Avian nest predation in forest margin areas in Lore Lindu National Park, Central Sulawesi, Indonesia

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1. INTRODUCTION

1.1 Background

The most anthropogenic use of forest in current time is clearing for logging and forest conversion for agricultural and residential purposes. These activities may lead to loss of forest habitat, forest degradation and often results in forest fragmentation. Habitat fragmentation is the process whereby a large continuous area of habitat is both reduced and divided into two or more fragments (Pullin, 2002). In general, forest conversion may generate forest margin habitats and edge habitats between newly-created landscapes and forest interior. The process of land clearing and forest degradation is continuing rapidly in many regions where tropical rainforest exists such as Southeast Asia and South America (Myers, 1988; Saunders et al, 1991). Tropical deforestation clears approximately 10 % of the original area per decade (Whitmore, 1997) and about half of the forest area has already gone in Southeast Asia. In many cases, tropical deforestation and the conversion of continuous forest to remnant forest patches within a matrix of non-forest vegetation, is increasing at an alarming levels (Whitmore and Sayer, 1992).

Deforestation and habitat alteration are principle causes of biodiversity change affecting the interaction among organisms living in those areas. Most analyses have been assigned to forest habitats and vertebrate populations because they are apparently more sensitive to harmful effects of fragmentation (Whitcomb et al., 1981; Wilcove, 1985). Extensive and prolonged deforestation has the effect of isolating small populations in the few remaining forest fragments (Fischer, 2002). Furthermore, forest margin habitats as a result of forest alteration may enhance the edge effect that influences the presence of wildlife.

Habitat alteration and fragmentation of natural habitats has had a major impact on birds in many parts of the world (Collar et al., 1994). A number of studies on effects of fragmentation on avian fauna have been studies in temperate regions. Habitat alteration and fragmentation is believed to be one of the reasons why birds have declined in Australian woodlands and forests (Howe, 1984; Taylor and Ford, 1998). In particular, habitat degradation may enhance predation pressure of nests, due to loss of understorey vegetation and an increase in nest predator varieties (Taylor and Ford, 1998).

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Several other studies in north temperate zone have also documented the effects of forest degradation and fragmentation on birds. Some of them, investigating the effects of forest fragmentation by agriculture, have shown that birds nesting in small fragmented forest patches suffer higher rates of predation than in larger blocks of forest, especially along edges (Wilcove, 1985; Paton, 1994; Andrèn, 1995). Forest fragmentation adversely affects abundance and distribution of insectivorous passerines in the eastern United States (Whitcomb et al., 1981). Increased degradation and habitat fragmentation of contiguous forest in central Canada may change the distribution and composition of bird communities because of a reduction in the quantity and quality of available breeding habitat (Saunders et al., 1991). Furthermore, the influx of predators from nearby habitats may be responsible for much of the nest predation in forest fragments in Maine, USA (Small and Hunter, 1988).

Habitat degradation and fragmentation have affected the population of vertebrate fauna in tropical forest. These changes, particularly the fragmentation and isolation of forest habitats, have been suggested as an important factor in the decline of the populations of Neotropical migrant songbirds (Robbins et al., 1989; Keyser et al., 1997). In the Colombian Andes, large–scale fragmentation has resulted in the decline and local extinction of bird populations (Arango–Vélez and Kattan, 1997). Therefore, large-scale anthropogenic disturbances have contributed to the biological impoverishment in many tropical ecosystems (Laurance and Bierregaard, 1997).

Tropical lowland and hill rainforests of Southeast Asia are continually being fragmented and drastically lost. In Indonesia, illegal logging, forest encroachment and forest fires have exacerbated the environmental destruction, with a sharp increase in degraded forest areas. The threat is rapidly expanding into lower montane forests because the vast majority of lowland areas have been converted for agricultural purposes. These current patterns of development cause a depletion of wildlife and its habitats. Given recent trends in agriculture, degradation of these rich tropical forests seems to continue (Collins et al., 1991), but little is known about the consequences of the large-scale habitat modification in this region (Wong et al., 1998).

Sulawesi (formerly Celebes) provides habitat for 328 bird species, mostly within rainforest. About 88 species (27 %) from 14 genera are endemic to the island (Kinnaird, 1995). Accordingly, Sulawesi has been identified as being amongst the most important Endemic Bird Areas (EBA) of the world (Stattersfield et al., 1998). Several species of understorey birds such as the Sulawesi Babbler (*Trichastoma celebense*), the Rusty-bellied Fantail (*Rhipidura teysmanni*), Yellow-vented Whistler (*Pachicephala sulfuriventer*) and the Mangrove Blue Flycatcher (*Cyornis omissus*) are endemic to the island (Coates et al., 1996).

Forest degradation and habitat alteration might be considered to be the main threat for understorey and ground-nesting forest birds in Sulawesi. Two endemic species, Snoring Rail (*Aramidosis plateni*) and Blue-faced Rail (*Gymnocrex rosenbergii*) are considered as threatened species due to intensive habitat destruction in this area (Shannaz et al., 1995). Understorey birds are regarded as being especially sensitive to forest alteration and habitat disturbances (Wong, 1985) and ground-nesting birds are often the first to disappear after fragmentation in tropical forests (Thiollay, 1992; Stouffer and Bierregaard, 1995; Söderström, 1999). However, many understorey forest birds in Central Sulawesi can also be found in disturbed habitats (Coates et al., 1997; Waltert et al., in prep.) and they also breed along forest edges.

One consequence of forest alteration and fragmentation is the creation of distinct boundaries or edges that influence the movement and distribution of organisms (Wiens, 1992; Restrepo and Gómez, 1998). Fragmentation and remnant intact forest results in an increase of forest edge and forest margin habitats (Hoover et al., 1995; Carlson and Hartman, 2001). These modification may lead to edge effects on nest predation. For example, these changes can affect the native biota as generalised predators that are adapted to edge habitats can infiltrate the remaining forest more easily (Whitcomb et al., 1981; Wilcove, 1985). Furthermore, it enhances the occurrence of parasitism compared to that in forest interiors (Gates and Gysel, 1978; Andrén and Angelstam, 1988; Santos and Tellería, 1992). Most edge effects seem to be deleterious to forest fragments by causing changes in abiotic and biotic conditions (Murcia, 1995; Laurance et al., 1997; Estrada et al., 2002). Edge effects may be a serious threat for certain bird populations because it enhances the risk of predation on eggs and nestlings.

Most of the protected areas in Indonesia are challenged by anthrophogenic disturbances mentioned above. Lore Lindu National Park is a protected area located in Central Sulawesi and is of high endemic value within the wider Wallacea region (figure 2.2 see study area). Despite several conservation initiatives from regional government and Non Government Organisations (NGO´s), deforestation and habitat degradation caused by agricultural and settlement development continues to present significant challenges for park management programmes. As a result, land-use systems such as forest gardens, plantation and annual crops continue to encroach into the park. The conversion of forest to agricultural practices generates a broad forest margin which covers significant areas of the park.

As the enforcement of park regulations is limited, small-scale anthropogenic use of forest margins has the potential to extend to a far larger scale. For example, in August 2001 local people established a new settlement in Dongi-Dongi, one of the main bird watching areas of the park. Approximately 640 hectares of forest habitat was cleared and planted in annual food crops. This process shows no sign of stopping and continues to expand into the forest interior.

Coffee and cacao plantations are the most widespread and economically important agroecosystems both surrounding and within Lore Lindu National Park. These land-use systems, particularly coffee plantations, existed before the park was established. In addition, forest gardens and secondary growth have also been developed in this area. Theprimary cause of tropical forest loss is conversion to agricultural systems of production (Houghton, 1994, Lindell et al., 2003). This has resulted in intensive clear cutting of forest vegetation within the park by local communities in order to establish new fields for annual crops. The land-use systems have been mainly developed in the park's valley areas where the people can easily access to the forest area

The high frequency of human activities along forest margin habitats may influence the interaction of wildlife in those areas. Forest margin habitats are particularly vulnerable to intense anthropogenic disturbance inside the national park due to ease of access and the ability of communities to enhance such development. This suggests that biodiversity conservation within increasingly fragmented natural habitats requires an understanding of the effects of forest margin habitats and edges in relation to community dynamics. Habitat degradation and fragmentation and accompanying edges are major problems faced by

wildlife (Temple and Carey, 1988). Research is needed to understand their effects in relation to a variety of factors such as nest predation pattern and fragmentation intensity in order to design suitable management practises (Ratti and Reese, 1988; Yahner, 1988).

Human activities might be more frequent along forest edge and forest margin areas than in the forest interior. As several land-use systems have already existed in the park area, it is clear that the local stakeholders maintain the plantation and harvest it regularly. The other activities such as fuel-wood collecting, rattan collecting, wild food plant collecting, pole sized timber for construction, crops and palm products, medicinal plant collecting and trapping enhance the intensity of people visiting these areas. It is assumed that human activities could indirectly influence the predation pressure along forest margin areas.

Furthermore, changes in forest margin structure may affect predation pressure on birds in terms of nest predator diversity, abundance and their response to prey. In some cases, habitat alterations attract non-forest species from surrounding landscapes as they enter the forest and forage amongst the newly available forest edge (e.g. Angelstam, 1986; Andrén and Angelstam, 1988; Small and Hunter, 1988). While local communities enhance their productive utility of forest habitat in these areas, the influx of introduced species is likely to continue. As a result, certain predator fauna might be more diverse in marginal habitats compared to forest interior. On the other hand, large mammals functioning as top predators may disappear in disturbed areas causing increased mesopredator populations (Crooks and Soulé, 1999). Predator responses may be considered as a function of regional differences in predator communities and land-use practices (Chalfoun et al., 2002). These factors could adversely affect the predation risk for forest bird species.

Compared to birds of the northern temperate region, those of the tropics tend to have smaller clutch sizes, longer breeding seasons, slower growth rates, more prolonged periods of parental care, make many more nesting attempts per year, and have a higher rate of adult survival (Skutch 1966; Ricklefs, 1969). Elevated nest predation together with greater food limitations and a stable tropical climate are likely to be the main factors influencing this evolution. However the unequivocal evidence for higher nest predation and lower food availability in the tropics is still inadequate (Martin, 1996; Fischer, 2000).

Few studies have been done on nest predation rates in the tropical forests of Southeast Asia, in spite of the rapid deforestation and habitat disturbance in this region. The only two reports are both from Singapore, where Cooper and Francis (1998) studied the influence of selective logging on nest predation rates and Wong et al. (1998) examined the variation of predation rates in relation to forest edge, forest types, forest areas, isolation and canopy closure. Further studies on nest predation which might be valuable to assess the effect of forest degradation and fragmentation on nesting success should be taken into account.

No study exists on nest predation reported on the island of Sulawesi, Indonesia. Considering the significant habitat threats that Sulawesi faces, there is an urgent need to study the nest predation that includes predator identification in this area. Understanding the factors affecting nest predation rates is important because nest predation is the primary cause of avian nest mortality. At a more general level, documentation of predation rates in forest remnants using artificial nests is important form of a wider conservation perspective (Burkey, 1993).

1.2 Aims and objectives

The principle objective of this study is to explore aspects of avian nest predation in relation to forest margin habitats and forest edge structure. In particular, differences in predation rates and predator fauna composition between forest margins compared with natural (undisturbed) forest in Palolo and Napu valley were assessed. The results of this study may be used as an indicator of how the forest disturbance affect predation pressure in forest margin areas. Through experimental trials, I examined the effect of habitat disturbances corresponding to several generally important determinants of the risk of nest predation; (1) edge effects (Gates and Gysel, 1978; Wilcove, 1985; Angelstam, 1986), (2) predator composition and abundances, (3) reduction of vegetation cover (Martin, 1993; Rudnicky and Hunter, 1993; Darveau et al., 1997) and (4) intensity of human activities.

The following questions were addressed in this study:
1. Does avian nest predation increase near forest edges?
2. Are the predation rate on ground nest similar to that on shrub nest?
3. Is predation pressure in forest margin habitats higher than in natural forest?
   If so, which factors influence the elevated rates of nest predation?

4. What kind of predator fauna prey upon ground and shrub nests? Some settlements are located along the buffer zone of the park and several transient huts are located close to forest margin areas; are there introduced species along forest margin habitats?

5. Are vegetation structures influence predation pressure in forest margin habitats?

6. Do human activities along forest margin habitats influence nest predation risk?

7. Do predation pressures affect understorey bird communities in the given areas?

1.3 Nest predation studies

Nest predation is a primary determinant of reproductive success in bird communities (Cody 1971, Loiselle and Hopes 1983; Martin 1988, Laurance et al., 1993). It is likely to be the main cause of egg and nestling mortality and then affect bird population density (Fretwell 1972, Lahti, 2001) as well as bird community structure (Martin 1988; Söderström, 1998). Some studies document that nest predation, on average, accounted for 80 % of nest losses across a wide variety of habitat, species and geographic locations (Martin, 1993). Nest predation is thus a natural regulator of many bird species. However, nest predation may also pose a significant threat to several bird populations if predation pressures increase too rapidly. Studies conducted in both temperate and tropical forests identified nest predation by vertebrates as one of the major limitations of forest bird populations (Telleria and Diaz, 1995; Cooper and Francis, 1998). Nest predation may influence species-area relationships (Martin,1988) and predation pressure may vary with habitat structure (Bowman and Harris,1980; Yahner et al., 1989; Söderström et al., 1998).

Studies in temperate forests have demonstrated that predation rates on bird's nests are higher at forest edges than interior forest (Gates and Gysel, 1978; Wilcove, 1985; Andrén and Angelstam, 1988). Other studies have shown either the opposite effect (Storch, 1991) or that there is no edge effect on predation rates (Small and Hunter, 1988; Keyser et al., 1998). Because forest fragmentation results in greater edge (Hoover et al., 1995) and predators select edges for foraging (Gates and Gysel, 1978), predation on avian nests could increase with extensive forest alteration and fragmentation (Noss, 1983; Yahner and Scott, 1988). Predation rates are affected by regional patterns of habitat fragmentation and local-scale attributes such as edge structure and patch sizes (Robinson et al., 1995; Chalfoun et al, 2002).

Edge effects on nest predation rates could be caused by the differences in the abundance of predators occupying forest margin areas and forest interior and species richness of nest predators (Bider, 1968; Andren, 1992). These rates could also be influenced by vegetation structure such as canopy closure and shrub layer density. Estrada et al. (2002) suggested that concealment of nests by the vegetation in forest habitats may have resulted in less predation pressure. In addition, anthrophogenic activities may be another factor which adversely enhance the edge effects on nest predation. The intensity of antrophogenic disturbance has affected the predation rates along hedges (Barkow et al., 2001).

Several studies in tropical rainforests have also documented the effects of habitat disturbance on nest predation. The rates of avian nest predation are higher along forest edge and marginal areas as well as in forest fragments, than inside primary or natural forest (e.g. Loiselle and Hopes, 1983; Gibbs, 1991; Burkey, 1993; Cooper and Francis, 1998).
It is clear that high predation rates on eggs and nestlings near edges may have consequences for bird species in fragmented tropical habitats (Ricklefs, 1969; Burkey, 1993). The negative association between forest fragment size and nest predation rates has been attributed to increased nest density, edge-related effects or a combination thereof (Keyser et al., 1998). Along with brood parasitism, nest predation is an important factor limiting the reproduction and population viability of many Neotropical bird species in fragmented landscapes (Robinson and Wilcove, 1994; Chalfoun et al., 2002). The high predation risk near edges may result from higher predator activity on edges than in the forest interior. Nest predation is often intensified in fragmented habitats (Laurance et al., 1993) and many bird species are poorly adapted for increased predation pressure in these habitats (Gates and Gysel 1978; Sieving,1992; Laurance, et al., 1993).

1.4 Artificial nests

Artificial nests have been used frequently in several studies on nest predation to understand patterns of predation on bird nests and also to investigate different nest predator fauna. The major objective of using this kind of nest is to test various ecological and behavioural hypotheses of predation theory (Gibbs, 1991). Major and Kendal (1996) suggested two other functions of artificial nests:

1. They provide sample sizes rarely available with real nests and the treatments of artificial nests can be readily standardised.

2. Experiments using artificial nests have provided information on the importance of different nest predators that is often lacking in studies using natural nests.

Artificial nests are frequently used in predation studies to provide an index of predation pressure (Wilcove, 1985). The evidence that forest alteration increases rates of nest predation comes from studies that have used artificial nests baited with quail or chicken eggs (Wilcove, 1985; Small and Hunter, 1988; Yahner and Scott, 1988). An assumption of this technique is that nest predators search for, encounter and respond to artificial nests in the same manner as to natural nests. Also, that predation sustained by artificial nests represents a reliable index of the relative predation intensity experienced by birds nesting naturally in the same habitat (Martin, 1987; Carlson and Hartman, 2001). Artificial nest experiments have been interpreted as reflecting the relative pattern of predation on real nests in different fragment sizes and various habitat types (Haskell, 1995).

The following sections discusses advantages of using artificial nests when studying predation patterns. In the use of artificial nests , the number and distribution of nests can be controlled and they are easier for a researcher to locate them than natural nests. The use of artificial nests in field studies affords the ability to measure variations in nest predation pressures among habitat types, after fixing the effect of other nest features which can also affect nest predation rates such as nest size, nest structure and egg size (Yahner and Wright, 1985; Telleria and Diaz, 1995). Field experiments using artificial nests can provide a reasonable index of predation pressure for birds nesting in a particular habitat (George, 1987; Major and Kendal, 1996; Fischer, 2000). Artificial nest experiments are considered as useful tools for comparing predation risk among habitat types (Wilcove, 1985; Angelstam, 1986).

Various eggs have been used as bait for artificial nest experiments, mainly quail and chicken eggs. Experiments using quail eggs were appropriate to imitate the natural eggs of many understorey bird species. Some species of Monarchidae and Rallidae lay eggs of a similar size to quail eggs (Pangau, personal observation, 2001) and some species of Pittidae produce eggs which appear similar in appearance to quail eggs (Cooper and Francis, 1998). Numerous researchers have used artificial nests with quail eggs in order to evaluate differences in predation rates among avian populations (see Paton, 1994 for review).

In this study, artificial nests were used because of the difficulties in locating suitable numbers of natural nests in the study areas. Artificial nest experiments were used to examine ground and shrub nest predation rates along forest margin habitats including edges and in natural forests in two different valleys of Lore Lindu National Park. These areas are under threat by rapid deforestation and habitat degradation by local human population growth and land development.

1.5 Output and contributions

The data from this studies may provide an indication of predation rates, the factors affecting predation pressure and potential nest predator fauna which may contribute to the understanding of avian reproductive success. The findings of this study are expected to indicate how the predation pressure in forest margin areas influences understorey and ground nesting bird communities. Understanding nest predation intensities in natural forest, compared to that at forest edge and forest margin habitats, may shed new light on the mechanism of habitat degradation that relates to species extinction in fragile tropical forest ecosystems. Knowledge about the effect of edges on nest predation may expectantly influence decisions about reserve design. Since there is a lack of studies on how habitat degradation and fragmentation affect wildlife in Sulawesi, this study may produce crucial information on the ecological processes occurring on this island. Hopefully the information will be useful for the conservation of Sulawesi's biodiversity.

The results of this study can contribute to land-use management decision making both within and surrounding the protected areas. In turn, this can facilitate better sustainable management practices at Lore Lindu National Park for the benefit of both wildlife and humans. Forest margin areas in buffer zones of national parks constitute significant elements in management plans. Subsequently, the results of this study have potentially significant implication for conservation and park management.

2. STUDY AREA

2.1 Sulawesi Island

2.1.1 Biogeographical history and Wallacea region

Sulawesi has a particularly biogeographical history which has made it one of the most exciting bioregion in the world. Powerful geological forces have continually pushed and pulled the separate land masses from two continents, Asia and Australia, that now comprise the island of Sulawesi. Factions from four different land masses collided some 12-16 million years ago to create the island and the remnants of these have emerged in its four distinctive geographical penninsulas (Whitten,1986).

The island became the largest and most central island of Wallacea, a unique region of the world where plants and animals from Asia and Australia merged. Several large mammals from the Asian continent such as large forest cats have ended their existence on Borneo island due to the deep sea between Borneo and Sulawesi (Kinnaird, 1995). On the other hand, the presence of fauna related to those found in eastern Indonesia and so-called Australasian fauna, revealed little connection between Sulawesi and these respective regions. The only remaining fauna which could explain the connection with the Australian continent is the presence of Dwarf cuscus (*Strigocuscus celebensis*) and Bear cuscus (*Phalanger ursinus*).

Wallacea sub-region was named after the famous nineteenth century naturalist Alfred Russel Wallacea. He established a line to mark the remarkable change in wildlife that inhabit areas east of a line drawn between Bali and Lombok and between Borneo and Sulawesi. To the east of Wallace's line the fauna changes, gradually becoming more Australasian in character (Kinnaird, 1995). The Dutch zoologist Max Weber suggested another line of faunal balance to mark the boundary of the islands which have Oriental affinities and those with truly Australian fauna. Weber's line was mainly based on mammal and mollusc species and it lies east of Sulawesi (MacKinnon, 1992).

The lithological and climatic variations of Sulawesi are reflected in its rich and varied ecological mosaic of plant and animal communities. Various systems have been formulated

to differentiate between forest types, such as those given by Whitten et al. (1987): (1) Lowland and hill forest, 0 –1000 m (2) Lower montane forest, 1000 – 2100 m (3) Upper montane forest, 2100 – 3000 m and (4) Subalpine forest, above 3000 m.

2.1.2 Endemism of the island

The long period of isolation from other major landmasses and their location in the Wallacea bioregion, has resulted in unique fauna not only particularly rich in species, but has a very high level of endemism. In fact, some of the highest levels of the endemism in the Indonesian archipelago are found on this island. Possibly, the four-narrow peninsulas support different patterns of species distribution. This might lead to a kind of biological process like speciation which has lead to the evolution of local endemic species.

Compared to other islands of Indonesia, Sulawesi is home to one of the most distinctive fauna composition particularly among the mammals. Of the 127 indigenous mammal species, 79 (62 %) are endemic species and this would rise to 98 % if bats were excluded (Kinnaird, 1995). Endemic mammals of Sulawesi include bats, rats, civet, macaques, tarsiers, wild buffalo and babirusa, but there is no evidence of the presence of large carnivores. The composition of the mammal fauna is very different to that of Kalimantan or Irian with many fewer families represented. It seemed that rats and bats are major components of the fauna on the island. There are around 54 species of rodents occurring in Sulawesi (Whitten et al., 1986) which comprise rats, squirrels and shrews.

Among 328 bird species with mostly inhabiting rainforest habitats, 88 species (27 %) from 14 genera are endemic to the island (Kinnaird, 1995) and 81 (25 %) are migratory (White and Bruce, 1986). Records of new species, previously unknown on Sulawesi are still being made (Wattling, 1983). Whitten et al. (1986) reported that half of the 88 endemic birds could be found in all regions of the island and half have partially-restricted distributions along Sulawesi. Moreover, five species are known to inhabit only the north peninsula, central area and southeast peninsula. Two species are particularly from the central area and southwest as well as southeast peninsulas and two species are from the central area and southwest peninsula. As a result, the number of endemic species is different between the main regions/peninsulas.

Despite the high endemism of the island, the rainforest as the main habitats of significant wildlife is continuously decreasing. In 1988, the lowland rainforest covered approximately 42 % of all Sulawesi and the montane forest was estimated to be 12 % (Collins et al, 1991). Large areas of mainly lowland and hill forest followed by lower montane forest have obviously been cleared since then and the current forest cover is likely to be much lower. However, no reliable official estimate seems to be available (Thiollay and Rahman, 2002).

2.2 Lore Lindu National Park (LLNP)

Lore Lindu National Park is located in Central Sulawesi, (119°90'-120°16' E : 1°8'-1°3'S). The park covers 217,000 hectares which consists of 20 % montane forest, 70 % hill and lower montane forest with most of the rest being lowland forest (± 10 %). It is composed of a complex rift of valleys and steeply folded mountains as a result of major tectonic movements during the Pliocene-Miocene epochs. The highest peaks are Mt. Nokilalaki (2355 m) and Mt. Rorekatimbu (2610 m). Bounded to the west by the deep cleft of the Palu /Lariang rift, to the east by the Owaingkaia river - a major tributary of the Lariang - and to the north by the Gumbasa and Sopu rivers, the whole area of the National Park totals about 250,000 ha, (Food and Agriculture Organisation FAO, 1977; The Nature Conservation, TNC, 2001)

The park is tied by four valleys: the Palolo to the north, Napu to the east, Bada to the south and Kulawi to the west. Two valley enclaves occurring in the middle of the park, Lindu and Besoa are excluded from the park. The annual rainfall ranges from 2000 – 3000 mm in the north to 3000 - 4000 mm in the south. It falls throughout the year and the heaviest period is during the northern monsoon which lasts from November to April. There is no pronounced wet and dry season. The daytime temperature in lowland areas of the park ranges from 26-32°C.

The mountainous topography of the park seems to be unsuitable for agriculture; soils are shallow and vulnerable to erosion during periods of high wet season (TNC, 2001). However, lowland, hill forest and lower montane areas are suitable for agriculture fields and people are attracted here to clear the forest and establish their field for crops. It enhances the elimination of this small part of the entire park areas.

2.2.1 Fauna in the park

Many of the endemic animals of Sulawesi are forest dwellers and can be found within the park. This includes Sulawesi's largest native mammals, the mountain Anoa (*Bubalus quarlesi*) and Babirusa (*Babyrousa babyrussa*), Sulawesi Warty Pig (*Sus celebensis*), two species of Tarsier (*Tarsius dianae, T. pumilus*), the Tonkean macaque (*Macaca tonkeana*), two species of the marsupial Cuscus (*Phalanger ursinus* and *Strigocuscus celebensis*) and Sulawesi's carnivore, the Sulawesi civet (*Macrogalidia musschenbroeckii*) (TNC, 2001). The introduced civet, the Malay palm civet (*Viverra tangalunga*) and Rusa deer (*Cervus timorensis*) are also known to live in the park (Departemen Kehutanan, 1995).

Bird species tend to inhabit very specific niches that vary with altitude and due to the park's great range of elevation, bird diversity is considerably high. Around 83 % of Sulawesi's endemic bird species have been seen within the park, although many are rare or exist only at low densities. Some other species are migratory and Lake Lindu provides a haven for water-birds passing through and over the park (TNC, 2001).

Regarding the small mammals, Lore Lindu National Park has quite a large number of bats, at least five species of squirrels, and 31 of 38 rat species are endemic.

2.2.2 Vegetation and forest types

The vegetation is generally classified into two major vegetation types based on altitudinal distribution with lowland rainforest below 1000 m and montane rainforest above 1000 m (TNC, 2001). Following the classification of forest type of Sulawesi given by Whitten et al. (1987), that lowland and hill forest ranged from 0 to 1500 m asl, two sub groups might be developed: (1) lowland forest, 0-1000 m and (2) hill forest, 1000-1500 m asl Sulawesi's lowland forests are generally characterised by (i) a tall canopy that generally reaches 30-50 m, with emergent reaching c. 70 m, (ii) large buttressed trees with smooth trunks and (iii) the presence of many woody climbers (Coates et al., 1997).

The floristic composition of rainforest below 1,000 m asl is somewhat heterogenous. Many species can be encountered in this area but there is no species domination. The common species are *Calamus spp, Ficus spp* and *Eucalyptus deglupta*. Other plant species found in

this area are *Syzigium, Dysoxylum, Mussaendopsis beccariana, Artocarpus spp, Pangium edulum, Dysoxyllum sp, Ficus sp, Miristica sp*, and many palms especially Livistona (e.g.: *Livistona rotundifolia*), *Arenga pinnata (enau), Caryota spp, Calamus sp* in the lower strata, and endemic palms, wanga (*Pigafetta filaris*). *Pigafeta filaris* is the palm species occurring in this forest type, which is obviously being a pioneer vegetation at the forest gap. All palms except rattan are generally restricted below 1000 m elevation. Wild gingers spring up in areas where light trough gaps in the canopy penetrate the forest floor. Lowland forest in the wetter regions are characterised by the conspicuous presence of thick climbers, large buttressed trees and the prevalence of trees with tall, smooth-barked trunks (Whitten et al., 1986). The height of trees reach 30-40 m with wide diameter bases around 70-80 cm.

At the lower montane forest (> 1,000 m asl), the vegetation gradually changes. Trees progressively become shorter and the diameter of trunks is smaller. Epiphytes are common in this forest type. There are around 88 species which have been identified within the park. Birdnest fern (*Asplenium nidus)* and Staghorn fern (*Platycerium sp)* are frequent and proliferate on tree branches. The high value timber species are represented from the tree families Myrtaceaea and Lauracea. In the past, *Agathis dammara* was a commercially important species. Several closely-related species are found within the park and their resin (called copal or damar) is tapped and sold for use in varnishes, lacquers and linoleum or used locally to fuel torches.

2.2.3 Encroachment and deforestation

The main issue in Lore Lindu National Park is encroachment and deforestation. The FAO (1977) considered the biggest temptation to law breakers was likely to be illegal logging in the park area and the collection of maleo eggs. People were frequently seen along the park borders with timber and the sound of chainsaws from the forest were clearly evidence of illegal logging operations. Local communities were also motivated to seek traditional rights to forest access, arising in conflicts between them and the National Park management.

The other main operations in the park areas were rattan collections and agricultural encroachment involving cash cropping of coffee and cacao. Some areas which were converted to agricultural fields and coffee/cacao plantations have infiltrated deep into park borders, thereby modifying habitats for forest-dwelling animals. Most people living in the villages know that the area is protected, but they are still running these operations mainly due to the unclear boundary of the park and tenuous law enforcement. At present, there seems to be a dichotomy arising between those who support stronger enforcement and those who prefer community-based conservation agreements.

Lowland forest and lower montane forest are the main target of encroachment and deforestation in the park area. This is due to uncomplicated topography for people to open up the forest and clear the vegetation. As a result, significant areas of land within the park are claimed as traditional property by local people resulting in several land-use systems and marginal forests. Within the park areas, land practices can be categorised into two main types:

1. land clearly traditionally owned by local people before park establishment
2. land newly opened-up or only recently used, since the park was established in 1993.

Both of these types have been expanded into two different land-uses, (1) resource gathering and hunting and (2) agriculture/agroforestry (TNC, 2001). In the past, those land-uses were for subsistence or village use. Most people living in the vicinity of the LLNP area usually collect and harvest forest products e.g. fruit of pandanus, rattan, small trees used as skeletons for the houses and medicinal plants. In this region, forest plants have numerous other local uses.

Under an agreement with the park authorities, the people who own the land can still harvest the crops, but they are not allowed to plant new plants on their land or extend the area. This agreement was spread out to the villages surrounding the LLNP with the assistance of village leaders. However, encroachment is still going on and some exotic perennial crops such as coconut, mango and durian were planted inside protected areas. Some people even extended their land through deforestation of secondary forest and natural forest to establish new fields. The reasons for these actions could be deduced from the following points: (1) tenuous law enforcement (ii) family growth, if the children of a farmer get married they need land-use to support their livelihood (iii) in some cases, the farmers who need money for education and marriage of their children should sell the land

to the other etnic groups like Buginesse group and consider the possibility of opening up the next forest block.

In Central Sulawesi, hunting and trapping were traditional activities. The hunters used to hunt and trap wild animals in the forest interior and stay several days until they found bushmeat. In the forest margin habitats or disturbed forest of Kamarora, several traditional rat traps can still be encountered. Some people from Kamarora, Wuasa and Bada villages still consume these wild rodents.

The other wild animals targeted for hunting and trapping are Anoa, Babirusa, Babi hutan, Cuscus, and Jungle fowl. Unlike other parts of Sulawesi where animal skins and meat are sold in the local markets, the hunter from the villages around LLNP bring bushmeat to the village for family consumption only. Part of that would also be distributed to the neighbours and relatives. There was no particular local market where bushmeat could be purchased.

2.2.4 Park management

Lore Lindu National Park was established in October 1993 from Lore Kalamanta Nature Reserve and Lake Lindu Recreation and Protection Forest. The park is a major catchment area of Gumbasa and Lariang rivers. It has been declared as a Man and the Biosphere Reserve (MAB) by UNESCO.

Unfortunately, the park boundary was established less carefully and significant areas of land within the park have been claimed as traditional property by local people. All land-use systems are spread out in the valleys where people first settled. Zoning of the park is still in management plans. Several paths and roads have been established in the park area due to the presence of settlements. These routes allow some access for both hunting, gathering forest product and cash cropping.

The main constraint at the current time is that local people have made land claims within the park. Some of these claims are valid because the land belongs to ethnic groups with a long history of so-called traditional "Adat law". To solve this problem, National Park

authorities and local government are working together to formulate a reconciliation with local communities concerning the property rights and utilisation of park areas.

An important part of zoning in the park is the establishment of a buffer zone. This is going to be undertaken through Central Sulawesi Integrated Agreement for Development and Conservation Project (CSIADCP) which works in close collaboration with local government (Badan Perencanaan Pembangunan Daerah, BAPPEDA). Following instructions from the Ministry of Internal Affairs, this zone should be contiguous with, but outside the national park. Its main purpose is to enhance both conservation in and around the park and socio-economic improvement. There is a clear need for close linkage between the buffer zone and internal zoning within the park, particularly that of the land-use systems and traditional use.

In order to control and monitor the park, 64 rangers (park guards) were appointed to work in three park stations; Kulawi, Kamarora and Wuasa. Their role is to keep the park area free from encroachment, illegal logging and other large-scale anthropogenic use. It seems that the number of rangers were not sufficient for such a large protected area.

According to the national park management plan of 1996, five main goals were identified. They are as follows:
1. To conserve Sulawesi's biodiversity and ecological processes within the park
2. To manage the park's natural resources and ecological processes to support agriculture in surrounding areas
3. To use the natural resources of the park and surrounding areas sustainably in response to the interests of local people
4. To develop nature and cultural-based tourism as an alternative source of income whilst maintaining the beauty of the landscape, the abundance of unique and endangered wildlife and the traditions and customs of local people
5. To build strong local support and involvement in park protection and management.

Figure 2.1 The road was established through the Lore Lindu National Park area as infrastructure for the villages surrounding the park.

Several management priorities which are ongoing programmes within the national park are as follows:

- Complete boundary demarcation
- Upgrading and better support for the park guard to stop illegal hunting and removal of forest products
- Establish buffer zones
- Increase public awareness and community support
- Promote tourism

2.3 Study sites

Study sites were determined in two different valleys of the park; Palolo valley and Napu valley. Some villages exist in the surrounding areas and encroachment as well forest disturbances seem to be more frequent in recent time.

The first fieldwork was carried out in Palolo valley (at 700-1100 m asl, see figure 2.2), along forest margin areas where intensive land-use practices occurred, and at Nokilalaki

mountainside where the natural forest still exists. The second experimental set-up was conducted in Napu valley (1100-1200 m asl) where the natural forest as reference habitat still exists. The hill forest are dissected by coffee and cacao plantations mainly planted before the park was established.

In Palolo valley, five types of landscape was selected taking into account a gradient from marginal area to indigenous forest. These are: (i) forest edge (ii) forest gardens (iii) coffee plantation (iv) secondary forest and (v) natural forest. Three study sites have been established in Napu valley (i) forest edge (ii) secondary forest and (iii) natural forest. Number (i) to (iv) were accounted for as forest margin habitats. They were also chosen by the STORMA (Stability of Rainforest Margin) project as forest margin habitats and natural forest, see http://www.storma.de.
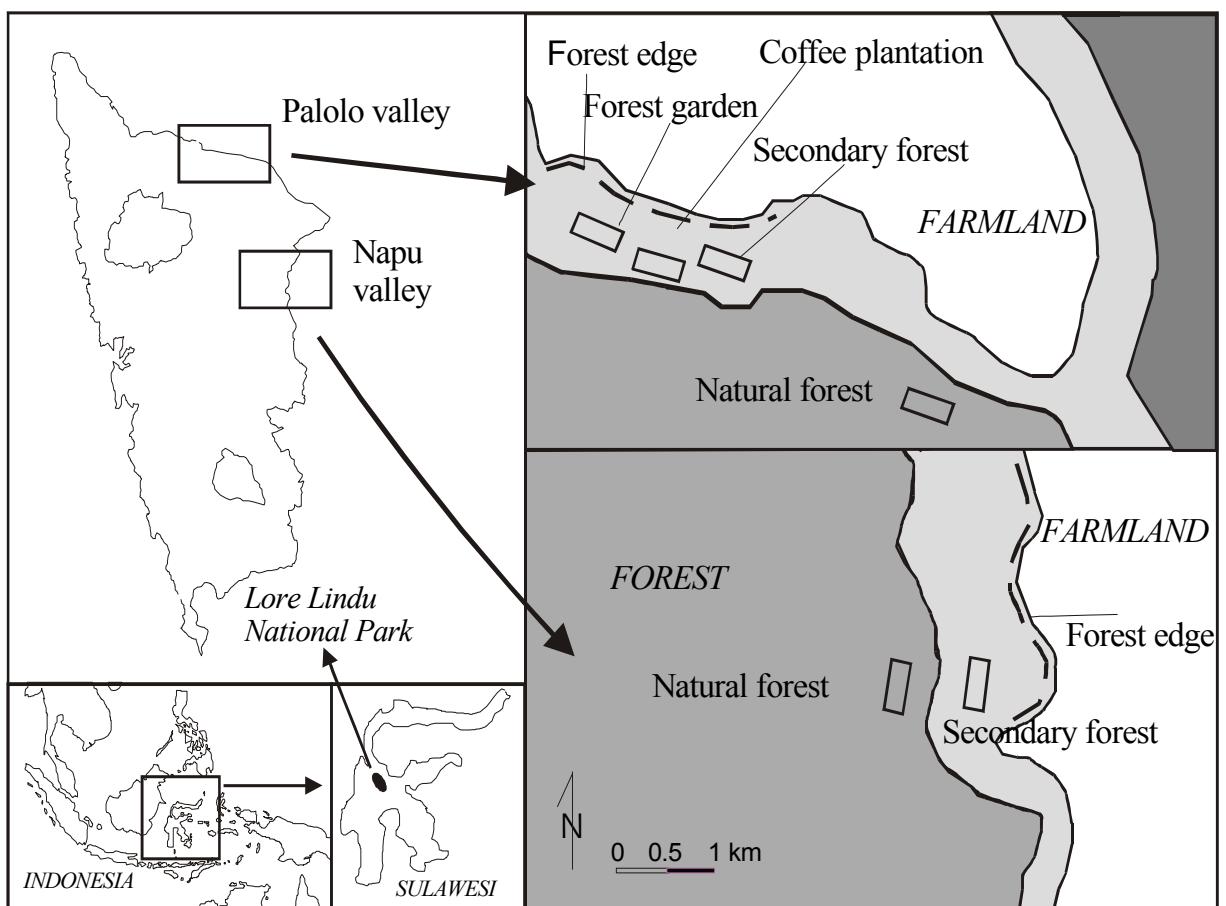
Figure 2.2 Study sites in Lore Lindu National Park, Central Sulawesi, Indonesia.

2.3.1 Forest edge

An edge can be defined as the connection of two different landscape elements such as plant community type, succesional stage and land-use (Yahner, 1988). Furthermore, he highlighted that this connection is either a well-defined boundary or a transition zone (ecotone) where plant and associated wildlife communities place into one another. Forest edge in this study is a linear intersection between forest landscape and agricultural fields (maize) and dirt roads in Palolo valley and between forest and maize field in Napu valley. In the Palolo valley site, there was no dominant tree species but in Napu valley, the occurrence of Macaranga was common.

2.3.2 Forest garden

Forest garden is defined as a traditional land-use form of forest margins containing cultivated plant species and their wild relatives as well as forest vegetation. This is a very typical system for Indonesian forest margin (Weidelt, 2000). The forest gardens in the park are an amalgamation of natural forest tree species (frequently fruit tree species), semi cultivated woody plants (palms, rattans, bamboo) and cultivated plants. In the study sites this land-use type is a relatively new development of natural forest trees mixed with old coffee and cacao plantations, palms and rattans and cultivated plants like mango (*Mangifera indica*), durian (*Durio zebethinus*), papaya (*Carica papaya*), aren palm (*Arenga pinnata)*, banana (*Musa sp*) and chili (*Piper spp*). The most common tree families are Rubiaceae followed by Euphorbiaceae, Sterculiaceae and Myristicaeae. Euphorbiaceae and Myristicaeae are the principal shade tree families of the canopy (Gradstein et al., 2003). Understorey is dominated by Urticaceae, ferns and cultivated shrubs such as *Piper spp*. Edible ferns are also common in this habitat.

2.3.3 Coffee plantation

Coffee plantations together with cacao plantations are considered to be main economic agroecosystems in the areas surroundings and within Lore Lindu National Park. This because of the current high price of these crops. That hold up villagers to enlarge their field or to establish new field for those who did not have any before. Consequently, the significant areas of the park were intersected by these kind of plantations. In this study

coffee plantation is a kind of habitat type where the coffee plants are still interspersed by several forest shade trees. These plantations could be found in some patches adjacent to forest gardens and secondary forest. The shade trees which are dominated by Euphorbiaceae are considered by the owners to have economic value.

2.3.4 Secondary forest

This type of habitat is defined as re-growth from disturbed primary forest where the break in continuity is still observable in the structure and floristic composition of the vegetation (Corlett, 1994; Wong et al., 1998). In this case, the secondary forest is frequently entered by local people for gathering non-timber forest products. Around 30 years ago, this area was cleared for shifting cultivation and selectively logged for *Agathis dammara*. It has been developed as secondary vegetation which is characterised by pioneer species that often possess such attributes as windborne seeds, light tolerant saplings and rapid rates of growth. The common families are Euphorbiaceae, Ulmaceae, Fabaceae, and Urticaceae which dominate the understorey layer. The common species are *Homalanthus populneus, Mallotus barbatus, Macaranga hispida, Trema orientalis, Erythrina sumbubran* and *Oreocnida rubescens* (Gradstein et al., 2003). *Eucalyptus deglupta* (Myrtaceae), *Ficus spp* (beringin)*,* and pandanus can also be found in this habitat.

2.3.5 Natural forest

The natural forest is defined as an area where the original forest cover is still present and where the natural forest trees are still growing (Corlett, 1994). The natural forest in this study was not originally primary forest because local people are running rattan collection in this area. Vegetation composition comprises Euphorbiaceae, *Autocarpus spp.*, Meliaceae, Gnetaceae, *Cananga odorata*, Ulmaceae, *Ficus spp.* and *Calamus spp.* The most common woody plant families are Lauraceae, Meliaceae, Rubiaceae and Urticaceae. In this habitat type the major canopy families are Lauraceae and Moraceae (genus *Ficus*) and the understorey vegetation is dominated by Meliaceae, Myrtaceae and Rubiaceae, Urticaceae (shrub) and Melastomataceae (shrub) (Gradstein et al., 2003).

3. RESEARCH METHODOLOGY

3.1 Experimental design of artificial nests

Since real predation events are exceedingly difficult to observe, one indirect way to determine how well bird species may be reproducing in their habitats is through artificial nest experiments (Wong et al., 1998). Such nest experiments have been used in many studies concerning avian life histories and the effects of habitat alteration as well as edge effects on avian reproduction. Artificial nest experiments could also be considered as a method to investigate potential nest predators.

The use of artificial nests instead of natural nests for studying nest predation rates has the advantage of allowing researchers to check variation in nest predation pressure along geographic gradients according to nest locations (Sieving, 1992; Telleria and Diaz, 1995). This method is thought to be valid when a comparison of relative predation rates is made between local habitats (Roper, 1992).

Two different valleys were determined as study sites; Palolo valley and Napu valley. Concerning land-use systems occurring in Lore Lindu National Park, five habitat types were chosen in Palolo valley and three in Napu valley. Three habitats in Napu valley were determined as replicates of habitat types in Palolo valley; forest edge, secondary forest and natural forest. The other two habitat types; forest garden and coffee plantation were only available in Palolo valley. In order to assess predation rates regarding habitat gradient from margins to forest interior, nest predation occurring in five habitats in Palolo valley were analysed separately.

Ten parallel line transects, at least 50 m (50-200 m) apart, were established at each habitat, except the forest edge. At the forest edge, the ten transects were located in one row parallel to, and approximately 10 m inside the forest from its edge. The forest edge was defined as the first line of tree trunks inside the forest. Each transect had a length of approximately 120 m and contained five plots at 30 m intervals. A plot consisted of one ground nest and one shrub nest, that were set up 15 m from each other. Their locations were marked with red tape tied to a plant at least 3 m away. To facilitate relocation, ground nests were

usually placed near buttresses of trees or the base of larger saplings (as done by Wong, 1998) and to emulate the nest sites of ground-nesting forest birds such as quails, rails, doves and pittas (Coates et al, 1997). Shrub nests were placed 1-2 m above the ground in shrubs or in the forked branches of plants to resemble nests of understorey shrub-nesting birds occurring in this region.

All nests were made of wire baskets, 12 (± 2) cm (in diameter) x 4 cm (in depth) and 10 cm (± 2) x 5 cm for ground and shrub nests respectively. They were lined on the inside and outside with dry vegetation such as grass, leaves and lichen found in the study area, so that their contents could not be seen from below (Figure 3.1).

Figure 3.1 Dummy nests used for shrub and ground nests during experimental trials

A total of 786 (393 ground and 393 shrub) nests were placed along the transects, consisting of 100 nests (50 ground and 50 shrub nests) at each site, except for forest garden (96 nests) and natural forest in palolo valley (90 nests). Nests were not placed in the same location in consecutive trials, nor were they placed on the vegetation with the plot markers. Domesticated Japanese Quail (*Coturnix japonicus*) eggs (33 x 27 mm) were purchased from local markets. They were cream-coloured with varying amounts of brown or black spots. Two eggs were placed in each nest. The eggs and nests were aired outdoors for at least one week prior to use in order to reduce artificial odours.

Experiment trials were conducted during two periods; from 8 January to 24 March 2001 in Palolo valley and from 2 January to 27 March 2002 in Napu valley. These periods coincided with the wet season in Sulawesi and might be considered as the breeding season for many bird species in the given area (personal observation). During the setting up of the experiments, nests and eggs were handled with gloves and boots were worn to minimise human scent cues to predators (Laurance et al., 1993). In order to compare rates of nest predation between habitats, nests were checked twice; at 4 days and 8 days after eggs had been introduced. Eggs were considered depredated if one or both eggs were missing, cracked or eaten. Nests occupied by ants, termites and other insects were recorded as successful as long as the eggs remained undamaged.

Each depredated nest was checked thoroughly and its contents were classified according to the type of damage sustained. The damage on quail eggs were classified in four categories: (1) perforated: eggs were intact, except for one or two perforation, (2) scratch: eggs were unbroken, but scratched, (3) shell remnants: the shell was broken into small pieces and (4) totally lost: one or both eggs were lost without any remnants. Chewed eggshells, tooth marks on shells, or a damaged nest were indicative of mammalian predation (Anderson, 1971; Small and Hunter, 1988) and egg shell fragments commonly exhibited the typical signs of rodent attack (Major, 1991; Laurance et al., 1993). Markings left by nest predators on eggs and nests were examined and compared to the tooth imprints, claws and other markings taken from animals captured during trapping periods. Additional proof was available after identifying the pictures of automatic cameras and the signs of predator attack on nests connected to the camera. Perforation of the shell without tooth marks was taken as evidence of damage by birds (Small and Hunter, 1988). Damage on depredated nests was also identified to support predator inventories. Some other studies have reported that predator inventories obtained during artificial nest trials through nest appearance following a depredation event (see Yahner and Wright, 1985; Small and Hunter, 1988). At the end of the experiments, all nests and remaining eggs were collected.

All sightings of potential predators during experimental trials were recorded. A list of known or suspected nest predators present in the study area was compiled from evidence in the literature and personal observation.

3.2 Identification of predators: automatic cameras

Many methods have been used to identify nest predators, but most have one or more disadvantages. For example, many predators do not leave eggshell remnants at nests (Angelstam, 1986), sticky-tape is rendered useless in wet weather (Major, 1991) and is ineffective for reptiles (Laurance and Grant, 1994). Additionally, artificial odours emanating from grease-plates (Angelstam, 1986) and plasticine eggs may deter or attract certain mammals and reptiles (Laurance and Grant, 1994).

Automatic camera systems have been used extensively to identify potential predator species as they are relatively free of the above limitations or biases (Laurance and Grant, 1994). For the present study, ten identical camera units were assembled in Göttingen, Germany, following the prototype camera design by Institut for Bird Research "Vogelwarte Helgoland", 21 Vogelwarte, 26386 Wilhelmshaven, Germany. The cameras were Fuji B36. Only eight camera units could be used during the fieldwork, as two cameras were damaged prior to installation. A ranger repaired the two camera units and they have been used since the middle of April 2001. Six units were installed simultaneously in each habitat in Palolo valley and Napu valley. The camera installation was carried out after nest predation trials; in Palolo valley from 28 March to 24 June 2001 and in Napu valley from 30 March to 27 June 2002.

Artificial nests of the same type used in the experiments, were baited with one quail egg. In each habitat, two units were connected to ground nests and the other two, to shrub nests. Camera nests were placed at random locations ca. 5 m to the left and right of the line transect which were at least 30 m away from each other. The installation was done on both the ground and shrub, along regular artificial nest transects (as in Bayne and Hobson, 1997). Each camera was mounted on a wooden tripod which was constructed in the National Park station. They were installed about 100 cm from an artificial nest. The height of the camera was about 100 cm for shrub nest, and 40 cm for ground nests.

A triggering mechanism was inserted into the nest with a micro-switch connected to an electrical plate and the camera. The trigger held one quail egg and the micro-switch functioned when the nest and egg were being attacked. The cameras had an automatic flash and were always loaded with 12-exposure rolls of colour print film (AGFA, film speed 200

ASA). All cameras were checked every day for 20 consecutive days (or until the nest was destroyed) and any damaged or missing eggs were replaced by fresh eggs within 24 h of their discovery or loss, respectively. If nest predation did not occur within 10 days of the installation of the nest, the camera and nest were moved to a new location.

A rechargeable battery TR 6-4 (6V 4Ah) was used to provide power for each camera and its electrical connection with cable to the nest. The battery was placed in a plastic box and hidden in bushy sapling or ferns. It provided power for three days when it was not raining, but only 24-36 h on rainy days. The cameras required manual resetting, because only one exposure could be taken per predation event. Rubber gloves were worn at all times to ensure that human odours on nests and camera units were minimised. The degree of background lighting was used as an indication of whether photographs had been taken during the day or night.

The cameras were set for a total of 20 days. Initially cameras were placed randomly, but as predation had not occurred at the first location after 10 days, the apparatus was moved to locations where predators were active. After a nest was attacked it was usually restocked with eggs for up to three photographs on subsequent nights. Afterwards, it was taken to a new location.

3.3 Standard trapping period

In an effort to capture nest predators in both sites, baited cage-traps (28 x 12 x 12 cm) were used for four consecutive nights at each habitat. Twenty traps were placed at 15 m intervals along the used-artificial nest transect in Palolo valley. Trapping at the Napu valley was also conducted over four consecutive nights, using 40 traps along artificial nest transects at 15 m intervals.

The cage trap door was closed when the animal entered and attached itself to a baited hanging hook. On all transects, three types of bait were used. The first cage was baited with ripe banana, the second with roasted mature coconut and the third with dried fish. This sequence was repeated along the entire transect. All traps were installed in the morning and checked each subsequent morning between 0700 and 1100 hrs. Each captured animal was removed from the trap and bagged in a white-cloth bag. The site code and bait

type were recorded for each animal. The bait was replenished as required. Animals were then identified to putative species, photographed and weighed (to nearest g). The captured were expressed as the number of captures per trap night. Most of the animals were released unharmed after they had been examined. Trapping period was undertaken in April 2001 (Palolo valley) and in March to April 2002 (Napu valley).

3.4 Vegetation structure

Nest appearance and location may strongly influence predator behaviour (Sieving, 1992). Therefore, the nest visibility and shrub cover for each ground and shrub nest was recorded. The percentage of shrub cover was estimated at a distance of 2 m from the shrub nest at each of the four compass directions. The estimation was also done from 1 m above and below where it was possible*. The shrub cover of each nest should indicate the degree to which nests would be concealed from the side or from above (Taylor and Ford, 1998).

The percentage of canopy cover where the nest was placed was measured in intervals of 0 - 100 % by looking skyward from the nest location through reversed 10 x 42 binoculars (giving a wide-angle lens view) (Cresswell, 1997). In addition, photographs of canopy cover were taken at each nest plot. The values for the percentage of foliage cover estimated from photographs were compared with those obtained using binoculars.

3.5 Observation and surveys

3.5.1 Potential predators and top predator surveys

Based on personal observations and lists of animals recorded within the park, potential nest predators in the study area include shrews (Soricidae), squirrels (Scirudiae)*, Dwarf cuscus (*Strigocuscus celebensis*), Bear cuscus (*Phalanger ursinus*), Black macaque (*Macaca tonkeana*), and an unknown number of snakes. Predators of adult birds, such as sparrowhawks (Accipitridae) and owls (Strigidae and Tytonidae) and nest-robbing birds like crows (Corvidae) were also observed at study sites during the experiments. Feral dogs (*Canis familiaris*) and cats (*Felis catus*) which were accounted as opportunistic nest predators (Wilcove, 1985), were also noted at study*. Tracks or single sightings of these potential nest predators were detected.

The abundance of nest predators may be affected by the presence of top predators so-called "meso-predator effect" (Laurance, 1993; Crooks and Soulé, 1999). Top predators in the park included the Malay palm civet (*Viverra tangalunga*) and the Sulawesi civet (*Macrogalidia musschenbroeckii*)**.** In order to determine whether these predators occurred at the study sites, the presence-absence (sighting frequency) of those animals was surveyed when the animals were driving through the experimental site. Dung and footprints of these animals were noted at each study sites. The rangers of the National Park who could reliably identify footprints and dung of these carnivores, assisted the surveys.

3.5.2 Natural nest surveys

Observations of natural nests and predation (or alternatively nest success) can be used to verify the results of artificial nest predator experiments. Bird nests were found by brief systematic searches at each habitat and opportunistically while walking transects during experiments. Such nests were observed every day until the young fledged, or the eggs or young were depredated. Nest site and shape were described and the plant species on which the nest was built was identified (assisted by the botanists from STORMA project who were working in Lore Lindu National Park at the same time). The following nest measurements were also taken; height above ground (in cm), nest size and diameter (in cm) and shrub and canopy cover (%, as per above).

3.5.3 Breeding Biology

Nest predation rates may also be affected by the breeding biology and behaviour of the species concerned. For instance, some species may defend their nests vigorously against all potential nest robbers, while others do not (Hansell, 2000). The eggs of species with long incubation periods are exposed for a longer period and are thus more vulnerable to predation than those of species with shorter periods.

Due to the dearth of information about the breeding biology of birds in Wallacea including Sulawesi, daily observations of 120 minute were carried out on newly built nests to establish: clutch size (and where possible, colouration and size of eggs); anti-intruder (or nest defence) behaviour; parental duties (where species sexually-dimorphic); incubation

and nestling periods; fate of eggs and young (nest and fledging success). Incubation period is defined as the average interval between the laying of an egg and the emergence of the young bird (Brooke and Birkhead, 1991). Nestling or fledging period is the interval between the hatching of an egg and the first ability for a young bird to fly.

3.5.4 Human activities in the park

The intensity of human activities in all habitat was quantified during the fieldwork. There was a total of 40 days observation in each habitat studied. Activities were classified into seven categories: (1) fuelwood and timber collecting (2) rattan collecting (3) maintaining plantation (4) wild food plant collecting (5) harvesting crops and palm products (6) medicinal plant collecting and (7) hunting and trapping. The frequency of those activities was scored for each site following the criteria below:

Frequency visit	score
1 – 10	1
11 – 20	2
21 – 30	3

3.6 Statistical Analysis

Predation events were counted for each nest, rather than each egg because two eggs in the same nest were probably not depredated independently. The percentage of nests lost in each transect of experiment were submitted to analysis of variance (ANOVA) after arc-sine transformation. Arc-sine transformation is needed to meet the requirements of normality and equal variance (Zar, 1999). The proportion of nest loss in the three habitats; forest edge, secondary forest and natural forest in Palolo valley and the replicates in Napu valley, were analysed with a three-way repeated measure analysis of variance (ANOVA). The three factors were; (1) sites (Palolo valley and Napu valley) (2) habitats (forest edge, secondary forest and natural forest) and (3) nest locations (ground vs. shrub). One-way ANOVA was used to assess the nest predation rate among five different habitats in Palolo valley (edge, forest garden, coffee plantation, secondary forest and natural forest) following the edge-interior gradients. In addition, a Tukey's HSD-test was used to assess the interaction between factors. In order to compare predation rates on artificial ground and shrub occurring in Palolo valley, a t-test was used. Contingency tables using a chi-square

test were used to determine whether the number of egg remnants was significantly different among habitat types.

To determine if the number of rodents occurring on ground and shrub nests (as documented by automatic cameras) differed among habitats, non-parametric analysis of variance (Kruskal-Wallis ANOVA) was used. This test was also used to determine whether the number of rodents captured varied among habitat types. The results obtained from live traps were too scarce to be presented as abundance indices. An univariate analysis to test for significant differences of rodents captured between each of the forest margin habitats and natural forest was performed using Mann-Whitney U-test. Descriptive statistics including mean values, standard deviations and standard error were also calculated. A Kruskal-Wallis test was also used to test whether the percentage of canopy cover and shrub density were varied among habitat types in Palolo valley and Napu valley. Spearman's rank correlation was used to determine if there was a relationship between canopy cover and predation rates as well as between shrub density and predation rates. Spearman's rank correlation was also used to test whether there was a relationship between predation rates and human activities within study sites.

The significance level for all statistical tests was set at 0.05 value. All statistical tests were done using STATISTICA 5.1. (Statsoft).

4. RESULTS

4.1 Total predation rates

During the experimental trials in Palolo valley and Napu valley, 786 artificial nests were set up as ground and shrub nests in different habitat types. The pattern of nest predation occurring in these two different valleys was similar, that the predation rates were higher along forest edge and forest margin habitats than in natural forest. Figure 4.1 shows the similarities of the percentage of nests depredated on ground and shrub nests in five habitats of Palolo valley and three habitats in Napu valley. The overall percentage of predation rates on ground and shrub nests together in Palolo valley was 61.9 % which means that 301 out of 486 artificial nests were preyed upon in eight day interval. Of the 301 depredated nests in the Palolo valley, 191 (63.5 %) were from ground nests and 110 (36.5 %) were from shrub nests. In Napu valley, 187 of 300 nests (62.3 %) were depredated in an eight day period. The 115 nests of 187 depredated (61 %), were ground nests and 72 of the 187 nests (39 %) were shrub nests. The depredated nests were calculated from each transect of 10 transects at each habitat type in Palolo valley and Napu valley.
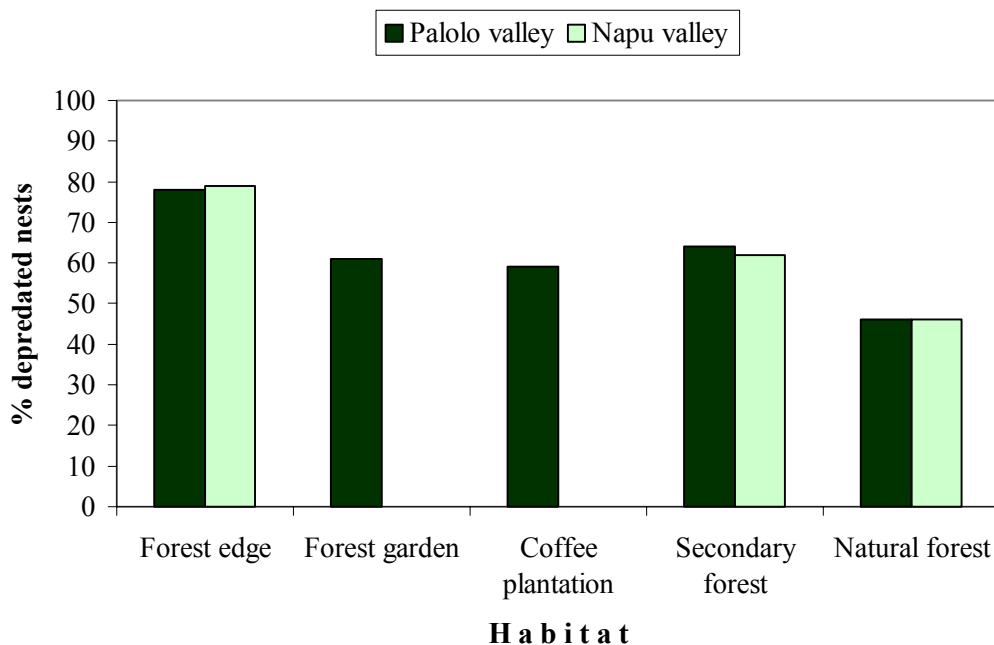
Figure 4.1 Percentage of nests depredated after 8 days in ten transects of five habitat types in Palolo valley and three habitats in Napu valley in Lore Lindu National Park, n = 100 except forest garden, n = 96 and natural habitat in Palolo valley, n = 90.

At the first exposure, in 4 days, 185 of 486 artificial nests (38 %) placed in Palolo valley were depredated as well as 113 of 300 nests (37.6 %) in Napu valley. The difference appeared after separating the number of nests depredated between ground nests and shrub nests at each valley (Table 4.1). The ground nests in Palolo valley experienced quicker predation risk than shrub nests (χ^2 = 32.048, df = 1, p < 0.0001), whereas the variation of predation rates in 4 days in Napu valley was not significantly different between ground and shrub nests (χ^2 = 1.991, df = 1, p > 0.05 (Table 4.1). In both sites, forest edge and forest margin habitats experienced the higher predation rate compared to natural forest.

Table 4.1 Percentage of nests depredated in Palolo valley and Napu valley in four days exposure. Each habitat consists of ten transects.

Site/Habitat	Palolo valley		Napu valley	
	Ground	Shrub	Ground	Shrub
Forest edge	62	26	31	27
Forest garden	53	19	-	-
Coffee plantation	46	24	-	-
Secondary forest	64	32	23	18
Natural forest	44	9	10	4
Total nests depredated	131	54	64	49

Furthermore, nest predation rates on three habitats of Palolo valley; forest edge, secondary forest and natural forest and their replicates in Napu valley were compared. The rates in five habitats in Palolo valley were analysed separately taking into account the habitat gradient from forest edge to natural forest.

4.2 The effects of site, habitat and nest type

An ANOVA-test showed no significant variation in the rate of nest predation between Palolo valley and Napu valley (F $1,108$ = 0.00029, p > 0.05 (Table 4.1). However predation rates differed significantly in three habitat types (F $2,108$ = 17.73, p < 0.05). Regarding the two nest types (ground nest and shrub nest), predation rates were also significantly different (F $1,108$ = 62.70, p < 0.005). The interaction between habitats and nest types are varied significantly (F $2,108$ = 7.34, p < 0.05).

Table 4.2 Results of three-way repeated-measures ANOVA which were performed on the arcsine-transformed percentage of nests depredated, with factors; 2 sites, 3 habitats and 2 nest types. Site type: Palolo valley, Napu valley; habitats: forest edge, secondary forest and natural forest; nest type: ground and shrub.

Factor	Sum of squares	d.f.	Mean squares	F	p-level*
Site (A)	0.11	1	0.11	0.00029	0.986
Habitat (B)	13201.97	2	6600.98	17.729	0.00002*
Nest type (C)	23345.60	1	23345.60	62.70	0.0002*
Site x Habitat	5.361	2	2.681	0.007	0.993
Site x Nest type	633.880	1	633.880	1.702	0.195
Habitat x Nest type	5463.621	2	2731.811	7.337	0.001*
Site x Habitat x Nest type	493.877	2	246.939	0.663	0.517

* Significance at $\alpha = 0.05$

There was no significant interactions of predation rates between site and habitat (F $_{2,108}$ = 0.01. p = 0.993) as well as between site and nest types (F $_{1,108}$ = 1.70, p = 0,195).

A posterior test, Tukey's HSD-test, revealed how different the nest predation rates between nest types within habitats in both sites (Table 4.3).

Table 4.3 p-levels of interaction of nest predation rates between nest types within habitats in two sites, as the results of Tukey's HSD-test. FEG = forest edge ground, SFG = secondary forest ground, NFG = natural forest ground, FES = forest edge shrub, SFS = secondary forest shrub, NFS = natural forest shrub.

Site	Habitat and Nest type	FEG	SFG	NFG	FES	SFS	NFS
Palolo valley	FEG	-	0.97	0.66	0.46	0.0001*	0.0001*
	SFG	0.97	-	0.96	0.85	0.0002*	0.0001*
	NFG	0.66	0.96	-	0.99	0.003*	0.0001*
Napu valley	FES	0.46	0.85	0.99	-	0.008*	0.0001*
	SFS	0.0001*	0.0002*	0.003*	0.008*	-	0.01*
	NFS	0.0001*	0.0001*	0.0001*	0.0001*	0.01*	-

* Significance at $\alpha = 0.05$

4.3 Pattern of predation rates in two sites

The following figures (Figure 4.2 and 4.3) show a similar pattern of predation rates on ground nests and shrub nests occurring in three different habitats and their replicates in two study sites (Palolo valley and Napu valley). Predation rates on ground nests were not significantly affected by different habitats. Although there was no significant difference of the rates among habitat types, figure 4.2 shows that the proportion of depredated nests in natural forest tended to be lower than those in secondary forest and forest edge.
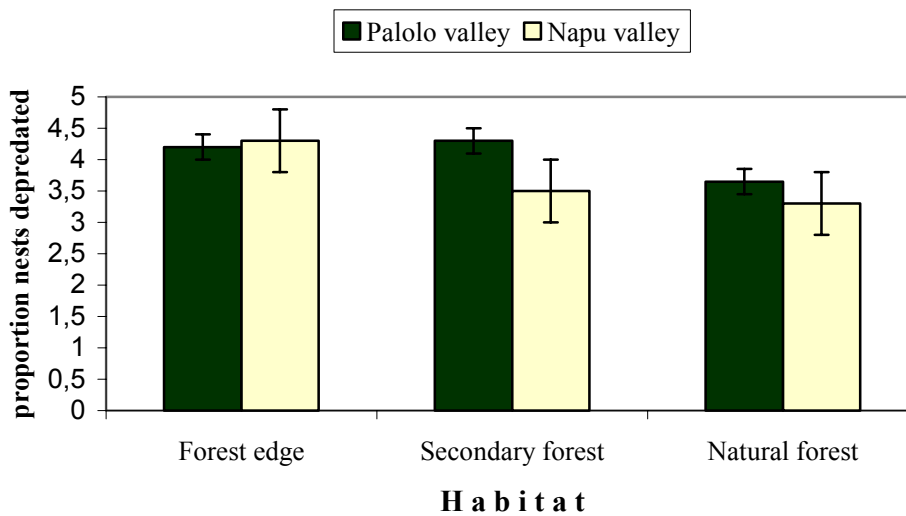
Figure 4.2 A comparison of mean proportion of depredated ground nests (± SE) per transect between Palolo valley and Napu valley, in different habitat types; forest edge, secondary forest and natural forest.

Figure 4.3 shows clearly that predation pressure on shrub nests were varied among habitat types. Both Palolo valley and Napu valley experienced a similar pattern of predation rates and that forest edge suffered the highest level of shrub nest predation with the lowest rate occurring in natural forest. Even though the comparison between Palolo valley and Napu valley for each habitat was not significantly different (F $_{2,108}$ = 0.01. p = 0.993) (Table 4.2), it revealed that Napu valley experienced more shrub nest predation than Palolo valley at each habitat type.
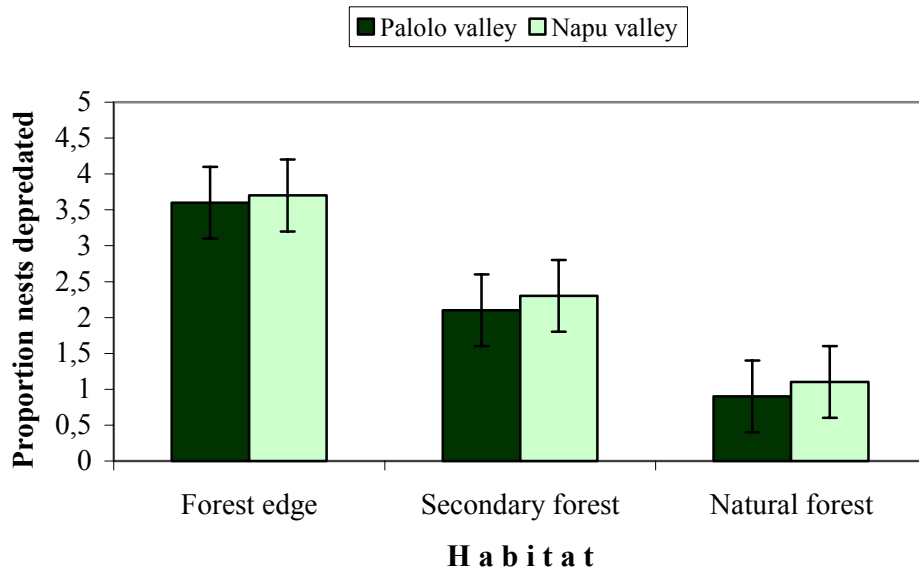
Figure 4.3 The difference in mean proportion of depredated shrub nests (± SE) per transect between Palolo valley and Napu valley, in different habitat types; forest edge, secondary forest and natural forest.

4.4 The effect of habitat gradient on nest predation in Palolo valley

A one-way ANOVA test showed that there was no significant difference among five habitat types concerning the gradient from forest edge to natural forest on predation rates of artificial ground nests (F $_{4,45}$ = 1.00, p > 0.419). On the other hand, the predation rates on shrub nests among these habitat types were significantly different F $_{4,45}$ = 7.25 p < 0.0001. Comparing the means of depredated nests per transect, natural forest experienced the lowest shrub nest predation rate (0.8) followed by secondary forest (2.1), coffee plantation (2.2) and forest garden (2.4) at intermediate level and the highest rate occurred in forest edge (3.6) (Figure 4.4).
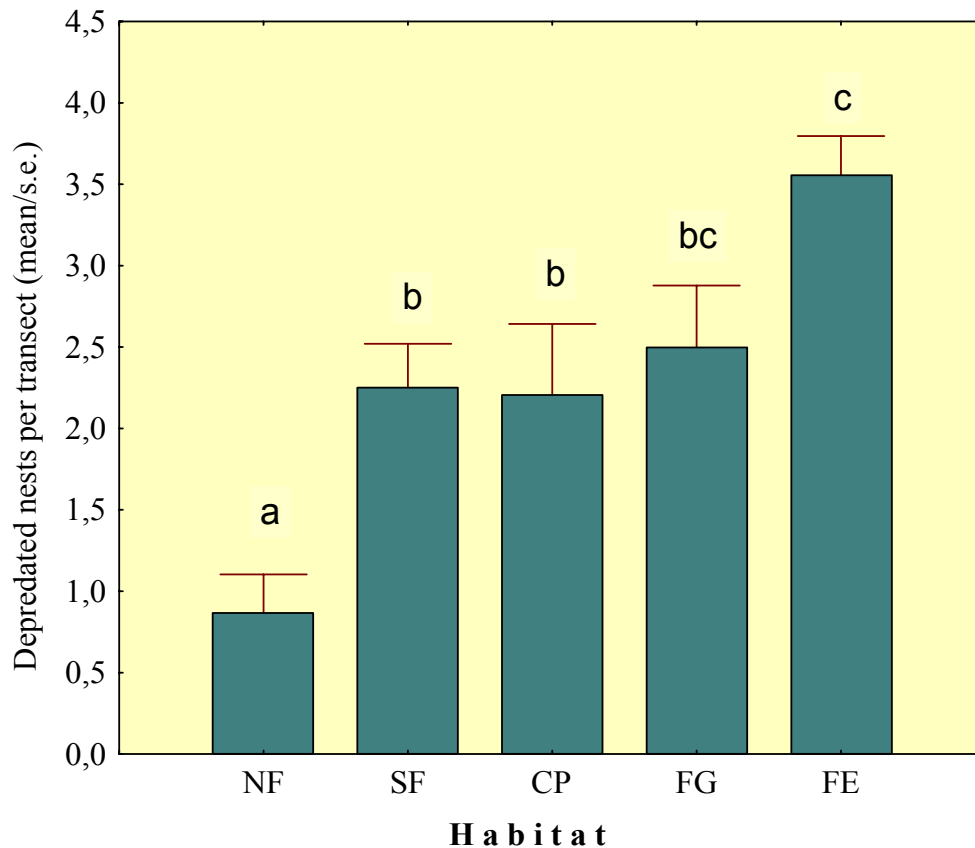
Figure 4.4 A comparison of mean predation rates after 8 days (+ 1 SE) on shrub nests (n = 243) in Palolo valley, NF = natural forest, SF = Secondary forest, CP = Coffee plantation, FG = Forest garden and NF = Natural forest, each habitat consisted of 10 transects. Different letters (a, b, c) show the significant difference (one-way ANOVA-test, p < 0.05).

Using a t-test to compare means, it was found that ground nests suffered generally higher predation pressure than shrub nests in all habitats studied (Figure 4.4). All the differences were significant, except those occurring along forest edge (t = 1.35, df = 9, p = 0.209) (Table 4.4).

Table 4.4 Differences in predation rates between artificial ground nests and shrub nests in various habitats of Palolo valley, n = depredated nests, df = 9.

Habitat	Ground (n)	Shrub (n)	t-test	p-level
Forest edge	42	36	1.351	0.209
Forest garden	36	23	3.330	0.0088*
Coffee plantation	37	22	2.281	0.048*
Secondary forest	43	21	4.494	0.0015*
Natural forest	34	7	6.074	0.00018*

* Significance at $\alpha = 0.05$

It seemed that habitat gradient from forest edge and forest margins to natural forest did not influence the predation rates on ground nests and all habitats suffered high predation rates on this nest type (Figure 4.5). Regarding shrub nests, it was clear that habitat gradient affected the predation rates. The highest rate occurred in forest edge and the lowest rate was in natural forest. The rates in forest garden, coffee plantation and secondary forest were at intermediate level.
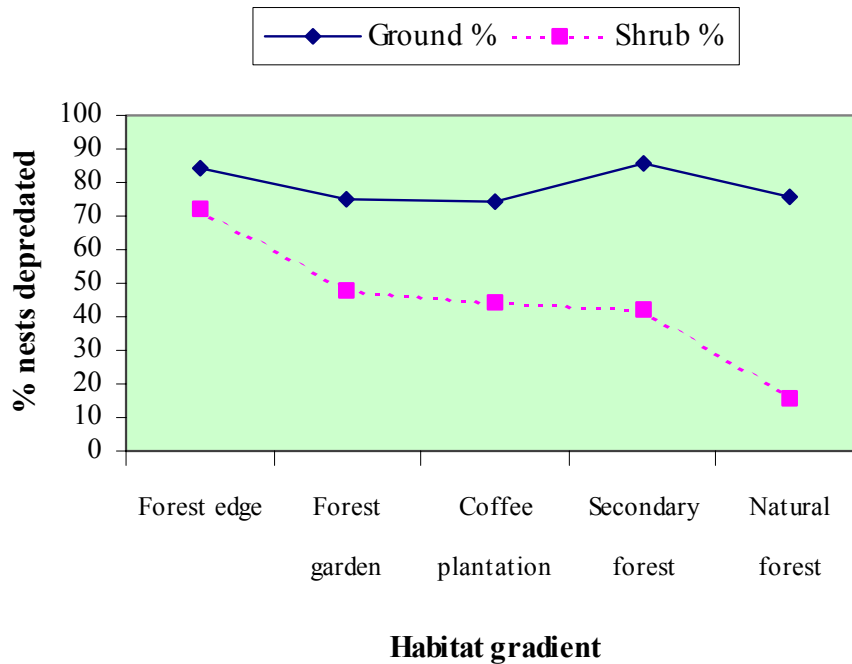
Figure 4.5 A comparison of percentage nest predation on ground and shrub nests in Palolo valley, n = 50 for edge, plantation and secondary forest, n = 48 for forest garden and n = 45 for natural forest.

4.5 Identity of nest predators

4.5.1 Evidence from artificial nests

Ground nests

Of the 191 ground nests depredated in five habitats of Palolo valley, 112 (58.6 %) showed egg damaged and egg loss (Appendix 3). Perforated shells (possibly caused by birds) were found only on eggs in coffee plantation. Other habitat types showed no perforation markings on the eggs attacked by predators. Scratched eggs assumed to be markings left by small rodents were evident in ground nests at all habitats. There was significant variation between habitats (χ^2 = 10.318, df = 4, p < 0.05) in the incidence of ground nest eggs that

were scratched in Palolo valley. This was most common at the forest edge sites and rarest in natural forest (Figure 4.6). The incidence of shell fragments on or near ground nests (possibly caused by larger rodents) also varied significantly between habitats ($\chi^2 = 10.235$, df = 4, p < 0.05), being commonest at the forest edge sites and least common in natural forest (Figure 4.5). Natural forest suffered more egg loss than other habitats ($\chi^2 = 16.759$, df = 4, p < 0.05).
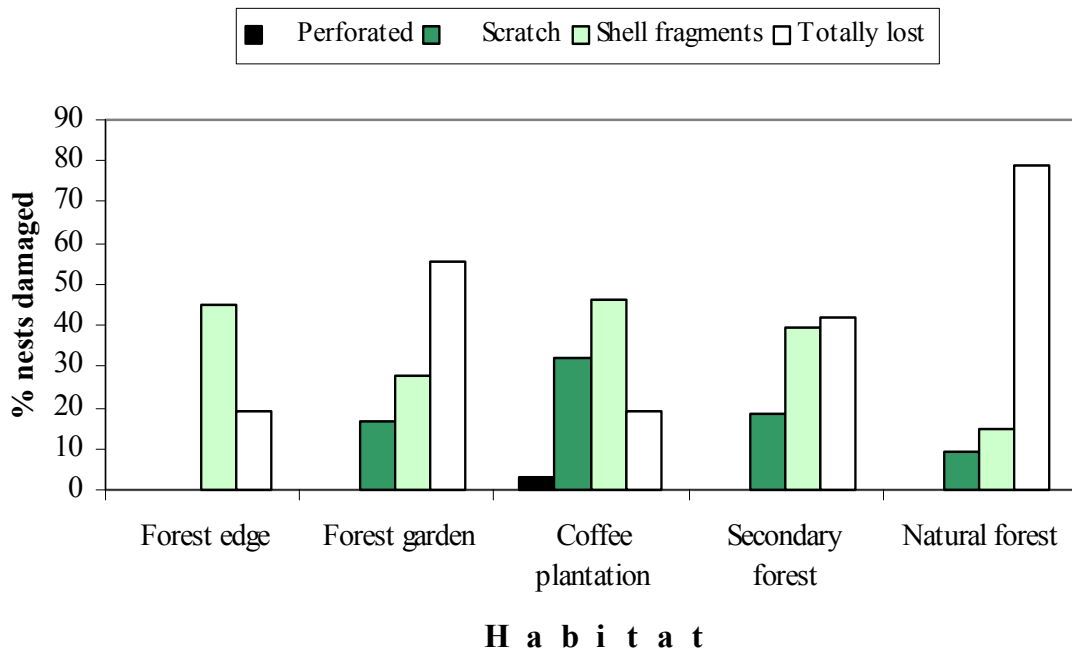
Figure 4.6 A comparison of remains found in depredated ground nests, by marking type and habitat type in Palolo valley.

In Napu valley, ground nests placed along forest edge suffered all kind of damages (Figure 4.7). Scratch signs were more common in secondary forest (23.7 %) than in other habitat types, e.g., forest edge (18.6%) and natural forest (8.3%). There was no significant difference of nests depredated with shell fragments in all habitats ($\chi^2 = 0.11$, df = 2, p > 0.05). This shows that the attacks of large rodents had a similar pattern across habitat types. Eggs disappeared more in forest edge (35 %) than in secondary forest (31.6 %) and natural forest (39 %) (Figure 4.7). However, the difference was not significant ($\chi^2 = 0.65$, df = 2, p > 0.05).
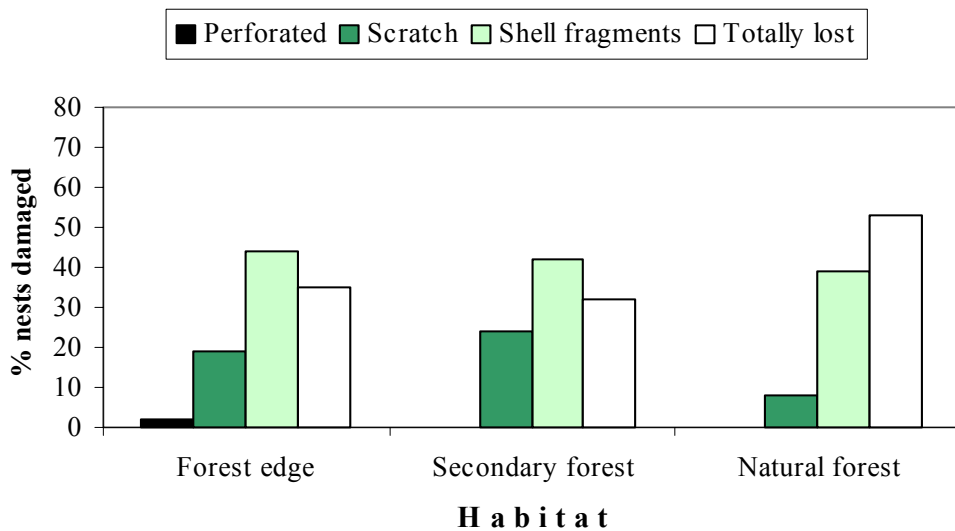
Figure 4.7 A comparison of remains found in depredated ground nests from artificial nest experiments in Napu valley, by marking type and habitat type.

Shrub nests

Of the 110 shrub nests considered depredated in Palolo valley, 85 (77.3 %) showed signs of predator attack (i.e., evidence of perforated, scratch and shell fragments). Perforations on quail eggs in shrub nests occurred in three habitats in Palolo valley (Figure 4.8) which indicated that avian nest predators might be more prevalent than the fate of ground nests suggested. The perforation on shrub nests showed the attack of birds along forest edge (2 nests), forest garden (1 nest) and secondary forest (2 nests). The data was not sufficient for statistical analysis.

Figure 4.8 also shows that shell fragments were the major markings on quail eggs in all habitat types. The comparison across all habitat showed that the variation of shell fragments left by predators was significantly different ($\chi^2 = 19.714$, df = 4, p < 0.05).
In secondary and natural forest, there was no scratch sign on quail eggs. In other habitats, scratch signs were found on 5 nests at forest edge, 2 nests in forest garden and 3 nests in coffee plantation. Shrub nests in forest garden experienced most of the total loss of quail eggs compared to other habitats ($\chi^2 = 11.417$, df = 4, p < 0.05).
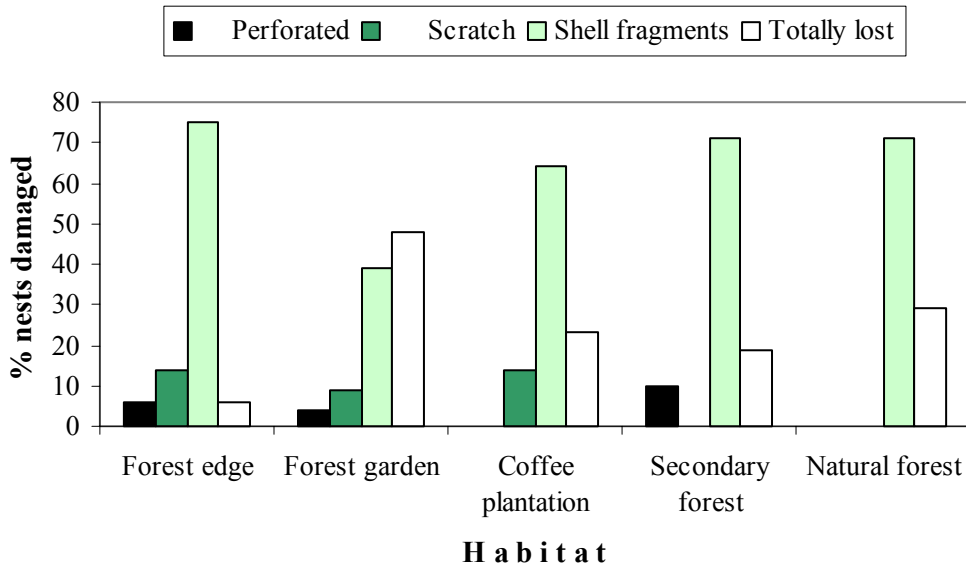
Figure 4.8 A comparison of remains found in depredated shrub nests, by marking type and habitat type in Palolo valley.

Unlike the case of shrub nests in Palolo valley, the incidence of perforation on quail eggs in Napu valley showed that this occurred in nests from secondary forest only. Quail eggs in 3 of 24 depredated nests (12.5 %) were found with perforation (Figure 4.8). The scratch was a kind of mark left in forest edge only which affected 5 of 37 depredated nests (12.8%) (Figure 4.9). Shell fragments were more common in secondary forest, (20 of 37 depredated nests or 51.3 %) and forest edge, (15 of 24 nests or 62.5 %) than in natural forest (5 of 11 nests or 45 %).
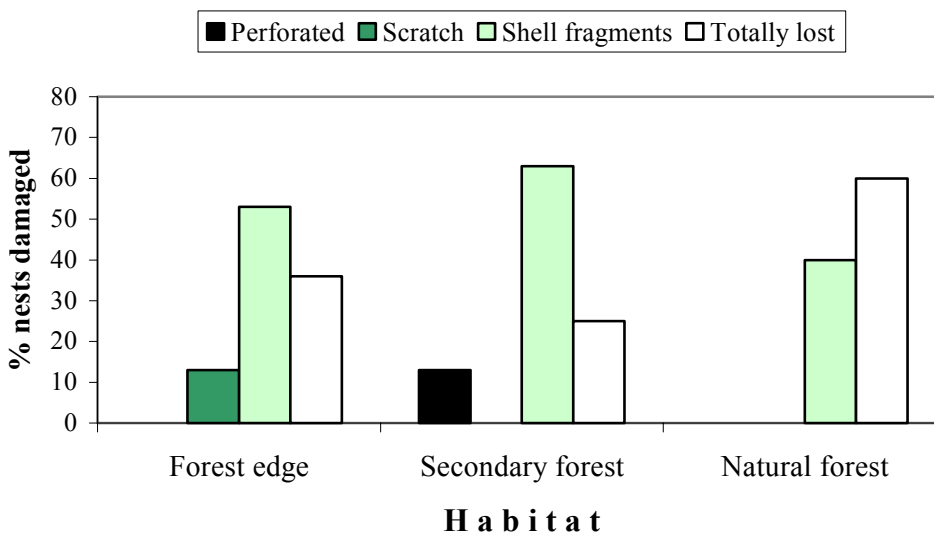
Figure 4.9 A comparison of remains found in depredated shrub nests, by marking type and habitat type in Napu valley.

The variance of shell fragments across habitats was significant (χ^2 = 8.77, df = 2, p < 0.01) but the disappearance of quail eggs was not significantly different among habitats (χ^2 = 3.0, df = 2, p > 0.05).

4.5.2 Nest damage

Many nests on both ground and shrub were attacked and damaged by predators. The nests were destroyed in some of the following ways; (1) dried vegetation as nest material was removed/extracted (2) nest was found upside down or (3) nest was moved away from the original location. In the majority of cases, the eggs had disappeared from these damaged nests, but in the some cases shell fragments were found.

Table 4.5 A comparison of damaged nests found during the exposures, by nest types and habitat types in Palolo valley and Napu valley.

	Habitat type					Nest type	
	Forest edge	Forest garden	Coffee plantation	Secondary forest	Natural forest	Ground	Shrub
Damaged nests (%)							
Palolo valley	17	4	12	5	3	33	8
Napu valley	12			10	2	11	13
Depredated nests (n)							
Palolo valley	78	59	59	64	41	192	109
Napu valley	82			62	46	115	72

It seemed that ground nests in Palolo valley suffered more nest damage (33 %) than those in Napu valley (11 %), whereas nest damage on shrub nests was higher in Napu valley (13 %) than in Palolo valley (8 %). However, a comparison of the total nests depredated showed the similarity of number of nests damaged in both sites; 13.6 % in Palolo valley and 12.8 % in Napu valley. Forest edge suffered more nest damage than the other habitats in both sites (Table 4.5).

4.5.3 Identification of nest predators from photography

4.5.3.1 Palolo valley

The number of pictures taken by the automatic cameras was variable in each habitat. It ranged from 4 to 12 pictures (Table 4.6). The automatic cameras installed in Palolo valley recorded 41 pictures taken from ground nests and 24 photographs from shrub nests in all habitat types. Nest predators could be identified to species level in 50 cases (77 %). It was not possible to discriminate individual animals consistently. More photographs were taken at the forest edge and forest garden sites than the other habitat types.

Table 4.6 Number of photographs taken from ground nests in five habitats of Palolo valley over 60 days installation (three cameras installed for 20 days at each habitat). These pictures could be identified as rodent visits. Most of them were Sulawesian giant rat (*Paruromys dominator*) and Wild Sulawesian rat (*Rattus hoffmanni*).

Habitat	Camera			Total	Identifiable	rodents
	C1	C2	C3		*Paruromys dominator*	*Rattus hoffmanni*
Forest edge	3	4	2	9	2	6
Forest garden	4	2	6	12	4	5
Coffee plantation	0	3	3	6	2	3
Secondary forest	2	1	4	7	3	4
Natural forest	2	2	0	4	3	1

All 38 (93 %) identified pictures taken from ground nests in five different habitats showed the visit of rodents (Table 4.6) and three pictures failed to show the nest visitors. No other predators than rats were detected. The identifiable pictures showed that the major visitors to artificial ground nests were Wild Sulawesian rat (*Rattus hoffmanni)* accounted for in 19 cases and Sulawesian giant rat (*Paruromys dominator*) documented in 14 cases. Of the total 38 identifiable pictures, 33 photos (87 %) were identified as from both species. These rodent species are endemic to Sulawesi (Figure 4.11). The other pictures could not be identified in species level, but they were all rodents.

After comparing the data obtained from each habitat, it revealed that the occurrence of rodents across habitat types was not significantly different (Kruskal-Wallis, $H = 7.816$, $p > 0.05$). However, forest garden tended to have the highest number of photographs of rodents (31 %), with the lowest number produced in natural forest, 11 % (Figure 4.10).

Every attributable case of predation on ground nests was due to rats, who mainly left shell fragments in nests.
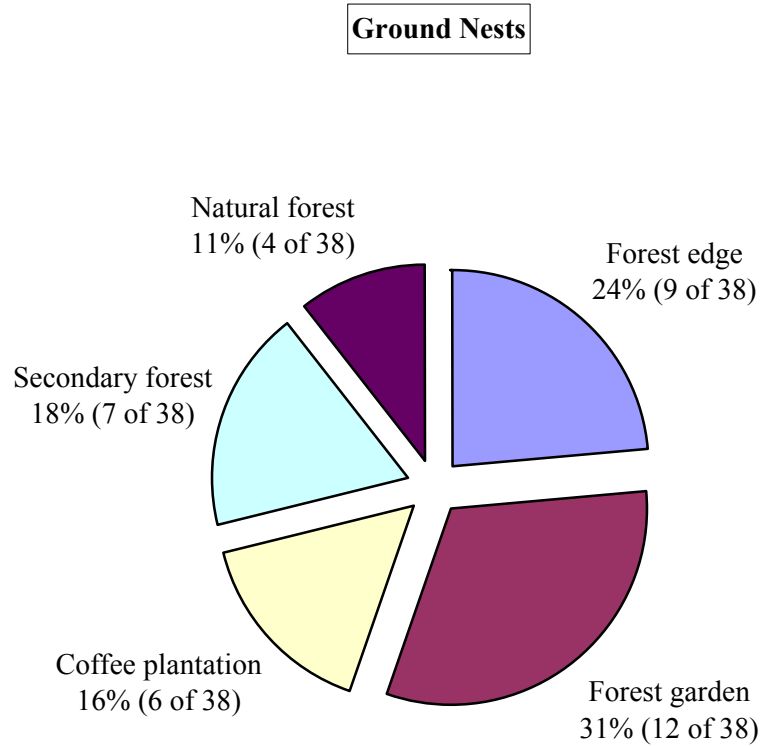
Ground Nests

Figure 4.10 A Comparison of percentage of rodents photographed as visitors to ground nests taken by self-triggering cameras in Palolo valley over 60 days installation (three cameras installed for 20 days at each habitat). Data was obtained from five habitats.

Figure 4.11 The examples of photographs of rodents as the main visitor to experimental ground nests in forest margin habitats in Lore Lindu National Park, a) forest edge   b) forest garden c) coffee plantation.

In the case of shrub nests, a comparison across habitats revealed that photographs of rodents were found more frequently along forest edge (46 %) than in the other habitats e.g., forest garden (24 %), coffee plantation (12 %), secondary forest (18 %) and no picture was produced from natural forest (Figure 4.12). The difference was significant after applying the Kruskal-Wallis test, $H = 12.349$, $p < 0.05$.
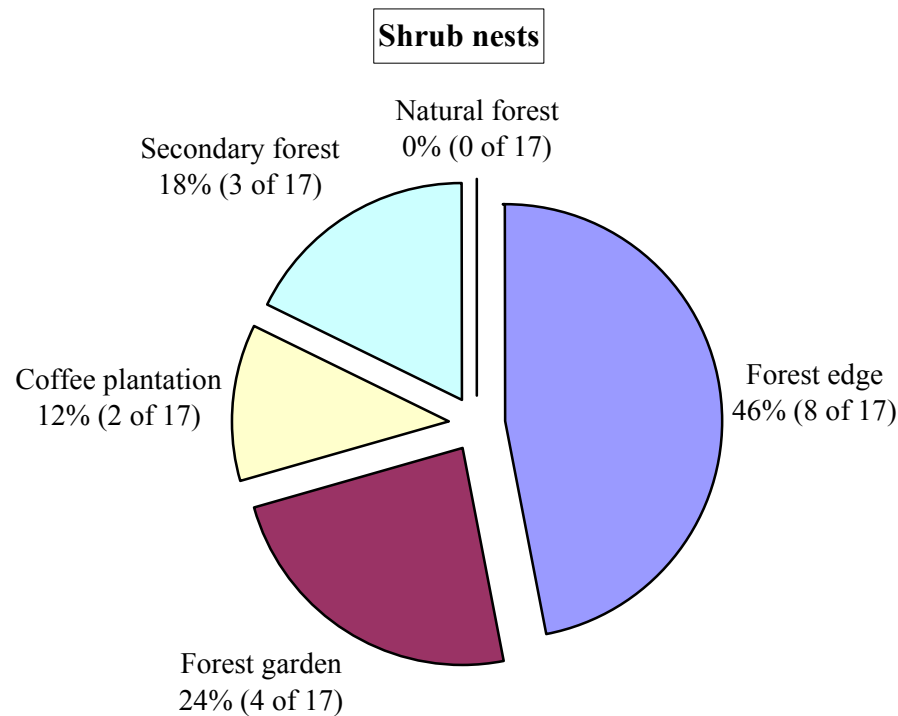
Figure 4.12 Comparison of percentage of photographs of rats as visitors to shrub nests taken by self-triggering cameras in Palolo valley over 60 days installation. Data was obtained from five habitats.

The pictures taken from shrub nests showed that the visitors or predators to the nests were not only rodents but also Dwarf cuscus (*Strigocuscus celebensis*) and squirrels (Sciuridae) (Figure 4.13). Dwarf cuscus accounted for 12.5 % and Sciuridae for 8.3 %, while rodents comprised 73.1 % of all photographs (n = 24) (Table 4.7). Overall, 22 of 24 photographs (90.5 %) were of small mammals and two pictured failed to identify the predator. Considering the background of the pictures, it may be said that all pictures appeared to have been taken at night. In all incidences, there was no evidence of birds and reptiles visiting the nests.

Table 4.7 Number of photographs of different visitors to shrub nests taken by self-triggering cameras at five habitats in Palolo valley in 60 days installation, FE=Forest edge, FG=Forest garden, CP=Coffee plantation, SF=Secondary forest and NF= Natural forest. Eggshell fragments were documented from each event.

Predator	Location					Eggshell fragments (n)	Total
	FE	FG	CP	SF	NF		
Muridae	8	4	2	3	0	14	17
Dwarf cuscus	1	1	1	0	0	3	3
Sciruidae	0	1	1	0	0	0	2
Unknown	1	0	0	0	1	0	2
Total							24
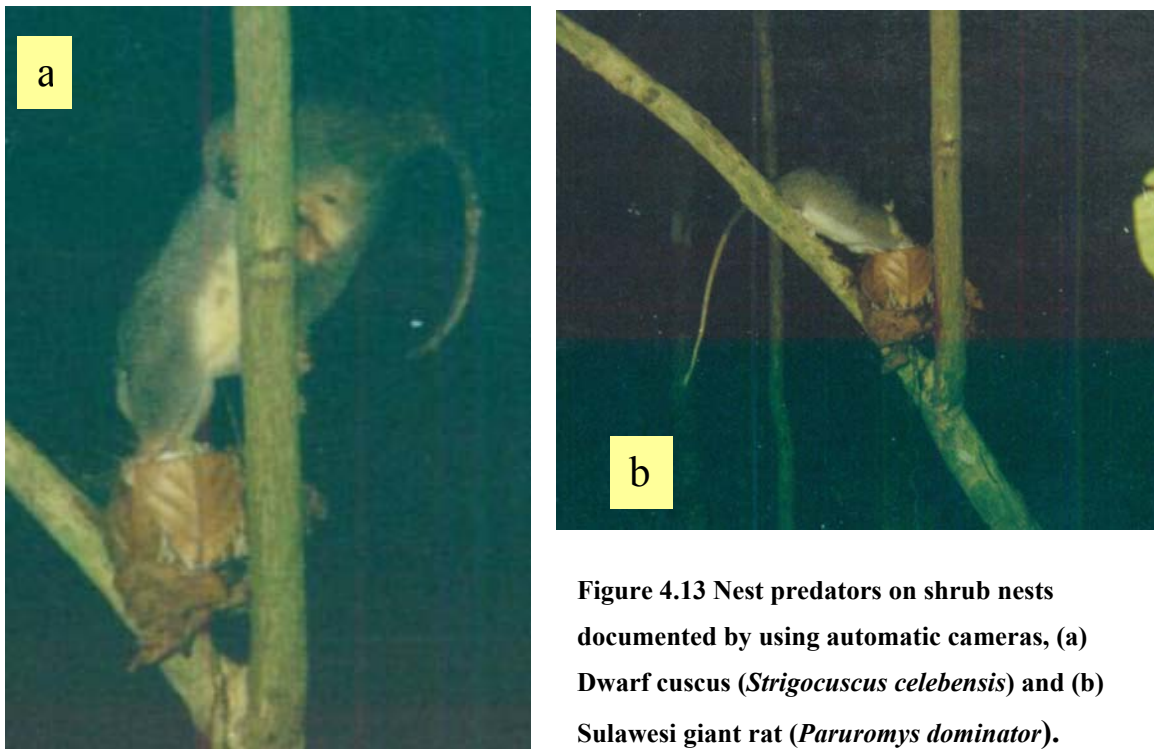
Figure 4.13 Nest predators on shrub nests documented by using automatic cameras, (a) Dwarf cuscus (*Strigocuscus celebensis*) and (b) Sulawesi giant rat (*Paruromys dominator*).

Fragments of eggshell left by predators were found on ground nests and shrub nests visited by rats and cuscus, but it were absent from the nests preyed on by Squirrels.

4.5.3.2 Napu valley

In this study site, all pictures could be identified as the visit of rodents and there was no evidence of other visitors. The cameras could not be optimally functioned because there was heavy rain during the camera installations in all habitat types. Only 6 of 10 cameras were available at that time. In total, the number of pictures taken by the cameras in all

habitat types were 12 and 10 from ground and shrub nests respectively. Of 22 pictures, more were taken from ground and shrub nests placed along forest edge (55 %) compared to other habitat types; secondary forest (36 %) and natural forest (19 %). There were no pictures taken from shrub nests in natural forest (Figure 4.14).

The frequencies of visitors to ground nests were not significantly different among three habitat types (Kruskal-Wallis, H = 4.986, p > 0.05), while the differences on shrub nests vary significantly (Kruskal-Wallis, H = 8.286, p < 0.05). Sulawesian giant rats comprises 63.6 % of all photographs taken from ground nests and the other pictures were identified as of Wild Sulawesian rat (*Rattus hoffmanni)* (34.4 %). Surprisingly, all pictures taken from shrub nests in three habitats were identified as Sulawesian giant rats.
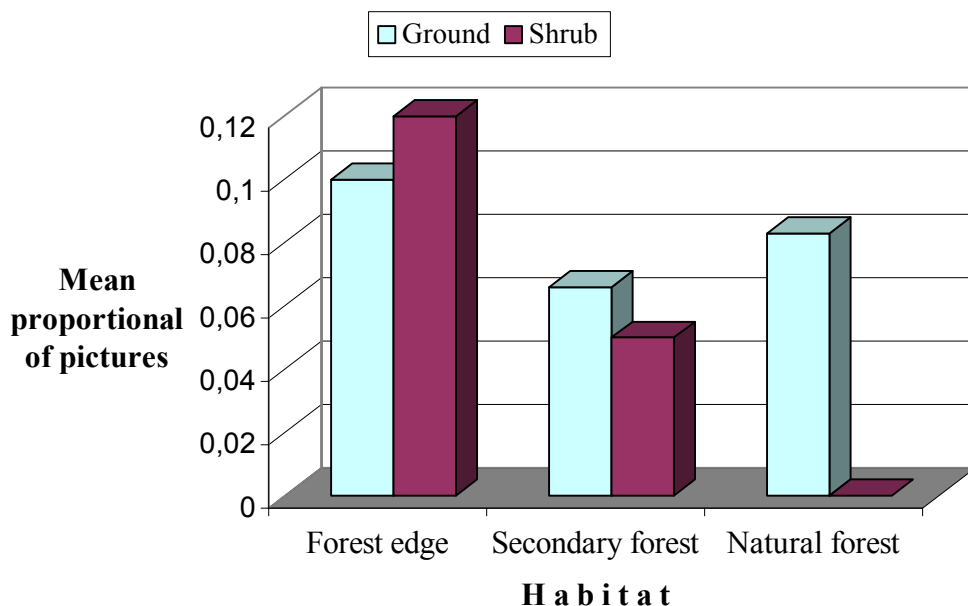
Figure 4.14 Mean of photographs taken by self-triggering cameras from ground and shrub nests in three habitats in Napu valley, 60 camera days (three cameras installed for 20 days at each habitat type) for each nest type.

The number of pictures taken from two sites could not be compared each other due to the malfunction of several cameras during the installation in Napu valley. However, it should be briefly emphasised that there was no evidence of visits of cuscus and squirrels in Napu valley compared to that documented from shrub nests in Palolo valley. All identified rats that visited shrub nests were Sulawesian giant rat (*Paruromys dominator*).

Additional information of potential predators

Additionally, sightings of potential predators have been recorded during the survey in both forest types. Some of the following predator fauna were seen in these areas:

- Arboreal snakes (e.g.: *Boiga irregularis*) were seen approaching the natural nest and nestlings of Black-naped Monarch (*Hypothymis azurea*), observed in forest garden of Palolo valley. Other snakes were also seen in other habitats during the artificial nest experiment in Palolo and Napu valley.

- Monitor lizard (*Varanus salvator*). This animal was seen visiting an artificial ground nest along forest edge in Palolo valley.

- Squirrels in coffee plantation in Palolo valley

- Bear cuscus (*Phalanger ursinus*) in Palolo valley

- Black macaque *(Macaca tonkeana)* in Napu valley

4.5.4 Are there any introduced nest predators in forest margin areas?

During predator surveys and observations on Palolo valley and Napu valley, several introduced predator fauna, assumed to be from agriculture field and settlement areas, were recorded. The presence of dogs was mainly seen whilst people ran activities in land-use areas and when they gathered forest products. Dogs were seen five times along forest edge and in forest margin habitats but were not seen in natural forest. It was assumed that the dogs which enter forest margin areas might considerably damage the artificial nests, by taking the quail eggs and then trying to find more eggs in the nests. In some cases, the artificial nests placed along forest margin habitats were found destroyed. Cats were seen three times at forest edge of Palolo valley. The other nest predator accounted for as an introduced species was house rat (*Rattus rattus)* which were captured along forest edge in Palolo valley and Napu valley (Figure 4.15 and 4.17) during the trapping period.

4.6 The occurrence of rodents

A total of seven rodent species were caught using live traps in all habitats in Palolo valley and Napu valley. The total captured were 21 individuals of five species in Palolo valley and 29 individuals of six species in Napu valley.

Five species of Muridae; *Bunomys chrisocomus, Paruromys dominator, Rattus hoffmanni, Rattus rattus* and *Taeromys celebensis* have been captured in different habitats of Palolo valley. *Bunomys chrysocomus* have been found in forest garden and secondary forest. *Paruromys dominator* and *Rattus hoffmanni* could be found in all habitat types. *Rattus rattus* only occurred along forest edge habitat and *Taeromys celebensis* were captured in natural forest (Figure 4.15).
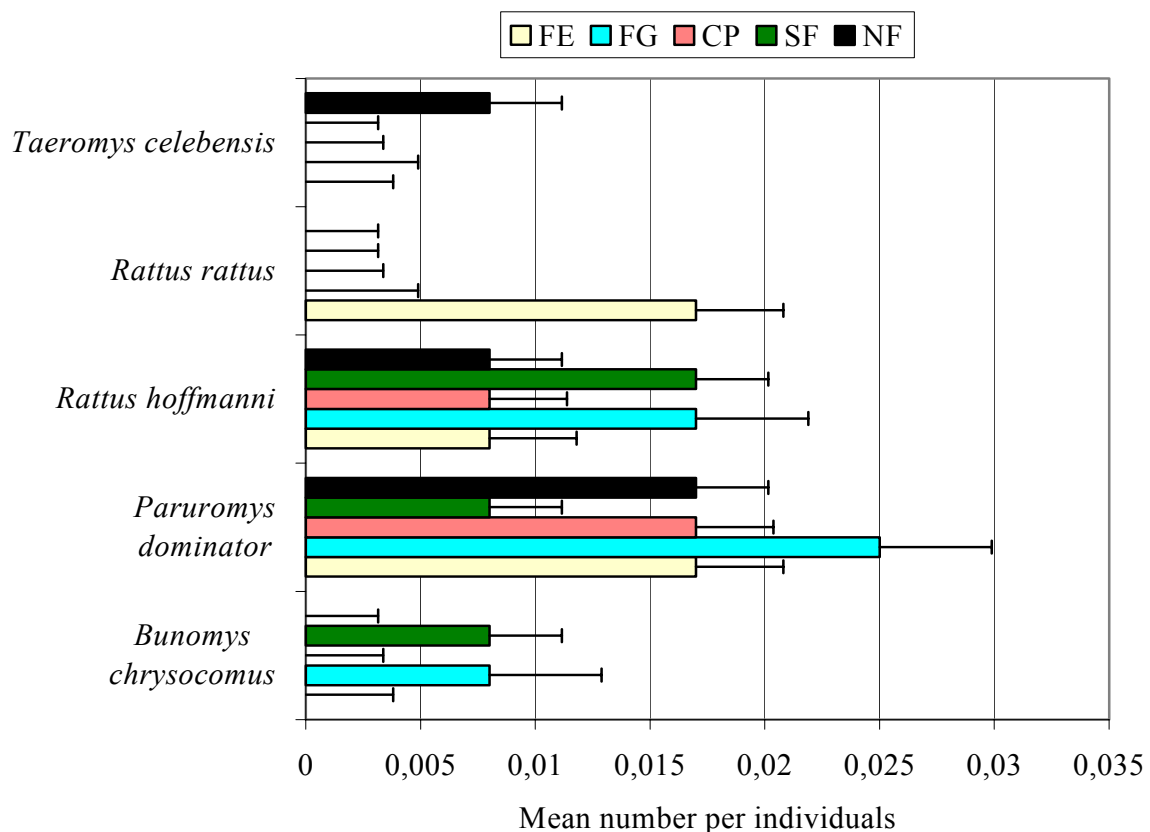
Figure 4.15 Comparing the frequency captures of rodents and species diversity based on the habitat types in Palolo valley, FE = forest edge, FG = forest garden, CP = coffee plantation, SF = Secondary forest and NF = natural forest, 120 trap-nights per habitat.

The average capture rates (captures per trap night) for this group of five species were 0.046 ± 0.01 at the forest edge, 0.05 ± 0.01 in forest garden, 0.028 ± 0.008 in coffee plantation, 0.33 ± 0.01 in secondary forest and 0.33 ± 0.01 in natural forest (Figure 4.16).
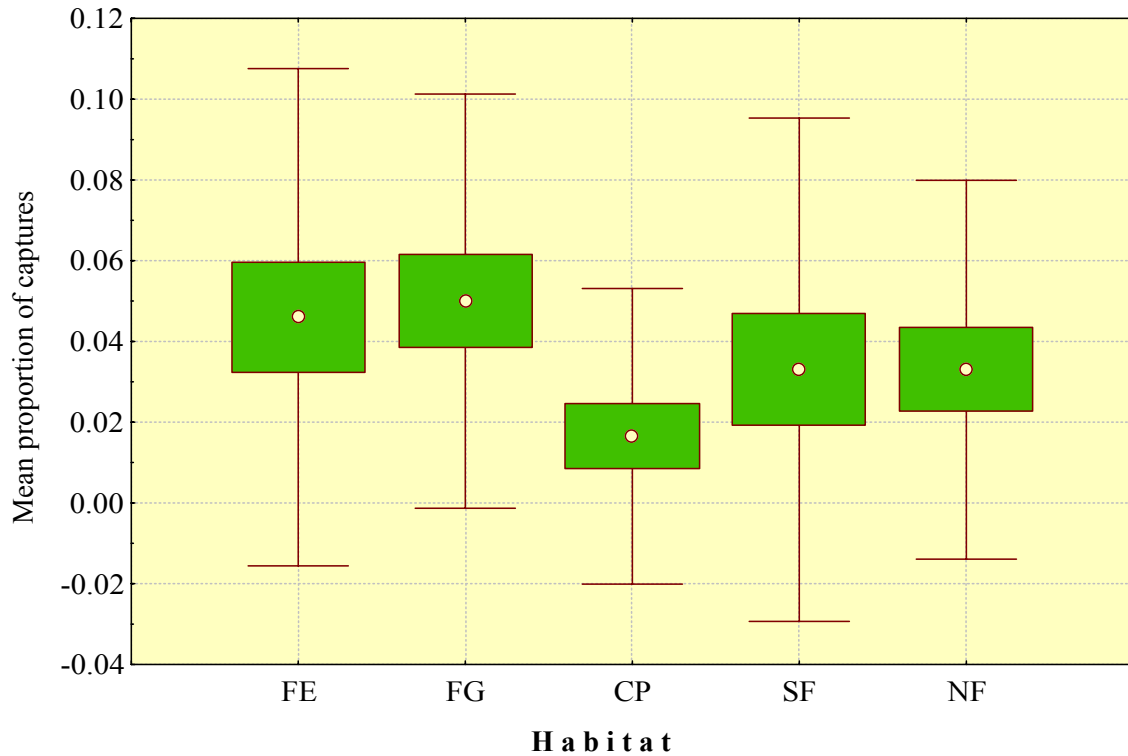
Figure 4.16 The average of five rodent species captured in different habitat types in Palolo valley, FE = Forest edge, FG = Forest garden, CP = Coffee plantation, SF = Secondary forest, NF = Natural forest. The bars indicate standard deviation, the box indicates standard error and the point in the box is the mean.

Differences between forest interior and each of the forest margin habitats (forest edge, forest garden, coffee plantation and secondary forest) for these capture rates were not statistically different (Mann-Whitney U-test, $p > 0.05$) in all cases. Sulawesian giant rat (*Paruromys dominator)* and Wild Sulawesian rat (*Rattus Hoffmanni)* were more frequently captured than the other three species. The number of captures of these species in 120 trap-nights were 8 and 6 individuals, respectively.

In Napu valley, six species of rodents have been captured in three habitats: *Bunomys chrisocomus, B. penitus, Paruromys dominator, Rattus hoffmani, Rattus rattus, and Rattus xanturus*. *Bunomys chrisocomus* have been found in forest edge and natural forest. *Paruromys dominator* and *Rattus hoffmanni* could be found in all habitat types. *Bunomys penitus* has only been found in secondary forest and *Rattus rattus* only occurred along forest edge habitat. *Rattus xanturus* was captured in natural forest only (Figure 4.17).
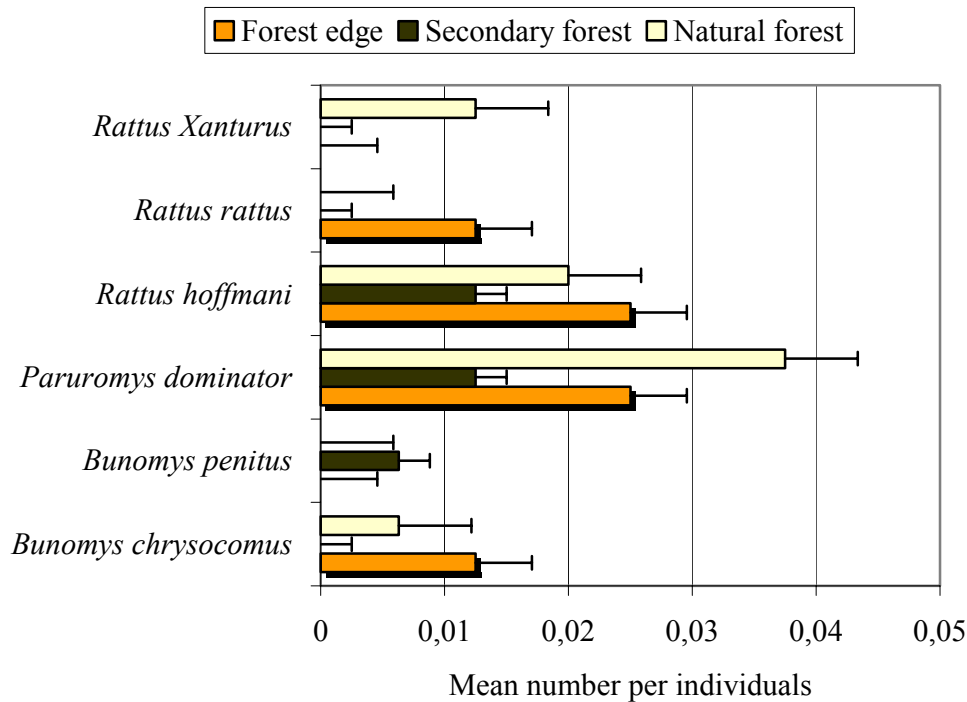
Figure 4.17 Distribution of rodents among three habitat types in Napu valley (mean number + 1 SE) of individuals recorded in 160 trap-nights per habitat.

In Napu valley, the average capture rates (captures per trap night) for this group of six species were 0.075 ± 0.02 at the forest edge, 0.025 ± 0.01 in secondary forest, and 0.081 ± 0.02 in natural forest (Figure 4.18). Differences between forest interior and each of the forest margin habitats (forest edge, and secondary forest) in these capture rates revealed a different pattern compared to the cases in Palolo valley. The rates between natural forest and secondary forest were significantly different (Mann-Whitney U-test, $Z = 2.08$ $p < 0.05$), while the difference between natural forest and forest edge was not significant (Mann-Whitney U- test, $Z = 0.367$, $p > 0.05$).

The most captured species were *Paruromys dominator* and *Rattus hoffmanni*. Twelve and eight individuals, respectively were trapped in 160 trap-nights.
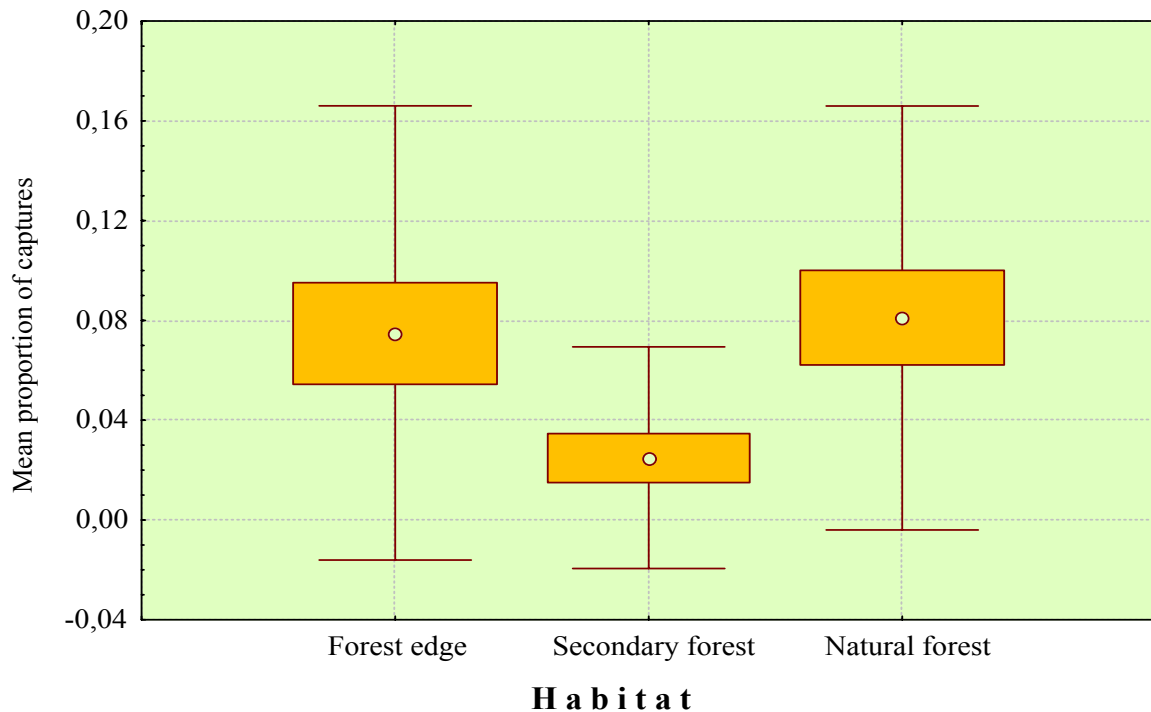
Figure 4.18 The average of six rodent species captured in different habitat types in Napu valley, the bars indicate standard deviation, the large box indicates standard error and the point in the box is the mean.

A comparison across these two sites revealed that *Bunomys penitus and Rattus xanturus* were absent in Palolo valley, while *Taeromys celebensis* was not captured in Napu valley (see Figure 4.15 and 4.17)

4.7 Top predators

Visual surveys and observation could detect the presence of viverrids and birds of prey (Accipitridae, Strigidae and Tytonidae) in the given areas (Palolo and Napu valleys). The Malay palm civet (*Viverra tangalunga*) was seen in natural forest of Palolo valley and dung was found in the same area. There was no sighting of animal or dung evidence in other habitat types. In Napu valley, visual surveys detected the presence of Malay palm civet in natural forest, but there was no evidence of this mammal in secondary forest and forest edge (Table 4.8). The Sulawesi civet (*Macrogalidia mussenbrockii*) could not be found in either valley. A report from a National Park survey supported the theory that

Sulawesian giant civet have been disappeared from Palolo and Napu valleys. However, local people were once successful in trapping this animal in natural forest of the Kulawi valley, the western part of the park (Yulisan, 2001 personal communication). The data collected was insufficient for statistical analysis.

Table 4.8 Evidence of the presence of viverrids and avian predators accounted for in habitat studies in Palolo valley and Napu valley, S=sightings, D=dung, number showing the frequency of sightings and dung found.

Species	Palolo valley					Napu valley		
	FE	FG	CP	SF	NF	FE	SF	NF
Viverrids								
Viverra tangalunga					S3,D2			S2,D2
Macrogalidia mussenbrockii								
Avian predators								
Hieraaetus kienerii					S1			S1
Spilornis rufipectus								S1
Otus manadensis							S1	
Ninox punctulata		S2						

The avian nest predators of family Accipitridae like *Hieraaetus kienerii* and *Spilornis rufipectus* were found in natural forest only, whereas the other avian predators such as *Otus manadensis* and *Ninox punctulata* could be encountered in forest margin areas.

4.8 Vegetation attributes

The percentage of canopy cover and shrub density have been measured from each plot of ground nest and shrub nest. The correlation between vegetation attributes and predation rates were analysed separately for each nest type placed in two sites.

4.8.1 Canopy cover

In Palolo valley, a comparison across five habitat types showed that the canopy cover was significantly varied over ground nest plots. The highest average of percentage of canopy cover was in natural forest (72.4 %) and the lowest was along forest edge (42.6 %). It was 46.1 % in forest garden, 42.8 % in coffee plantation and 51.4 % in secondary forest, which was considered to be an intermediate level. The percentage of canopy cover was

significantly different (Kruskal-Wallis, H = 92.802 P < 0.01, N = 243 in all cases) across habitat types.

When each nest type was analysed separately, there was no significant negative correlation between canopy cover and ground nest predation rates (Spearman-rank correlation coefficient r_s = - 0.30, p > 0.05 in all cases). Figure 4.19 summarises the fact that canopy cover did not affect the nest predation on ground nests in forest margin habitats as well as in natural forest. Although the natural forest was covered with more canopy, the predation rate was relatively high.

Figure 4.19 Average of percentage of canopy cover over *ground nests* in Palolo valley in comparison to nest predation rates in different habitats (bars indicate standard error ± SE).

The percentage of canopy cover over shrub nests was significantly different after applying the Kruskal Wallis test (H = 125.79, p < 0.01, in all cases, N = 243). The lowest cover was measured in coffee plantation (average 33.4 %) and the highest cover was in natural forest (average 73.8 %). It seemed that the canopy cover has an effect on nest predation rates because there was significantly negative correlation between canopy cover and nest predation on shrub nests (Spearman-rank correlation coefficient rs > - 0.70, p < 0.05) (see Figure 4.20).
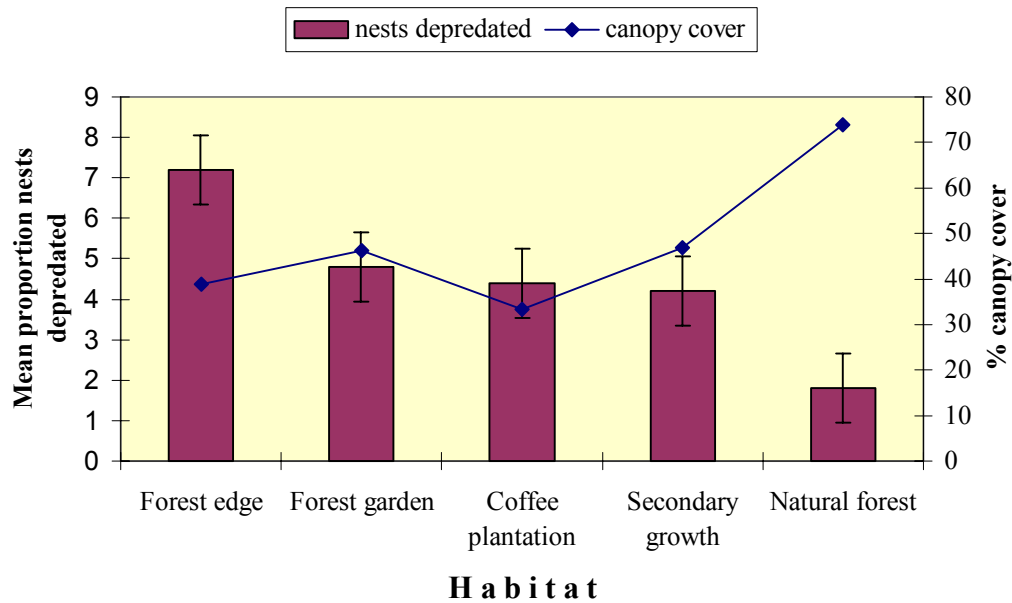
Figure 4.20 Average of percentage of canopy cover over *shrub nests* in Palolo valley in comparison to nest predation rates in different habitats (bars indicate standard error ± SE). Note the percentage of canopy cover in natural forest.

Visual surveys in Napu valley recorded that the percentage of canopy cover above ground nests across three habitats was significantly different (Kruskal-Wallis, H = 108.165, p < 0.01 in all cases, N= 150). The highest average of percentage of canopy cover was in natural forest (76.6 %) and the lowest was at forest edge (50.4 %) (Table 4.9). The average cover in forest garden was at an intermediate level (64.4 %). There was no correlation between canopy cover and predation rates on ground nests (Spearman-rank correlation coefficient rs = - 0.20, p > 0.05).

The average of percentage of canopy closure on shrub nests was 51.8 % along forest edge, 63 % in secondary forest and 74.6 % in natural forest (Table 4.9). There was significant variation of canopy cover across habitat types (Kruskal-Wallis, H = 96.507, p < 0.01 in all cases, N= 150). In Napu valley, there was a relationship between the percentage canopy cover and predation rates on shrub nests (Spearman-rank correlation coefficient rs > - 0.60, p < 0.05).

Table 4.9 Comparison between average percentage of canopy cover over ground and shrub nests in Napu valley and depredated nests occurring in this site.

Habitat	Canopy closure (%)		Depredated nests (n)	
	Above ground nests	Above shrub nests	Ground	Shrub
Forest edge	50.4	51.8	42	37
Secondary forest	64.4	63	38	24
Natural forest	76.6	74.6	35	11

4.8.2 Shrub density

The percentage of the shrub density on ground nests at each habitat type in Palolo valley indicated that the shrub layer was significantly lower in coffee plantation than in the other habitat types. This suggests a greater exposure of nests during the day, to visually oriented predators in this habitat. The lowest average of shrub cover along coffee plantation was 41.4 % followed by forest edge 50.7 %, secondary forest 51.1 %, natural forest 52.6 % and the highest was in forest garden 61.3 %. In coffee plantation, it was relatively changeable because people regularly clean the understorey layer for crop maintenance. The percentage of shrub density was significantly different across habitat types (Kruskal-Wallis, H= 50.498 p < 0.01, N = 243 in all cases). The percentage of shrub cover in each habitat was found to be closely related to number of nests attacked. There was no correlation between shrub density and nest predation rate (Spearman-rank correlation coefficient r_s = - 0.30, p > 0.05) (Figure 4.21).
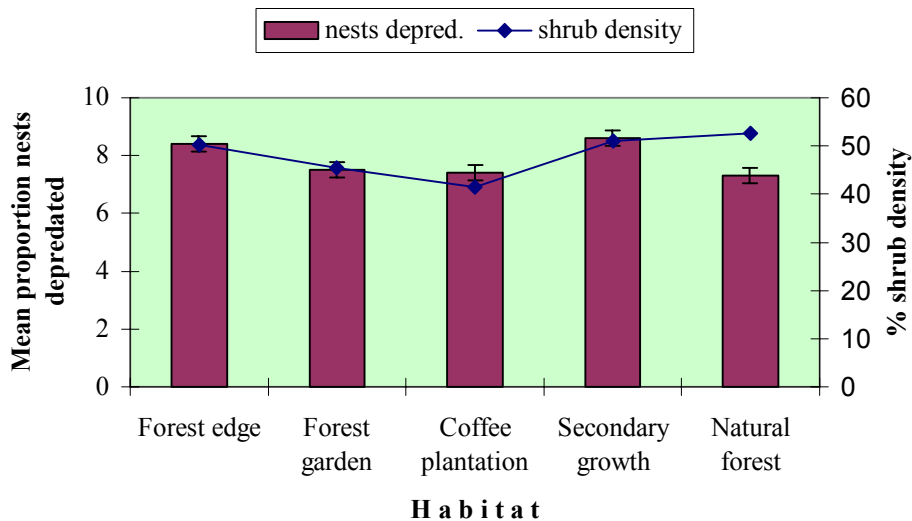
Figure 4.21 Average of percentage of shrub density over *ground nests* in Palolo valley in comparison to nest predation rates in different habitats (bars indicate standard errors ± SE).

In Palolo valley, there was significant variation of shrub density on shrub nests across habitat types (Kruskal-Wallis, $H = 24.021$, $p < 0.01$, $N = 243$). Although the percentage of shrub layer in secondary forest was higher than in other habitats, the predation rate was somewhat high compared to that occurring in natural forest (note figure 4.22). In this case, there was no significant correlation between shrub density and predation rates on shrub nests (Spearman-rank correlation coefficient $r_s > - 0.20$, $p > 0.05$).
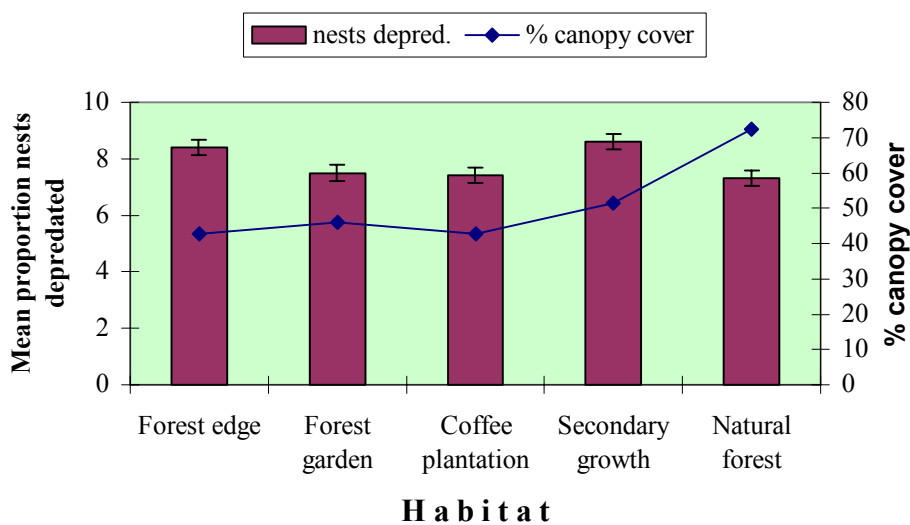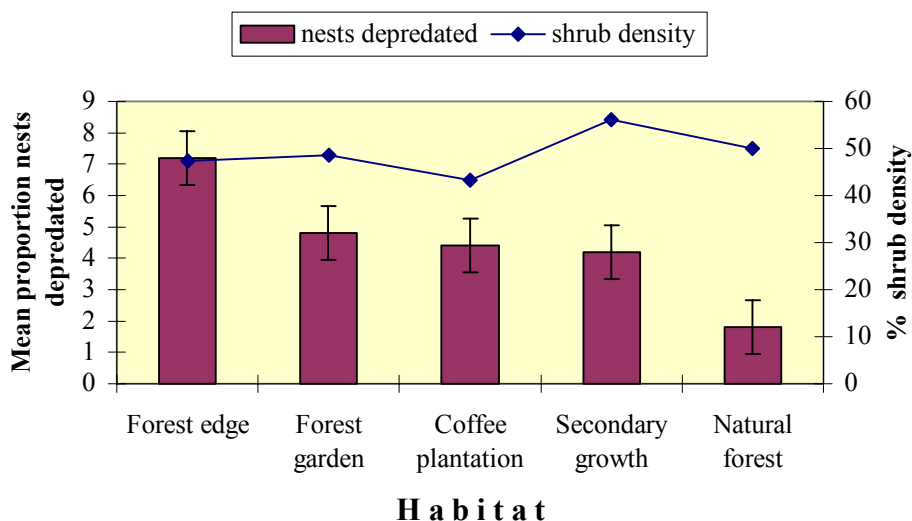

Figure 4.22 Average of percentage of shrub density over *shrub nests* in Palolo valley in comparison to nest predation rates in different habitats (bars indicate standard errors ± SE).

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The results obtained from Napu valley revealed that the pattern of shrub density on ground nests in forest edge, secondary forest and natural forest was similar to that occurring in Palolo valley habitats. The percentage of shrub density on ground nests was significantly lower in natural forest (45.5 %) than in the other habitat types, 56 % in secondary forest and 68.5 % along forest edge (Table 4.10). These variations were significant (Kruskal-Wallis, H = 87.523, p < 0.01), suggesting a greater exposure of nests during the day to visually oriented predators in these habitat types.

Comparing data collected from shrub nests regarding shrub density, showed that there was a significant difference among habitat types (Kruskal-Wallis, H = 83.278, p < 0.01). The highest average of percentage of shrub density was in forest edge (65 %), the intermediate level was in secondary forest (60.5 %) and the lowest was in natural forest (48.5 %). The relationship between percentage shrub density and predation rates on shrub nests was significantly negative (Spearman-rank correlation coefficient r_s > - 0.70, p < 0.05).

Table 4.10 Comparison between average percentage of shrub density on ground and shrub nests in Napu valley and depredated nests occurring in this site.

Habitat	Shrub density (%)		Depredated nests (n)	
	Ground nests	Shrub nests	Ground	Shrub
Forest edge	68.5	65	42	37
Secondary forest	56	60.5	38	24
Natural forest	45.5	48.5	35	11

4.9 Human activities

The frequency of human activities in each habitat of the study sites was observed in order to get a better understanding of the intensity of disturbance driven by humans. The correlation of these activities and predation rates was also taken into consideration.

Data obtained showed the high intensity of human activities occurred in forest margin habitats both in Palolo valley and Napu valley (Figure 4.23). The natural forest was less frequently visited and the only activity in this habitat was rattan collecting in Palolo valley and were rattan collecting and wild food plant collecting in Napu valley. Harvesting crops

and palm products was only reported from Palolo valley where intensive land-use within the park area occurred.

Figure 4.23 The difference in mean of frequency of visits of people in forest margin areas and natural
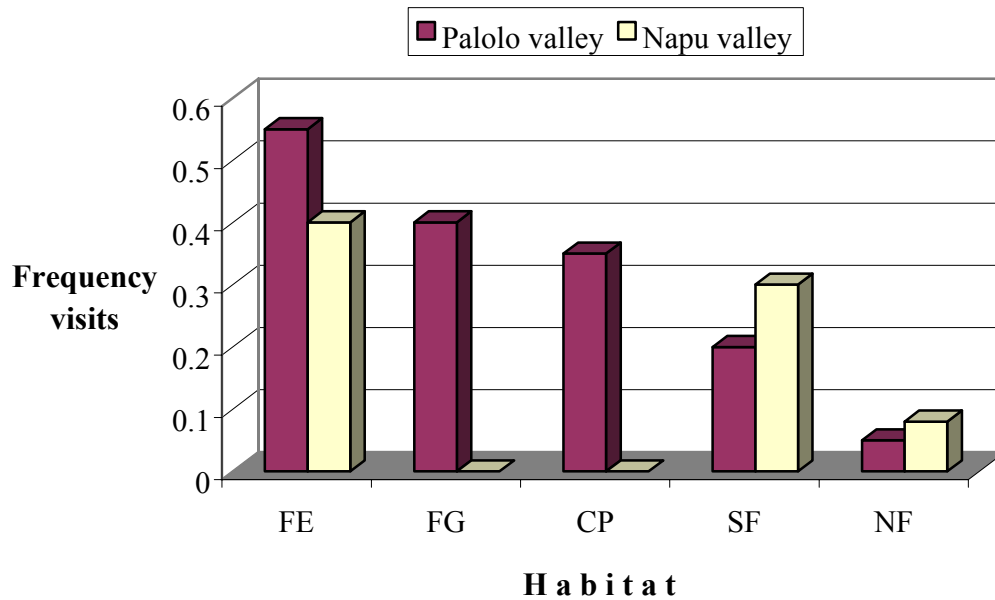
forest in Palolo valley and Napu valley, each habitat was observed for 40 days, FE = forest edge, FG = forest garden, CP = coffee plantation, SF = secondary forest and NF = natural forest.

Considering the high frequency of human activities in forest margin areas, these habitats could be classified as: (1) much disturbed area for forest edge, forest garden and coffee plantation (2) slightly disturbed for secondary forest and (3) undisturbed area for natural forest. The relationship between human intervention and total predation rates in Palolo valley showed a significantly positive correlation (Spearman-rank correlation coefficient rs > 0.7, N $= 5$, $p < 0.05$). The interaction occurring in Napu valley revealed a very strong positive correlation (Spearman-rank correlation coefficient rs $= 1.0$, $p < 0.05$).

4.10 Understorey and ground-nesting birds inhabiting forest margin areas

There are about 50 understorey and ground dwelling bird species inhabiting the array of habitats in Lore Lindu National Park (Watling, 1983; Coates et al., 1997). Bird communities in the study sites were dominated by understorey flycatchers (Waltert et al., in prep.). During experimental periods and surveys in the study area, a number of understorey and ground-nesting birds (31 species) were accounted for in both Palolo and Napu valley (Table 4.11).

Table 4.11 Understorey and ground-nesting birds observed in Palolo and Napu valley of Lore Lindu National Park, U = Undestorey, G = Ground-nesting birds, PV = Palolo valley, NV = Napu valley, E = endemic to Sulawesi, E(ss) = endemic sub species, R = Resident, n = sighting number of individual.

Species	U/G	Forest type		Status
		PV (n)	NV (n)	
Amourornis isabellinus (Isabelline bush-hen)	G	2	0	E
Aramidopsis plateni (Snoring rail)	G	1	0	E
Gallus gallus (Red junglefowl)	G	0	1	R
Ducula radiata (Grey-headed Imperial Pigeon)	U	0	2	E
Treron griseicauda (Grey-cheeked green pigeon)	U	2	0	R
Macropygia amboinensis (Brown Cuckoo-dove)	U	0	2	R
Phaenicophaeus calyorhynchus (Yellow-billed Malkoha)	U	7	4	E
Ceyx fallax (Sulawesi Dwarf Kingfisher)	U	2	0	E
Meropogon forsteni (Purple.bearded Bee-eater)	U	2	0	E
Pitta erythrogaster celebensis (Blue-breasted Pitta)	U	1	0	E (ss)
Trichastoma celebense (Sulawesi Babbler)	U	4	2	E
Zoothera erythronota (Red-backed Thrush)	U	1	0	E
Turdus poliocephalus (Island Thrush)	U	0	1	R
Gerygone sulphurea (Flyeater)	U	0	2	R
Bradypterus castaneus (Chesnut-backed Bush-warbler)	U	0	1	E
Phylloycopus sarasinorum (Sulawesi Leaf-warbler)	U	0	1	E
Rhinomyias colonus (Henna-tailed Jungle-flycatcher)	U	0	0	E
Eumyias panayensis (Island Verditer Flycatcher)	U	0	2	E
Ficedula rufigula (Rufous-throated Flycatcher)	U	3	2	E
Ficedula westermanni (Little Pied Flycatcher)	U	2	2	R
Cyornis omissus (Mangrove Blue Flycatcher)	U	3	2	E (ss)
Hypothymis azurea (Black-naped Monarch)	U	15	8	R
Rhipidura teysmanni (Rusty-bellied Fantail)	U	1	2	E
Culicicapa helianthea (Citrine Flycatcher)	U	1	2	R
Coracornis raveni (Maroon-backed Whistler)	U	2	0	E
Pachycephala sulfuriventer (Yellow-vented Whistler)	U	2	3	E
Nectarinia jugularis (Olive-backed Sunbird)	U	7	4	R
Aethopyga siparaja (Crimson Sunbird)	U	2	1	R
Dicaeum celebicum (Grey-sided Flowerpecker)	U	3	2	E
Zosterops chloris (Yellow -billed Whitw-eye)	U	5	0	R
Zosterops atrifrons (Black-fronted White eye)	U	0	2	R
Total individu		68	48	

4.10.1 Observation on natural nests

During the nest surveys in Palolo valley, seven used nests and three new nests were found in the period February to April 2001. These nests were identified as the nests of *Hypothymis azurea*, *Zoosterops chloris* and *Treron griseicauda* and unknown species (Table 4.12).

Table 4.12 Descripton of natural nests encountered in study sites in Palolo valley, HAG = Height above ground.

Species	Number of nests	Shape	Nest diameter (cm)	Tree/ shrub	HAG (cm)	Habitat
Hypothymis azurea	5 old, 1 new*	open-cup	D=10 cm, 5 cm depth	Urticaceae, palms, liana	135-168	forest edge, forest garden, secondary forest
Zoosterops Chloris	1 old, 1 new	open-cup	D= 7 cm, 4 cm depth	Citrus tree	215-220	forest edge
Treron griseicauda	1 new	simple platform	D=15.5 cm	*Terminalia katappa*	265	forest edge
Unknown	1 old	domed	D= 12 cm	*Ficus sp.*	158	forest garden

*with two eggs

Unlike the results obtained in Palolo valley, natural nests found in Napu valley were all considered to be the nests of Black-naped Monarch (*Hypothymis azurea)*. Four used nests and one new nest were encountered in all habitat types (Table 4.13). This species mainly built its nests in forest margin areas. Additionally, a nest of Rallidae spp with two eggs was found in natural forest in Palolo valley (Waltert, 2001, personal communication).

Table 4.13 The characteristics of five nests of Black-naped Monarch from three different habitats in Napu valley , HAG = Height above ground.

Nest	Location	HAG (cm)	Nest diameter (cm)	Concealment Shrub cover (%)	Canopy closure (%)	Habitat
1	Major branch	270	8.4	40	60	forest edge
2	Fork shape	164	9.3	30	60	forest edge
3	Minor branch	137	7.5	50	50	secondary forest
4	Minor branch	143	10.1	40	70	natural forest
5	Major branch*	152	9.5	40	75	natural forest

* new nest with two eggs

4.10.2 Breeding biology

Breeding of Yellow-bellied White-eye (Zoosterops chloris)

Two nests of Yellow-bellied White-eye *(Zoosterops chloris)* were found at forest edge of the Palolo valley. This species built the new nest on the same tree where the old nest was found. The new nest was found as the adult birds were building it on the branch of a citrus tree. Both female and male seemed to seek and bring the nest materials which was mainly dried vegetation from forest and surroundings.

The old and the new nests were found at the height of 215 cm and 220 cm above the ground, respectively. The new nest was first seen on 21st March. The adult only built it until 27th March and then left the nest. It was assumed that the intensive activities of people around the nest location was disturbing and forcing the adult birds from their nest. Since the adult birds did not finish the nest, little information was obtained about the breeding behaviour of Yellow-bellied White-eye.

Breeding of Grey-cheeked Green Pigeon (Treron griseicauda)

The nest of this species was found on the branch of a big tree, *Terminalia katappa* (ketapang) in forest margin habitat. The nest was built of interwoven twigs at the height of around 265 cm above ground. When the nest was encountered, two eggs had hatched. During observation, it was undoubtedly both parents took care of and fed the nestlings. They were clearly fed by regurgitation of 'pigeon milk', as produced by most pigeons and doves. This is a kind of nutrious secretion produced from glands inside the crops of both parents. During the feeding, female stayed longer on the nest than male did. Observation only took place for three days (13-15 April 2001), because the next day, the young birds had disappeared. They were presumably taken by people who normally enter this area for collecting forest products or by a nest predator.

Breeding biology of Black-naped monarch (Hypothymis azurea)

Five used nests and one new nest of the Black-naped Monarch were found in secondary forest, forest garden and forest edge of Palolo valley (Table 4.12). The used nests were built on branches and on the fork of a tree. They were mainly found on Urticaceae. Unlike all used (old) nests which were found on branches and on the fork shape of a tree, the

newly built nest was constructed between two branches of liana hanging down from a big tree and almost reached the small stream. The type of nest was cup-shaped. Nest materials were mostly dried vegetations and the bark of palm tree which was layered on the outside by moss (see figure 4.25). Its size was 9 cm diameter by 5 cm depth and the height of the nest from surface of the stream was 148 cm. Two eggs of different sizes, 16 x 12 mm and 17 x 13 mm were laid on the nest. They were whitish with pale brown spots and looked like quail eggs (Figure 4.25).

The incubation period could not be accounted exactly because the eggs had been already laid when the nest was found. However, it could be assumed that the incubation period was more than 12 days which was calculated from when the nest was found until the first egg hatched. The second egg hatched one day later. The fledgling period was about 13-14 days because the first young could fly 13 days after hatching and the other flew on day 14. Since the young birds started flying at different times, it seemed that they were asynchrony. During the incubation period, both parents brooded on the nest, but the female laid longer than the male. Both female and male took responsibility for feeding the young birds. In this case, the male came more frequently than the female. During feeding, the first fledging seemed to be more intensive in competition. The identifiable forages were mainly supposed to be insects such as butterflies and grasshoppers and also larvae.

In the fledging period, one black tree-snake (*Boiga irregularis*) was seen nearby approaching the nest. It was evidence of nest predator occurrence. It was observed that the adult birds tried to protect the nestlings by perching nearby and calling loudly in order to warn the predator.

During the observations on natural nests in Napu valley, the presence and location of four old nests and one new nest of Black-naped Monarch (*Hypothymis azurea*) were encountered. These nests were found in different habitat (Table 4.13). The breeding biology of this species has been recorded (Pangau and Mühlenberg, in prep.). One unidentified old nest was also found in secondary forest. This nest was presumed to be the nest of a dove because of its shape a simple platform. All nests were found in the period of February to April 2001 and 2002.

Figure 4.24 Natural nest with two eggs found in natural forest habitat in Napu valley on 26 March 2002. This nest was built on Urticaceae.

Figure 4.25 Natural nest and nestling of Black-naped Monarch (*Hypothymis azurea*) found in forest garden of Palolo valley; (a) 3 days old (b) 8 days old. Nest was built above a small stream indicating an antipredator strategy.

5. DISCUSSION

5.1 Nest predation rates in Sulawesi rainforest

Experiments on nest predation in the tropics are few and the results are heterogeneous. This study is to our knowledge the first attempt to investigate nest predation rates in tropical Indonesia. Based on the results obtained from experimental trials in Lore Lindu National Park, it is believed that general predation pressure in this region appear relatively high after eight days (63.5 % in Palolo valley and 62.3 % in Napu valley). Nest predation in two sites seemed to follow a similar pattern. The most salient result of these experiments is the finding that nest predation rates in Palolo and Napu valley occurred in a similar pattern and the fact that ground nests suffered more predation pressure than shrub nests in both sites. Predator diversity and abundance, vegetation structure and degree of habitat disturbance due to human activities, might be considered as significant factors affecting the high predation rates in this region.

The results of the first exposure (in 4 days) also showed that the two sites experienced similar rates of predation pressure. However, ground nests in Palolo valley seemed to suffered more predation pressure (70.1 %) than those in Napu valley (56.6 %). In the case of shrub nests the predation rate was more pronounced in Napu valley than in Palolo valley. Two reasons might explain these facts. Firstly, ground nests were more detectable in Palolo valley than those placed in Napu valley and vice versa for the shrub nests. Secondly, the patterns of predator communities were different, therefore there were variations of predator strategies for finding the nests.

Although nest predation rates appear relatively high in Sulawesi rainforest, three factors might complicate direct comparisons between this and other studies conducted in tropical rainforest. Firstly, we conducted the artificial experiments in different land-use systems within the park area in order to get a better understanding of habitat gradient effects. The other studies placed more emphasised on the distance from forest edge to forest interior (e.g. Gibbs, 1991; see Laurance et al., 1993). Secondly, the exposure time varied, we carried out the experimental trials for 8 days, while the other studies in Costa Rica and in

Amazonian-Colombian conducted the experiments for 7 days (Gibbs, 1991; Telleria and Diaz, 1995) and 3 days in tropical Australia (Laurance et al., 1993). Thirdly, some investigators have used bigger eggs (such as chicken eggs) (Laurance et al., 1993; Carlson and Hartman, 2001, Estrada, et al, 2002). Fourthly, nest types used in experiment trials varied, e.g.: covered and exposed nests (Cooper and Francis, 1998), ground nests only (Gibbs, 1991; Carlson and Hartman, 2001; and Estrada et al., 2002) and ground and shrub (Telleria and Diaz, 1995).

Despite the differences in study design, predation rates could generally be compared across regions with tropical forests. The total predation on ground and shrub nests occurring in Sulawesi rainforest (63 % in 8 days) was higher than that reported by Telleria and Diaz (1995) for ground nests and shrub nests placed along a natural gradient of Amazonian rainforest (26.4 % in 7 days). Further comparisons for each nest type (ground or shrub) are described in following section.

The elevated nest predation rate in this region compared to other tropical areas could also be the result of the various vegetation structures and of the assemblage of predatory vertebrates. Variation in nest predation intensity in different regions may relate to the relative abundance of ground-dwelling mammals (Gibbs, 1991).

Regarding the latitudinal variation in predation intensity, this study provides evidence which supports the assertion that ground nests in tropical regions experience significantly higher predation rates than in temperate forests (Söderström, 1999). In this study 72-86 % of nests were depredated in eight days. Excessive predation in tropical forests is usually attributed to the presence of predator faunas that are more diverse and abundant in tropical than temperate forests (Gibbs, 1991). It could be assumed that the predator assemblages of Sulawesi rainforest are somewhat unique, characterised in particular by a lack of large-sized mammalian predators and a high diversity of small mammals. The absence of top predator fauna might influence the predator dynamics and nest predation rates with respect to forest margin habitats. Therefore, Sulawesi rainforest may experience particular case of predation pressure.

5.2 Edge effects on nest predation in forest margin areas

The effect of habitat edge on nest predation has been studied in both temperate and in tropical regions. In temperate zones, some studies have found edge effects on predation of distance to edge (Gates and Gysel, 1978; Wilcove, 1985; Andrén et al, 1985; Andrén and Angelstam, 1988; Burger, 1988; Möller, 1989), whereas others have reported the opposite (Storch, 1991) or no edge effect at all (Yahner and Wright, 1985; Angelstam, 1986; Santos and Telleria, 1992; Small and Hunter, 1988; Huhta, 1995; Keyser et al., 1998). The general conclusion on predation rates in temperate regions is an increased nest predation close to edges (for review see Patton 1994; Andren 1995).

In the current studies, the intensity of encroachment and deforestation might become a serious threat for certain forest dwelling animals through edge effects. Results of our experimental trials clearly showed that a significantly higher number of nests were attacked by predators along forest edge and forest margin habitats. It is considered that when an edge is created, where previously there was continuous pristine forest, the edge effect may affect the community structure through its impact on egg-laying animals (Burkey, 1993). The prevailing explanation for increased predation near forest edges has been the high concentration of predators from the surrounding matrix entering forest habitats to forage (Angelstam, 1986; Andrén and Angelstam; 1988, Small and Hunter, 1988). A high productivity matrix would also support a high number of generalist predators (Angelstam, 1986). It might be that several kinds of habitat discontinuity exhibit an edge effect whereas others do not and edge habitat could be an appropriate foraging area where predators are more active than in forest interior. Telleria and Diaz (1995) suggested that while the abundance of predators does not increase, those that prefer edge habitat may be more efficient in raiding nests than those occurring in forest interior.

What is the case in our study? see the following section.

5.2.1 Effects on ground nests

The results of experimental trials in this study indicate that the predation rates on ground nests along forest edge (84 % and 86 % in two sites respectively) was not significantly different from those in natural forest (73 % and 66 %). Although ground nests in Napu

valley showed a trend towards lower predation risks in natural forest than at the edge, the differences were not significant. The other experiments on ground nest predation in the tropics reported a variety of results. Gibbs (1991) documented an increased predation risk of ground nests at edges between indigenous and second growth forest in Costa Rica, but not at edges between forest and pastures. Similarly, studies conducted in Andean montane forest (edges of forest fragments), Southeast Asian lowland rainforest remnants (primary-secondary forest edges) and in montane forest of Tanzania (forest-tea plantation edges) demonstrated the absence of an edge effect on ground nest predation (Arango-Vélez and Kattan, 1997; Wong et al., 1998, Carlson and Hartman, 2001). However, other studies in neotropical and Southeast Asian rainforest reported the edge effects on ground nest predation at various edges, including transitions between a minor road and forest, logged-unlogged forest as well as forest-pasture edges (Burkey 1993; Cooper and Francis, 1998; Estrada et al., 2002).

It is apparent that the edge type is certainly a major determinant of edge effects. Edges can be classified into soft edges that have much vegetation cover and hard edges that bear little vegetation cover (Söderstrom, 1998). Our experiments were carried out between the forest and agricultural fields in which the edge was a steep alteration between two structurally different habitats, the edge type is therefore considered to be a hard one. Gibbs (1991) suggested that the lack of an edge effect in the forest-field transition could be related to the extremely artificial surroundings of the forest habitat which do not support the activity of potential nest predators. The forest edges we studied in Sulawesi were adjacent to intensively used agricultural fields (Napu valley) or dirt road/maize fields (Palolo valley). The forest was the dominant element and edge contrast was equivalent to farmland-forest ecotones of extensive agricultural landscapes. It is possible that these structurally very different habitats prevented ground-living forest mammals from entering the edge, similar to that in Costa Rica (Gibbs 1991). Furthermore, abundance and species richness of predators on ground nests might have been similar in all sites as indicated by small mammal trapping in the study area. It means that nest predators are occupying edge habitats in a similar pattern to that in natural forest. This was also confirmed by the photography identification of nest predation attempts where the main predators were the Sulawesian giant rat and the Wild Sulawesian rat (Muridae), both forest species.

It can be assumed that forest dwelling species were the main predators responsible for nest predation in natural forest as well as in forest edge. This was confirmed by the pictures produced from automatic cameras and rodents captured from all habitats (discussed in the following section). The high intensity of human activities along forest margin areas probably deter forest dwelling species from approaching the edges. This assumption supports the pattern occurring in tropical forests of Tanzania, that the potential predators are restricted to certain habitats and not attracted to sharp habitat edges (Carlson and Hartman, 2001).

Although it revealed no edge effects on ground predation rates, the high level of predation occurring in these areas should be put into account. Compared to other studies in tropical forest, it is apparent that the mean rate of predation on the ground in Sulawesi rainforest (38 % in 4 days, Table 4.1.) was higher than that documented by Gibbs (1991) for ground nests in similar habitats in Costa Rica (33 % in 7 days), but lower than that reported by Laurance, et al. (1993) for ground nests in Queensland forests (44 % in 3 days) and the dramatic rate of 100 % in 2 days reported from Barro Colorado Island, Panama (Loissele and Hoppes, 1983).

5.2.2 Effects on shrub nests

In contrast to ground nests, predation rates on shrub nests were significantly different between edges and natural forest. There was a substantially increased predation rate near the edge and intermediate levels in disturbed habitats but the lowest rate was in natural forest. Regardless of the habitat structures, Palolo valley and Napu valley experienced the same pattern of nest predation on shrub nests. One important reason for this finding might be the high number of potential nest predators on this type of nest along forest edge. The alteration of habitats may attract a various nest predator fauna to operate along the edges. Andrén and Angelstam (1988) suggested that edge effects on predation rates at forest edge vs. forest interior were usually attributed to the increased potential nest predators along the edges.

The most likely assemblages of nest predators on shrub nests at our study sites were small scansorial (climbing) mammals like Dwarf cuscus (*Strigocusus celebensis)* and Sciuridae as well as some arboreal rats such as *Paruromys dominator*. It is known that such an

assemblage of scansorial nest predators may favour the tangled vegetation of the forest edge (Burkey, 1993; Estrada et al., 2002). We can also expect avian species and reptiles to be predators of shrub nests (Telleria and Diaz, 1995; Cooper and Francis, 1998), although there was only a few of these predators evident at our study sites. In temperate regions, avian species accounted for most of the predation events on shrub nests whereas mammals mainly preyed upon ground nests (Andrén et al., 1985; Angelstam, 1986; Söderström, 1998).

High predation on shrub nests at the forest-agriculture field edge could also probably be a result of an easy contact of predator species to nests due to insufficient vegetation cover along the edges. This may indicate an increased exposure of nests to potential predators that visit these habitats. In this study, the forest edge transects were only situated 10 m away from the outer forest edge and the site had sparse shrub vegetation cover. This hard edge could not support the concealment of shrub nests from the outlook of potential predators such as avian predators and cause an edge effect at the edges (Söderström, 1998). However, birds did not seem to play a major role at our sites as results from camera-traps revealed.

Nest predators probably respond to this kind of habitat edge due to the fact that vegetation structure across the ecotone is more pronounced than at other habitat types. Angelstam (1986) suggested that an edge effect on nest predation might be most likely to occur where there is a steep gradient in primary productivity across the edge (e.g. forest/agriculture and forest/grassland edges) and is least possible to occur where this gradient is less obvious (e.g. agriculture/grassland edges). It seemed that the edge area was used by some nest predators as a travel corridor for foraging, thereby increasing the variety of shrub nest predators occurring or operating along the edges. Marini et al. (1995) and Andrén (1995) summarised a number of reasons why forest edges may support relatively diverse and abundant predator assemblages: (i) the presence of a combination of predators from both the forest and adjacent habitats (ii) incursion into forests of generalist predators that reach high densities within adjacent modified habitats (iii) use of edges as travel lanes by potential predators. Thus, increased predator compositions at edges may reduce the nest success of understorey birds who build their nests in the shrub. This is because a greater variety of search strategies could lead to more nests being found (Marini et al, 1995, Piper et al, 2002).

A variety of animal responses may generate along edges, some of them are favourable and some are harmful. Bider (1968) found high utilisation of ecotone habitat by many different species. He suggested that forest edges acted as "biological barriers" along which animals forage. Even though habitat edges were formerly considered beneficial to birds because of the increased density and diversity of species that often occurred there, currently edges are regarded to be detrimental (Saunders et al, 1991). Prefential use of edge habitat by shrub nest predators may lead to increased nest loss in these "ecological traps" (Gates and Gysel, 1978).

5.3 Why ground nests suffer higher predation pressure than shrub nests?

In this study, ground nests experienced significantly higher predation rates than shrub nests at all sites both in Palolo valley (63.5 % : 36.5 %) and in Napu valley (61 % : 39 %). These results may support the few previous studies conducted in tropical forest which reported that artificial nest predation rates seem to be greater for ground nests than shrub nests (Loiselle and Hoppes, 1983; Wilcove, 1985; Martin, 1987). Considering the results from this study and other reports from tropical studies, ground nests may be expected to have significantly high nest predation levels compared to shrub nests in tropical forest. This is different to temperate regions where predation rates on ground and shrub nests are similar, as documented in studies undertaken in Northern Hemisphere temperate forests (for a review see Söderström, 1999 and see Rudnicky and Hunter, 1993). In fact, a comparative analysis of predation rates on natural nests are generally lower for ground than for shrub nesting species (Martin, 1995).

The high number of rodent species occurring in tropical study sites might enhance predation risk on ground nests. Sulawesi rainforest supports a high diversity of small mammals: 46 species of Muridae, nine species of either Sciuridae or Soricidae (Whitten, et al., 1988) and they are considered to be forest dwelling fauna. There are 38 species of rats and five species of squirrels which have been reported to occupy the area of Lore Lindu National Park (TNC, 2001). These animals were considered responsible for high predation rates occurring in study sites (Palolo valley and Napu valley). Other researchers have documented that small mammals are believed to be the main predators on ground nests in tropical forest in Costa Rica, Australian tropical forest, Singapore and Mexico (Gibbs, 1991; Laurance et al., 1993; Wong et al., 1998, Estrada et al., 2002).

Based on the results obtained, artificial nests placed above ground or on shrub nests could offer possibilities to other predator fauna like snakes, birds, cuscus and squirrels, while rodents and lizard prey mostly on ground nests. Predator species on shrub nests were likely to be different from those on ground nests. It seemed that differences in the predator assemblage between ground and shrub nests may account for the differences in predation rates. Nests within different height classes are exposed to different predator assemblages and often vary in success rate (Martin, 1993; Södestrom, 1999). Predation levels within a habitat may vary between nest types (Martin, 1987; Piper et al., 2002).

Predation risk on artificial nests could be used to predict the possible pattern of predation pressure on natural nests. If predation on natural nests in tropical forest exhibit the same pattern as on artificial nests and if nest predation affects avian life histories, this would affect ground nesting birds who would have shorter nestling periods, more broods and a smaller clutch size compared to shrub nesters (see Martin 1993, 1995). In addition, if nest predation rates differ between ground and shrub nests, selection should also favour nest sites associated with a low probability of nest predation (Collias and Collias, 1984; Martin, 1992).

5.4 Nest predation in relation to habitat gradient

Results from experimental trials clearly revealed that a significantly higher number of shrub nests were attacked by predators along forest margin areas than in the natural forest. In fact, the vegetation structure of coffee plantation, forest garden and secondary forest are different from each other but they bore similar shrub nest predation rates; 42-48 % in Palolo valley and 46 % in Napu valley. These habitats all have something in common; that they were frequently visited by people which could accommodate the operation of predator fauna through the opening of patches by the establishment of footpaths creating "edges". This might have similar effects on nest predation to the forest-logged forest edges reported by Cooper and Francis (1998). It might be assumed that forest gardens and secondary forest attract small mammals to search for prey and probably provide more abundant food resources than are available at the forest interior (Leck, 1987; Carlson and Hartman, 2001). In addition, this may also favour certain forest dwelling animals for foraging, e.g. nocturnal Dwarf cuscus (*Strigocuscus celebensis*), Sciuridae and Soricidae.

The shrub nest predation rate in natural forest, 16 % for Palolo valley and 22 % for Napu valley was found to be the lowest that occurred compared to the forest margin habitats. We suggest two potential reasons for this fact: (1) Low intensity of human activities (rattan collection only) in this habitat type has no significant influence on predation pressure compared to interventions at other sites. Variation in nest predation intensity within forest patch mosaics seemed largely dependent on the impact of humans on predator populations in patches and on surrounding cultivated land (Gibbs, 1991), and (2) The variety of predator fauna along forest edge and forest margin habitats may enhance the increase of predation rate. Observation and pictures from automatic cameras showed the presence of Dwarf cuscus and Sciuridae at the forest edge and forest margin habitats but not in the natural forest. It might be assumed that these animals used a wide range of habitats, particularly in disturbed forests where they could easily move about using terrestrial openings. Additional influx of shrub nest predators from the nearby surrounding areas, like non-forest avian species may be another reason to elevate predation risk at the forest margin habitats.

Natural forest area may be ecologically different from forest margin habitats where the most anthropogenic disturbance emerged. Such differences may influence predator abundance and behaviour (Picman and Schriml, 1994; Flaspohler, 2001). In this study, predator fauna were more pronounced along forest margin habitats than in natural forest.

The predation pressure on ground nest was high at all habitats including natural forest, could suggest the following points; (i) Predator fauna respond in a similar pattern at each habitat. Small mammals were counted as main predators on ground nests. In this case, they may possibly operate along forest margin areas in the same manner as in natural forest (ii) Diversity and abundance of nest predators operating on ground nests were homogenous at those habitat types. For example, distribution of terrestrial rodents was not only restricted in forest margin areas but were observed commonly in natural forest. If the community dynamics in natural forest remains naturally, where the presence of top predators might regulate the population of medium-sized predators, that condition might not threaten the reproductive success of understorey and ground nesting birds inhabiting this habitat. The problem arises in forest margin habitats where the lack of top predators might enhance the predation risk, so-called mesopredator release (Soulé, et al.,1988).

5.5 Is different predation pressure caused by various predators?

The high predation rates in habitat studies in both Palolo valley and Napu valley (74-84 % nest depredated in 8 days) might indicate the high diversity and abundance of potential predator fauna in the given areas. The most frequent explanation for the high level of nest predation within the tropical region is the high variety of nest predators (Zimmermann, 1997). In his study in a tropical wet forest in Costa Rica, Gibbs (1991) highlighted that excessive predation in tropical forests is usually attributed to the presence of predator faunas that are more diverse and dense in tropical than temperate forest. The large number of small mammals inhabiting Sulawesi rainforest may be considered as the major nest predators followed by other potential predator fauna such as marsupials, macaques, reptiles and avian species.

When the fragmentation and degradation of natural habitats continue, the predator fauna are confined to a smaller area. As a result, this may have the effect of concentrating predator species in some habitats, thus increasing the levels of nest predation (Fischer, 2000). This may have happened in forest margin habitats that suffered more predation pressure than natural forest.

Identification of predator fauna in this study was undertaken based on the markings left by predators and the pictures produced by automatic cameras. Egg remains left by predators suggested that several types of predators were involved at each habitat. Scratch and shell fragments are considered to be evidence of rodents and cuscus visits and totally lost of eggs might accounted for the presence of squirrels and probably reptiles. Perforation on eggs referred to the attack of avian predators.

The frequency of avian predator attack was only found in a few cases; six nests in Palolo valley and 4 nests in Napu valley. This evidence of avian predators was encountered along forest margin habitats and considered as the signs of avian nest predators which occupy this area such as Rufous-bellied Eagle (*Hieraaetus kienerri*) and Sulawesi Serpent-eagle (*Spilornis rufipectus*). Theoretically, several avian species such as *Otus sp., Ninox sp.*, Accipitridae, and Falconidae have been reported as potential predators of eggs, nestlings and adult birds in Sulawesi (Coates et al., 1997). The other predator, the Sulawesian giant rat (*Paruromys dominator*) not only attacked ground nests but shrub nests as well. It is

assumed that this species actively forage at all vertical levels in the forest and thus would have access to a variety of terrestrial and arboreal nests.

Predator identity is crucial for the management of some endangered bird populations. Knowing the potential predator fauna preying upon particular nest types may contribute to the understanding of the main factors influencing the reproductive success of avian fauna. However, predator identification could not be generalised from one tropical forest area to another because of the various patterns of predator assemblages at each region. For instance, the composition of nest predators documented in the Neotropical rainforest of Mexico (Estrada et al., 2002) was completely different from the results obtained in the Sulawesi rainforest. Predator communities should be evaluated on a region by region basis.

In general, the foraging behaviour of nest predators has not been investigated and therefore there was insufficient information on how predators find bird nests (Marini, 1997), especially the findings from tropical forests. Ricklefs (1989) suggested that different nest sites (e.g. ground and shrub nests) are probably vulnerable to different predators due to differences in search strategies and sensory inputs (e.g. visual or olfactory cues). Avian predators normally use visual cues, while mammals rely on olfactory signs to find bird nests (Södeström, 1998). Our artificial-nest experiment corroborates this contention by revealing the differences of the composition of the nest predator fauna between ground and shrub nests.

There was a clear separation of predator faunas between shrub and ground nests as identified from the pictures produced by automatic cameras. The following section (5.5.1 and 5.5.2) might be considered as potential mechanisms to explain predator differences occurring on ground and shrub nests.

5.5.1 Potential predator fauna on ground nests

Egg remains left by predators might suggest that several types of predator on ground nests were involved at each habitat in Palolo valley and Napu valley. They included rodents, avian nest predators and possibly reptiles as well.

After identification of markings left by predators in Palolo valley the large rodents were found to be more prevalent (36 %) in all habitats than small rodents (23 %). Large rodents were found in proportionately more nests along forest edge and forest margin habitats than in natural forest. This pattern also occurred in Napu valley where large and small rodents preyed on more eggs (60 %) than other predators. The possible reason to explain this fact is that rodents are responsible as the major nest predator fauna in all habitats. More shell fragments were found along forest margin habitats than in natural forest and egg loss was higher in natural forest than in other habitats. These results are different from the findings in Pasoh Forest Reserve, Singapore, where egg shell fragments were more common in the forest interior than near the edge (Cooper and Francis, 1998). However, consistent with our study, egg loss was higher in natural forest than in other habitats in both Palolo valley and Napu valley. Other small mammals and reptiles such as Monitor lizard (*Varanus salvator)* were presumably responsible for the eggs which were recorded as disappeared at all habitats (41 % of 191 depredated nests). In his study in a lowland forest of southern Mexico, Estrada (2002) reported that the presence of snakes and mammals have removed the majority of disappeared hen eggs during experimental trials. However, rats evidently sometimes carried eggs from nests before attempting to eat them (Major, 1991). This means rats might be partly responsible for the disappeared eggs both in Palolo valley and Napu valley.

As documented from successive photographs, Sulawesian giant rat (*Paruromys dominator)* and Wild Sulawesian rat (*Rattus hoffmanni)* were dominant nest predators on ground nests along forest margin areas. These rats are abundant and well distributed in disturbed areas although occasionally they were counted in natural forest as well. These species were counted among seven major species captured in Lore Lindu National Park during mammal surveys carried out by The Nature Conservancy, TNC (Maryanto and Yani, 2002). The dominance of the rodents as a ground nest predator is reasonable since the Sulawesi rainforest has a high diversity of rodents.

Despite the few incidents of perforation, the presence of avian predators was found to occur along forest margin areas (forest edge in Palolo valley and coffee plantations in Napu valley). Avian predators appear to attack the nests in disturbed habitats, probably due to the less complex vegetation towards the open habitats which would facilitate easier nest detection.

Nest appearance after depredation showed that several nests suffered not only egg attacks from predators but also nest damage. These evidence seemed to have the markings of mammal visits, probably introduced predators such as cats and dogs, who try to find more eggs and then damaged the nests. Sightings of these introduced species were only recorded from forest margin areas. These occurrences were more frequent on ground nests than shrub nests, indicating that ground nests were more vulnerable to such introduced species. These animals might pose a significant threat to ground-nesting forest birds. Sanders and Maloney (2002) reported that the main introduced nest predators in the Upper Waitaki Basin, South Island, New Zealand were cats (*Felis catus*). From other studies in Los Tuxtlas, Mexico, cats and dogs (*Canis familiaris*) accompanying ranchers and farmers were found to be predators on ground nests (Estrada et al., 2002).

Although Soricidae and Scirucidae are occasionally terrestrial animals, they were absent among the predator fauna visiting ground nests during this study, as identified from the camera pictures and rodent trapping. This may be due to insufficient methods to detect their presence or the notion that these families have a lower diversity in this region.

Results of this study support the previous assertion that predation by small mammals is proportionately more common as predators than bird species in tropical forest (see Söderström, et al., 1998). Laurance et al., (1993) in their study in Australian tropical rainforest documented that omnivorous rodents, especially the white-tailed rat, might be key predators on some ground nesting birds. Similar findings have been reported for the wet forests in Costa Rica (Gibbs, 1991) and Singapore (Wong et al., 1998).

5.5.2 Potential predator fauna on shrub nests

Few studies have been done on shrub nests in tropical forest and little is known about potential nest predators of shrub nests. Therefore, it is rather difficult to have a comparison between the presence of predator species and the relative importance of these species as predators on shrub nests. In the temperate zone, birds like corvids were the dominant predators on shrub nests, while mammals almost exclusively depredated ground nests (Andrén, 1995; Söderström, et al., 1998). Studies conducted in Amazonian rainforest reported that birds appear to have been the main predators on shrub nests (Telleria and Diaz, 1995).

In contrast however, this study showed a different pattern that mammals dominate the predator fauna preying upon shrub nests. As shown by the pictures, the nest predators were mainly rodents (rats) followed by other animals such as Dwarf cuscus (*Strigocuscus celebensis*) and Sciruidae (squirrels). Tree snakes (Boiga spp) were also involved in depredation on shrub nests. Pictures from automatic cameras show the occurrence of Dwarf cuscus in forest edge and forest garden in Palolo valley. This animal is actually frugivorous (Kinnaird, 1998) but in this case they were found to prey upon the eggs. Squirrels were only recorded from forest garden and coffee plantations, implying that this animal only operates in forest margin habitats. They are mainly terrestrial and hunt food both day and night. In fact, squirrels are insectivores but they also eat other small mammals such as frogs and lizard (Francis, 2001). In this region they also preyed on birds egg. The incidence of Dwarf cuscus and squirrels in this study might be accounted for as opportunistic nest predators. Squirrels were also documented as nest predators in other tropical forest (see Carlson and Hartman, 2001; Estrada et al., 2002). In a review of published studies, Angelstam (1986) deduced that most vertebrate nest predators were opportunistic and attacked nests in approximate proportion to their relative abundance. The variety of predator fauna on shrub nests in LLNP was somewhat different than those reported from temperate regions.

Identification of markings left by predators indicated the high frequency of large and small rodent visits on shrub nests. In Palolo valley, large and small rodents which left shell fragments and scratch markings were found to be more prevalent (72.6%) in all habitats than other predator types. Egg shell fragments were found in proportionately more nests along forest edge and forest margin habitats than in natural forest. This model also occurred in Napu valley where the large and small rodents preyed upon more eggs (60 %) than the other predators. This suggests that rodents could be considered as the main predators on shrub nests in all habitat types. In Palolo and Napu valley, egg loss which could probably be attributable to other mammals and reptiles was found to be higher in forest margin habitats than in natural forest. It is possible that forest margin areas may attract other nest predators from adjacent landscapes to forage in these habitats.

Despite the little evidence obtained, the perforation on eggs can presumably account for the presence of avian predators. In Palolo valley habitats, perforation were found at forest edge, forest garden and secondary forest, but absent in coffee plantations and natural

forest. This means that avian predators only attacked the shrub nests placed along forest margin areas. However, corvids and other potential avian nest predators were rarely seen in these areas during observations.

Among rodents, the Sulawesian giant rat (*Paruromys dominator)* was the most frequent visitor at shrub nests in Palolo valley and Napu valley as documented through automatic cameras. They attacked more shrub nests in forest edge than those in other habitats, but had no incidence in natural forest. This suggests they favour finding prey along edges and forest margin areas. It is possible that the lack of top predator in forest margin habitats might support the elevated foraging activities of this species. There was no evidence of other rats visiting, thus showing that they were unable to reach and access the shrub nests. In Napu valley, the identifiable pictures taken from shrub nests have been all identified as ratsonly. However, the identification from egg remains might explain some other possibilities of potential predators inhabiting this site. Perforation on eggs were found on quail eggs at each habitat type which means that avian predators have attacked several shrub nests in all habitats. However, the cameras in this case failed to document the presence of avian predators. Additionally, a number of damaged nests found in this forest type may elucidate the visit of other mammals such as macaques and possibly feral cats. Macaques have been reported to prey on bird nests and damage the nests in Napu valley (Pombo, 2002 personal communication).

Sulawesian giant rats might be considered as the most common shrub nest predator encountered in Napu valley. Identification from photographs showed that they preyed on the shrub nests placed at each habitat. Although they also occurred in natural forest, they were found to be more prevalent in forest margin areas than in natural forest. This pattern was rather similar to what happened in Palolo valley and may explain the impact of their presence on elevated predation levels in forest margin habitats.

It can be concluded that small mammals dominate the predator fauna on both ground and shrub nests in Lore Lindu National Park. This finding did not support the results from temperate region that mammals are responsible for ground nests and avian predators for shrub nests (Andrén, 1995). Mammals might be relatively more important as nest predators in tropical rather than in temperate forest (Gibbs, 1991; Arango-Vélez and Kattan, 1997; Söderström, 1999). The possible mechanism for this is that the high structural complexity

of tropical forests prevents efficient foraging by visually seeking avian predators (Söderstöm, 1999). The other explanation is that mammals, which rely on olfactory cues to find bird nests, may not be affected to the same extent by a complex vegetation structure.

5.5.3 Rodents in the forest margin areas and mesopredator release

Sulawesi is acclaimed as having many endemic genera of rodents (Corbet and Hill, 1992). Three genera of seven rodent species captured in Palolo valley and Napu valley are endemic genera; Bunomys, Taeromys and Paruromys. It means that several endemic rodent species still occupy forest margin areas, and some of them being responsible for nest predation rates on ground and shrub nests. The results from live trap surveys in Palolo valley indicated that the presence of rodents was distributed equally along edges, forest margin habitats and natural forest. It is apparent that the abundance of rodents inhabiting Napu valley was affected by habitat differences, but a comparison between rodent abundance in forest edge and in natural forest was not significantly different. Based on photographic identification, the number of rodents dwelling in ground layer was not affected by habitat differences in both valleys. This suggests that rodents operate in a similar pattern in all habitat studies, thus they might be responsible for the high predation rates occurred in forest margin habitats and natural forest as well. Furthermore, the occurrence of Sulawesian giant rats and Wild Sulawesian rat was found in a similar pattern in both Palolo valley and Napu valley (Figure 4.15 and 4.17). Their pictures taken from ground nests have been also identified from all habitat types (Table 4.6, Figure 4.10). Since these species were considered to be responsible for the major nest predators on ground nests as documented by photography, their equal distribution might explain the similar pattern of predation rates on ground nest in all habitats in both valleys. Additionally, the frequency of capture of Sulawesian giant rats and Wild Sulawesian rat was somewhat higher than that of other species suggest that their abundance support the high predation rates on ground nests not only along marginal areas but also in natural forest.

Regarding the frequency of rodents operating in shrub layer, it was found that they only occupy forest margin areas. There was no occurrence in natural forest either in Palolo valley or Napu valley. It is possible that the Sulawesian giant rats who preyed upon shrub nests avoid to operate in natural forest in both valleys. This would be considered as the

main reason of low predation rates on shrub nests in natural forest compared to that in forest margin habitats.

The most likely explanation for the above findings on shrub nests is that the top predators probably no longer exist in forest margin areas in Palolo valley and Napu valley. This evidence might lead us to the term "mesopredator release", meaning that the absence of top predators may drive the increase of populations of small mammals like rodents. Mammalian carnivores are particularly vulnerable to extirpation in disturbed habitats and their disappearance may lead to increased numbers of smaller carnivores that are the principle predators of birds (Crooks and Soulé, 1999).

Mesopredator release

Unlike other islands of west Indonesia, most large carnivores are noticeably absent from Sulawesi because they failed to cross the deep sea channel separating Sulawesi and Borneo (Kinnaird, 1995). The only species which successfully distributed on this island are civets. Two species, the Malay palm civet (*Viverra tangalunga*) and the Common palm civet (*Paradoxurus hermaphroditus*) were introduced species and the third one, the Sulawesi civet (*Macrogalidia musschenbroeckii*), is endemic to the island and has become one of the world's least-known carnivores. These animals eat primarily small mammals and some fruit (MacKinnon, 1992; Kinnaird, 1995), therefore they might be considered as top predators in the tropical rain forest of Sulawesi. They are nocturnal and suspected to be arboreal predators.

Another reason for the low predation rate on shrub nests in natural forest of both sites (Palolo valley and Napu valley), might be that the top predators are still present in this habitat type and in turn, they may control the density of small mammals that occupy and prey upon bird eggs. We found foot prints and faeces of the Malay palm civet (*Viverra tangalunga*) in natural forest of both Palolo valley and Napu valley, thus providing evidence of their presence. This habitat type is reported to have a small number of rodents operating on shrub nests, whereas forest margin habitats were accupied by large number of rodents as mentioned before. It would be consistent with the "mesopredator release hypothesis", that small-sized mammals inhabiting disturbed forest become abundant following the extirpation of dominant predators which require large and undisturbed areas

of habitat for survival (Terborg, 1974; Södestrom, 1999). Such mesopredator release has been implicated in the decline and extinction of prey species (Crook and Soulé, 1999) and this phenomenon appears to be common in forest patches of both temperate and tropical ecosystems (Terborg and Winter, 1980; Sieving, 1992). The presence of top predators in natural forest could reduce the number of small mammals like rodents which in turn, could minimise predation risk on birds.

The intense activities of people along forest margin habitats may deter the persistence of civets for at least foraging. Civets tended to avoid approaching the edges and forest margin areas where they could be hunted or chased by humans. Therefore, these animals have been disappeared from marginal areas of Lore Lindu National Park. The decline of civet occurrence in Sulawesi rainforest may also be due to habitat destruction and reprisals for stealing kampung chickens (MacKinnon,1992).

The significance of civets suggests they are helping to control the nest predators (arboreal rodents), possibly contributing to the maintenance of the understorey forest birds nesting on shrub (Figure 5.1). According to mesopredator release hypothesis, the top predator should have an indirect and positive effect on bird population (Fretwell, 1987). It was assumed that civets commonly preyed upon rodents including Sulawesian giant rats, which were scarcely found in natural forest. As comparison, coyotes considered to be large predators in coastal southern California, may lower the rate of extinction of chaparral-requiring birds by reducing the abundance of smaller nest predators (Soulé et al., 1988).

In this study sites, the mesopredator release hypothesis could be described in the following diagram:

natural forest	*forest margin areas*
Top predators (+)	**Top predators (-)** **(extirpation)**
↓ **high pressure**	↓ **low pressure**
Rodents (-)	**Rodents (+)**
↓ **low pressure**	↓ **high pressure**
Bird nests (+)	**Bird nests (-)**
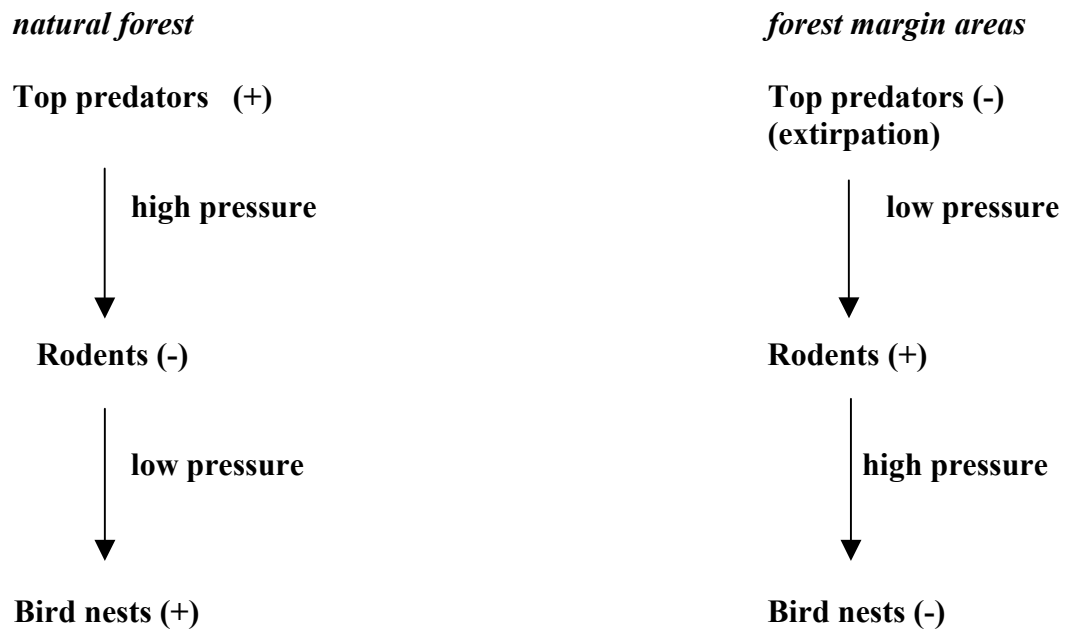
Figure 5.1 Diagram of the combined effects on the top predators (civets), mesopredators (rodents) and prey (bird's egg and nestling) in natural forest and forest margin areas. Direction of the interaction is indicated with a plus or minus.

The lack of top predators in forest margin areas may indirectly affect the bird population. Changes in mammalian predator assemblages, in this case increased abundance of small mammals in forest margin areas, may account for the increased predation rates. Mesopredator release has been suggested as one of main causes of forest bird extinction following habitat alteration (Sieving and Karr, 1997).

5.6 Effects of vegetation structure on ground and shrub nest predation

The canopy cover and shrub cover may possibly play important roles for the nesting success of understorey birds and ground-nesting birds. Some nest predators such as avian predators benefit from the lookouts ability in order to find nests to be prey upon. Flying birds can easily detect the location of nests in habitats with sparse vegetation cover. Nests located away from edges or in areas characterised by increased vegetative structure tend to be preyed upon less than those within edges or in areas of reduced vegetative structure

(Bowman and Harris, 1980, Yahner and Wright, 1985). As a generalisation, nests surrounded with more cover are less likely to be depredated (Yahner and Scott, 1988; Martin, 1992; Rudnicky and Hunter, 1993). It is assumed that the canopy cover and shrub density influence the predation pressure occurred in Sulawesi rainforest particularly on shrub nests.

5.6.1 Canopy cover

Vegetation structure in forest margin areas seemed to be affected by intensive forest utilisation particularly fuel-wood collecting, pole sized timber for construction and wild food plant harvesting. Degrees of disturbance, e.g. the shrub layer along forest edge, remain scarce probably due to the intensive clearings at shrub strata. In Napu valley, the vegetation growing at forest edges was also available for transient people who need some materials for building huts and other activities relating to their fields. These activities may lead to the sparse understorey layers.

The high percentage of canopy cover in natural forest, both in Palolo valley and Napu valley, did not negatively influence the ground nest predation rate in this habitat. It is reasonable to find high predation rates in forest margin areas where canopy cover is rather sparse. However, natural forest covered by the highest percentage of canopy also experienced a high rate of ground nest predation. One possible explanation for this is that the main predators on ground nests were not avian species who could be hindered by canopy closure.

Predation rates on the shrub nests was significantly different among habitat types. Canopy closure, which varied significantly across habitats, suggests that nest concealment is important for shrub nests. Predators using lookouts when finding nests may be among the potential nest predators on shrub nests. Even though there was only small evidence of avian predators, it revealed that the visit of these predators was more common on shrub nests than on ground nests. In Palolo valley and Napu valley, the percentage canopy cover was higher in natural forest than in forest margin areas. Less canopy closure in forest margin areas might drive the intensive operations of avian nest predators on shrub nests in these habitats. Predation of artificial nests by birds has been reported to be higher on shrub

than ground nests (Latta et al., 1995; Telleria and Diaz, 1995: Estrada et al., 2002). The risk of nest predation may be influenced by vegetation complexity (Martin, 1988).

We placed both ground and shrub nests with equal concealment concerning forest canopy cover, but the predation rates were found to be significantly different between ground and shrub nests in Palolo valley and Napu valley. Ground nests suffered more nest predation rate than shrub nests in all cases. This suggested that nest concealment was of little importance for ground nests. Disturbance on vegetation structure could influence the interaction between predators and prey in forest margin areas. The risk of nest predation is influenced by habitat features at the nest location such as ground, shrub or cavity (Wilcove, 1985; Yahner and Scott 1988; Rudnicky and Hunter, 1993).

5.6.2 Shrub density

The sparse shrub layer along forest edge and forest margin habitats could support the likeliness for predator fauna to find the shrub nests. Therefore, predation rates on this nest type was significantly higher at forest margin areas than in natural forest which in fact has a relatively similar level of shrub layer. It is assumed that the combination between shrub layer and high canopy cover in natural forest cold hindered the location of shrub nests. Whereas, the shrub layer and low canopy closure in forest margin areas could not support the concealment of shrub nests.

Some evidence exists that avian predators (using visual cues) are more likely to prey upon shrub nests particularly in less vegetation cover areas (e.g. Moller, 1989). However, birds were responsible for predation pressure only 8.3 % along forest edge, 4.3 % in forest garden and 9.5 % in secondary forest of Palolo valley and 12.5 % in secondary forest of Napu valley. We offer two possible explanations for this result. Firstly, avian predators were rare in these study areas. Corvids that are responsible for high predation in temperate forest did not commonly occupy altered landscapes in this region. Secondly, birds may generally prey more on high tree nests, conspicuous to birds flying over the canopy, than on ground nests or low tree nests (Yahner and Cypher, 1987; Darveau et al., 1997).

The lack of sufficient shrub layer along forest edge and forest margin habitats suggests an increased exposure of nests to potential predators which therefore drives the elevated

predation rates in these habitats. This assertion supported the study on artificial nests in the Amazonian rainforest which exposed that the shrub nest predation pressure increased as vegetation structure became less complex (Telleria and Diaz, 1995). Rangen et al. (1999) suggested that less vegetation increased nest visibility and may have allowed the scent of eggs (both real and artificial) to be more easily detected by predators. In our study, some visitors such as squirrels and cuscuses may benefit from reduce concealment of shrub nest location in forest margin habitats. The structural complexity of the vegetation at natural forest compared to forest margin areas, might provide a substantially greater volume of habitat for predators to search for nests and where birds can hide nests (Latta et al., 1995).

Degradation may simplify the habitat, particularly through the loss of understorey vegetation (Taylor and Ford, 1998) and reduces concealment of nests which would make them more vulnerable to predation from lookouts of predators (Estrada et al., 2002). High nest predation risk on shrub nests might be affected by the vegetative structure of ecotones of open-forest transitions. In forest margin areas, human activities may provide permanent change and an increased food supply (e.g., from crops) that may lead to a higher density of generalist predators (Angelstam, 1986). The factors affecting forest birds in agroforests like forest gardens, may involve canopy foliage volume, vertical diversity of vegetation structure and variety of food resources (Thiollay, 1995).

The data on shrub layer and canopy cover suggest that the concealment of nests by the vegetation complexity in the natural forest may have resulted in less predation risk occurring in this habitat. The nests placed in high vegetation density will be less obvious to the predators. It is suggested that the dense vegetation in forest habitats could limit predator movements (Duebbert, 1969; Schranck, 1972). Crabtree et al. (1989) provide more support for this suggesting that dense vegetation reduces the olfactory and visual abilities of nest predators. Despite the sparse shrub layer in this habitat, shrub nests might still be hindered by the high density of canopy cover. Increased illumination during the day and possibly at night by stars and moonlight may facilitate detection of nests by both diurnal and nocturnal predators at forest margin areas (Estrada et al, 2002). It might be assumed that nest predation risk on shrub nests seem to be higher in more exposed habitats such as forest edge and forest margin habitats than in the forest interior.

5.7 The influence of human activities on predation pressure

Human activities in forest margin areas were found to be more intensive than in forest interior at both study sites. The presence of forest gardens and coffee plantations in the park have driven the regular visits of the owners and farmers. Although the park authorities have made an agreement to manage these areas by allowing them to harvest the crops without planting new ones, some people have tried to expand their field/territories. It seemed that the insufficient number of park guards patrolling the park area was one of the main reasons for a high degree of disturbance in forest margin areas. The other reason was unclear boundary of the national park area. Easy access to reach forest margin areas could also enhance the frequency of people coming to collect forest resources. Bynum (1999) reported that due to the location of lowland and hill forest along park boundaries, it is more vulnerable to the effects of human activities. Fuelwood and wild food plants were the main forest products collected by people living in surrounding Palolo valley.

People were observed to be rarely visit natural forest both in Palolo valley and Napu valley. The only activities here were rattan collecting and wild food plant collecting. Long distances to reach these areas might be one of the main reasons for the few visits of people. The other reason was that they could be easily caught by park guards during their activities. The low frequency of people activities in natural forest did not play important role for predation rates in this habitat type. It may indicate that these habitats did not suffer elevated levels of anthropogenic disturbance and therefore may support the persistence of wildlife.

The high frequency of human activities along forest margin habitats could be considered among the factors adversely affecting the predation risk in these areas. Some potential reasons might explain this effect. Firstly, problems between certain wildlife fauna and people could emerge in forest edge and forest margin habitats, thus top predator animals might avoid operation along disturbed areas. Newmark et al. (1994) reported that people living adjacent to protected areas were likely to have conflicts with wildlife. These conflicts may deter forest dwelling species from approaching the edges where they may be trapped, hunted or chased by humans (Carlson and Hartman, 2001). Other effects might be

that unsustainable extraction of forest products profoundly depletes the flora and fauna, especially the relatively rarer large mammals and top predators (Terborgh and van Schaik, 1997; Bynum, 1999). As a result, these areas might lack the ecological function of top predators in regulating the population of middle predators. Secondly, some nest predators could benefit from the paths established by humans as foraging lanes, particularly for finding bird eggs and nestlings. Thirdly, over harvesting of flora along forest margin areas could enhance the greater exposure of shrub nests, because shrub layer could be adversely damaged during human activities in collecting forest products.

Human activities might also destroy vegetation around the nest and make it more visible, leaving a scent trail and establishing a path through the surrounding vegetation (Major, 1989). This may have been a serious problem in forest margin areas where people tended to do more intense activities. They usually cleared the understorey vegetation particularly when creating a path and pulling fuelwood and timber for constructions. Indications of human impact along forest margin habitats were also noticeable in destroying natural nests and collecting eggs. Forest edge in Palolo valley and Napu valley revealed the greatest impact of human disturbance, probably due to the locations which are adjacent to some villages. Given the above considerations, it might be said that high frequency of human visits affect the elevated predation rates in these areas. Considering the significant points above, it might be said that anthropogenic disturbance may lead to several effects which may further reduce biodiversity. A comparative study in the Colombian Andes documented that large-scale human activities has resulted in widespread decline and local extinction of forest bird populations (Vélez and Kattan, 1997).

5.8 Does the high nest predation pressure affect bird population development?

Predation is an important factor influencing reproductive success in birds (Ricklef, 1969). Deforestation and habitat degradation along Lore Lindu National Park have generated high predation pressure with a tendency for higher shrub nest losses near edges and in forest margin areas than in forest interior. The high density of predators at edges and margin habitats may reduce nest success of understorey birds. These can cause population declines and species extinction for the shrub nesting species inhabiting disturbed habitats. Population declines may also be hastened by the tendency for unsuccessful breeders to disperse from the site of a failed nesting attempt (Harvey et al., 1979; Greenwood, 1980;

Wilcove, 1985). As a comparison, increased fragmentation of contiguous forest in central Canada may change the distribution and composition of bird communities because of a reduction in the quantity and quality of available breeding habitat (Saunders et al., 1991). Furthermore, changes in nest predation may result the change of bird community (Burkey, 1993).

Very little work has been done on bird communities and their populations in forest margin areas of Lore Lindu National Park. However, Waltert (2002) documented 23 species in the study sites and seven species (six endemic) of insectivorous understorey birds which were typical for Palolo valley and Napu valley in Central Sulawesi. Observation during this study showed that four ground-nesting species and 26 understorey birds occurred in Palolo valley and Napu valley. Among those birds, 17 species were counted as endemic to Sulawesi. They occupy not only natural forest but forest margin habitats as well. This may explain the high diversity of understorey and ground-nesting birds facing the risk of high predation pressure in these areas.

The rates of nest predation along forest edge and forest margin habitats may be high enough to cause high reproductive failure and nestling mortality of birds. It can generate extirpation of local population or population sinks in these habitats in which reproductive output does not compensate for adult mortality (Dias, 1996). Furthermore he said that this kind of habitat might be considered as poor quality or "sink" habitats. Populations that mostly occupy forest margin habitats may show a decreasing pattern of abundance over time. In contrary, the natural forest which suffered low predation levels may provide suitable and good quality habitat for forest birds to support stable or increasing populations. This habitat may be considered as a "source" habitat, if productivity can exceed adult mortality (Pulliam, 1988). He also stated that this habitat will sustain a population and generate emigration to other areas.

The high predation rates on shrub nests may reflect the relatively elevated predation risk on understorey birds who build nests on the shrub or on the tree. The greater exposure of shrub nests and the variation of potential nest predators in forest margin areas suggests that these might be high risk habitat for understorey birds. This supports the contention that the high level of habitat alteration and fragmentation of the forest landscapes causes high edge habitat availability for nest predators. Additionally, high rates of nest predation in these

areas may indicate reduced local viability and thus a reduced numbers of birds (Zanette and Jenkins, 2000; Estrada et al, 2002).

Forest margin areas might favour understorey and ground-nesting forest birds because of the high food productivity in these habitats. However, intensified nest predation in forest margin areas may be causing the decline of specialist avifauna, because they have not adapted with certain conditions where predation risk is high. Many edge-sensitive species might decrease because they lack the ability to discriminate between edge and natural habitats. Consequently, many individuals can find themselves in an "ecological trap", that they live in edge habitats that appear suitable, but in fact are not (Gibbs et al., 1998). Edge habitats may be considered as ecological traps for breeding birds. If they attract many birds because of apparently favourable conditions, they became trapped because in fact they have higher nest predation levels than those in interior habitats (Gates and Gysel, 1978; Marini et al., 1995).

Some species of understorey birds would probably change such a nesting strategy in order to survive in high-predation habitats. When nest predation rates differ among habitats or areas, predation can be a strong selective agent for birds and may influence life history traits, habitat use, population and community patterns and species-area relationships (Martin, 1995). Higher predation rates have been invoked to explain the smaller clutch size found in tropical forest birds (Ricklefs, 1969). If predation can determine clutch size, it is expected that ground-nesting birds in Sulawesi region would have a small clutch size. Furthermore, if predation on natural nests in tropical forest exhibit the same pattern and if nest predation affects avian life histories, in turn, this would affect ground nesting birds which suffering from high predation rates. They would be more likely to have shorter nestling periods, more broods and a smaller clutch size compared to shrub nesters (Martin 1993, 1995).

5.9 Fact findings of breeding biology of several understorey birds in LLNP

Despite the high endemism of avifauna in Sulawesi rainforest, little is known about the breeding biology of understorey birds in this region. The results of this study may describe some findings and information on breeding time and nest location as well as nesting and breeding behaviour. Although only 4 new nests and 11 old nests were found during this study, several findings are discussed as follows.

Based on the observation undertaken in Palolo valley and Napu valley, it could be said that some understorey birds tend to breed in the period of February to April, before the rainfall in park areas reaches the highest average. This is probably due to the availability of food during this period of time. Several studies have shown that breeding seasons are often timed to the seasonal peak in food level (Brooke and Birkhead, 1991). This study did not cover observation on breeding time over a year, therefore it is not possible to say that those birds only breed in this period. However, they probably breed throughout the year with one period of high breeding. In contrast to the breeding seasons of temperate species, which may last only 2-3 months, birds of the tropics have a longer breeding season which may extend over much of the year (Ricklefs, 1969; Oniki, 1979). There was no report on the breeding season of birds of Wallacae. MacKinnon and Phillipps (1993) documented that birds of Borneo, Sumatera, Java and Bali breed in different ways in response to the wet weather. Many insectivorous species breed at the end of the wet season when insects are most numerous. It could be proposed that the wet season may be a determinate for several understorey forest birds in Sulawesi as many of them nested during the wet season. Noske and Franklin (1999) reported that avian breeding seasons in the moonsonal tropics of northern Australia vary; some species nest in the dry season, some in the wet season and others throughout the year.

According to Hansell (2000) females have at least three options to ameliorate the effects of predation and parasitism on seasonal fecundity: (1) renest following predation (2) abandon and renest following parasitism and (3) renest following a successful first brood. Some species found in this study such as Black-naped Monarch (*Hypothymis azurea*) and Yellow-bellied White-eye (*Zoosterops chloris*) built the second nest on the same tree as the

first nest. It is considered, that these species renested following a successful first brood, otherwise they will find other location for breeding.

Black-naped Monarch and Yellow-bellied White-eye were found to breed more along edges and forest margin areas and were more commonly found in locations where there was only scarce shrub density. This suggests that nest concealment was of little importance for this species. The evidence against predators was shown through attack of both female and male. As observed, the Black-naped Monarch was rather aggressive towards predators and often attempted to chase them away. Creswell (1997) stated that species defending their nests will show little correlation between risk of nest predation and nest concealment, whereas species that cannot defend their nests will show a strong correlation. He concluded that nest concealment will benefit individuals because it will be difficult for nest predators to find the nest and therefore the total costs of nest defence will be reduced.

Black-naped Monarch also built their nests above small stream. Coates (1986) support this finding that the monarch flycatchers often build their nests over water. This was presumably a strategy of the adult bird to minimise the possibilities of nest predators reaching the nest. This kind of habit has been perceived as an ”antipredator strategy” (Immelman, 1961). This nesting behaviour has been also documented from several understorey bird species in tropical Australia (Fischer, 2000).

Regardless the fact that incubation period could not be counted from the first day of laying eggs by adult birds, the information obtained might be useful for further investigation on understorey birds related to predation pressure. Incubation behaviour (length of incubating bouts and periods of absence) also affect nest predation rates (Martin, 1993). He also explain that the eggs of species with long incubation periods are exposed for a longer period, and are thus more vulnerable to predation, than those of species with shorter periods. The incubation period and fledging period of Black-naped Monarch was all together approximately 26 days. Normally, the Passerines have incubation period 13 days and pfledging period 13 days (Brooke and Birkhead, 1991). It is apparent that the incubation and pfledging period of Black-naped Monarch found in these study sites have the same pattern as the other Passerines.

6 Implication for Conservation and National Park Management

6.1 Conservation of understorey and ground-nesting forest bird

Forest disturbance and the consequent forest margin areas can ameliorate the determinant factors which are responsible for predation pressure such as edge effects, predator composition and abundance, vegetation structure, persistence of top predators and human activities. These factors may play important role on predation pressure in forest margin habitats which furthermore, might be a serious threat for forest bird populations. Since many bird species are poorly adapted for increased predation pressure in these habitats (Gates and Gysel 1978; Sieving 1992; Laurance 1993), forest margin areas accompanied with high predation risk tend to be "ecological traps" for those birds. If nest predation acts in performance with the other crucial factors like food and climate, a relatively small increase in nest predation could cause extinctions of bird populations (Wilcove, 1985). Since nest predation is an important process affecting the local demography of nesting birds and potentially of avian populations, understanding the factors affecting predation rates could contribute to conservation approaches for forest bird populations (Chalfoun et al., 2002).

It is clear that the most detrimental effects of forest destruction emerged along edges and forest margin areas suffered the high predation rates in this region. Increased amount of edges may contribute to the exposure of bird nests to a variety of nest predators. Results of this study are in agreement with those of other studies indicating the occurrence of edge effects on predation rates of shrub nests. With increased connection to agricultural fields, transients and dirt road, the influx of introduced nest predators from surrounding areas such as house rats, feral cats and dogs, would be more pronounced. It was found that forest margin may host a variety of nest predator communities including marsupials and squirrels which were absent in natural forest.

The vegetation structure is also changing over time and understorey layers in forest margin habitats is gradually decreasing due to the intensive activities of humans. Sparse vegetation cover in these areas may reduce nest concealment and support the strategies of different predators to find bird nests. Reducing over-harvesting on forest resources and allowing the

vegetation to recover along forest margin areas may result in sufficient cover and lower detectability of shrub nests from nest predators.

The absence of top predators in forest margin areas may indirectly lead to the decline of bird populations, because they play an important role in regulating the number of small mammals which are responsible for high predation pressure. Conflict between wildlife and humans should be avoided, in order to maintain the persistence of top predators. Birds tend to successfully reproduce their offspring in conditions where the population of small mammals as mesopredators is regulated by the presence of top predators (Crooks and Soulé, 1999).

Even though artificial nests used in this study were neither defended by adult birds nor as well concealed as most natural nests, it is considered that the predator fauna detect and respond to artificial nests in a manner similar to natural nests (Gibbs, 1991). It means that all understorey birds nesting with open-cup form on the shrub or fork of the trees along edges and forest margin habitats, such as Black-naped Monarch and Yellow-bellied white-eyes, will be affected by the high predation rates.

Most understorey bird species are still found in both forest margin habitats and natural forest (Waltert et al., in prep.). However, their long-term persistence will largely depend on remaining forest habitats. Understorey birds are most sensitive to disturbances in forest structure, therefore they ought to be reliable indicators for forest regeneration (Wong, 1985). Many species of understorey and ground nesting birds occupying Palolo valley and Napu valley are endemic. Regarding the current management plans of Lore Lindu National Park, the endemism has been determined as one of the main criteria for conservation approaches. Knowledge about the effect of deforestation on nest predation may hopefully influence decisions about reserve design.

6.2 Land-use and park management

Considering the effects of forest disturbance and habitat alteration on predation pressure, the current and on-going land-use occurring and emerging in these parts of protected area should be managed appropriately. Several efforts may be crucial when designing land management policies in order to reduce the size of forest edges. The extension of land-use

such as coffee plantation and forest garden may reduce the intact forest and threaten the viability of natural habitats for forest birds. Because the interspersion of habitat with land-use may provide additional sustenance for nest predators (Chalfoun et al., 2002), it is therefore of crucial importance to make restrictions for land owners and farmers continuing clear-cutting and opening natural forest in the park areas.

In Lore Lindu National Park, the existence of vertebrate fauna have been surveyed and monitored to support the design of park zoning (TNC, 2002). It was found that understorey and ground-nesting birds also inhabit forest margin areas and several forest bird so-called edge species, still use this area for breeding and foraging. When the assessment for park management is undertaken based on this knowledge only, forest margin habitats could be categorised as suitable areas for the forest birds. However, forest margin areas including edges could not provide suitable and viable habitats for understorey forest birds, because of elevated nest predation and subsequent ecological traps. It is clear that the creation of habitat edge by partial clearing of forest for human land-use may have negative consequences for birds breeding in remaining forest patches (e.g. Kroodsma, 1984; Piper et al., 2002). Therefore, the knowledge of interaction among vertebrate fauna (in this case, nest predation) and the effects of habitat disturbance on this ecological process should be considered as important aspects for National Park management.

Since the intensive human activities are correlated positively to the elevated predation rates along forest margin areas, particular attention should be given to managing the interaction between local people and protected areas. Clear and detailed information about National Park boundaries and zoning should be delivered to local people living in the surrounding these areas. Furthermore, law enforcement from National Park authorities might play important role in reducing the extension of land-use practices within the park areas.

Natural forest can provide "source habitat" for forest bird populations. It is therefore important that contiguous areas of natural forest should be left intact. These areas as core zone is ideally the most important zone for maintaining biological diversity. In terms of park zoning, it is better that reserves of natural forest should be surrounded by areas of managed forest than by farmland (Collins et al, 1991). Agroforestry systems might be one among other available alternatives that can be used as a buffer zone in managing the park area which may integrate the existence of local people living in areas surrounding

protected areas. If the existing forest margin habitats can be managed properly, they may be used as a buffer zone to preserve the core zone of protected areas from intense activities of humans. Since forest margin areas and buffer zones of the National Park constitute significant elements in management plans, the results of this study could be considered as a contribution to land-use management both within and surrounding the protected areas. In turn, this can facilitate better sustainable management practices at Lore Lindu National Park for the benefit of both wildlife and humans.

7. Summary

Forest destruction and habitat alteration in Sulawesi rainforest which mainly caused by anthropogenic disturbances may generate significant areas of forest margin habitats and large sizes of forest edges. These changes are considered to enhance nest predation pressure and cause the decline of understorey and ground-nesting forest birds. This study has been conducted in order to investigate and to assess the effect of forest edge, predator composition, vegetation cover and human activities on predation pressure of ground and shrub nests and subsequently forest bird populations in forest margin areas and natural forest.

The field study has been carried out in two different valleys of Lore Lindu National Park where the forest disturbance and habitat alteration was drastically happened. Five different habitats: forest edge, forest garden, coffee plantation, secondary forest and natural forest were chosen in Palolo valley and three habitats: forest edge, secondary forest and natural forest were selected in Napu valley. Artificial ground and shrub nests were used in experimental trials to examine nest predation rates in forest margin habitats and natural forest. Automatic cameras connected to artificial nests were used to identify nest predators. The remains of predator attacks and nest position found on artificial nests during experimental trials were also investigated to identify possible nest predators. A standard trapping period with live traps was applied to assess variety and abundance of rodents. Observations and surveys were also done to determine the presence of top predators, potential nest predators, natural nests and breeding biology as well as the human activities in Lore Lindu National Park.

It seemed that edge effect and habitat differences did not affect the predation rates on ground nests. They were found to be in a similar pattern in all habitat types in Palolo valley and Napu valley. The composition and abundance of rodents might have an important role in this case. Rodents were found to be equally distributed in ground layer at all habitat types in both study sites.

Predation pressure on shrub nests were varied among habitat types and the pattern was similar in both valleys. The highest predation rates occurred in forest edge and the lowest were in natural forest. Edge effect and habitat variation was considered to be one of the

significant reasons for the increased predation rate. It is also apparent that shrub nest predators were more diverse in forest margin habitats compared to those in natural forest. As documented from the pictures produced by automatic cameras, Dwarf cuscus and Sciuridae could only be found in forest margin habitats. Furthermore, the identification on the attacked nests indicated the visits of avian predators in forest edge, forest gardens and coffee plantation.

In general, ground nests suffered higher predation rates than shrub nests in all habitat types. The composition and abundance of nest predators were substantially more pronounced in ground layer than in shrub layer.

Rodents (Rodentia) and reptiles (e.g.: *Varanus salvator*) are considered to be responsible as nest predators on ground nests. The rodent predators were dominated by Sulawesian giant rats (*Paruromys dominator*) and Wild Sulawesian rats (*Rattus hoffmanni*). Introduced predators such as house rat (*Rattus rattus*), feral cats (*Felix catus)* and dogs (*Canis familiaris*) were also detected as nest predators on ground nests. The major predators on shrub nests included Sulawesian giant rats (*Paruromys dominator*), Dwarf cuscus (*Strigocuscus celebensis*) and squirrels (Sciuridae). Additionally, the other potential predators such as feral cats (*Felix catus*), macaques, (*Macaca tonkeana*) avian predators and tree snakes (e.g. *Boiga irregularis*) should be taken into consideration. Predator communities in forest margin areas may differ greatly from that found in the relatively natural or undisturbed forest of Lore Lindu National Park.

The presence of top predators like Malay palm civet (*Viverra tangalunga*) was only detected in natural forest in both study sites. Top predators in this habitat could reduce the number of small mammals like rodents which in turn, could minimise predation risk on shrub nests. The lack of top predators in forest margin areas may indirectly cause the increased predation pressure on shrub nests, because the population of small mammals might not be regulated.

Vegetation structure is one determinant factor for increased predation pressure on shrub nests. The rare shrub layer along forest edge and forest margin habitats could support the likeliness for predator fauna to find the shrub nests. It seems that the combination between shrub layer and high canopy cover in natural forest could hinder the location of shrub

nests. Whereas a similar amount of shrub layer and low canopy closure in forest margin areas could not support the adequate concealment of shrub nests from the predator search.

In general, the total predation rate (combined ground and shrub nests) in both study sites was influenced by the frequency of human activities. The regular visits of the owners and the farmers of land-use in forest garden and coffee plantation followed by fuelwood collecting, wild food plant collecting and trapping, have driven the high level of anthropogenic disturbance in forest margin areas. This might generate several mechanisms affecting elevated nest predation pressure. For example, some nest predators could benefit from the paths established by humans as foraging lanes, particularly for finding bird eggs and nestlings.

It can be concluded that increased shrub nest predation in forest margin areas was adversely affected by edge effect, predator variety and density, lack of top predators and intensive human activities. These factors emerge as the results of forest destruction and habitat alteration. Since these changes have serious consequences for nesting birds, current conservation approaches and park management should take them into account. Understanding of nest predation intensities and the factors influencing predation pressure in forest margin areas can be used to assess land-use management both within and surrounding the National Park to preserve understorey and ground-nesting forest birds. Conservation of the Sulawesi rainforest and the avifauna of this region requires policy changes that limit the growth of agriculture and land-use practises both within and surrounding the protected areas.

8. Zusammenfassung

Die sulawesischen Regenwälder werden durch anthropogenen Einfluss in ihrer natürlichen Dynamik gestört. Waldstrukturen werden zerstört und durch Habitatfragmentierungen nachhaltig verändert. Es entstehen große Flächen von Waldrand-Lebensräumen. Im Rahmen dieser Arbeit wurde der Einfluss von Prädatoren, Vegetationsdeckung und anthropogenen Aktivitäten auf die Population von Vogelarten, die ihre Nester auf dem Boden oder in der Strauchschicht bauen, in ursprünglichen und veränderten Habitaten untersucht.

Die Freilanduntersuchungen wurden auf Sulawesi in zwei unterschiedlichen Tälern (Palolo- und Napu-Tal) durchgeführt, wo die Zerstörungen und Habitatveränderungen ursprünglicher Waldgebiete sehr stark sind. Folgende Habitattypen wurden zum Vergleich ausgewählt: Naturwald und verschiedene Landnutzungstypen (Waldrand, Waldgarten, Kaffeeplantage und Sekundärwald).

In Feldexperimenten mit künstlichen Nestern, die auf dem Boden und in der Strauchschicht installiert waren, sollte die Prädation auf das Gelege untersucht werden. Für die Identifizierung der Nesträuber wurden automatische Kameras in Nestnähe aufgebaut. Die Haupt-Prädatoren wurden mit Lebendfallen gefangen, die Arten bestimmt und ihre Dichte ermittelt. Des Weiteren wurden das natürliche Brutverhalten der oben genannten Vogelarten und die Störungen durch anthropogene Aktivitäten untersucht.

Ergebnisse:
In allen untersuchten Habitattypen gab es bei den Nestern auf dem Boden keinen signifikanten Unterschied in der Prädationsrate. Die Prädatoren waren auf allen Flächen gleichmäßig verteilt.

Die Prädationsrate der Nester in der Strauchschicht unterschied sich aber signifikant mit den Habitattypen. Der höchste Prädationsdruck zeigte sich an Waldrändern und der geringste im Naturwald.

Insgesamt wurden die Gelege auf dem Boden stärker beraubt als die Gelege in der Strauchschicht. Die Artenzahl und Abundanz von Prädatoren waren auf dem Boden höher

als in der Strauchschicht. Im Vergleich der Habitattypen zeigte der Naturwald die geringste Artenzusammensetzung an Prädatoren.

Folgende Prädatoren wurden beobachtet:
Bei den Nestern auf dem Boden: Nagetiere (z.B. Ratten) und Reptilien (z.B. Warane und Schlangen), Katzen und Hunde. Bei den Nestern in der Strauchschicht: Nagetiere (Muridae und Sciuridae), Zwergcuscus, Makkaken, Katzen, Vögel und Schlangen. Einige Prädatoren (z.B. Hausratte, Katzen und Hunde) wurden erst durch den Menschen in die Waldrandgebiete eingeführt. Die Familie der Muridia (Nagetiere) wie z.B.: *Paruromys dominator* und *Rattus hoffmanni* stellte den Hauptanteil der Prädatoren.

Es spielte auch die Anwesenheit von Top-Prädatoren, die wiederum Einfluss auf andere Räuber haben, eine Rolle. Top-Prädatoren (z.B. *Viverra tangalunga* - Malay palm civet) wurden nur im Naturwald entdeckt. Sie können in diesem Habitat die Anzahl kleiner Nagetiere (z.B. Ratten) reduzieren und das Risiko eines Nestraubes in der Strauchschicht vermindern. Das Fehlen eines Top-Prädators in den Waldrandgebieten mag dieses Risiko nicht mindern, da die Populationen kleiner Nagetiere nicht beeinflusst werden.

Die Vegetationsdeckung scheint ein entscheidender Faktor für den Prädationsdruck in der Strauchschicht zu sein. Durch menschliche Aktivitäten werden die Strauchschichten im Waldrandbereich gelichtet und somit die Wahrscheinlichkeit, dass Prädatoren das Gelege entdecken, erhöht. Die Kombination zwischen Strauchdichte und starker Kronendeckung eines Naturwaldes kann die Nester in der Strauchschicht besser schützen. Die geringe Strauchdichte und schwache Kronendeckung in den Waldrandgebieten bieten diesen Schutz nicht.

Die menschlichen Aktivitäten (z.B. Plantagenwirtschaft mit Kaffee und Kakao, Sammeln von Wildpflanzen, Nutz- und Brennholz und Fallenjagd) begünstigen die Strategien der Prädatoren beim Auffinden der Vogelnester und deren Gelege und stören das Brutverhalten der Vögel.

Die expandierende Landwirtschaft und andere fortschreitende Landnutzungen sind zwei Hauptfaktoren, die die Wälder Sulawesis immer stärker bedrohen. Die Fragmentierung ursprünglicher Wälder, die daraus resultierenden Randeffekte, die Artenzusammensetzung

der Prädatoren und ihre Abundanz, die Abwesenheit eines Top-Prädators, die reduzierte Vegetationsdeckung und die menschlichen Aktivitäten bewirken einen erhöhten Prädationsdruck auf die Nester in der Strauchschicht in Waldrandgebieten. Die Erkenntnisse dieser entscheidenden Faktoren können für das Management in einem Nationalpark nützlich sein und sollten berücksichtigt werden. Mit Hilfe eines Schutzkonzeptes können die optimalen Habitateigenschaften für die betroffenen Vogelarten erhalten bzw. neu geschaffen werden, damit auch unsere nachfolgenden Generationen die sulawesischen Waldgebiete und deren Vogelfauna in ihrer einzigartigen Vielfalt erleben.

9. Ringkasan

Kerusakan hutan dan perubahan habitat seperti fragmentasi di hutan hujan tropis Sulawesi dapat mengakibatkan terbentuknya habitat baru di hutan margin dan meluasnya pinggiran hutan. Hal ini dianggap penyebab utama tingginya tingkat pemangsaan (predasi) terhadap telur dan anak burung. Selanjutnya bisa berakibat punahnya jenis-jenis burung yang bersarang di atas tanah dan burung yang hidup di lapisan bawah hutan (bersarang di pohon, 1-3 m dari atas tanah). Penelitian ini telah dilakukan untuk mempelajari dan mengkaji dampak kerusakan hutan dan perubahan habitat terhadap tingkat predasi burung di daerah hutan margin. Pengaruh tersebut dapat dipelajari dan dianalisa dengan memperhatikan faktor-faktor penentu tingkat predasi seperti efek pinggiran hutan, komposisi dan kepadatan pemangsa keberadaan pemangsa utama, perubahan struktur tumbuhan dan intensitas kegiatan manusia.

Lokasi penelitian adalah kawasan Taman Nasional Lore Lindu yang mengalami kerusakan hutan yang serius. Lokasi ini terbagi dua yaitu lembah Palolo (5 habitat) dan lembah Napu (3 habitat). Lima habitat pertama adalah: pinggiran hutan, hutan kebun, kebun kopi, hutan sekunder dan hutan primer, sedangkan tiga habitat lainnya adalah: pinggiran hutan, hutan sekunder dan hutan primer.

Sejumlah 786 sarang buatan telah digunakan untuk mengetahui sejauh mana tingkat predasi yang terjadi di hutan margin dibandingkan dengan yang terjadi di hutan primer. Kamera otomatis yang dihubungkan dengan sarang burung buatan dipakai untuk mengidentifikasi jenis-jenis hewan pemangsa. Selain itu pengamatan terhadap sarang yang ditinggalkan pemangsa dapat memberi informasi tentang pemangsaan dan jenis pemangsa. Kepadatan mammalia kecil seperti tikus yang diduga mendominasi pemangsa telur burung dipelajari dengan menggunakan metode standard period trapping. Observasi dan survei juga dilakukan untuk menentukan keberadaan pemangsa utama (top predator) dan jenis-pemangsa lainnya, mengamati sarang asli dan perkembangbiakan burung, dan untuk mempelajari frekwensi kunjungan manusia ke dalam daerah penelitian.

Efek pinggiran hutan dan perbedaan habitat tidak mempengaruhi tingkat predasi pada sarang burung di atas tanah. Pola predasi yang diperoleh di kedua lokasi penelitian tidak berbeda nyata. Dalam hal ini, keragaman dan kepadatan tikus sebagai pemangsa dominan

mempunyai peranan penting. Penyebaran, keragaman dan kepadatan tikus yang beroperasi di atas tanah ditemukan merata pada semua habitat. Selanjutnya ditinjau dari vegetasi, tajuk hutan dan penutupan understori tidak berkaitan dengan tingginya tingkat predasi pada sarang burung di atas tanah.

Pola tingkat predasi pada sarang di atas pohon bervariasi antara habitat di hutan margin dan hutan primer, dan tidak berbeda nyata antara kedua lokasi. Tingkat tertinggi terjadi di pinggiran hutan, sedangkan tingkat terendah adalah di hutan primer. Efek pinggiran hutan merupakan faktor penentu yang berpengaruh nyata pada tingginya tingkat predasi di hutan margin. Selain itu jenis-jenis pemangsa yang beroperasi di atas pohon lebih beragam di hutan margin dibandingkan dengan hutan primer. Identifikasi dari gambar hasil kamera otomatis menunjukkan bahwa kehadiran kuskus dan tupai hanya ditemukan di hutan margin. Rendahnya tingkat predasi di hutan primer berkaitan dengan ketidakhadiran sejenis tikus arboreal yang merupakan predator dominan pada sarang di atas tanah. Selain itu, tajuk hutan dan penutupan vegetasi understori di hutan margin tidak cukup untuk melindungi sarang burung dari incaran pemangsa.

Tingkat predasi pada sarang burung di atas tanah selalu lebih tinggi dibandingkan dengan predasi pada sarang di atas pohon. Hal ini disebabkan keragaman dan kepadatan pemangsa utama yang berbeda pada kedua lokasi sarang burung. Jenis tikus lebih banyak ditemukan beroperasi pada sarang di atas tanah.

Jenis-jenis predator yang ditemukan memangsa sarang di atas tanah antara lain Rodentia (tikus), Reptilia (biawak dan ular) serta pemangsa pendatang seperti kucing dan anjing. Sementara itu pemangsa pada sarang di atas pohon meliputi Rodentia (tikus dan tupai), kuskus, monyet, ular dan burung.

Keberadaan pemangsa tingkat tinggi (top pemangsa) berpengaruh secara tidak langsung terhadap tingkat predasi. Jenis pemangsa tersebut seperti musang pohon (*Viverra tangalunga*) hanya ditemukan di hutan primer. Hewan ini berfungsi untuk meregulasi populasi Rodentia yang selanjutnya menyebabkan berkurangnya tingkat predasi. Ketidakhadiran top pemangsa di hutan margin mengakibatkan meningkatnya populasi Rodentia yang menjadi penyebab tingginya tingkat predasi di daerah tersebut.

Perubahan struktur tumbuhan merupakan salah satu faktor penentu tingkat predasi yang terjadi pada sarang di atas pohon. Tingginya intensitas kegiatan manusia menyebabkan perubahan struktur vegetasi understori di hutan margin yang berakibat mudahnya pemangsa menemukan sarang burung. Kombinasi antara vegetasi understori dengan tajuk hutan yang lebat di hutan primer dapat melindungi sarang burung dari incaran pemangsa.

Total tingkat predasi di kedua lokasi penelitian (Palolo dan Napu) dipengaruhi oleh intensitas kegiatan manusia. Beberapa aktivitas rutin dalam kebun hutan dan kebun kopi seperti pemeliharaan kebun serta kegiatan mengumpul kayu bakar, bahan makanan dan menjerat hewan liar menjadi sebab utama tingginya kunjungan manusia. Hal ini menimbulkan beberapa mekanisme yang menyebabkan tingginya tingkat predasi. Salah satunya adalah bahwa beberapa pemangsa memanfaatkan jalan kecil yang dibuat manusia sebagai jalur mencari makan termasuk mencari sarang burung untuk memangsa telur dan anak burung.

Kerusakan dan konversi hutan untuk lahan pertanian yang berkelanjutan merupakan faktor utama yang mengancam hilangnya hutan hujan tropis di Sulawesi. Perubahan dan fragmentasi habitat menyebabkan pengaruh signifikan dari beberapa faktor penentu tingkat predasi pada sarang di atas pohon. Pemahaman tentang tingkat predasi di hutan margin dan faktor-faktor penting yang mempengaruhinya, berguna untuk pelestarian burung hutan yang beberapa jenis di antaranya adalah endemik. Di samping itu, informasi tentang mekanisme yang ditimbulkan oleh kerusakan hutan dapat dijadikan masukan untuk pengelolaan lahan dan hutan di kawasan Taman Nasional Lore Lindu.

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Appendices

Appendix 1. Artificial ground nests depredated in five habitats in site I (Palolo valley)

Table 1. Number and percentage of ground nests depredated in two exposures (1-4 days and 5-8 days). Data were transformed to arc-sine, Tr-data.

Transect	Habitat	Nest (n)	Nests 1-4days	depredated 5-8days	Total	Total (%)	Tr-data
1	FE	5	2	1	3	60	50,77
2	FE	5	2	2	4	80	63,43
3	FE	5	2	0	2	40	39,23
4	FE	5	2	3	5	100	90
5	FE	5	1	4	5	100	90
6	FE	5	3	1	4	80	63,43
7	FE	5	4	0	4	80	63,43
8	FE	5	5	0	5	100	90
9	FE	5	5	0	5	100	90
10	FE	5	5	0	5	100	90
1	FG	5	4	0	4	100	90
2	FG	5	1	3	4	80	63,43
3	FG	4	3	0	3	75	60
4	FG	5	3	2	5	100	90
5	FG	5	2	1	3	60	50,77
6	FG	5	4	1	5	100	90
7	FG	4	1	2	3	75	90
8	FG	5	3	1	4	80	63,43
9	FG	5	2	1	3	60	50,77
10	FG	5	2	0	2	40	39,23
1	CP	5	1	3	4	80	63,43
2	CP	5	3	0	3	60	50,77
3	CP	5	2	2	4	80	63,43
4	CP	5	1	1	2	40	39,23
5	CP	5	4	1	5	100	90
6	CP	5	4	0	4	80	63,43
7	CP	5	1	1	2	40	39,23
8	CP	5	2	2	4	80	63,43
9	CP	5	4	1	5	100	60
10	CP	5	1	2	3	60	50,77

Table 1 (continued)

Transect	Habitat	Nest (n)	Nests 1-4days	depredated 5-8days	Total depr.	Total depr.(%)	Tr-data
1	SF	5	4	0	4	80	63,43
2	SF	5	3	1	4	80	63,43
3	SF	5	2	2	4	80	63,43
4	SF	5	3	1	4	80	63,43
5	SF	5	3	0	3	60	50,77
6	SF	5	4	1	5	100	90
7	SF	5	2	3	5	100	90
8	SF	5	3	0	5	100	90
9	SF	5	5	0	5	100	90
10	SF	5	3	1	4	80	63,43
1	NF	5	3	0	3	60	50,77
2	NF	4	1	2	3	75	60
3	NF	4	3	0	3	75	60
4	NF	4	2	2	4	100	90
5	NF	4	1	0	1	25	30
6	NF	5	1	1	2	40	39,23
7	NF	5	3	2	5	100	90
8	NF	5	3	2	5	100	90
9	NF	5	2	3	5	100	90
10	NF	4	1	2	3	75	90

Table 2. Number and percentage of shrub nests depredated in two exposures (1-4 days and 5-8 days). Data were transformed to arc-sine,Tr-data.

Transect	Habitat	Nest (n)	Nests 1-4days	depredated 5-8days	Total	Total (%)	Tr-data
1	FE	5	1	0	1	20	26,57
2	FE	5	0	4	4	80	63,43
3	FE	5	0	3	3	60	50,77
4	FE	5	2	2	4	80	63,43
5	FE	5	3	2	5	100	90
6	FE	5	3	2	5	100	90
7	FE	5	0	4	4	80	63,43
8	FE	5	2	3	5	100	90
9	FE	5	0	2	2	40	39,23
10	FE	5	2	1	3	60	50,77
1	FG	5	1	1	2	40	39,23
2	FG	5	0	4	4	80	63,43
3	FG	4	0	2	2	50	45
4	FG	5	0	2	2	40	39,23
5	FG	5	1	1	2	60	50,77
6	FG	5	2	2	4	80	63,43
7	FG	4	0	1	1	25	30
8	FG	5	4	0	4	80	63,43
9	FG	5	1	0	1	20	26,57
10	FG	5	0	1	1	20	26,57
1	CP	5	1	0	1	20	26,57
2	CP	5	0	1	1	20	26,57
3	CP	5	0	0	0	0	0
4	CP	5	2	2	4	80	63,43
5	CP	5	2	1	3	60	50,77
6	CP	5	1	2	3	60	50,77
7	CP	5	3	1	3	60	50,77
8	CP	5	2	2	4	80	63,43
9	CP	5	1	1	2	40	39,23
10	CP	5	0	1	1	20	26,57

Table 2 (continued)

Transect	Habitat	Nest (n)	Nests 1-4days	depredated 5-8days	Total depr.	Total depr.(%)	Tr-data
1	FE	5	1	0	1	20	26,57
2	FE	5	0	4	4	80	63,43
3	FE	5	0	3	3	60	50,77
4	FE	5	2	2	4	80	63,43
5	FE	5	3	2	5	100	90
6	FE	5	3	2	5	100	90
7	FE	5	0	4	4	80	63,43
8	FE	5	2	3	5	100	90
9	FE	5	0	2	2	40	39,23
10	FE	5	2	1	3	60	50,77
1	FG	5	1	1	2	40	39,23
2	FG	5	0	4	4	80	63,43
3	FG	4	0	2	2	50	45
4	FG	5	0	2	2	40	39,23
5	FG	5	1	1	2	60	50,77
6	FG	5	2	2	4	80	63,43
7	FG	4	0	1	1	25	30
8	FG	5	4	0	4	80	63,43
9	FG	5	1	0	1	20	26,57
10	FG	5	0	1	1	20	26,57

Appendix 2. Artificial nests depredated in three habitats in site II (Napu valley)

Table 3. Number and percentage of ground nests depredated in two exposures (1-4 days and 5-8 days). Data were transformed to arc-sine, Tr-data.

Transect	Habitat	Nest (n)	Nests depredated		Total depr.	Total depr.(%)	Tr-data
			1-4days	5-8days			
1	FE	5	4	1	5	100	90
2	FE	5	3	0	3	60	50,77
3	FE	5	5	0	5	100	90
4	FE	5	3	1	4	80	63,43
5	FE	5	3	2	5	100	90
6	FE	5	1	1	2	40	39,23
7	FE	5	4	1	5	100	90
8	FE	5	3	2	5	100	90
9	FE	5	1	2	3	60	50,77
10	FE	5	4	1	5	100	90
1	SF	5	2	2	4	80	63,43
2	SF	5	3	2	5	100	90
3	SF	5	4	1	5	100	90
4	SF	5	0	2	2	40	39,23
5	SF	5	2	0	2	40	39,23
6	SF	5	2	2	4	80	63,43
7	SF	5	3	0	3	60	50,77
8	SF	5	2	3	5	100	90
9	SF	5	3	2	5	100	90
10	SF	5	2	1	3	60	50,77
1	NF	5	1	3	4	80	63,43
2	NF	5	1	2	3	60	50,77
3	NF	5	2	3	5	100	90
4	NF	5	0	4	4	80	63,43
5	NF	5	1	2	3	60	50,77
6	NF	5	1	4	5	100	90
7	NF	5	0	1	1	20	26,57
8	NF	5	1	1	2	40	39,23
9	NF	5	2	2	4	80	63,43
10	NF	5	1	3	4	80	63,43

Table 4. Number and percentage of shrub nests depredated in two exposures (1-4 days and 5-8 days). Data were transformed to arc-sine, Tr-data.

Transect	Habitat	Nest (n)	Nests depredated		Total depr.	Total depr.(%)	Tr-data
			1-4days	5-8days			
1	FE	5	2	1	3	60	50,77
2	FE	5	3	0	3	60	50,77
3	FE	5	4	1	5	100	90
4	FE	5	2	2	4	80	63,43
5	FE	5	2	0	2	40	39,23
6	FE	5	3	1	4	80	63,43
7	FE	5	3	0	3	60	50,77
8	FE	5	3	1	4	80	63,43
9	FE	5	4	1	5	100	90
10	FE	5	1	3	4	80	63,43
1	SF	5	1	0	1	20	26,57
2	SF	5	3	1	4	80	63,43
3	SF	5	2	0	2	40	39,23
4	SF	5	1	1	2	40	39,23
5	SF	5	3	1	4	80	63,43
6	SF	5	2	0	1	20	26,57
7	SF	5	1	2	3	60	50,77
8	SF	5	2	0	2	40	39,23
9	SF	5	1	2	3	60	50,77
10	SF	5	2	0	2	40	39,23
1	NF	5	1	0	1	20	26,57
2	NF	5	0	0	0	0	0
3	NF	5	0	2	2	40	39,23
4	NF	5	0	1	1	20	26,57
5	NF	5	0	0	0	0	0
6	NF	5	0	1	1	20	26,57
7	NF	5	0	1	1	20	26,57
8	NF	5	1	0	1	20	26,57
9	NF	5	1	2	3	60	50,77
10	NF	5	1	0	1	20	26,57

Appendix 3. Predator identification

Table 5. A comparison of numbers and percentage of remains found in depredated ground nests, by marking type and habitat type in Palolo valley.

| Habitat types | Type of markings | | | | | | | | Total |
| | Perforated | | Scratch | | Shell fragments | | Totally lost | | Total |
	n	%	n	%	n	%	n	%	predated
Forest edge	-	-	15	35.7	19	45.2	8	19	42
Forest garden	-	-	6	16.6	10	27.8	20	55.6	36
Coffee plantation	1	2.7	12	32	17	46	7	19	37
Secondary forest	-	-	8	18.6	17	39.6	18	41.9	43
Natural forest	-	-	3	9	5	15.1	26	78.8	33
Total	-	-	44	23	68	35.6	79	41.4	191

Table 6. A comparison of numbers and percentage of remains found in depredated shrub nests, by marking type and habitat type in Palolo valley.

| Habitat types | Type of markings | | | | | | | | Total |
| | Perforated | | Scratch | | Shell fragments | | Totally lost | | Total |
	n	%	n	%	n	%	n	%	predated
Forest edge	2	6	5	14	27	75	2	6	36
Forest garden	1	4	2	9	9	39	11	48	23
Coffee plantation	0	0	3	14	14	64	5	23	22
Secondary forest	2	10	0	0	15	71	4	19	21
Natural forest	0	0	0	0	5	71	2	29	7
Total	5	4.5	10	9	70	63.6	24	22.7	109

Table 7. A comparison of numbers and percentage of remains found in depredated ground nests, by marking type and habitat type in Napu valley.

| Habitat types | Type of damage | | | | | | | | Total |
| | Perforated | | Scratch | | Shell fragments | | Totally lost | | Total |
	n	%	n	%	n	%	n	%	predated
Forest edge	1	2.3	8	18.6	19	44.2	15	34.9	43
Secondary forest	0	0	9	23.7	17	44.7	12	31.6	38
Natural forest	0	0	3	8.3	14	38.9	19	52.8	36

Table 8. A comparison of numers and percentage of remains found in depredated shrub nests, by marking type and habitat type in Napu valley.

| Habitat types | Type of damage | | | | | | | | Total |
| | Perforated | | Scratch | | Shell fragments | | Totally lost | | Total |
	n	%	n	%	n	%	n	%	predated
Forest edge	0	0	5	12.8	20	51.3	14	35.9	39
Secondary forest	3	12.5	0	0	15	62.5	6	25	24
Natural forest	0	0	0	0	4	40	6	60	10

Appendix 4. Rodents

Table 9. Numbers of rodents captured in five habitats in Palolo valley

Species	Habitat type				
	FE	FG	CP	SF	NF
Bunomys chrysocomus	0	1	0	1	0
Paruromys dominator	2	3	2	1	2
Rattus hoffmanni	0	2	1	2	1
Rattus rattus	2	0	0	0	0
Taeromys celebensis	1	0	0	0	1
Total	5	6	2	4	4

Table 10. Numbers of rodent captured in three habitats in Napu valley

| Species	Habitat type		
	Forest edge	Secondary forest	Natural forest
Bunomys chrysocomus	0,0125	0	0,0063
Bunomys penitus	0	0,0125	0
Paruromys dominator	0,025	0,0063	0,044
Rattus hoffmani	0,025	0,0063	0,02
Rattus rattus	0,0125	0	0
Rattus Xanturus	0	0	0,0125
Total	12	4	13

Appendix 5. Human activities

Table 11. Frequency of human activities in each habitat in Palolo valley, the number 1, 2, 3 were the score of their visit, FE = Forest edge, FG = Forest garden, CP = Coffee plantation, SF = Secondary forest and NF = Natural forest. Observation was done for 40 days

Activities	FE	FG	CP	SF	NF
Fuelwood collecting	3	1	-	3	-
Rattan collecting	-	-	-	-	1
Maintenance plantation	-	-	2	-	-
Wild food plant collecting	1	2	2	1	-
Harvesting crops and palm products	-	3	2	-	-
Medicinal plant collecting	-	-	-	1	-
Hunting and trapping	3	-	1	-	-
Collecting timber for construction	3	1	-	1	-

Table 12. Frequency of human activities in each habitat in Napu valley, the number 1, 2, 3 were the score of their visit. Observation was done for 40 days.

Activities	Forest edge	Secondary forest	Natural forest
Woods	3	2	-
Rattan collecting	-	-	1
Maintainance plantation	1	-	-
Wild food plant collecting	2	2	1
Medicinal plant collecting	-	1	-
Hunting and trapping	-	-	-
Collecting timber for construction	2	1	-

Appendix 6. Photograph section
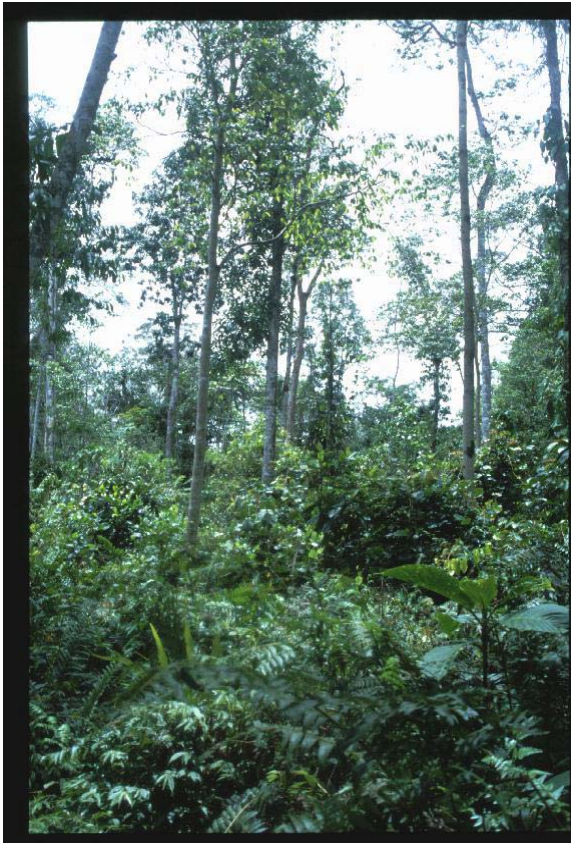
Forest margin areas in Palolo valley and Napu valley

Secondary forest in Napu valley

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