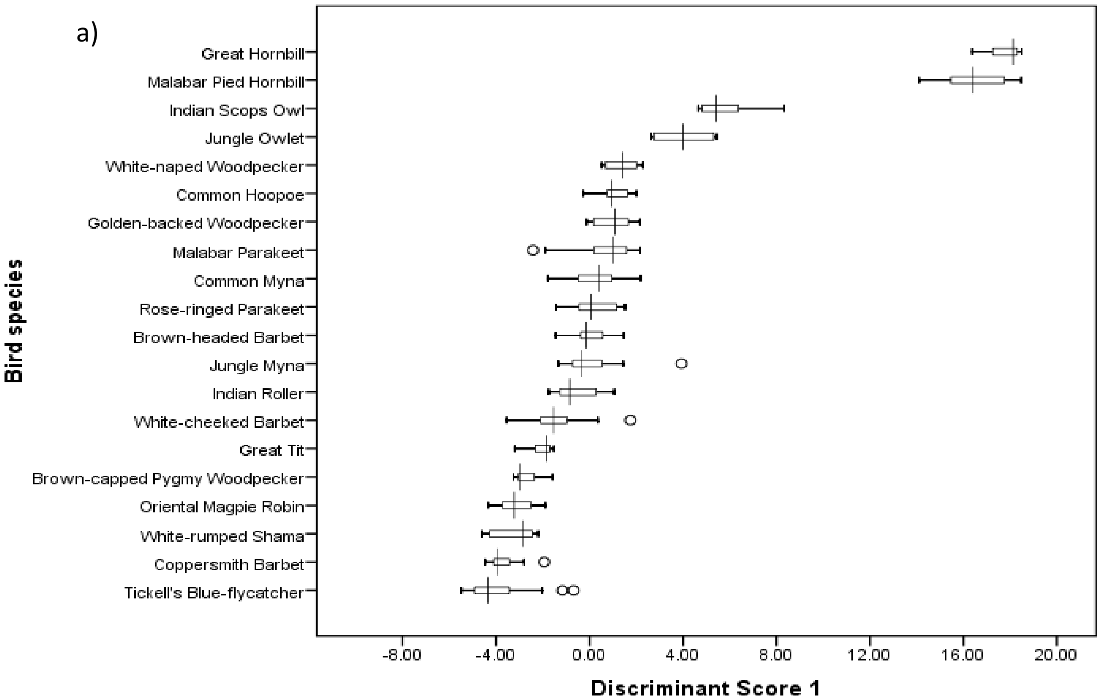
(The highest and most significant variables for each function is indicated by bold letters)

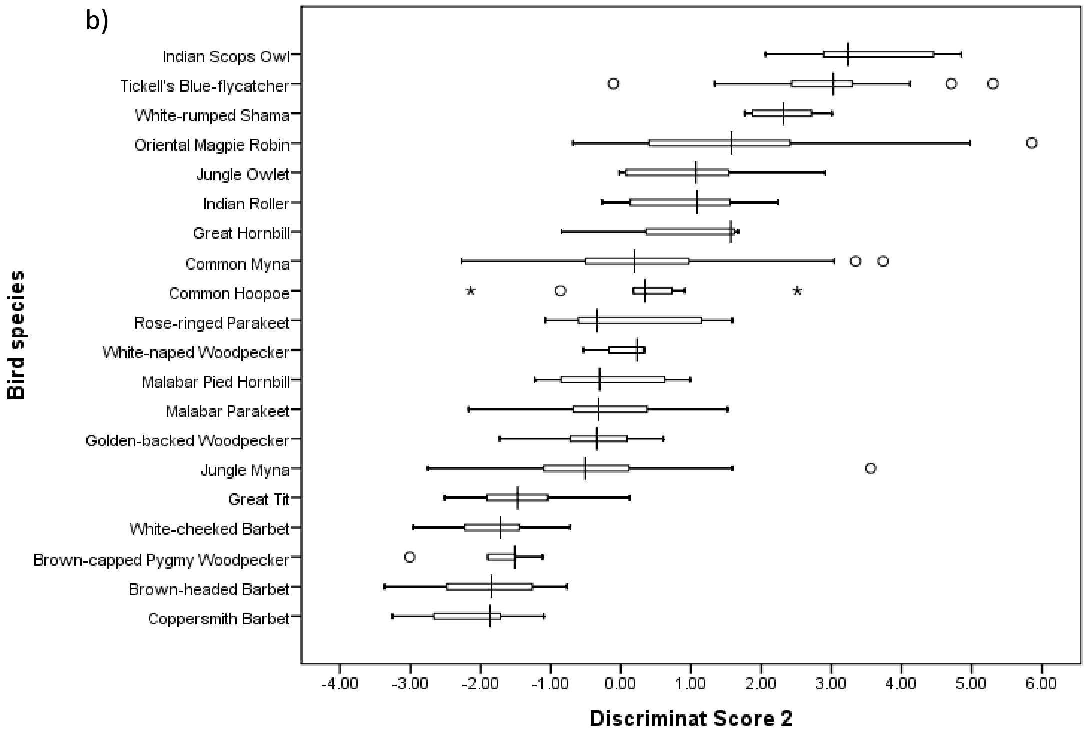
VARIABLES	Correlation with Discriminant Functions		
	1	**2**	**3**
Nest site variables			
Distance from Agriculture land (m)	0.02	-0.02	-0.39
Distance from Settlements (m)	0.17	0.13	0.07
Distance from water (m)	-0.12	-0.04	0.05
No. of Neighbour trees (NBTs)	-0.14	-0.06	-0.33
No. of shrubs	-0.12	-0.06	-0.20
Live Pole	-0.14	-0.07	**-0.31**
Dead Pole	0.01	0.08	-0.21

VARIABLES	**Correlation with Discriminant Functions**		
	1	**2**	**3**
Nest tree variables			
Tree height (m)	0.19	-0.16	0.03
Tree GBH (cm)	0.16	-0.12	-0.16
Tree Diameter (cm)	**0.48**	0.25	0.35
Tree condition (live)	-0.01	0.01	0.02
Tree condition (partially dead)	0.08	0.10	-0.06
Tree condition (snag)	-0.07	-0.13	0.04
Height at 1st branch	0.14	0.04	0.21
Wood condition	-0.15	**-0.38**	-0.19
Foliage Percent (%)	0.02	0.03	-0.12
Crown Class	0.14	0.19	0.01
Crown Radius (m)	0.10	0.00	-0.15
Presence of Fungal fruit body	-0.13	**-0.34**	-0.05
Ganoderma sp.	-0.07	-0.18	-0.08
Polyporus sp.	-0.10	**-0.31**	-0.06
Heart Rot fungus	-0.04	0.05	0.14
Nest Tree species			
Madhuca longifolia	**0.36**	-0.01	-0.03
Mangifera indica	0.14	-0.10	-0.06
Melia dubia	0.03	-0.09	0.30
Syzygium cumini	-0.03	0.02	0.13
Terminalia arjuna	0.04	-0.03	-0.13
Nest cavity variables			
Nest cavity height (m)	0.22	-0.23	-0.09
Girth at nest height (cm)	**0.48**	0.25	0.35
Nest at main trunk	0.16	0.22	**0.40**
Nest at primary branch	0.05	0.18	0.14

VARIABLES	Correlation with Discriminant Functions		
	1	**2**	**3**
Nest at secondary branch	-0.08	-0.17	-0.29
Nest at tertiary branch	-0.11	-0.20	-0.19
Nest at 4th branch	-0.11	-0.19	-0.24
Nest substrate (live/dead)	0.26	0.50	**0.56**
Cavity Depth (cm)	**0.99**	-0.09	0.03
Cavity Diameter (cm)	0.54	**0.72**	-0.24
Cavity Length (cm)	0.45	**0.70**	-0.24
Cavity Width (cm)	0.61	**0.68**	-0.21
Cavity Height (cm)	0.12	-0.05	-0.08
Cavity Circumference (cm^2)	0.54	**0.72**	-0.24

The first function discriminant (DFA1) was correlated most significantly with *Madhuca* trees with large girth at nest and with deep and large diameter holes. Great Hornbill and Malabar Pied Hornbill preferred to nest in *Madhuca longifolia* with large girth and cavities (Figure 7.14a). The second discriminant function was (DFA2) significantly associated with cavity diameter, cavity length, cavity width, cavity circumference, presence of fungal fruit bodies (-ve), *Polyporus* sp (-ve) and wood condition (-ve) (Hard wood with fungi *Polyporus*, and with cavities of large length, diameter and width). Indian Scops Owl, Oriental Magpie Robin, Tickell's Blue-flycatcher and White-rumped Shama mostly used cavities with large entrance length and width. Most of the nest trees used by these bird species had fungal fruit bodies. These four bird species had higher dicriminant score values compared to other species within the group (Figure 7.14b). The third discriminant function (DFA3) was significantly associated with live pole (-ve), nest cavity at main trunk, and nest substrate condition (Nest cavities at main trunk of dead trees and at nest sites with more dead poles). The Indian Roller, Rose-ringed Parakeet, Golden-backed Woodpecker, Common Myna, Malabar Parakeet and White-naped Woodpecker nest cavities were mostly located at the main trunk. These bird species had higher discriminant scores compared to the remaining species within the group (Figure 7.14c).


a)
Great Hornbill
Malabar Pied Hornbill
Indian Scops Owl
Jungle Owlet
White-naped Woodpecker
Common Hoopoe
Golden-backed Woodpecker
Malabar Parakeet
Common Myna
Rose-ringed Parakeet
Brown-headed Barbet
Jungle Myna
Indian Roller
White-cheeked Barbet
Great Tit
Brown-capped Pygmy Woodpecker
Oriental Magpie Robin
White-rumped Shama
Coppersmith Barbet
Tickell's Blue-flycatcher
Bird species
-8.00
-4.00
0.00
4.00
8.00
12.00
16.00
20.00
Discriminant Score 1


b)
Indian Scops Owl
Tickell's Blue-flycatcher
White-rumped Shama
Oriental Magpie Robin
Jungle Owlet
Indian Roller
Great Hornbill
Common Myna
Common Hoopoe
Rose-ringed Parakeet
White-naped Woodpecker
Malabar Pied Hornbill
Malabar Parakeet
Golden-backed Woodpecker
Jungle Myna
Great Tit
White-cheeked Barbet
Brown-capped Pygmy Woodpecker
Brown-headed Barbet
Coppersmith Barbet
Bird species
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Discriminat Score 2

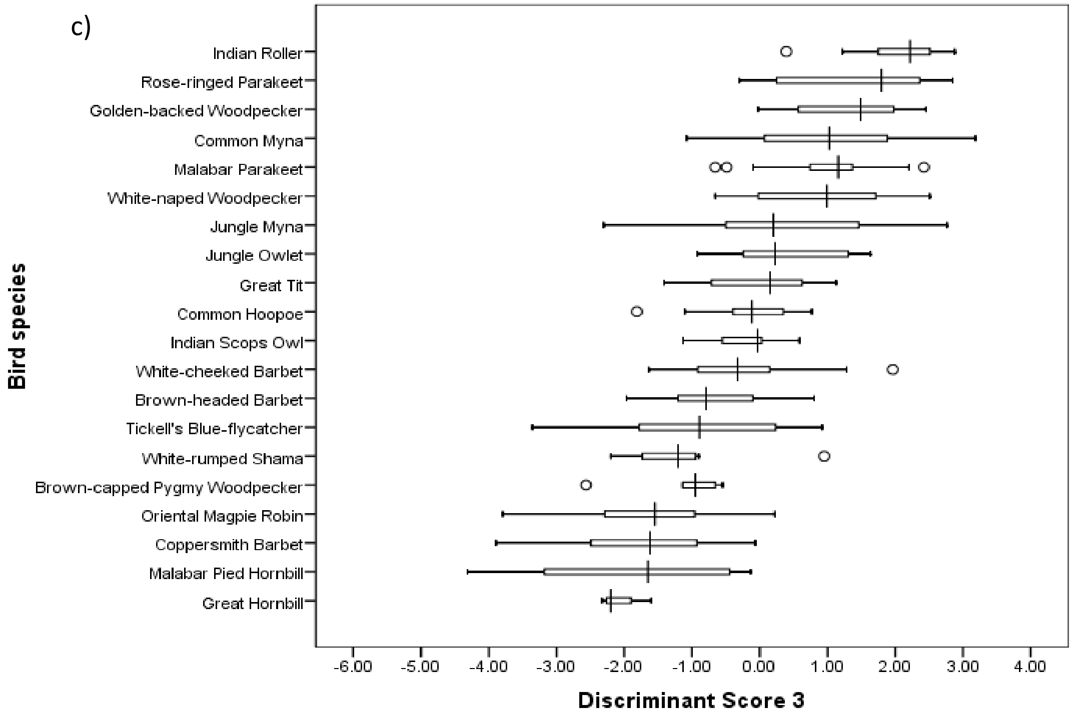


Figure 7.14 Discriminant scores of each bird species on the first (a), second (b), and third (c) discriminat functions. [The box plots present the median (vertical line), 25% and 75% of box, and range (whiskers)].

Tables (7.9, 7.10 and 7.11) represent mean discriminant scores used to group cavity nesting bird species based on Tukey's Multiple Comparisons. (Note: Positive mean scores indicate positive association with the particular discriminant score i.e., they are positively influenced by the variables that have significant correlations with that Discriminant Function and vice versa. High values of the scores indicate high/low association, as per the nature of sign (+ or-+) associated. Letters A, B, C, D, E, F, G, H, I and J are indicative of similar means or bird groups with similar nesting requirements with regard to variables that have high and significant correlations with that Discriminant Function.

Table 7.9. Grouping of bird species based on significant differences (p<0.05) among mean discriminant scores 1 (Tukey's Multiple Comparisons) (Gr. = Group of bird species).

Bird Species	Mean Discriminant Score 1	Gr. 1	Gr. 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 7	Gr. 8	Gr. 9	Gr. 10
GH	17.666	A									
MPH	16.46727	A									
ISO	5.750667		B								
JO	4.020167			C							
WNW	1.3864				D						
CH	1.012909				D	E					
GBW	0.965333				D	E					
MP	0.682				D	E					
CM	0.291479				D	E					
RRP	0.17625				D	E					
BHB	0.000469				D	E	F				
JM	-0.02731				D	E	F				
IR	-0.50782					E	F	G			
WCB	-1.48272						F	G	H		
GT	-2.0525							G	H	I	
BCW	-2.6412								H	I	J
OMR	-3.11973									I	J
WRS	-3.2415									I	J
CSB	-3.71167										J
TBF	-4.03415										J

Table 7.10. Grouping of bird species based on significant differences (p<0.05) among mean discriminant scores 2 (Tukey's Multiple Comparisons) (Gr. = Group of bird species).

Bird Species	**Mean Discriminant Score 2**	**Gr .1**	**Gr. 2**	**Gr. 3**	**Gr. 4**	**Gr. 5**	**Gr. 6**	**Gr. 7**	**Gr. 8**	**Gr. 9**
ISO	3.532889	A								
TBF	2.894111	A	B							
WRS	2.32575	A	B	C						
OMR	1.678423		B	C	D					
JO	1.108667			C	D	E				
IR	0.949182			C	D	E				
GH	0.796333			C	D	E				
CM	0.354521				D	E				
CH	0.320455				D	E				
RRP	0.1565				D	E	F			
WNW	0.0376					E	F			
MPH	-0.16191					E	F			
MP	-0.20859					E	F	G		
GBW	-0.4					E	F	G	H	
JM	-0.40769					E	F	G	H	
GT	-1.40475						F	G	H	I
WCB	-1.79551							G	H	I
BCW	-1.8066								H	I
BHB	-1.88816								H	I
CSB	-2.12647									I

Table 7.11. Grouping of bird species based on significant differences ($p<0.05$) among mean discriminant scores 3 (Tukey's Multiple Comparisons) (Gr. = Group of bird species).

Bird Species	**Mean Discriminant Score 3**	**Gr .1**	**Gr .2**	**Gr .3**	**Gr .4**	**Gr .5**	**Gr .6**	**Gr .7**	**Gr .8**	**Gr .9**
IR	2.036546	A								
RRP	1.476167	A	B							
GBW	1.28825	A	B	C						
CM	1.034141	A	B	C	D					
MP	0.971636	A	B	C	D					
WNW	0.9082	A	B	C	D					
JM	0.418886		B	C	D	E				
JO	0.371333		B	C	D	E	F			
GT	-0.01963		B	C	D	E	F			
CH	-0.173			C	D	E	F	G		
ISO	-0.18267			C	D	E	F	G		
WCB	-0.30715				D	E	F	G	H	
BHB	-0.68681					E	F	G	H	I
TBF	-0.86063					E	F	G	H	I
WRS	-1.127					E	F	G	H	I
BCW	-1.172						F	G	H	I
OMR	-1.63842							G	H	I
CSB	-1.67733							G	H	I
MPH	-1.79018								H	I
GH	-2.04367									I

7.3.6 Nest cavity orientation of cavity nesting birds

Orientation of nest entrances is grouped into eight compass directions, namely South, North, East, West, North-east, South-west, South-east and North-west. For both primary and secondary cavity nesters, orientation of the nest cavity entrances was randomly distributed. Most of the nest cavity entrances of both primary and secondary cavity nesting birds were oriented in south and south-east direction.

Primary cavity nesters' nest orientation had mean angular vector μ =147° ± 67° (95% Confidence Intervals = 133° – 160°) with statistical preference (Rayleigh test, Z = 28.47, p < 0.001 and Watson's test, U^2 = 1.57, p < 0.005; n=116) (Figure 7.15a). Secondary cavity nester nest orientation had mean angular vector μ = 141° ± 90° (95% Confidence Intervals = 124° – 157°) with cavity nesters statistical preference (Rayleigh test, Z = 12.24, p < 0.001; Watson's test, U^2 = 1.29, n=260, p < 0.005) (Figure 7.15b) respectively. Mean orientation did not significantly differ between primary and secondary cavity nesting birds (Watson's two sample U^2 test: U^2 = 0.33, p > 0.5; n=116 for PCNs & n= 260 for SCNs).

a)

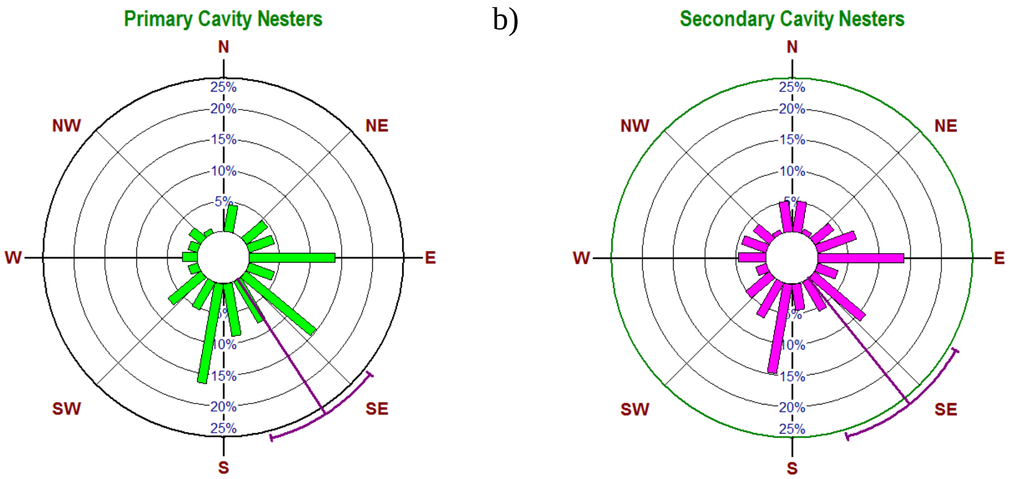


Figure 7.15 Nest orientations of primary (a) secondary cavity nesters (b) in the riparian forest

7.4 Discussion

7.4.1 Primary Cavity Nesters (PCNs)

Woodpeckers and barbets constitute primary cavity excavators in Asian forests. In tropical forests of southern Western Ghats of India, woodpeckers and barbets formed sole cavity excavators (Santharam, 2006; Yahya, 1988). According to Hussain *et al.* (2013) Woodpeckers and Blue-throated barbets constituted the primary cavity nesters in the mixed forests of the Himalayas in Pakistan. In Taiwan, Koh and Lu (2009) reported that Taiwan Barbet *Megalaima nuchalis* constitute the primary cavity excavator. From the studies from India and neighbouring Asian countries it is inferred that woodpeckers and barbets constitute the major nest excavators in the tropical Asia.

The preference for tall trees and high nest placement was exhibited by primary cavity nesters like woodpeckers and barbets. It appears to be an adaptation to avoid predation by terrestrial predators. The secondary cavity nesters also choose tall trees with large diameter trees for nesting. They nested in bird excavated cavities or suitable natural cavities. Large diameter nest trees may restrict predators from reaching the nest by allowing cavities to have thicker walls (Kilham, 1971; Harestad and Keisker, 1989). Generally strong excavators excavated cavities of high wall thickness (Christman and Dhondt, 1997).

Primary cavity nesters excavated their nests in higher locations of trees. The reason for choosing higher nest sites by the excavators is to avoid predation (Hussain *et al*., 2013). In the present study, this trend was observed, that is the excavators excavated their nest cavity high up on trees.

In the study area, woodpeckers favoured tree species which are taller and larger in diameter for nesting. Greater Golden-backed Woodpecker and White-napped Woodpecker placed their nests high up in larger trees, and this tendency was also observed in the case of barbets (Coppersmith Barbet, Brown-headed Barbet and White-cheeked Barbet). Similar trend was reported by Kosiński *et al.* (2006) in a riverine forest in Central Poland.

Many investigators reported that woodpeckers nest in large trees (Bull and Meslow, 1977; Welsch and Howard, 1983; Zarnowitz and Manuwal, 1985; Schreiber and deCalesta, 1992). Woodpeckers chose trees that were larger in diameter than adjacent potential nest trees. There are many possible advantages to nesting in larger trees.

Larger trees may contain more places to excavate and probably older and therefore more chance for decay. Additionally, larger trees enable construction of cavities with thicker walls, which provide thermal insulation, protection from predators, and lower probability of breaking at cavity height (Kilham, 1971; Miller and Miller, 1980). A similar finding was reported by Adkins Giese and Cuthbert (2005) in Upper Midwestern, Kosinski and Kemba (2007) in Western Poland, Haretad and Keisker (1989) in British Columbia, Joy (2000) in North Central British Columbia, McClelland and McClelland (2000) in the Flathead National forest, North Western Montana, USA, King *et al.* (2007) in Wisconsin, USA, Martin *et al.* (2004) in interior British Columbia. Both large and small woodpeckers commonly prefer trees with greater diameters and large trees. This tendency has been observed in several woodpeckers (Yamauchi *et al.,* 1997) in urban and rural areas in Japan; (Hooge, *et al.* 1999) in Hastings Natural History Reservation Central Coastal California; (Hartwig *et al*., 2004) in South Eastern Vancouver Island, British Columbia; (Unno, 2004) in forest habitat, Hokkaido, (Newlon and Saab, 2011) in a riparian habitat in Idaho, North America, (Santharam, 2006) in dry deciduous forest in Western Ghats (Hussain *et al.,* 2013) in a coniferous forest in Pakistan. According to Miller and Miller (1980), larger trees enable construction of cavities with thicker walls, which provide thermal insulation and protection from predators.

In the present study, small woodpeckers (Brown-capped Pygmy Woodpecker) preferred taller trees with large girth. This tendency has been reported previously for several woodpecker species (Yamauchi *et al*. 1997; Hooge *et al*., 1999; Hartwig *et al*., 2004; Unno *et al*., 2004; Newlon and Saab, 2011). Shiina *et al*. (2013) found that Japanese Pygmy woodpecker (small size) chose large dead trees.

The nest tree diameter of woodpecker nest trees generally corresponded with woodpecker body size. Generally, woodpeckers with large body sizes require large diameter nest trees (Conner *et al*., 1975). It is found to be similar to other studies *viz.*, Conner *et al.,* 1975; Brawn *et al.,* 1984; Raphael and White, 1984; Li and Martin, 1991). Woodpeckers chose nest trees that were taller than adjacent potential nest trees. When taller trees are available, nest heights tend to be higher because high nests make nest cavities less easily detected to be reached by predators (Miller and Miller, 1980). A nest located high in the tree gives the woodpecker more time to dislodge or discourage a predator climbing the trunk (Kilham, 1971). Other investigators have also found that woodpeckers choose taller trees (Welsch and Howard, 1983; Zarnowitz and Manuwal, 1985; Sedgewick and Knopf, 1990; Joy, 2000).

The mean nest tree height and nest cavity height of woodpeckers differed significantly among the various species of woodpeckers in the present study. This is in correspondence with the findings of Conner *et al.* (1975), Stauffer and Best (1982), Brawn *et al*. (1984), Raphael and White (1984) and Harestad and Keisker (1989).

Tree condition

In the study area, most nests of woodpeckers were in live trees. This is in correspondence with the results reported by Nielsen-Pincus and Garton (2007) for Black-backed Woodpeckers in the Blue Mountains of North Eastern Oregon. The more stable microclimate inside the holes within living trees might be the consideration (Wiebe, 2001) of woodpeckers for choosing live trees.

In present study, secondary cavity nesters' nest cavities located in tall trees and large girth trees with live trees. Secondary cavity nesters also use larger and live trees for nesting in Mongolia (Bai *et al.,* 2003) in primeval temperate forest, Poland (Wesolowski, 1989). Security could be an important advantage of nesting in a living tree. The more stable microclimate inside holes within live trees might be another consideration (Wiebe, 2001).

Nest height

In the present study, the excavated cavities were found comparatively at a greater height. This could be related to the assumption that excavators tend to prefer higher nest sites to avoid predation. This trend has been reported in a coniferous forest in Pakistan (Hussain *et al.,* 2013), in a primeval forest of Mongolia (Bai *et al.,* 2003), in mixed deciduous forest, south central British Columbia (Harestad and Keisker, 1989) and in a moist mixed deciduous forest of Western Ghats, Kerala (Santharam, 2006) in a deciduous forest, Sweden (Carlson *et al.,* 1998).

Nest location

Cavities opted by cavity nesters had narrower small entrance holes and were at greater heights in trees which are thought to be important for reducing predation risk (Nilsson, 1984; Alatalo *et al.,* 1988, 1991; Carlson *et al.,* 1998). However, there are certainly more attributes of a cavity that render them predator safe, for instance whether the entrance hole is visible from the ground. The differences between the vertical diameter of the entrance and the entrance area probably reflect a difference in body size between the Greater Golden backed and White napped woodpeckers. The small variation in the entrance as compared to other nest cavity dimensions is most likely to constitute an anti-predator adaptation. Similar findings have been reported by other studies (Kawada, 1980; Yamauchi *et al*., 1997; Kosenko and Kaygorodova, 2003). In all cited studies, the entry widths were the least variable of all cavity characteristics.

Greater foliage cover around cavity nests may increase nest predation because parent birds may have difficulty detecting approaching predators (Nilsson, 1984; Belles-Iseles and Picman, 1986; Finch, 1989). In the study area, except pygmy woodpecker other woodpeckers nested on main trunk or main branch of live trees probably for easily detecting approaching predators (snakes). This similar tendency by Acorn Woodpeckers has been observed in live trunks (Arsenault, 2004) coniferous-deciduous forests, Mexico.

In my study area, Greater Golden-backed Woodpeckers excavated the nest cavities in high up on tree trunk live substrates and additional two to three cavities excavated along the tree trunk, above and below the nest hole. Santharam (2006) opined that creation of additional cavities would help the adult birds for greater vigilance of nests against the predators.

In the present study area, large woodpeckers' cavity entrances were vertically faced probably for facilitating easy perch at the base of the cavity entrance. However, all the nests of Brown-capped Pygmy Woodpecker were facing downwards. Studies have reported that cavities facing downwards may prevent the rain water coming inside the hole. (Jackson, 1976; Gutzwiller and Anderson, 1987; Ingold and Densmore, 1992; Ingold, 1994).

Brown-capped Pygmy Woodpeckers' nest entrances were almost uniformly inclined downwards. A similar observation were recorded in some other woodpecker species (Conner, 1975; Hooge *et al.,* 1999) but was not yet reported for Greater Golden-backed Woodpecker and White-napped Woodpecker. It is likely that primary cavity nesting birds (woodpeckers and barbets) deliberately select entrances in downward inclined locations to avoid precipitation entering the nest, as suggested by Conner (1975) and Yahya (1988). Although downward facing cavities should provide increased protection from wind and rain and perhaps enhance fungal growth that would facilitate the nest excavation (Conner, 1975), vertical-facing cavities must be superior in other ways e.g., lack of parasites, more suitable dimensions Gutzwiller and Anderson (1987).

In the present study area, barbets (*Psilopogon* spp) excavated cavities in tall trees (18.5±5.0 m) having large girth (286.4±132 cm). The utilization of tall trees with huge girth by barbets has been observed in a Broadleaved forest in Taiwan (Koh and Lu, 2009), in a Garden site at Bangalore, India (Vergese and Govindakrishnan, 1975), in the Periyar Tiger Reserve, Western Ghats, India (Yahya, 1988).

In the present study area, barbets (*Psilopogon zeylanica*, *P. rubricapila* and *P. haemacephala*) were found to excavate nests in select tree species. Higher proportions of nests were found in snags and dead branches of *Terminalia arjuna* and *Mangifera indica*. Barbet species highly favoured dead substrate for nesting. This tendency has been observed by Yahya (1988) in the dry deciduous forests of Western Ghats, Ho (1990) in Yang-mingshan National Park, Taiwan, Koh and Lu (2009) in Taipei Botanical Garden, Taiwan. Compared to woodpeckers, barbets do not have sharp bill and hence favour dead tree trunks or dead branches for nest excavation as it is easier to excavate cavities in dead branch/trunk.

Barbets always prefer more or less horizontal branches and excavates strictly on the underside of the branch, to avoid predators and it prevents rain water from entering the nest cavity (Yahya, 1988). He further observed that barbet excavated holes with small entrance, the narrow nest cavity is of advantage as it protects the nest from predators (Yahya, 1988). In present study, barbets chose dead branches as nest site and excavated cavity in horizontal side of branches probably to avoid predators such as Jungle Crow and Shikra.

Substrate condition

Large woodpecker species select and nest more on the trunks having larger diameter at the nest height and most used live substrates (Santharam, 2006). Similar findings emerged from the present study which was evident from the observation that Golden-backed Woodpeckers and White-napped Woodpeckers had excavated nest cavities in live trees with large diameter. Woodpeckers excavated their nest cavity in healthy, more resistant live trees and the woodpeckers spend more energy in cavity excavation. It was opined that the wood hardness may be a good defense mechanism against nest predation (Kilham, 1971).

Weak excavators need softer substrates to excavate their cavities (Hagvar *et al.,* 1990). Besides that, smaller diameter nests ensure that the nest holes are not taken over and used by larger species (Short, 1979; Hagvar *et al*., 1990). Such conditions are met when birds choose dead substrate and smaller branches, which are usually located higher up in the trees. Large woodpecker species have been choosing opposite trend. They nest mostly on trunks having larger diameter at the nest height and mostly use live substrates (Arsenault, 2004; Santharam, 2006).

Since the hardness of trees decreased with their increasing height (Schepps *et al*., 1999) nesting in higher and softer parts may be beneficial for species with weaker excavating abilities. This statement is supported by the smaller woodpecker species excavated nest holes relatively higher, more frequently in limb/branch and generally in weakened and dead tree fragments compared to larger species (Hagvar *et al*., 1990). In the case of large woodpeckers of my study site, nesting at greater height may be a form of protection against predators like Rat Snake and Monitor Lizard.

In the preset study, Brown-capped Pygmy woodpeckers preferred small dead branches for nesting probably to avoid large predators approaching the nest holes. This is in correspondence with the findings of King *et al*. (2007) on Red-headed Woodpeckers *Melanerpes erythrocephalus* in Restored Savannas of Central Canada.

Excavating cavity in harder substrate and large diameter trees (i.e. thicker walls) may make nests less susceptible to predation (Christman and Dhondt, 1997; Schepps *et al.,* 1999). These characteristics may make the cavity inaccessible for smaller, weaker predators that are unable to scratch or chew through and or the energetic input for the predator exceeds an acceptable threshold.

Barbet species highly favoured dead substrate for nesting because they have weak excavator ability. This tendency has been observed by Yahya (1988) in the dry deciduous forests of Western Ghats, Ho (1990) in Yang-mingshan National Park, Taiwan, Koh and Lu (2009) in Taipei Botanical Garden, Taiwan, Lok and Lee (2009) in an urban area in Singapore. Compared to woodpeckers, barbets do not have sharp bill and hence favour dead tree trunks or dead branches for nest excavation as it is easier to excavate cavities in dead branch/trunk.

Cavity size

To distract competitors and predators, nest-hole entrances are excavated in the smallest possible dimensions (Short, 1979; Hebda, 2009). In the present study, primary cavity nesters (barbets and small woodpeckers) were found to make cavities with small entrances. Primary cavity nesters such as Coppersmith Barbet and Brown-capped Pygmy Woodpecker created cavities with smaller entrances to avoid nest predation. They frequently choose small lengthy dead branches for nesting because large predators do not enter and affect the nest cavity.

Brown-capped Pygmy Woodpeckers build smaller nest cavities, excavate high in the trees with thin substrate than Greater Golden-backed woodpeckers and White-napped woodpeckers. This might have been evolved to reduce cavity leptoparasitism and prevent predators. Similar finding was reported in woodpeckers that they use softer parts of the tree (dead substrate) which are beneficial for species with weaker excavating abilities such as the Middle-spotted Woodpecker (Jenni, 1981; Schepps *et al*., 1999). Lesser Spotted Woodpecker (Charman *et al*., 2012), Great Spotted Woodpeckers (Kosinski and Ksit, 2007; Mazgajski, 2002), Japanese Pygmy Woodpeckers (Shiina *et al*., 2013), White-bellied woodpecker (Santharam, 2003), Red-bellied and Red-headed woodpeckers (Ingold, 1994), Black woodpecker (Conner *et al*., 1975), Pileated woodpecker (Bull and Meslow, 1977), Norwegian woodpecker (Hagvar *et al*., 1990). In present study Brown-capped Pygmy woodpeckers chose large trees and they nested only in dead branches of small thickness in live trees for nesting. A similar trend was observed in other studies (Gutzwiller and Anderson, 1987; Sedgwick and Konpf, 1990; Shiina *et al*., 2013; Charman *et al.*, 2012; Santharam, 2003, 2006; Dempsey, 2013). In the present study area, Brown-capped Pygmy woodpeckers preferred lengthy dead branches with small thickness for nesting to avoid large predators. A similar observation was seen in Red-headed woodpeckers in Restored Savannas of Central Canada (King *et al*., 2007).

In the present study area, primary cavity nesters excavated their cavity based on their body size. Small woodpeckers and barbets' cavity entrance and cavity size were smaller when compared to cavities of large woodpeckers *viz.,* Greater Golden-backed woodpeckers and White-napped woodpeckers. Cavity height and hole entrance area can influence predation risk (Nilsson, 1984), while internal cavity size may relate to fecundity and fledging success. Li and Martin (1991) found that secondary cavity nesters use cavities that are lower and more concealed than excavators. In other studies, Tree Swallows, Red-napped Sapsuckers, Black-caped Chickadees and Mountain Chickadees preferred higher nests, while Northern Flickers preferred lower nests (Hill and Lein, 1988; Dobkin *et al.,* 1995).

Barbets' nest cavities have small entrance holes and are related to the bird sizes. To prevent squirrels, raptors, Monitor Lizard *Varanus indicus* and other predators from invading the nest cavity, bird species in the family Capitonidae usually design the entrance size according to their body size of their mate and themselves (Yahya, 1988). The potential predators of *Psilopogon haemacephalus viz.*, Jungle Crow *Corvus macrorhynchos* and Shikra *Accipiter badius* can only watch their preys from outside the nest and can not successfully enter the nest cavity due to narrow entrances.

Cavity size is an important factor in determining cavity use because it influences the array of species able to use the cavity, and because it can affect reproductive success, competition, and predation. Entrance size limits the range of species that can use a cavity (Peterson and Gauthier, 1985). Smaller entrance holes are advantageous in deterring predators and in reducing the chance of eviction from the cavity by a larger competitor (Zeleny, 1978; Moeed and Dawson, 1979; Robertson and Rendell, 1990). Peterson and Gauthier (1985) found that cavity volume and entrance size were the most important variables in determining cavity occupancy by flickers and several secondary cavity nesters in British Columbia. Large cavities may allow for better thermoregulation by chicks on hot days (Balen, 1982) and reduce competition for space and feeding positions among siblings (Slagsvold, 1989).

Cavity depth may influence predation risk, as deeper cavities can prevent mammalian predators from reaching in to remove young. In the present study area, Tickell's Blue-flycatcher and White-rumped Shama chose natural cavities, which were open, small, deep cavity for nesting. In this type of nest cavity, eggs and young ones fall easy prey for predators such as Rat snake and Monitor Lizard.

Generally, the ideal cavity to maximize fecundity and minimize depredation is a large-volume cavity with a small entrance. The optimal cavity size and volume should scale to the body size of each species, thus allowing considerable scope for niche partitioning in a diverse community of cavity nesters (Wesolowski, 2002; Mitrus, 2003; Remm *et al.,* 2006).

7.4.2 Secondary Cavity Nesters (SCNs)

In the present study area, the secondary cavity nesters such as Hornbills (Great Hornbill, Malabar Pied Hornbill), Mynas (Common Myna, Jungle Myna), Parakeets (Malabar Parakeet, Rose-ringed Parakeet), Owls (Indian Scops Owl, Jungle Owlet) Common Hoopoe, Indian Roller, Oriental Magpie Robin, Tickell's Blue-flycatcher and White-rumped Shama utilized both live and dead trees for nesting. However, the proportion of live trees used was found higher. In a Canadian Temperate Forest, 55% of secondary cavity-nester nests were found in live trees and remaining 45 percent on unhealthy trees (Martin *et al.,* 2004). Gibbs *et al.* (1993) observed that in temperate forests, dead trees were mostly used by secondary cavity nesters. Steeger and Dulisse (2002) reported that dead trees were mostly used by secondary cavity nesters in British Columbia. In the present study area, majority (62.69%) of the nests of secondary cavity nesters were found on live trees, higher than the values reported in other studies. The lesser proportion of snag use in the present study site may be due to the non-availability of sufficient number of dead trees. Hornbills are secondary cavity nesters; they use natural cavities of large trees in the forest (Kemp, 1995). In the present study, Great and Malabar Pied hornbills nested in tall and large live trees with an average nest height of 14.4 m above from the ground and 168 cm girth at nest height. Studies on hornbills by Mudappa and Kannan (1997), Maheswaran and Balasubramanian (2003), Datta and Rawat (2004) and Santhoshkumar and Balasubramanian (2010) reported the use of tall and large trees by hornbills in Indian forests.

Some secondary cavity nesters prefer small entrance cavities. In the present study area, SCNs such as mynas, parakeets, Great Tit, Jungle Owlet, Indian Roller prefer cavities with entrances not much larger than themselves, thus exclude the entry of larger predators. These species relied on cavities excavated by primary cavity nesters. One of the major secondary cavity nesters of the study area, the Hornbills used natural cavities with large entrance owing to their large body size. Some secondary cavity nesters such as Tickell's Blue-flycatcher, Common Hoopoe, White-rumped Shama and Indian Scops Owl chose only natural cavities and never used bird excavated cavities. Similar findings were reported by Cockle *et al.* (2011b) in a Neotropical Atlantic forest, Argentina.

Secondary cavity-nesters in the Atlantic forest used cavities excavated by woodpeckers in proportion to their availability. In contrast, SCNs in Europe (Remm *et al.*, 2006; Wesołowski, 2007), Canada (Aitken and Martin, 2007; Cockle *et al.*, 2011b) and in the present study area used bird excavated cavities.

In the present study area, majority of the secondary cavity nesters used bird excavated nest cavities for nesting and less proportion of SCNs used natural cavities. Natural cavities used for nesting tended to be larger internally and had larger entrances than were the excavated cavities. Both cavity entrance size and internal size have been linked with fecundity and reproductive success in cavity nesters. Cavities with larger volume may allow for larger clutch sizes, better thermoregulation and protection from predators (Alatlo *et al.*, 1988; Slagsvold, 1989; Wiebe and Swift, 2001). Conversely, cavities with small entrances may restrict access by medium and large nest predators (Wesolowski, 2002; Remm *et al.*, 2006). Among the species using natural cavities there may be a trade-off between the potential advantage of larger internal area and potential disadvantage of layer entrance area.

Nest height may influence nest success, as small birds or mammals are capable of depredating lower nests more quickly and efficiently by not providing parent birds time for detection and defense (Nilsson, 1984). Nest cavities at higher locations of the tree also help to obscure auditory and olfactory cues provided by nestlings and vocalizing adults to terrestrial predators (Mahon and Martin, 2006).

In the present study, secondary cavity nesters chose suitable cavities that had good visibility, located on high on tree trunk or branches. According to Cockle and Bodrati, 2009; Cockle *et al.*, 2011b, secondary cavity-nesters select deep, high cavities in relatively isolated trees with good visibility, perhaps reducing their risk of predation (Purcell and Verner, 1999) and which can be another advantage to maximize nest space and thermal insulation (Joy, 2000; Aitken and Martin, 2004). Although cavity height was positively correlated with cavity depth and tree height, cavity height seems more likely to be the characteristic that birds select directly. Deeper cavities were selected and reused more often by a wide variety of cavity nesters in temperate and subtropical forests (Gibbons *et al*., 2002; Aitken and Martin, 2004; Berkunsky and Reboreda, 2009; Koch *et al*., 2008a; Politi *et al*., 2010). Higher cavities were also selected preferentially by secondary cavity-nesters in the subtropical forests in the Andes (Politi *et al*., 2009) and Australia (Cameron, 2006) and temperate forest in Europe (Wesołowski and Rowinski, 2004). Several studies have shown that nest success is greater in cavities higher above the ground, with larger internal volume (Nilsson, 1984; Li and Martin, 1991; Wiebe and Swift, 2001; Mahon and Martin, 2006).

7.4.3 Nest Cavity Orientation

Compass orientation of cavity nesting birds' nest entrances has been found to be non-random for some cavity nesting birds (Reller, 1972; Conner, 1975; Inouye *et al.,* 1981; Aitken and Martin, 2007) and random for certain others (Rendell and Robertson, 1994). Nest cavities oriented to the south and east, may allow sun light to warm the nest or permit nest ventilation by prevailing winds (Conner, 1975).

In the present study area, although nest entrance directions are non-randomly distributed, a higher proportion was facing south and southeast. Similar findings were reported by Arsenault (2004) in mixed coniferous-deciduous forest, New Mexico, Losin *et al*. (2006) in Aspen Woodlands of Western Colorado and Aitken and Martin (2007) in a old mixed forests of Western Canada. Many birds select their nest cavities based on microclimate characteristics (Wachob, 1996). Woodpeckers and some secondary cavity nesters preferred south facing cavities for cool environments (Inouye, 1976; Dobkin *et al.,* 1995). Rendel and Robertson (2004) reported that south facing cavities are exposed to sun for a longer period during the day, and this may help to warm their young ones and keep the cavity dry. Losin *et al*. (2006) reported that sapsuckers' nest entrances faced south and it may be to get exposure to direct sun there by creating a warmer nest microclimate. According to Dawson *et al*. (2005) warm nest temperature increases survival and growth rates of Tree Swallows. Since nest-site preferences appear to be influenced by microclimatic conditions it could be expected that woodpeckers would prefer to orient nest-holes to direct insulation, i.e., towards the South East (e.g. Hooge *et al*., 1999; Wiebe, 2001).

8 NEST CAVITY SEQUENTIAL UTILIZATION BY BIRDS AND NEST WEBS IN THE RIVERINE FOREST

8.1 Introduction

Cavity nesting bird communities form a major component of the forest communities and rely on the resource of tree cavities for nesting (Scott *et al.,* 1980). The tree cavities are an essential resource for species of wild fauna that require cavities for nesting and roosting (Steeger and Dulisse, 2002; Cockle *et al.,* 2011b) and their nestlings, eggs and chicks get protection from the unfavorable and predators (Ingold and Densmore, 1992; Ingold, 1994; Newton, 1994; Nowak, 1999; Kunz and Lumseden, 2003). Martin and Eadie (1999) proposed a direct analogy to 'food webs' that cavity nesting bird communities can be described as hierarchical 'nest webs' with the cavities as the main resource, which have inter-specific and intra-specific interactions within the cavity nesting bird communities. Nest webs are interaction webs analogous to trophic webs, wherein tree cavities are the resource that flows from producers to consumers. Cavity nesting birds are classified into different guilds according to their mode of cavity acquisition. Primary cavity nesters, including woodpecker and barbet species, excavate cavities on trees for nesting. Secondary cavity nesters cannot excavate their own cavity, and thus rely on the excavated cavities constructed by primary cavity nesting birds (Steeger and Machmer, 1995; Martin *et al.,* 2004) or utilize the naturally formed cavities (McClelland *et al*., 1979; Newton, 1994; Martin and Eadie, 1999). Woodpeckers and barbets (primary cavity excavators) typically excavate new cavities each year for nesting and their nest cavities and abandoned or surplus cavities are regularly used by secondary cavity nesters (non-excavators). As "ecosystem engineers", woodpeckers excavate cavities that provide nesting, roosting and resting sites for secondary cavity users (SCUs), which are interactions between inter-species and intra-species dependent on cavities (Raphael and White, 1984). The primary cavity nesting birds can be considered "keystone species" in forest ecosystems, because many other species of wildlife are dependent on them for cavities (Wilson, 1992; Dailey *et al.,* 1993; Gorman, 2004;

Wiebe *et al.,* 2007; Michalczuk *et al.,* 2011). Cavities are an important resource in forests for many birds and mammals which use them for nesting, roosting and escaping from predators (Mudappa and Kannan, 1997). Conservation of these communities may depend critically on understanding species interactions and key relationships between producers and consumers (utilisers) of the cavity resource (Cockle *et al.,* 2011a; Cornelius *et al.,* 2008).

Cavity reuse patterns are central to understanding the bird population and evolution of cavity nesting birds (Sedgwick, 1997). Interspecific sequential cavity use may indicate similar preferences for nest sites (Balen *et al.,* 1982). Yet studies on cavity reuse were mainly focused on the reuse by single species (Mazgajski, 2003; Stanback and Rockwell, 2003; Monterrubio-Rico *et al.,* 2006; Berkunsky and Reboreda, 2009; Rivera *et al.,* 2011; Ibarra *et al.,* 2014) or the specific of species of woodpecker cavities used by others (Kühlke, 1985; Johnsson *et al.,* 1993; Bonar, 2000; Kotaka and Matsuoka, 2002). Few studies have considered the reuse pattern of the whole cavity nesting bird species (Wesołowski, 1989; Sedgwick, 1997; Aitken *et al.,* 2002; Martin *et al.,* 2004; Blanc and Walters, 2008a; Saab *et al.,* 2009).

Globally, tree and nest cavity characteristics are a critical component of forest ecosystems and are well studied in temperate Europe, North America and Australia (Goldingay, 2009; Remm and Lohmus, 2011). Many studies on nest-site selection have been carried out by using nest boxes (Drent, 1987; Møller, 1989; Sonerud, 1993; Davis *et al.,* 1994; Rendell and Verbeek, 1996a,b; Summers and Taylor, 1996; Purcell *et al.,* 1997; Mitrus, 2003; Smith *et al.,* 2007; Camprodon *et al.,* 2008) and a few studies on bird excavated cavities or natural cavities used by secondary cavity nesting birds (Li and Martin, 1991; Martin and Eadie, 1999; Aitken *et al.,* 2002; Bai *et al.,* 2003; Martin *et al.,* 2004; Wiebe *et al.,* 2007; Sánchez *et al.,* 2007; Blanc and Walters, 2008b; Cockle *et al.,* 2011b). Nothing much is known about nest tree characteristics, cavity features and cavity reoccupation by secondary cavity nesters in Asia. Only a few researchers have investigated the breeding ecology of cavity nesting bird community in India. Most of the studies on cavity nesting birds in India focused on single species Malabar Parakeet (Gokula and Venkatraman, 2003), Indian Roller (Sivakumaran and Thiyagesan, 2003), Malabar Grey Hornbill (Maheswaran and Balasubramanian, 2003) Great Hornbill (James and Kannan, 2009), Indian Grey Hornbill (Santhoshkumar and

Balasubramanian, 2010), Barn Owl (Santhanakrishnan *et al*., 2011), Oriental Magpie Robin (Bhatt *et al*., 2014), Common Myna (Nithiyanandam and Asokan, 2015), barbets (Yahya, 1988), woodpeckers (Santharam, 2006). There are only two studies on the cavity nesting bird communities in India, *viz.*, Thiyagesan (1991) in an agricultural landscape in southern India and Pandey and Mohan (1993) in Tons river Valley, northern India.

In this chapter, nest data are incorporated into nest web diagrams (Martin and Eadie, 1999), which reflect the flow of cavity creation and use between levels of primary cavity nesting birds, secondary cavity nesting birds and cavity resources (trees) to determine cavity producer species level or guild level, the cavity use by the cavity nesting bird community and the characteristics of reused cavities were investigated in the riverine forest.

8.2 Methodology

8.2.1 Nest searches

Active nest cavities were searched of cavity nesting birds in the riparian forest site. The nest cavities were examined at least twice in a week in the breeding season from December 2013 to July 2015. All active nest cavities were identified and marked in year 2013 and year 2014 (Chapter-VI). Those active nest cavities (previous year used cavities) were counted and repeatedly checked weekly twice in the subsequent years (year 2014 and year 2015) as cavity re-usage.

Cavities were classified into the following different types: 1) bird excavated cavities and non-excavated (natural) cavities, which formed from fallen branches and natural damages of tree trunk. If any birds or other animals were found, the cavity was classified as 'occupied' and as excavated and natural cavities. The occupied cavities were located and identified and the bird species occurring in the cavity was noted. Nest cavities were located from the ground by observing breeding behaviour of adult birds, or begging chicks, and scratching or knocking on cavity trees and searching for evidence of cavity re-use (feathers, droppings, and nest materials) at the base of trees. A cavity was defined as an active nest when an adult bird was observed bringing in nesting material or food. These observations were made from the ground by using a pair of binoculars.

8.2.2 Nest tree and nest cavity features

For each nest cavity the following parameters were recorded: (1) Features of the nest tree, including tree species, tree girth at breast height (gbh), tree condition (categorized as living, partially dead and snag), and (2) characteristics of the nest cavity, cavity type (excavated or natural cavities), nest cavity height, substrate circumference, substrate condition (categorized as living or dead), cavity entrance diameter, cavity entrance area (circumference) and cavity internal length and width.

8.2.3 Sequential cavity use

Analysed the reuse pattern of the active nest cavities found in the subsequent year (2013 and 2014). Non-parametric Chi-square test was applied to compare the reuse patterns of guild level (between strong excavators, weak excavators and non-excavators) and at species level. To compare the characteristics of cavities that were reused with those that were not reused by birds, Non parametric Chi-square test was applied for categorical variables (tree condition, cavity type, substrate condition). Relationship between cavity sizes and bird body mass were tested for simple linear regression test. The mean body mass data from the literature were used for this (Dunning Jr, 2008) and regressed estimated body mass against entrance cavity size and cavity internal width (diameter). Some secondary cavity nesting bird species such as Common Hoopoe, Indian Scops Owl, Oriental Magpie Robin, Tickell's Blue-flycatcher, White-rumped Shama were excluded from the regression analysis because of the irregular size of natural cavities chosen by them (shallow cavity, chimney with wide cavity entrance).

8.2.4 Nest web Analysis

Finally, nest data incorporated into nest web diagrams following Martin and Eadie (1999), which reflect the flow of cavity creation and use between levels of primary cavity excavators, secondary cavity nesting birds and trees (cavity resources). Nests used in the web include reuse of the same cavity across years but not renesting attempts by the same species in the same cavity within the same year. Nest webs are shown thick lines to indicate the proportion of a species' nests produced by a given source.

In the study area, woodpecker cavities were excavated by the Greater Golden-backed woodpecker, Brown-caped woodpecker and White-naped woodpecker (primary cavity nesters). Barbet induced cavities were excavated by the Brown-headed barbet, Coppersmith barbet and White-cheeked barbet (primary cavity nesters). These two types of cavities were referred as excavated cavities and the others as non-excavated cavities. Tree resources formed the fundamental level in the nest web. Excavated cavities by primary cavity nesters and non-excavated cavities (natural cavities) constituted the second level. A primary cavity nester (PCNs) species was linked to a tree species with different health condition of trees (live, partially dead, snag). The strength of the linkage was indicated by the proportion of nests of this primary cavity nester species excavated in the tree resource. Natural cavities (non-excavated cavities) were linked to tree resources (live, partially dead, snag). Secondary cavity nesters (SCNs) represented the third level in the nest web. A secondary cavity nester species was linked to cavity excavators- the primary cavity nester species or linked to natural cavities. The strength of linkage was also decided by the percentage of nest usage. The nest web was then applied to test the roles of excavator species (woodpeckers, barbets) and nest tree resources in the cavity nesting bird community. After checking each variable separately, a cluster analysis (using average linkage between groups) was applied to species with similarities in nest cavity and tree characteristics (cavity height above ground, cavity entrance circumference, cavity entrance diameter, vertical depth and tree GBH) to calculate the nest site similarity among species.

8.3 Results

8.3.1 Nest sequential reuse at guild level

A total of 318 active cavities were recorded during 2013-2015 which were used by 20 bird species. During 2013, 118 cavities were recorded, in 2014 additional 174 cavities were found and in 2015, 26 cavities were added new. Of the 118 cavities found during the first year (2013), 31.43% was reused in 2014. Of the total 292 cavities (1^{st} year + 2^{nd} year) 68.57% was reused in 2015 (Table 8. 1). A summary of reuse of nesting cavities by cavity nesting birds are given in Table 8. 2.

Table 8.1 Nest cavities reused by cavity nesting birds in subsequent years of study (2014-15)

Year	Cavities recorded	Cavities reused	
		#	%
2013	118	--	--
2014	174	33	31.43
2015	26	72	68.57
Total	318	105	100

Among the 118 nest cavities, 31 cavities were created and used by excavator species (primary cavity nesters) and 87 cavities were used by secondary cavity nesting birds in year 2013. Seventeen out of 31 nest cavities created by excavators were reused by different secondary cavity nesting birds of which 13 (41.93%) were in 2014 and 4 (12.90%) in 2015. Of the 87 nest cavities used by secondary cavity nesting birds in 2013, 16 (18.39%) were reused by same species and 4 nests (4.59%) by different species in 2014. In the year 2015, 21.83% reused by same species and 6.89% reused by different species. Among the 174 nest cavities, 71 were cavities created and used by primary cavity nesting birds and 103 were nest cavities used by secondary cavity nesting birds in 2014. Of the 71 excavated cavities, 19 (26.76%) were reused by different species of primary and secondary cavity nesting birds. Of the 103 cavities used by secondary cavity nesting birds during 2014, 21 (20.38%) were reused by same species and 3 (2.91%) reused by different species in 2015 (Table 8.2). Woodpeckers (strong excavator) and barbets (weak excavator) used cavities were highly reused by different guild of non-excavators (SCNs) (75% and 25.58%) and few nest cavities of weak excavators were reused by same guild. The reuse rate of weak excavator (barbet) cavities was significantly lower than that of non-excavator (SCNs) cavities (χ^2 = 21.77, *df* = 1, *p* = 0.000; n= 93). Cavity reuse by same species of non-excavators is higher than that of the reuse by weak excavators (χ^2 = 45.07, *df* =1, *p* = 0.000; n=60) (Figure 8.1).

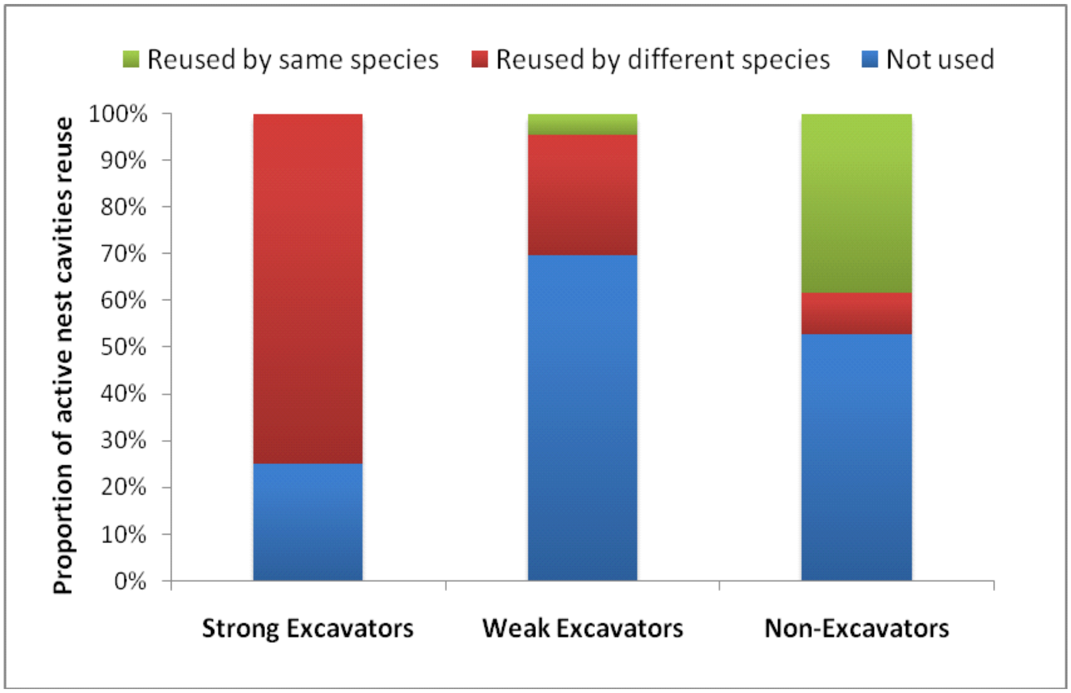


Figure 8.1 Proportion of active nest cavities reused in subsequent years in relation to cavity nesting guild.

8.3.2 Nest use at species level

Among the primary cavity nesting birds, Greater Golden-backed woodpecker excavated 4 cavities each in 2013 and 2014. These nest cavities were reused by Common Myna and Jungle Myna in year 2014. In the year 2014, previous cavities made by Greater Golden-backed woodpeckers were reused by Indian Roller and Common Myna (reuse rate 50% and 25%) in year 2015. Brown-capped Pygmy Woodpecker and White-naped woodpecker excavated three cavities each in year 2014. Two out of three nest cavities of Brown-capped Pygmy Woodpecker were used by Coppersmith barbet (33.33%) and White-cheeked Barbet (33.33%) in year 2015 which were renovated and reused by barbet species. Three cavities of White-naped woodpeckers were reused each one cavity by Common Myna (33.33%), Malabar Parakeet (33.33%) and Rose-ringed Parakeet (33.33%) in year 2015 (Figure 8.2). For barbets, 27 cavities were recorded in 2013 which of Brown-headed Barbet (n=11), Coppersmith Barbet (n=2) and White-cheeked Barbet (n=14) in year 2013. In 2014, 61 nest cavities of barbets were recorded which included Brown-headed Barbet (n=19), Coppersmith Barbet (n=12) and White-cheeked Barbet (n=30). Five out of 11 Brown-headed barbet nest cavities were reused by Common

Myna, Jungle Myna, Malabar Parakeet, Indian Roller and Great Tit in 2014. In the year 2015, 10 nest cavities of Brown-headed Barbet were reused by Common Myna, Jungle Myna, Great Tit and Rose-ringed Parakeet. Of the 14 White-cheeked barbet nest cavities found in year 2013 four cavities were used by Coppersmith Barbet, Common Myna, Jungle Myna and Oriental Magpie Robin in 2014. In the year 2015, 2 out of 30 nest cavities were created and used by White-cheeked barbet in 2014 which were reused by Great Tit in 2015 (Figure 8.2). Among the secondary cavity nesting birds, the cavities of Common Myna, Malabar Pied Hornbill, Malabar Parakeet, Rose-ringed Parakeet, Indian Scops Owl, and Common Hoopoe were highly reused by same species. Of the 31 Common Myna nest cavities found in year 2013, eight cavities were reused by same species and six were used by different species in 2014. Twenty three nest cavities of Common Myna were found in 2014 of which three cavities were reused by same species and one cavity used by Malabar Parakeet in 2015. Four nest cavities of Malabar Pied Hornbill were found in 2013 of which three were reused by same species in 2014. Out of the four nests that were found to be used by Malabar Hornbill in 2014, two were reused by same species in 2015 and one cavity occupied by Great Hornbill in 2015 (Figure 8.2). Malabar Parakeets were nesting in nine cavities in 2013 of which one cavity reused by same species in year 2014 and two were reused one each by the same species and different species in 2015. Of the six nest cavities used by Jungle Myna in 2013, three were reused by same species in 2015, while two were different species in year 2014 (Figure 8.2).

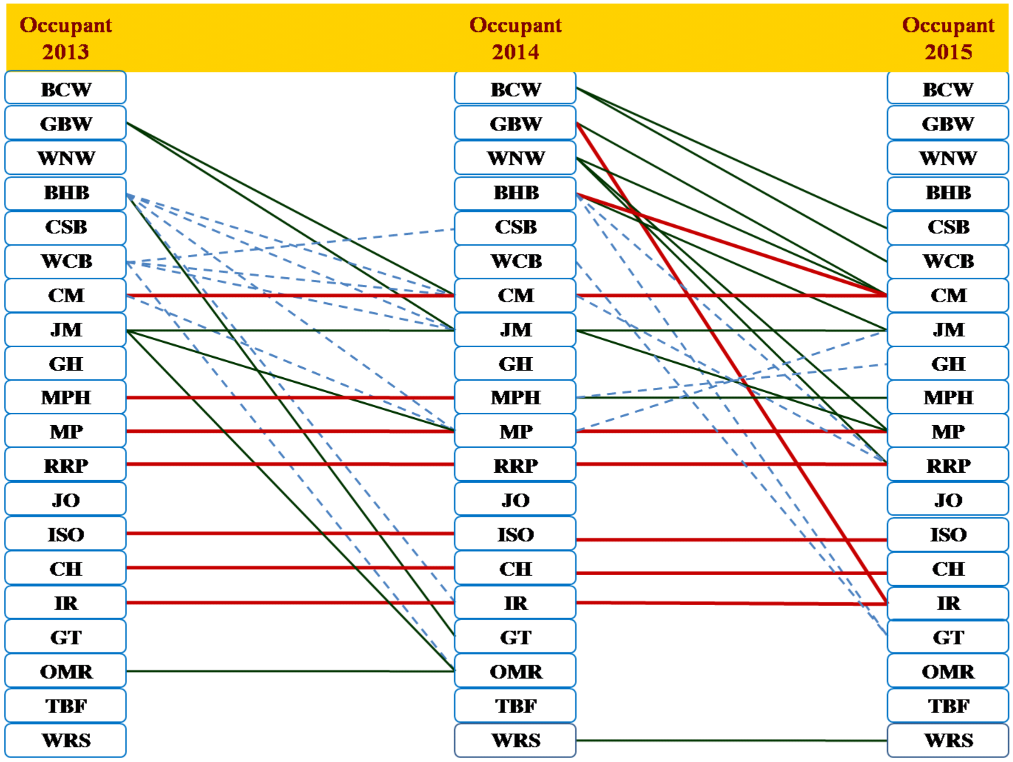


Figure 8.2 Reuse of nest cavities of 2013 to 2014 and 2014 to 2015 for each bird species

Dace lines (blue): reuse rate < 25%, thin lines (green): reuse rate 25-50%, thick lines (red): reuse rate > 50%.

Additionally, 18 cavities used by seven bird species were reused by three different animal groups such as reptiles (Monitor Lizard, Garden Lizard, Rat Snake), small mammals (Indian Giant Squirrel, Indian Palm Squirrel) and one insect (Honey bee). Overall, the proportion of nest cavities used by different animals namely Monitor Lizard (33.33%), Rat Snake (22.22%) and Garden Lizard and Indian Palm Squirrel 16.66% each and Indian Giant Squirrel and Honey bee 5.55% each. The proportion of bird- used cavities used by various other taxa is shown in Figure 8.3.

Table 8.2 Summary of reuse of nesting cavities by cavity nesting birds in riverine forest, Athikadavu Valley (2013-2015)

Bird species	**No. of nests found in 2013**	**Reuse in 2014**						**Reuse in 2015**						**No. of nests found in 2014**	**Reuse in 2015**					
		Unused		**Same species**		**Different species**		**Unused**		**Same species**		**Different species**			**Unused**		**Same species**		**Different species**	
		#	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**		**#**	**%**	**#**	**%**	**#**	**%**
PCNs																				
BCW	0	0	0.0	0	0.0	0	0.0	0	0.00	0	0.0	0	0.0	3	1	33.33	0	0.0	2	66.66
GBW	4	0	0.0	0	0.0	4	100.0	2	50.0	0	0.0	2	50.0	4	1	25.0	0	0.0	3	75.0
WNW	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	0	0.0	0	0.0	3	100
BHB	11	6	54.54	0	0.0	5	45.45	9	81.81	0	0.0	2	18.18	19	10	52.63	0	0.0	9	47.36
CSB	2	2	100.0	0	0.0	0	0.0	2	100.0	0	0.0	0	0.0	12	12	100.0	0	0.0	0	0.0
WCB	14	10	71.42	0	0.0	4	28.57	14	100.0	0	0.0	0	0.0	30	28	93.33	0	0.0	2	6.66
Total	**31**	**18**	**58.06**	**0**	**0.0**	**13**	**41.93**	**27**	**87.09**	**0**	**0.0**	**4**	**12.90**	**71**	**52**	**73.23**	**0**	**0.0**	**19**	**26.76**
SCNs																				
CM	31	26	83.87	3	9.67	2	6.45	22	70.96	5	16.12	4	12.90	23	19	82.60	4	17.39	0	0.0
JM	6	3	50.0	1	16.66	2	33.33	3	50.0	3	50.0	0	0.0	16	14	87.5	2	12.5	0	0.0
GH	1	0	0.0	1	100.0	0	0.0	1	100.0	0	0.0	0	0.0	1	1	100.0	0	0.0	0	0.0
MPH	4	1	25.0	3	75.0	0	0.0	1	25.0	2	50.0	1	25.0	4	1	25.0	2	50.0	1	25.0
MP	9	8	88.88	1	11.11	0	0.0	7	77.77	1	11.11	1	11.11	6	2	33.33	2	33.33	2	33.33

Bird species	No. of nests found in 2013	Reuse in 2014						Reuse in 2015						No. of nests found in 2014	Reuse in 2015					
		Unused		Same species		Different species		Unused		Same species		Different species			Unused		Same species		Different species	
		#	%	#	%	#	%	#	%	#	%	#	%		#	%	#	%	#	%
RRP	3	2	66.66	1	33.33	0	0.0	1	33.33	2	66.66	0	0.0	2	0	0.0	2	100.0	0	0.0
JO	1	1	100.0	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	5	5	100.0	0	0.0	0	0.0
ISO	5	3	60.0	2	40.0	0	0.0	3	60.0	2	40.0	0	0.0	2	0	0.0	2	100.0	0	0.0
CH	2	1	50.0	1	50.0	0	0.0	1	50.0	1	50.0	0	0.0	7	5	71.42	2	28.57	0	0.0
IR	2	0	0.0	2	100.0	0	0.0	1	50.0	1	50.0	0	0.0	5	3	60.0	2	40.0	0	0.0
GT	2	2	100.0	0	0.0	0	0.0	1	50.0	1	50.0	0	0.0	4	3	75.0	1	25.0	0	0.0
OMR	10	9	90.0	1	10.0	0	0.0	9	90.0	1	10.0	0	0.0	12	11	91.66	1	8.3	0	0.0
TBF	9	9	100.0	0	0.0	0	0.0	9	100.0	0	0.0	0	0.0	13	13	100.0	0	0.0	0	0.0
WRS	2	2	100.0	0	0.0	0	0.0	2	100.0	0	0.0	0	0.0	3	2	66.66	1	33.33	0	0.0
Total	**87**	**67**	**77.01**	**16**	**18.39**	**4**	**4.59**	**62**	**71.26**	**19**	**21.83**	**6**	**6.89**	**103**	**79**	**76.69**	**21**	**20.38**	**3**	**2.91**

BCW - Brown-capped Pygmy Woodpecker; GBW - Greater Golden-backed Woodpecker; WNW - White-naped Woodpecker; BHB - Brown-headed Barbet; CSB -Coppersmith Barbet; WCB - White-cheeked Barbet; CM - Common Myna; JM - Jungle Myna; GH - Great Hornbill; MPH - Malabar Pied Hornbill; MP - Malabar Parakeet; RRP - Rose-ringed Parakeet; JO - Jungle Owlet; ISO - Indian Scops Owl; CH - Common Hoopoe; IR - Indian Roller; GT - Great Tit; OMR - Oriental Magpie Robin; TBF -Tickell's Blue-flycatcher; WRS - White-rumped Shama.

Tree cavities used by Reptiles and Mammals in the riverine forest

Rat Snake

Common Bronzeback Snake

Garden Lizard

Garden Lizard

Monitor Lizard

Monitor Lizard

Indian Giant Squirrel

Indian Palm Squirrel

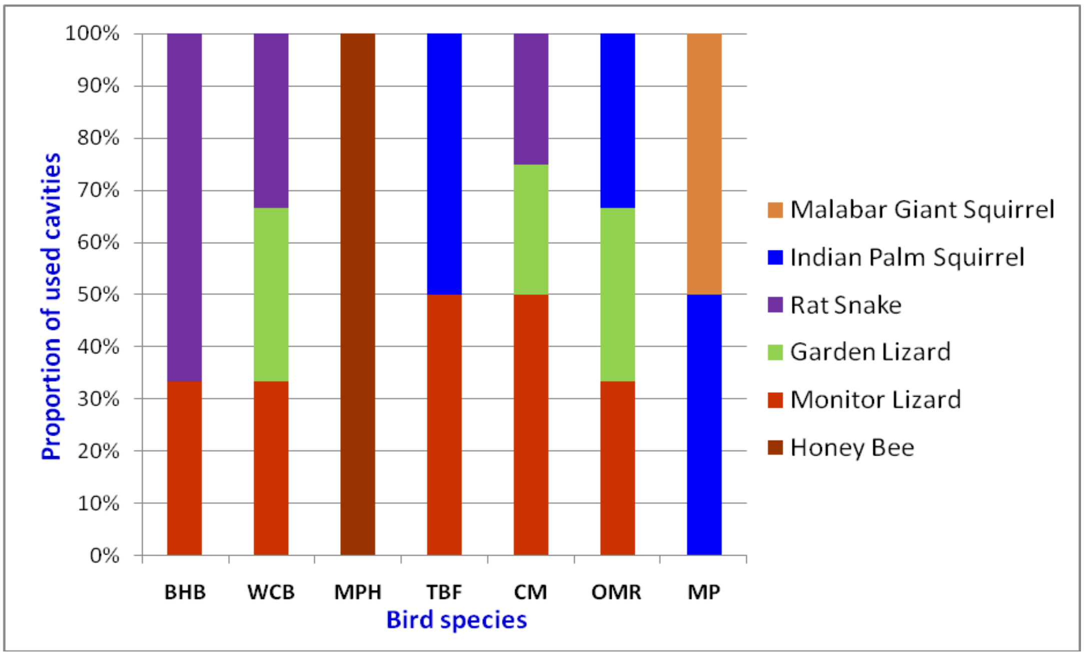


Figure 8.3 Proportion of bird used nest cavities reused by other taxa; BHB - Brown-headed Barbet; WCB - White-cheeked Barbet; MPH - Malabar Pied Hornbill; TBF - Tickell's Blue-flycatcher; CM - Common Myna; MR - Oriental Magpie Robin; MP - Malabar Parakeet

8.3.4 Characteristics of reused cavities

There were significant associations between cavity reuse and tree condition, cavity type and substrate condition (Table 8.3). Most of the reused cavities (66.66%) were located in living trees which had more suitable cavities that were frequently reused by secondary cavity nesting birds. Regarding cavity type, the proportion of reused bird excavated cavities included barbet excavated cavities (44.70%) and woodpecker cavities (40.62%) while naturally formed cavities (14.58%) were reused under proportionally. Most of the bird nest cavities were found in live substrates (62.50 %) that were most frequently reused by birds.

Table 8.3 Comparison of reused and not reused cavities in the riverine forest

Attributes (in %)	Nest cavities of 2013 & 2014		χ^2	*P* value
	Reused (n=95)	Not reused (n=197)		
Tree Condition				
Live	66.66	80.20	48.25	< 0.000
Partially Dead	18.75	9.64		
Dead (Snag)	14.58	10.15		
Cavity Type				
Woodpecker cavities	40.62	23.86	15.43	< 0.000
Barbet Cavities	44.79	41.12		
Natural Cavities	14.58	35.03		
Substrate Condition				
Living	62.50	42.13	6.00	< 0.01
Dead	37.50	57.87		

8.3.5 Nest distribution in two types of cavities in different categories of tree resource

Of the 376 nests, 280 (74%) were found in live trees, 57 (16%) in partially dead trees and 39 (10%) in snags. Out of the 280 nests found in live trees 196 nest cavities belonged to secondary cavity nesting birds and 84 belonged to primary cavity nesting birds. In partially dead trees, 57 nest cavities were recorded out of which 14 nest cavities belonged primary cavity nesting birds and 43 nest cavities belonged to secondary cavity nesting birds. A total of 39 nest cavities were found in snags of which 18 nests belonged to primary cavity nesting birds and 21 belonged to secondary cavity nesting birds (Figure 8.4). Primary cavity nesting birds mostly used cavities excavated by them and these nesters did not use natural cavities for nesting. Of the 116 nests of primary cavity nesters, 84 (89.21%) nest cavities were found in live trees, 14 (12.06%) were in partially dead trees and 18 (15.51%) were in snags. Secondary cavity nesters used cavities that were excavated by primary cavity nesters as well as natural cavities. Fifty eight percent of secondary cavity nesting bird nests (n=152) (non-excavators) was in excavated cavities created by woodpeckers and barbets and

42% (n=108) were in natural cavities. Of the 152 nests used by SCNs, 72.36% were in live trees, 15.78% in partially dead trees and 11.84% in snags. Of the 108 natural cavities used by SCN, 79.62% were in live trees, 17.59% in partially dead trees and 2.77% in snags (Figure 8.4). Barbets and woodpeckers excavated cavities were used by secondary cavity nesting birds.

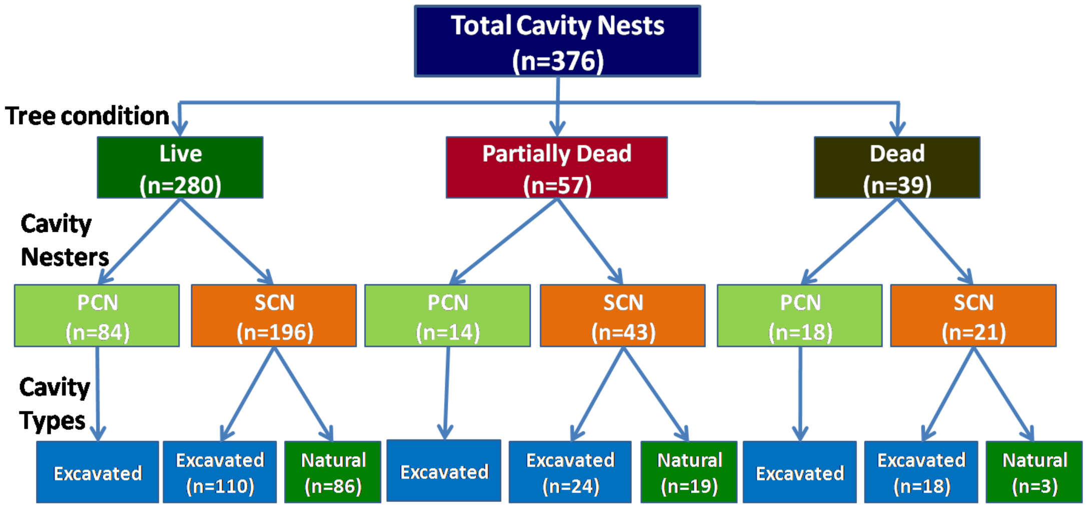


Figure 8.4 Cavity nesting bird nests distribution in excavated and natural cavities in different categories of tree sources

8.3.6 Cluster Analysis

Cluster analysis of cavity height above ground, cavity entrance diameter, cavity circumference, cavity vertical depth and girth at nest cavity (nest substrate circumference) produced five clusters of bird species as shown in Figure 8.5. The first branch contained one species (Indian Scops Owl). Second branch of the dendrogram contained two species of hornbills (Great Hornbill and Malabar Pied Hornbill), which had the greatest separation from and least similarity to the other species. The third group included three secondary cavity nesting birds (Oriental Magpie Robin, Tickell's Blue-flycatcher, White-rumped Shama) and these bird species most frequently used natural cavities. Fourth group contained four species of primary cavity nesting birds (Brown-headed Barbet, White-cheeked Barbet, Coppersmith Barbet, and Brown-capped Pygmy Woodpecker) and one species of secondary cavity nesting bird (Great Tit). The fifth group consisted of seven species of secondary cavity nesting birds (Jungle Myna, Malabar Parakeet, Rose-ringed Parakeet, Common Myna, Indian Roller, Common Hoopoe, Jungle Owlet) and two species of primary cavity nesting birds (Greater Golden-backed Woodpecker and White-naped Woodpecker).

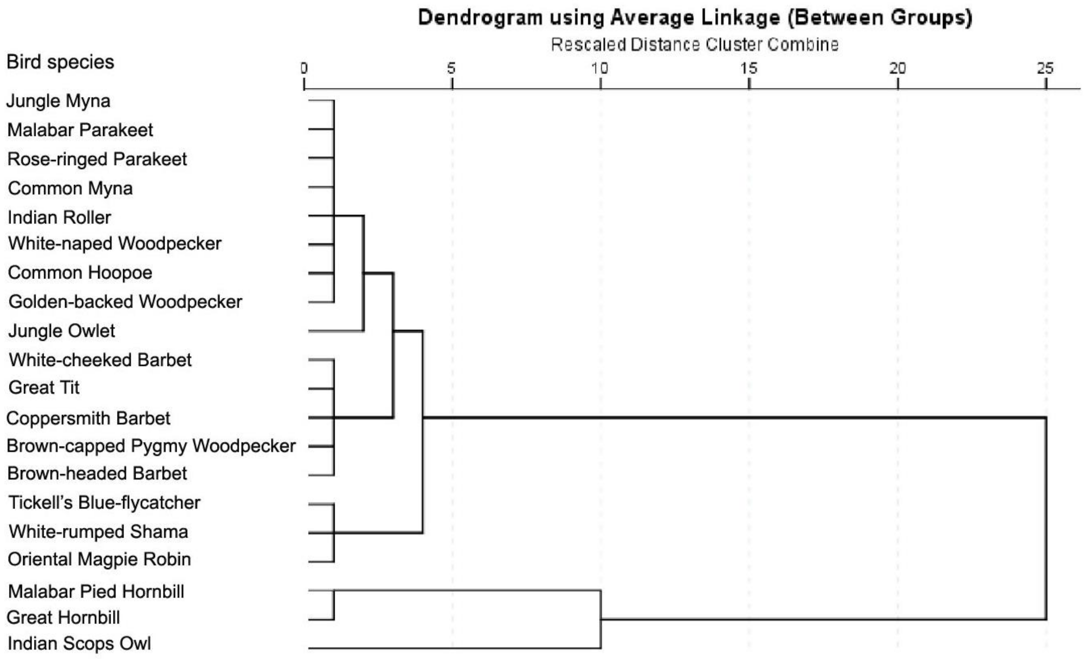
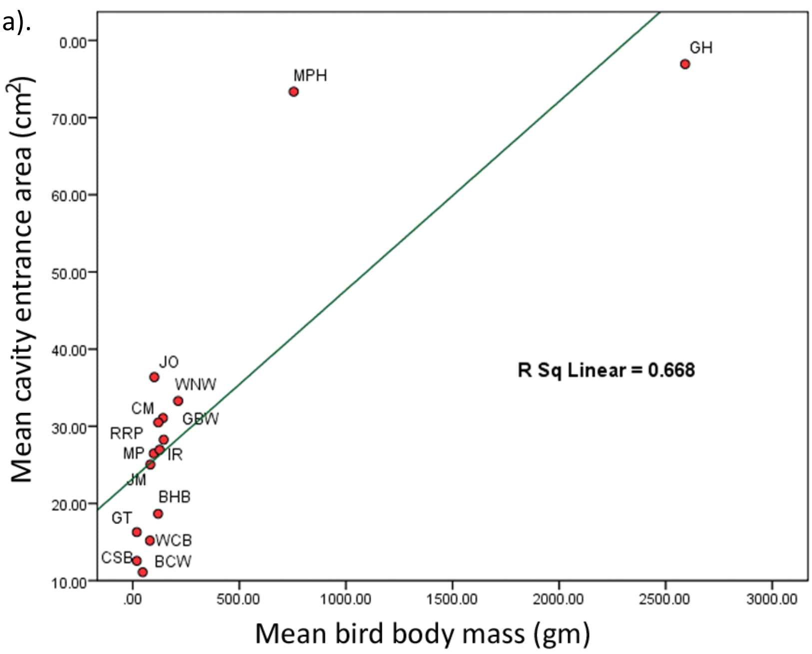


Figure 8.5 Dendrogram based on hierarchical cluster analysis using average linkage of various cavity nesting birds and nest characteristics in the riparian forest

Body size of cavity nesters is a major component determining the degree of resource overlap in cavity nests. A strong correlation was found between the bird body mass (gm) and nest cavity dimensions (cavity entrance circumference and cavity inner width (cm). Overall strong positive relationships was noticed with body mass (g) and cavity entrance area (cm^2) (r^2 = 0.66; $F_{1,13}$ = 26.10, p < 0.001) (Figure 8.6a), as well as with cavity inner width (cm) (r^2 = 0.86; $F_{1,13}$ = 79.61, p < 0.000) (Figure 8.6b).

a).



b).

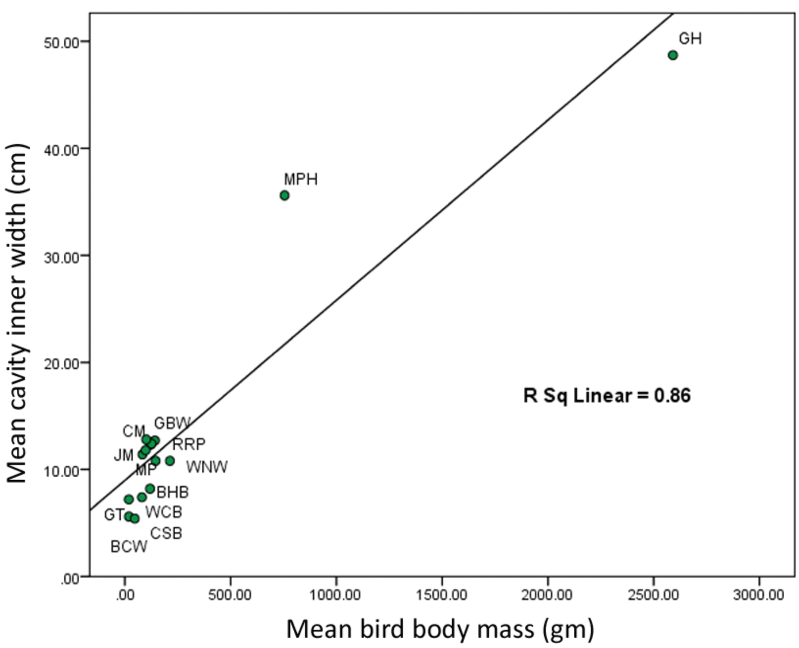


Figure 8.6 Preliminary examination of nest cavity size and body size relationships for cavity nesting birds showing significant positive relationships between mean body mass (gm); a) mean cavity entrance area (cm^2), b) mean cavity inner width (cm).

8.3.7 Nest Web Analysis

Integrating nest trees and nest tree characteristics, the nest cavity usage by different guild of cavity nesting birds are explained as nest web which shown in Figure 8.7. The web illustration shows the links between the cavity-nesting species and cavity resources (trees) in the riverine forest of Athikadavu Valley. Species at each level depend on species to which they are linked on the level below. Thick lines show greater proportion of nest dependence, while thin lines show lesser proportion of nest dependence. The primary cavity nesting birds are connected to the tree resource in which their cavities were excavated. The secondary cavity nesting birds are connected to the species that excavated their nest cavities (primary cavity nesters) and natural cavities. The links indicated the proportion of tree (resource) cavity utilization of each bird species.

All primary cavity nester species most often excavated cavities on live trees (69.28%). Their excavated cavities were most frequently utilized by secondary cavity nesting birds. Majority of the natural cavities were found in live trees (30.71%) (Figure 8.7). Fifty eight percent of the 152 nests of secondary cavity nesting birds were in excavated cavities made by primary cavity nesting birds and 42% of the 108 nests were in natural cavities. Among the primary cavity nesters, 73.05% of cavities were excavated by barbets and 26.95% cavities by woodpecker species and these excavated cavities were highly reused by secondary cavity nesting birds. The primary cavity nesting birds, Brown-headed barbet and Greater Golden-backed woodpecker provided greatest proportion of excavated cavities for the secondary cavity nesting birds. In all, among the secondary cavity nesters, Common Myna utilized maximum number of cavities (n=71). Of the 71 cavities, 60 were bird excavated and 11 were natural cavities. The 60 bird excavated cavities used by Common Myna belonged to Greater Golden-backed woodpecker (34.04%), White-naped woodpecker (29.78%), Brown-headed barbet (10.63%) and White-cheeked barbet (10.63%). The 29 nests of Jungle Myna found in bird excavated cavities belonged to Greater Golden-backed woodpecker (28.12%), Brown-headed barbet (21.87%), White-cheeked barbet (18.75%), White-naped woodpecker (15.62%). All Great Tit nests were found in barbet excavated cavities. Majority (90.9 %) of the Indian Roller nests were located in woodpecker excavated cavities (Greater Golden-backed, White-naped woodpecker) and 9.09% of nests in excavated cavities by Brown-headed barbet. The Rose-ringed Parakeets chose bird excavated cavities and located nests in Greater Golden-backed woodpecker 50%, in White-naped woodpecker 33.33% and in Brown-headed barbet 16.66% excavated cavities. Ninety four percent of Malabar Parakeet nests were found in bird excavated cavities while 6% nests were in natural cavities. Cavities used by Malabar Parakeet excavated by Greater Golden-backed woodpecker (52.94%), White-naped woodpecker (23.52%), Brown-headed barbet (11.76%) and White-cheeked barbet (5.88%). Additionally, natural cavities supported the secondary cavity nesting birds such as Great Hornbill, Malabar Pied Hornbill, Common Hoopoe, Indian Scops Owl, Tickell's Blue-flycatcher and White-ruped Shama. The secondary cavity nesting birds nested only in natural cavities which were abundant in large live trees (Figure 8.7).

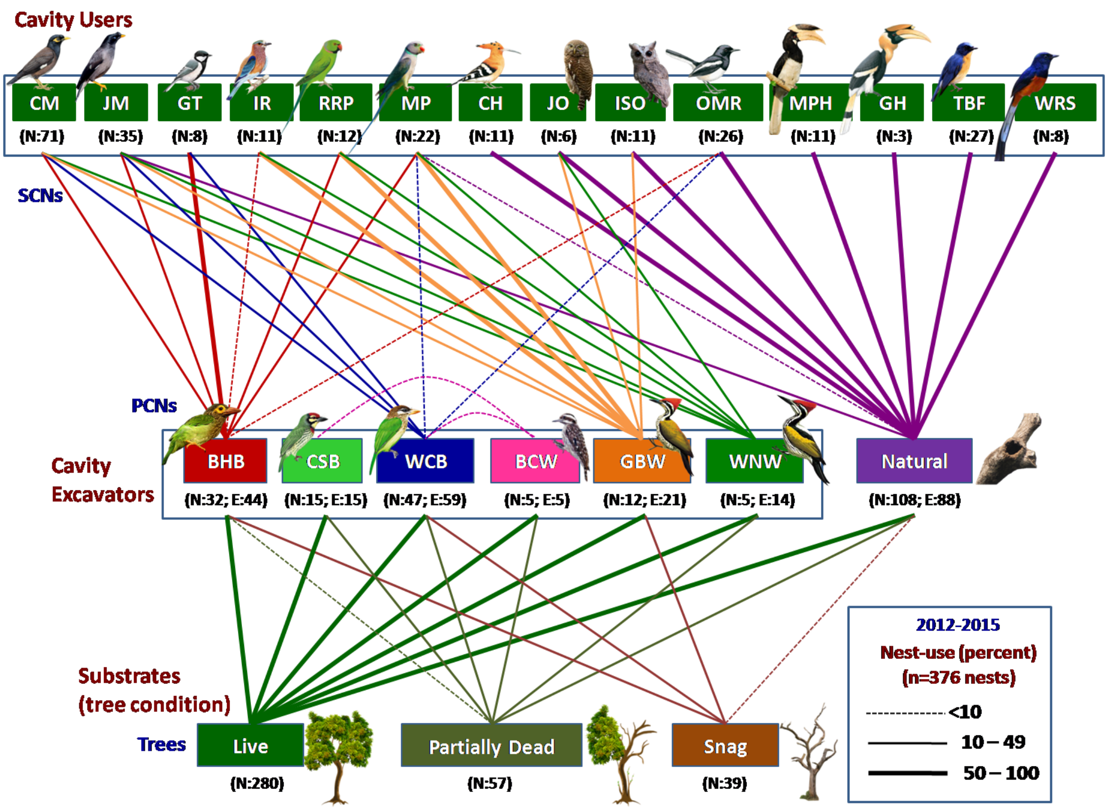


Figure 8.7 Nest web showing links between trees, cavity excavators (PCNs) and cavity users (SCNs) in the riverine forest, 2012 - 2015. [N indicates the number of nests found; E indicates the total number of all nest cavities excavated by that species. Links between the level of secondary cavity-nesting birds and the primary cavity-excavator represent the proportion of nests of secondary cavity-nesting species found in a cavity excavated by the indicated excavating species].

8.4 Discussion

Cavity-nesting birds comprise a major component of forest communities. About 10 percent of all avian species (Newton, 1994) and many other taxa like as insects, reptiles, mammals use tree cavities as nesting or shelter places (Hansell, 2000). In North America, more than 25% of forest vertebrate animal species use cavities for nesting or roosting (Bunnell *et al.*, 1999; Martin *et al.*, 2004). In the present study, 20 % of the 32 birds in the riverine forest were found to be cavity nesters. These bird species used cavities excavated by them and as well as natural cavities for nesting or roosting. The fact that the cavities created by primary cavity nesting birds (woodpeckers and barbets) are often used by secondary cavity nesting birds in more than expected percentage highlights the key role the excavators play in the forest ecosystem as indicated by Martin *et al.* (2004) and Cornelius *et al.* (2008).

In the present study, cavities created by woodpecker species (Golden-backed and White-naped Woodpecker) and barbet species (Brown-headed barbet, Coppersmith barbet and White-cheeked barbet) were reused by several secondary cavity nesting birds (Common Myna, Jungle Myna, Malabar Parakeet, Rose-ringed Parakeet, Great Tit, Indian Roller, Jungle Owlet), small mammals (Malabar Giant Squirrel, Indian Palm Squirrel), reptiles (Monitor Lizard, Garden Lizard, Rat Snake) and insects (Honey bee). In British Columbia, excavated cavities excavated by Northern Flickers, Red-naped Sapsuckers and Hairy Woodpecker cavities were reused by secondary cavity nesting birds and small mammals (Martin *et al.,* 2004; Aitken and Martin, 2007; Cockle and Martin, 2015). In a Aspen woodland forest of Colorado Rocky Mountains, USA. Daily *et al.* (1993) reported that cavities excavated by Violet-green Swallows and Tree Swallows were reused by Red-naped Sapsukers. In a food-hill model forest in Canada, owls and ducks most frequently nested in Pileated woodpecker excavated cavities (Bonar, 2000). In a longleaf pine forest of Florida, Red-cockaded woodpecker *Leuconotopicus borealis* cavities were highly used by Eastern Screech Owl. Northern Flicker excavated cavities were used by Great-crested Flycatcher *Myiarchus crinitus* and Eastern Screech Owl *Megascops asio* (Blanc and Walters, 2008a). In a Boreal forest of Mongolia, Bai and Mühlenberg (2008) reported the Great-spotted Woodpecker *Dendrocopos major* nest cavities being used by Wood Nuthatches *Sitta europaea*. In the present study area, secondary cavity nesting birds such as large-bodied hornbills (Great Hornbill, Malabar Pied Hornbill) and medium-sized birds (Indian Scops Owl, Common Hoopoe) and small birds (Oriental Magpie Robin, Tickell's Blue-flycatcher, White-rumped Shama) most often used natural cavities. These birds predominantly nested in natural cavities. The utilization of high proportion of natural cavities by secondary cavity nesting birds was reported in a deciduous forest of Sweden (Carlson *et al.,* 1998), in the mixed forests of British Columbia (Bai *et al.,* 2003), in a primeval boreal forest of Mongolia (Aitken *et al.,* 2002; Martin *et al.,* 2004; Aitken and Martin, 2007). In Europe, most of the secondary cavity nesting birds nested in natural cavities of the riverine forest (Remm *et al.,* 2006).

In the present study, Great Tit nest cavities were mostly located in Brown-headed Barbet excavated cavities because these cavities had smaller cavity entrance and internal cavity dimensions that were correlated with Great tit body mass. In the present study, two species of secondary cavity nesting birds namely Tickell's Blue-flycatcher and White-rumped Shama used natural cavities. These species predominantly nested in shallow open cavities with wide entrance. The utilization of open shallow cavities by flycatchers have been reported for Narcissus Flycatcher *Ficedula narcissina* in Japan (Okahisa *et al.*, 2012) and China (Wang *et al.,* 2008). In Canada, Bonar (2000) reported that most of the shallow cavities were used by some specific species of secondary cavity nesting birds such as Owls, Wood Duck and Common Flicker.

Parakeets very often used natural cavities in the study area. Majority of the parakeet (Malabar Parakeet, Rose-ringed Parakeet) nests was located in excavated cavities made by large woodpeckers. In Mexico, Monterrubio-Rico and Enkerlin-Hoeflich, 2004; Monterrubio-Rico *et al.,* 2006) found that Thick-billed Parrots most often nested in woodpecker excavated cavities in a coniferous forest. Owls utilize natural cavities found in the trunks of live trees. Whitford (2002) in an Australian forest habitat found that owls preferred hollows in the tree trunk rather than nesting on branches. Leadprathom *et al*. (2009) observed that most of the nests of Collared Scops Owl *Otus bakkamoena* were on live trees. He attributed that the owl's open top nests, allows rainwater to easily flood the nest, as nest drainage is likely a significant factor in chick survival. In Mexico, Arsenault (2004) reported the Flammulated Owls and Western Bluebirds predominantly nested in excavated cavities created by Northern Flickers and Acorn woodpecker.

Cluster analysis results showed that five groups of cavity nesting birds are found in the cavity nesting bird community of the study area. Indian Scops Owl that used irregular shaped natural cavities occurred in the first group. The second group had two species of hornbills namely Malabar Pied Hornbill and Great Hornbill. Both hornbills used natural cavities of large sizes which were correlated with their body mass. Third group had three species, Oriental Magpie Robin, Tickell's Blue-flycatcher, White-rumped Shama which used open shallow natural cavities. The fourth and fifth group in the cluster analysis also got separated according to cavity dimensions and body size. These groups have more cavities created by excavator species of woodpeckers and barbets. Greater Golden-backed and White-naped Woodpecker excavated cavities were used by Malabar Parakeet, Rose-ringed Parakeet, Common Myna, Jungle Myna, Indian Roller and Jungle Owlet. Great Tit mostly used barbet excavated cavities (Brown-headed barbet, White-cheeked barbet). Although they have similar body sizes and cavity dimensions between the excavated cavities and cavity utilization by secondary cavity nesting birds.

The reuse of same cavities by some secondary cavity nesting birds was common in the present study area. The cavity reuse in the secondary cavity nesting birds by the same species was found higher. The secondary cavity nesting birds such as Common Myna, Malabar Parakeet, Rose-ringed Parakeet, Malabar Pied Hornbill, Indian Scops Owl and Indian Roller mostly reused same cavities. Similar results have been reported in British Columbia (Aitken *et al.,* 2002) and Poland (Wesolowski, 1989).

Secondary cavity nesting birds reuse rate was higher because they used cavities (excavated or natural) that have large entrance size and depth. Cavity entrance size and cavity internal dimensions are important factors in determining cavity use because they control the type of species able to use the nest cavity. Similar results were reported by Aitken *et al.* (2002), Aitken and Martin (2004) in British Columbia, Gibbons *et al.* (2002) in south-eastern Australia. Larger cavity area is considered to increase clutch sizes (Robertson and Rendell, 1990; Rendell and Verbeek, 1996b; Stewart and Robertson, 1999). Large cavities may also provide better shelter places form thermal insulation on during the summer days (Miller and Miller, 1980; Alatalo *et al.*, 1988; Joy, 2000; Wiebe and Swift, 2001) and reduce the competition for spacing (Slagsvold, 1989). According to (Zeleny, 1977; Moeed and Dawson, 1979; Robertson and Rendell, 1990) predation risk was higher in large cavity entrance sizes because predators easily enter in cavity.

Some excavated cavities used by secondary cavity nesting birds have small cavity entrance and deep in internal dimensions. These cavities prevent large and medium size predators inside the nest (Schepps *et al*., 1999; Wesolowski, 2002; Mitrus, 2003; Remm *et al.,* 2006; Hebda, 2009). Our results suggest that the secondary cavity nesting birds more frequently reused cavities in live substrates than dead substrates. Similar findings were reported by (Bai and Mühlenberg, 2008) in a boreal forest of Mongolia. Nesting in live trees are known to have several advantages which have higher structural stability and less prone to tree fall and nest cavities located on live part of large trees suffer less predation (Li and Martin, 1991; Christman and Dhondt, 1997; Wiebe, 2001; Wesolowski, 2002; Remm *et al.,* 2006). In addition, larger predators that could not reach the nest through cavity entrance usually destroy the cavity wall, which is less likely to happen when the cavity is surrounded by solid living wood. According to (Hooge *et al.*, 1999; Wiebe, 2001; Remm *et al.,* 2006) microclimate inside cavities in live substrates is considered to be more stable.

9 SUMMARY AND RECOMMENDATIONS

9.1 Summary

A study on nest tree utilization and preferences by cavity nesting birds was carried out in the riverine forests of Athikadavu Valley, Western Ghats, India from August 2012 to July 2015. In India, more than 100 species of tree-cavity nesting birds have been identified, but very little information is available about their nesting habits. In the above background, it is felt that a study on tree diversity and its use by birds in the riverine forests of an important river system-the Bhavani a tributary of Cauvery in southern India would be useful in planning biodiversity conservation. The objectives of the study were, i) Quantify the woody vegetation of the riverine forest of Bhavani river in Athikadavu Valley, ii) Find out the nest tree preferences of cavity nesting birds, and iii) Ascertain the characteristics of nest trees and nest cavities used by cavity nesting birds.

Study Area: The study area, Athikadavu Valley is located between 11^{o}11'26" to 11^{o}16'26" N and 76^{o}43'49" to 76^{o}50'25" E, Altitude 500-600m) in the Melur slopes Reserve Forests of Coimbatore Forest Division, Western Ghats, India. The study site comprised a 12 km stretch riparian forest along Bhavani River from Sundapatti to Nellithurai. This Valley which is contiguous to Nilgiri south-eastern slopes forms an ecologically important region owing to the presence of pristine semi-evergreen forests alongside the Bhavani River. Average rainfall varies from 600 to 850 mm per annum. The temperature is high (36°C) during summer and low (18°C) during winter nights

Methodology: Woody vegetation of the riverine forest was quantified by using belt-transect method. Sampling was done in two belt transects, each measuring 1 ha (1000x10m). The belt transect was divided into 10x10 m subplots and all the stems measuring >20 cm gbh (girth at breast height) were recorded. Bird census was done by using line transect method as per Bibby *et al.* (1992). Censuses were carried out once in a month during morning (0700 and 0900 hrs) on the river bank. Two, 1 km long transects with a width of 10 m either side of the census route were used for the census. Nests of cavity nesting birds were searched in trunks of all trees >50 cm girth along the river bank.

Nest trees were located by making repeated walks along river banks. Nest tree features such as girth at breast height (GBH), tree height, nest height, girth at nest height and nest tree condition were studied. Nest cavity characteristics such as nest cavity height, nest location, cavity type, substrate condition, substrate size (girth at nest height), nest cavity shape, cavity orientation, cavity entrance diameter and cavity depth were recorded. Nest tree preferences were assessed by using Ivlev's Index.

Results: In the riverine forests of Athikadavu valley, a total of 70 woody species belonging to 34 families were recorded. Dominant tree species included *Pongamia pinnata* (IVI-74.64) *Diospyros peregrina* (41.75) and *Mangifera indica* (41.16). Family Moraceae constituted the largest family with eight species. In the dry mixed deciduous forest, a total of 63 woody plant species belonging to 26 families were recorded. The dominant tree species included *Chloroxylon swietenia* (IVI-52.31), *Drypetes sepiaria* (IVI-51.23), and *Pleiospermium alatum* (IVI-22.0). Family Mimosaceae with eight species constituted the largest family.

A total of 158 avian species belonging to 18 orders of 52 families were recorded. Passeriformes with 81 species formed the most predominant order followed by Piciformes with 10 species. Family Accipitridae and Muscicapidae constituted the largest family with nine species. Of the 32 cavity nesting birds, nine species comprised primary cavity nesting birds (PCNs) (woodpeckers, barbets) and 23 species were secondary cavity nesting birds (SCNs) (parakeets, mynas, hornbills, owls etc.).

Results: A total of 257 nest trees were used by 20 different cavity nesting birds. Highest number of cavity nesting species (15 out of 20 species) used *Mangifera indica.* Highest proportion of primary cavity nesters nests were located in *Terminalia arjuna* (14.66%) followed by *Mangifera indica* (13.79%). Interestingly, highest proportions of secondary cavity nester nests were also found in *Terminalia arjuna* (13.46%) and *Mangifera indica* (8.85%). Primary cavity nesting birds mainly excavated nest cavities above 100 cm girth size of trees and highest proportion of nests was found in 201-300 cm girth class. Maximum proportion of secondary cavity nesting bird nest cavities were found in

201-300 cm of girth classes of nest trees (31.92 %). In the riverine forests, two tree species namely, *Mangifera indica* and *Terminalia arjuna* were found to be highly preferred by both primary and secondary cavity nesting birds.

A total of 376 active nest cavities were found in the study area, 116 belonged to primary cavity nesters and 260 to secondary cavity nesters. In the case of primary cavity nesting birds, mean values of nest tree height and nest tree girth were $19.71 \pm 4.99_{SD}$ m and $283.75 \pm 126.21_{SD}$ cm respectively. The nest tree height of primary cavity nesters significantly varried among different species ($F_{5,116} = 3.89$, $p < 0.000$). Nest height of primary cavity nesters positively correlated with tree height ($r = 0.569$, $p < 0.000$), girth at breast height of the nest trees was positively correlated with nest hieght ($r = 0.204$, $p < 0.02$). Mean values of nest tree height and tree girth at breast height for the secondary cavity nesting birds were $19.31 \pm 6.42_{SD}$ m and $292.26 \pm 141.27_{SD}$ cm respectively. The nest tree height of secondary cavity nesters significantly varried among different species ($F_{13, 260} = 7.20$, $p < 0.000$). Hornbills selected trees which were taller and larger (huge girth) for nesting compared to other secondary cavity nesting birds namely, mynas ($Z = -4.61$, $p < 0.000$), parakeets ($Z = -3.38$, $p < 0.001$) and owls ($Z = -2.91$, $p < 0.004$).

The nest cavities of the primary cavity nesters were located in live trees (71.55 %) followed by partially dead trees (15.52 %) and snags (12.93 %) ($\chi^2 = 74.7$, $df = 2$, $p < 0.000$). The nests of secondary cavity nesting birds were placed in live trees (62.31 %) followed by dead trees (29.23 %) and snags (8.46 %) ($\chi^2 = 195.9$, $df = 2$, $p < 0.000$). Higher proportion of nests of both primary (88.79%) and secondary (65.76%) cavity nesting birds was placed on dead substrate. The number of nests placed in the dead substrate was significantly higher than the live substrate in both primary and secondary cavity nesters ($\chi^2 = 69.82$, $df = 1$, $p < 0.001$ for PCNs; $\chi^2 = 18.84$, $df = 1$, $p < 0.001$ for SCNs). The proportion of nests located were significantly higher in branches than in the main tree trunk in both primary and secondary cavity nesters ($\chi^2 = 60.82$, $df = 1$, $p < 0.001$ for PCNs; $\chi^2 = 40.01$, $df = 1$, $p < 0.001$ for SCNs). Nest cavity dimensions of the primary cavity nesting birds were assessed. Mean cavity entrance diameter was $5.75 \pm 2.07_{SD}$ cm and mean cavity depth was $26.82 \pm 5.21_{SD}$ cm. Mean values for cavity entrance diameter and cavity depth for secondary cavity nesting birds were $11.21 \pm 5.45_{SD}$ cm and $31.15 \pm 16.76_{SD}$ cm respectively. Most of the nest cavity entrances of both primary and secondary cavity nesting birds were oriented in south and south-east direction. Primary cavity nesters' nest orientation had mean angular vector μ =147° ± 67° (95% CI = 133° – 160°) with statistical preference (Rayleigh test $Z = 28.47$, $p < 0.001$. Secondary cavity nester nest orientation had mean angular vector μ = 141° ± 90° (95% CI = 124° – 157°) with cavity nesters statistical preference (Rayleigh test $Z = 12.24$, $p < 0.001$. Integrating nest trees and nest tree characteristics, the nest cavity usage by different guild of cavity nesting birds is explained as nest web.

From the study it is inferred that in the low elevation riparian forests of Athikadavu Valley in the Western Ghats, woodpeckers and barbets play a crucial role in creating cavity resources for several other bird and animal species. Snags were found crucial for barbets as they exclusively rely on dead trees for nesting.

9.2 Recommendations

9.2.1 *Protection of nest trees*

Tree species such as *Mangifera indica, Diospyros peregrina, Madhuca longifolia, Terminalia arjuna* and *Syzygium cumini* in the riverine habitat offer suitable substrate for roosting and breeding of riparian forest birds. The following suggestions are made to the forest department. The local nursery at Mulli near Athikadavu could raise the saplings of native trees and the same could be planted in the degraded riparian patches. Protection needs to be offered to the nest trees of birds especially hornbills.

9.2.2 *Conservation of snags*

Dead trees (snags) of certain species (*Mangifera indica, Terminalia arjuna, Alseodaphne semecorpifolia, Hopoea ponga, Madhuca longifolia, Diospyros peregrina* and *Strychnos nux-vornica*) are utilized by primary cavity nesting birds such as barbets and woodpeckers. Barbets mainly rely on snags for nest excavation and hence snags have great conservation significance. Removal of snags would directly affect the survival of barbets and also the secondary cavity nesting birds. Protection of snags by the forest department would benefit the barbets as they mainly rely on snags.

9.2.3 *Awareness Education on Biodiversity Conservation*

To minimize the anthropogenic disturbances, awareness camps need to be organized for various stakeholders. This could be done in collaboration with Environmental NGOs, Forest Department officials and researchers. Awareness program could be organized for the local communities about the livestock grazing impacts on riverine vegetation, importance of riparian forest biodiversity and the need for its conservation.

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APPENDIX 1

List of woody plants recorded in riverine and mixed dry deciduous forests of Athikadavu Valley

S. No.	Name of the species	Family	Riverine forests	Mixed dry deciduous forests
1	*Acacia cineria*	Mimosaceae	-	√
2	*Acacia leucopholea*	Mimosaceae	-	√
3	*Acacia nilotica*	Mimosaceae	-	√
4	*Acacia planifrons*	Mimosaceae	-	√
5	*Acacia polyacantha*	Mimosaceae	√	-
6	*Aglaia roxburghiana*	Meliaceaee	√	-
7	*Ailanthus excelsa*	Simaroubaceae	-	√
8	*Albizia amara*	Mimosaceae	-	√
9	*Albizia chinensis*	Mimosaceae	√	-
10	*Albizia lebbeck*	Mimosaceae	√	√
11	*Alphonsea sclerocarpa*	Annonaceae	√	√
12	*Alseodaphne semecarpifolia*	Lauraceae	√	√
13	*Anamirta cocculus*	Menispermaceae	√	-
14	*Ardisia solanacea*	Solanaceae	√	-
15	*Atalantia racemosa*	Rutaceae	√	√
16	*Azadirachta indica*	Meliaceae	-	√
17	*Bauhinia racemosa*	Caesalpiniaceae	-	√
18	*Bombax ceiba*	Bombacaceae	-	√
19	*Butea parviflora*	Fabaceae	√	√
20	*Calophyllum apetalum*	Cluciaceae	√	-
21	*Capparis grandis*	Capparaceae	-	√
22	*Cassine glauca*	Celastraceae	√	√
23	*Catunaregam spinosa*	Rubiaceae	-	√
24	*Celtis philippinensis*	Ulmaceae	√	-
25	*Celtis tetrandra*	Ulmaceae	√	-

S. No.	Name of the species	Family	Riverine forests	Mixed dry deciduous forests
26	*Chionanthus mala-elengi*	Oleaceae	√	-
27	*Chloroxylon swietenia*	Rutaceae	-	√
28	*Cordia monoica*	Cordiaceae	-	√
29	*Crataeva magna*	Capparaceae	√	-
30	*Dalbergia lanceolaria*	Fabaceae	-	√
31	*Dalbergia latifolia*	Fabaceae	√	-
32	*Dalbergia paniculata*	Fabaceae	-	√
33	*Dichrostachys cinerea*	Mimosaceae	-	√
34	*Diospyros ferrea*	Ebenaceae	√	√
35	*Diospyros melanoxylon*	Ebenaceae	-	√
36	*Diospyros montana*	Ebenaceae	-	√
37	*Diospyros ovalifolia*	Ebenaceae	√	√
38	*Diospyros peregrina*	Ebenaceae	√	-
39	*Drypetes roxburghii*	Euphorbiaceae	√	√
40	*Drypetes sepiaria*	Euphorbiaceae	-	√
41	*Ehretia ovalifolia*	Cordiaceae	-	√
42	*Erythrina stricta*	Fabaceae	√	-
43	*Erythroxylum monogynum*	Erythroxylaceae	-	√
44	*Euphorbia antiquorum*	Euphorbiaceae	-	√
45	*Ficus amplissima*	Moraceae	√	-
46	*Ficus benghalensis*	Moraceae	√	√
47	*Ficus drupacea*	Moraceae	√	-
48	*Ficus microcarpa*	Moraceae	√	-
49	*Ficus racemosa*	Moraceae	√	-
50	*Ficus religiosa*	Moraceae	√	-
51	*Ficus tomentosa*	Moraceae	-	√
52	*Ficus virens*	Moraceae	√	-
53	*Garcinia gummi-gutta*	Clusiaceae	√	-

S. No.	Name of the species	Family	Riverine forests	Mixed dry deciduous forests
54	*Gardenia resinifera*	Rubiaceae	-	√
55	*Givotia moluccana*	Euphorbiaceae	-	√
56	*Gmelina arborea*	Verbencae	√	-
57	*Gmelina asiatica*	Verbenaceae		√
58	*Gyrocarpus asiaticus*	Hernandiaceae	√	√
59	*Hardwickia binata*	Caesalpiniaceae	-	√
60	*Hiptage benghalensis*	Malpighiaceae	√	√
61	*Holoptelea integrifolia*	Ulmaceae	-	√
62	*Homonoia riparia*	Euphorbiaceae	√	-
63	*Hopea ponga*	Dipterocarpaceae	√	-
64	*Hydnocarpus pentandra*	Flacourtiaceae	√	-
65	*Ixora pavetta*	Rubiaceae	√	√
66	*Ligustrum perrottetii*	Oleaceae	√	-
67	*Litsea deccanensis*	Lauraceae	√	-
68	*Madhuca longifolia*	Sapotaceae	√	√
69	*Mallotus philippensis*	Euphorbiaceae	√	-
70	*Mangifera indica*	Anacardiaceae	√	-
71	*Manilkara hexandra*	Sapotaceae	√	√
72	*Melia dubia*	Meliaceae	√	-
73	*Memecylon edule*	Melastomataceae	√	-
74	*Mimusops elengi*	Sapotaceae	√	√
75	*Murraya paniculata*	Rutaceae	√	-
76	*Nothopegia beddomei*	Anacardiaceae	√	-
77	*Olea dioica*	Oleaceae	√	-
78	*Phyllanthus polyphyllus*	Euphorbiaceae	√	√
79	*Pleiospermum alatum*	Rutaceae	√	√
80	*Pleurostylia opposita*	Celastraceae	√	√
81	*Pongamia pinnata*	Fabaceae	√	√

S. No.	Name of the species	Family	Riverine forests	Mixed dry deciduous forests
82	*Premna tomentosa*	Verbenaceae	√	√
83	*Prosopis juliflora*	Mimosaceae	-	√
84	*Psydrax dicoccos*	Rubiaceae	√	√
85	*Pterocarpus marsupium*	Fabaceae	√	√
86	*Salix tetrasperma*	Salicaceae	√	-
87	*Santalum album*	Santalaceae	-	√
88	*Sapindus emarginatus*	Sapindaceae	-	√
89	*Schleichera oleosa*	Sapindaceae	√	√
90	*Scleropyrum pentandrum*	Santalaceae	√	-
91	*Scutia myrtina*	Rhamnaceae	-	√
92	*Shorea roxburghii*	Dipterocarpaceae	√	-
93	*Sterculia guttata*	Sterculiaceae	√	-
94	*Streblus asper*	Moraceae	√	√
95	*Streospermum personatum*	Bignoniaceae	√	-
96	*Strychnos nux-vomica*	Loganiaceae	√	√
97	*Strychnos potatorum*	Loganiaceae	-	√
98	*Syzygium cumini*	Myrtaceae	√	-
99	*Tamarindus indica*	Caesalpiniaceae	√	-
100	*Terminalia arjuna*	Combretaceae	√	-
101	*Terminalia bellirica*	Combretaceae	√	-
102	*Trewia polycarpa*	Euphorbiaceae	√	-
103	*Vitex altissima*	Verbenaceae	√	√
104	*Walsura trifolia*	Meliaceae	-	√
105	*Ziziphus mauritiana*	Rhamnaceae	-	√
106	*Ziziphus oenoplia*	Rhamnaceae	-	√

APPENDIX 2

List of bird communities in the riverine forest of Athikadavu Valley

S. No.	Order / Common Name	Scientific Name	Families
1	**Galliformes** Indian Peafowl	*Pavo cristatus*	Phasianidae
2	Grey Jungle fowl	*Gallus sonneratii*	Phasianidae
3	Common Quail	*Coturnix coturnix*	Phasianidae
4	Jungle Bush-quail	*Perdicula asiatica*	Phasianidae
5	Painted Bush-quail	*Perdicula erythrorhyncha*	Phasianidae
6	**Piciformes** Common Flameback	*Dinopium javanense*	Picidae
7	Rufous Woodpecker	*Micropternus brachyurus*	Picidae
8	Brown-capped Pygmy Woodpecker	*Picoides nanus*	Picidae
9	Greater Golden-backed Woodpecker	*Chrysocolaptes guttacristatus*	Picidae
10	Yellow-fronted Pied Woodpecker	*Dendrocopos mahrattensis*	Picidae
11	White-naped Woodpecker	*Chrysocolaptes festivus*	Picidae
12	White-cheeked Barbet	*Psilopogon viridis*	Capitonidae
13	Brown-headed Barbet	*Psilopogon zeylanicus*	Capitonidae
14	Malabar Barbet	*Psilopogon malabaricus*	Capitonidae
15	Coppersmith Barbet	*Psilopogon haemacephalus*	Capitonidae
16	**Bucerotiformes** Malabar Pied Hornbill	*Anthracoceros coronatus*	Bucerotidae
17	Great Hornbill	*Buceros bicornis*	Bucerotidae
18	Indian Grey Hornbill	*Ocyceros birostris*	Bucerotidae
19	**Upupiformes** Common Hoopoe	*Upupa epops*	Upupidae
20	**Trogoniformes** Malabar Trogon	*Harpactes fasciatus*	Trogonidae
21	**Coraciiformes** Indian Roller	*Coracias benghalensis*	Coraciidae

S. No.	Order / Common Name	Scientific Name	Families
22	Common Kingfisher	*Alcedo atthis*	Alcedinidae
23	Pied Kingfisher	*Ceryle rudis*	Alcedinidae
24	Black-capped Kingfisher	*Halcyon pileata*	Alcedinidae
25	Stork-billed Kingfisher	*Pelargopsis capensis*	Alcedinidae
26	White-throated Kingfisher	*Halcyon smyrnensis*	Alcedinidae
27	Little Green Bee-eater	*Merops orientalis*	Meropidae
28	Chestnut-headed Bee-eater	*Merops leschenaultia*	Meropidae
29	Blue-bearded Bee-eater	*Nyctyornis athertoni*	Meropidae
30	**Cuculiformes** Chestnut-winged Cuckoo	*Clamator coromandus*	Cuculidae
31	Jacobin Cuckoo	*Clamator jacobinus*	Cuculidae
32	Common Hawk-cuckoo	*Hierococcyx varius*	Cuculidae
33	Grey-bellied Cuckoo	*Cacomantis passerines*	Cuculidae
34	Asian Koel	*Eudynamys scolopaceus*	Cuculidae
35	Blue-faced Malkoha	*Phaenicophaeus viridirostris*	Cuculidae
36	Sirkeer Malkoha	*Taccocua leschenaultia*	Cuculidae
37	Greater Coucal	*Centropus sinensis*	Cuculidae
38	**Psittaciformes** Vernal Hanging-parrot	*Loriculus vernalis*	Psittacidae
39	Rose-ringed Parakeet	*Psittacula krameri*	Psittacidae
40	Malabar Parakeet	*Psittacula columboides*	Psittacidae
41	Plum-headed Parakeet	*Psittacula cyanocephala*	Psittacidae
42	**Apodiformes** Little Swift	*Apus affinis*	Apodidae
43	**Strigiformes** Indian Scops Owl	*Otus lettia*	Strigidae
44	Brown Fish-owl	*Ketupa zeylonensis*	Strigidae
45	Rock Eagle-owl	*Bubo bengalensis*	Strigidae
46	Jungle Owlet	*Glaucidium radiatum*	Strigidae
47	Brown Hawk-owl	*Ninox scutulata*	Strigidae

S. No.	Order / Common Name	Scientific Name	Families
48	Spotted Owlet	*Athene brama*	Strigidae
49	**Columbiformes** Grey-fronted Green Pigeon	*Treron affinis*	Columbidae
50	Nilgiri Woodpigeon	*Columba elphinstonii*	Columbidae
51	Rock Pigeon	*Columba livia*	Columbidae
52	Emerald Dove	*Chalcophaps indica*	Columbidae
53	Spotted Dove	*Streptopelia chinensis*	Columbidae
54	Red Collared-dove	*Streptopelia tranquebarica*	Columbidae
55	**Gruiformes** White-breasted Waterhen	*Amaurornis phoenicurus*	Rallidae
56	**Charadriiformes** Red-wattled Lapwing	*Vanellus indicus*	Charadriidae
57	Little Egret	*Egretta garzetta*	Ardeidae
58	Intermediate Egret	*Egretta intermedia*	Ardeidae
59	Cattle Egret	*Bubulcus ibis*	Ardeidae
60	Indian Pond Heron	*Ardeola grayii*	Ardeidae
61	Grey Heron	*Ardea cinerea*	Ardeidae
62	Green-backed Heron	*Butorides striata*	Ardeidae
63	**Ciconiiformes** Common Sandpiper	*Actitis hypoleucos*	Scolopacidae
64	Asian Openbill	*Anastomus oscitans*	Ciconiidae
65	**Falconiformes** Jerdon's Baza	*Aviceda jerdoni*	Accipitridae
66	Black Kite	*Milvus migrans*	Accipitridae
67	Lesser Fish-eagle	*Ichthyophaga humilis*	Accipitridae
68	Crested Serpent-Eagle	*Spilornis cheela*	Accipitridae
69	Changeable Hawk-eagle	*Nisaetus cirrhatus*	Accipitridae
70	Bonelli's Eagle	*Aquila fasciata*	Accipitridae
71	Brahminy Kite	*Haliastur indus*	Accipitridae
72	Black Eagle	*Ictinaetus malayensis*	Accipitridae
73	Shikra	*Accipiter badius*	Accipitridae

S. No.	Order / Common Name	Scientific Name	Families
74	**Podicipediformes** Little Grebe	*Tachybaptus ruficollis*	Podicipedidae
75	Oriental Darter	*Anhinga melanogaster*	Anhingidae
76	**Suliformes** Little Cormorant	*Microcarbo niger*	Phalacrocoracidae
77	Great Cormorant	*Phalacrocorax carbo*	Phalacrocoracidae
78	**Passeriformes** Indian Pitta	*Pitta brachyuran*	Pittidae
79	Asian Fairy-bluebird	*Irena puella*	Irenidae
80	Golden-fronted Leafbird	*Chloropsis aurifrons*	Irenidae
81	Bay-backed Shrike	*Lanius vittatus*	Laniidae
82	Rufous Treepie	*Dendrocitta vagabunda*	Corvidae
83	House Crow	*Corvus splendens*	Corvidae
84	Indian Jungle Crow	*Corvus culminates*	Corvidae
85	Ashy Woodswallow	*Artamus fuscus*	Artamidae
86	Black-hooded Oriole	*Oriolus xanthornus*	Oriolidae
87	Eurasian Golden Oriole	*Oriolus oriolus*	Oriolidae
88	Black-naped Oriole	*Oriolus chinensis*	Oriolidae
89	Large Cuckooshrike	*Coracina macei*	Campephagidae
90	Black-headed Cuckooshrike	*Coracina melanoptera*	Campephagidae
91	Orange Minivet	*Pericrocotus flammeus*	Campephagidae
92	Small Minivet	*Pericrocotus cinnamomeus*	Campephagidae
93	Black Drongo	*Edolius macrocercus*	Dicruridae
94	White-bellied Drongo	*Edolius caerulescens*	Dicruridae
95	Ashy Drongo	*Edolius leucophaeus*	Dicruridae
96	Bronzed Drongo	*Chaptia aeneus*	Dicruridae
97	Spangled Drongo	*Dicrurus hottentottus*	Dicruridae
98	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	Dicruridae
99	Asian Paradise-flycatcher	*Terpsiphone paradise*	Monarchidae
100	Common Iora	*Aegithina tiphia*	Aegithinidae
101	Common Woodshrike	*Tephrodornis*	Malconotinae

S. No.	Order / Common Name	Scientific Name	Families
		pondicerianus	
102	Malabar Woodshrike	*Tephrodornis virgatus*	Malconotinae
103	Eurasian Blackbird	*Turdus simillimus*	Turdidae
104	Malabar Whistling-thrush	*Myophonus horsfieldii*	Turdidae
105	Indian Robin	*Saxicoloides fulicatus*	Muscicapidae
106	Oriental Magpie-robin	*Copsychus saularis*	Muscicapidae
107	White-rumped Shama	*Copsychus malabaricus*	Muscicapidae
108	Pied Bushchat	*Saxicola caprata*	Muscicapidae
109	Tickell's Blue-flycatcher	*Cyornis tickelliae*	Muscicapidae
110	Asian Brown Flycatcher	*Muscicapa latirostris*	Muscicapidae
111	Verditer Flycatcher	*Eumyias thalassinus*	Muscicapidae
112	Brown-breasted Flycatcher	*Muscicapa dauurica*	Muscicapidae
113	Nilgiri Flycatcher	*Eumyias albicaudatus*	Muscicapidae
114	Common Myna	*Acridotheres tristis*	Sturnidae
115	Jungle Myna	*Acridotheres fuscus*	Sturnidae
116	Hill Myna	*Gracula religiosa*	Sturnidae
117	Brahminy Starling	*Sturnia pagodarum*	Sturnidae
118	Chestnut-tailed Starling	*Sturnia malabaricus*	Sturnidae
119	Rosy Starling	*Pastor roseus*	Sturnidae
120	Velvet-fronted Nuthatch	*Sitta frontalis*	Sittidae
121	Great Tit	*Parus nuchalis*	Paridae
122	Pacific Swallow	*Hirundo tahitica*	Hirundinidae
123	Red-vented Bulbul	*Pycnonotus cafer*	Pycnonotidae
124	Red-whiskered Bulbul	*Pycnonotus jocosus*	Pycnonotidae
125	White-browed Bulbul	*Pycnonotus luteolus*	Pycnonotidae
126	Asian Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae
127	Yellow-browed Bulbul	*Acritillas indica*	Pycnonotidae
128	Ashy Prinia	*Prinia socialis*	Cisticolidae
129	Plain Prinia	*Prinia inornata*	Cisticolidae
130	Grey-breasted Prinia	*Prinia hodgsonii*	Cisticolidae
131	Common Tailorbird	*Orthotomus sutorius*	Cisticolidae

S. No.	Order / Common Name	Scientific Name	Families
132	Oriental White-eye	*Zosterops palpebrosus*	Zosteropidae
133	Greenish Warbler	*Phylloscopus trochiloides*	Sylviidae
134	Paddyfield Warbler	*Acrocephalus agricola*	Sylviidae
135	Blyth's Reed-Warbler	*Acrocephalus dumetorum*	Sylviidae
136	Booted Warbler	*Hippolais caligata*	Sylviidae
137	Tawny-bellied Babbler	*Dumetia hyperythra*	Timaliidae
138	Jungle Babbler	*Turdoides striata*	Timaliidae
139	Yellow-eyed Babbler	*Chrysomma sinense*	Timaliidae
140	Common Babbler	*Turdoides caudata*	Timaliidae
141	Indian Bushlark	*Mirafra erythroptera*	Alaudidae
142	Singing Bushlark	*Mirafra cantillans*	Alaudidae
143	Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	Dicaeidae
144	Thick-billed Flowerpecker	*Pachyglossa agile*	Dicaeidae
145	Purple Sunbird	*Cinnyris asiatica*	Nectarinidae
146	Purple-rumped Sunbird	*Leptocoma zeylonica*	Nectarinidae
147	Loten's Sunbird	*Cinnyris lotenia*	Nectarinidae
148	House Sparrow	*Passer domesticus*	Passeridae
149	White Wagtail	*Motacilla alba*	Motacillidae
150	White-browed Wagtail	*Motacilla maderaspatensis*	Motacillidae
151	Yellow Wagtail	*Motacilla flava*	Motacillidae
152	Grey Wagtail	*Motacilla cinerea*	Motacillidae
153	Forest Wagtail	*Dendronanthus indicus*	Motacillidae
154	Tricoloured Munia	*Lonchura malacca*	Estrididae
155	Scaly-breasted Munia	*Lonchura punctulata*	Estrididae
156	White-rumped Munia	*Lonchura striata*	Estrididae
157	Indian Silverbill	*Lonchura malabarica*	Estrididae
158	Common Rosefinch	*Carpodacus erythrinus*	Fringillidae

APPENDIX 3

Cavity nesting birds recorded in the riparian forest of Athikadavu Valley

S. No.	Family & Common Name	Scientific Name	Cavity nesting birds Code
1	**Primary Cavity Nesters (PCNs)** **Capitonidae** White-cheeked Barbet	*Psilopogon viridis*	WCB
2	Brown-headed Barbet	*Psilopogon zeylanica*	BHB
3	Coppersmith Barbet	*Psilopogon haemacephala*	CSB
4	Malabar Barbet*	*Psilopogon rubricapila*	MB
5	**Picidae** Brown-caped Pygmy Woodpecker	*Dendrocopos nanus*	BCW
6	Common Flameback*	*Dinopium javanense*	CF
7	Greater Golden-backed Woodpecker	*Chrysocolaptes guttacristatus*	GBW
8	Rufous Woodpecker*	*Celeus brachyurus*	RW
9	White-naped Woodpecker	*Chrysocolaptes festivus*	WNW
10	**Secondary Cavity Nesters (SCNs)** **Psittacidae** Malabar Parakeet	*Psittacula columboides*	MP
11	Rose-ringed Parakeet	*Psittacula krameri*	RRP
12	Plum-headed Parakeet*	*Psittacula cyanocephala*	PHP
13	Vernal Hanging Parrot*	*Loriculus vernalis*	VHP
14	**Muscicapidae** Oriental Magpie Robin	*Copsychus saularis*	OMR
15	White-rumped Shama	*Copsychus malabaricus*	WRS
16	Tickell’s Blue-flycatcher	*Cyornis tickelliae*	TBF
17	**Coraciidae**	*Coracias benghalensis*	IR

S. No.	Family & Common Name	Scientific Name	Cavity nesting birds Code
	Indian Roller		
18	**Bucerotidae** Malabar Pied Hornbill	*Anthracoceros coronatus*	MPH
19	Great Hornbill	*Buceros bicornis*	GH
20	Indian Grey Hornbill*	*Ocyceros birostris*	IGH
21	**Sturnidae** Common Myna	*Acridotheres tristis*	CM
22	Jungle Myna	*Acridotheres fuscus*	JM
23	Hill Myna*	*Gracula religiosa*	HM
24	Brahminy Starling*	*Sturnus pagodarum*	BS
25	**Paridae** Great Tit	*Parus major*	GT
26	**Upupidae** Common Hoopoe	*Upupa epops*	CH
27	**Tytonidae** Spotted Owlet*	*Athene brama*	SO
28	Jungle Owlet	*Glaucidium radiatum*	JO
29	Brown Hawk Owl*	*Ninox scutulata*	BHO
30	Brown Fish Owl*	*Ketupa zeylonensis*	BFO
31	Indian Scops Owl	*Otus bakkamoena*	ISO
32	**Sittidae** Chestnut-bellied Nuthatch*	*Sitta castanea*	CBN

*bird species nests not recorded during the study period