THE ECOLOGY OF MALAYAN SUN BEARS (*Helarctos malayanus*) IN THE LOWLAND TROPICAL RAINFOREST OF SABAH, MALAYSIAN BORNEO

By

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The ecology of Malayan sun bears (*Helarctos malayanus*) in the lowland tropical rainforest of Sabah, Malaysian Borneo

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ABSTRACT

Six Malayan sun bears (*Helarctos malayanus*) were captured and radio-collared from June 1999 to December 2001 in Ulu Segama Forest Reserve, Sabah, Malaysia to study food habits, home-range characteristics, movement patterns, activity patterns, and bedding sites. Food habits were studied by analyzing scats, examining feeding sites, and making direct observations. Invertebrates such as termites (Isoptera), beetles (Coleoptera), and beetle larvae (Coleoptera), were the predominant food items with 57% frequency of occurrence in scat samples. Figs (*Ficus* sp.) were the most common fruit consumed (61% frequency of occurrence) during the non-mast fruiting season. A total of 343 locations of radioed bears were recorded using ground triangulation. Home range sizes, calculated by the 95% adaptive kernel method, averaged 14.8 $\pm$ 6.1 (SD) km^2. Daily movement distances from these bears averaged 1.45 $\pm$ 0.24 (SD) km, and were affected by food availability. Male Malayan sun bears were primarily diurnal, but a few individuals were active at night for short periods. The first peak of activity occurred early morning, the second started 1300 h, and activity remained high until dusk. A total of 26 sun bear bedding sites were found in the study area. The majority of the bedding sites consisted of fallen hollow logs. Other bedding sites included standing trees with cavities, cavities underneath fallen logs or tree roots, and tree branches high above ground. We observed a period of famine in the study area from August 1999 to October 2000 when all six radioed Malayan sun bears were in poor physical condition, and two were later found dead. We surmise that the famine resulted from prolonged scarcity of mass fruiting in the study area. Lowland tropical rainforest trees of Borneo display supra-annual synchronized mass fruiting. We believe that the starvation we observed and the generally low density of large animals in Borneo forests is a consequence of a history of prolonged food scarcity during non-mass fruiting years.

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CHAPTER I

INTRODUCTION

The Malayan sun bear (*Helarctos malayanus*) is the only tropical bear species inhabiting lowland tropical forest of Bangladesh, Myanmar, Thailand, Laos, Kampuchea, Vietnam, Southern China, Peninsular Malaysia, and the islands of Sumatra and Borneo (Servheen 1990). They are the smallest of the eight living bear species, which, in combination with its long claws, is possibly an adaptation for its habit of climbing trees for feeding and resting (Meijaard 1999a). Adults are about 120 to 150 cm long and weigh 27 to 65 kg. Males are 10 to 20 % larger than females (Sterling 1993). They have short, sleek, black coats with a more or less crescent-shape white or yellowish ventral patch. Often this ventral patch is dotted with black spots, and varies in size, shape, and color. The name of the sun bear in Thailand and Malaysian Chinese translates to “dog bear,” probably because of their small size, short hair, and smaller head that is more dog-like than those of the Asiatic black bears (*Ursus thibetanus*) (Servheen 1990).

The sun bear has been listed under the Convention on International Trade in Endangered Species of Wild Fauna (CITES) as an Appendix I species since July 1, 1975. As such, international trade in the species or its parts is prohibited without proper permits, but illegal international trade has been documented (Kemf et al. 1999). Live sun bears and their body parts are commonly available for sale in most countries where they live (Kemf et al. 1999). The species was listed as protected in Peninsula Malaysia and Indonesia in 1972 and 1973, respectively (Khan 1988; Santiapillai and Santiapillai 1996). In the Malaysian state of Sabah, sun bears are listed as a totally protected animal under Wildlife Conservation Enactment 1997; hunting of this species is prohibited (Sabah Government 1997). The species receives little conservation attention in any country within its range. This lack of attention stems from the fact that the sun bear is uncommon, rarely seen, and competes for conservation attention with major species of conservation interest in its range, such as Sumatran rhinoceros (*Dicerorhinus sumatrensis*), tigers (*Panthera tigris*), Asian elephants (*Elephus maximus*), orangutans (*Pongo pygmaeus*), and several smaller primate species.

Davies and Payne (1982) report the Malayan sun bear throughout dipterocarp and lower montane forests, of Sabah, Malaysia from 0 to 1350 m, but indicate that it uncommon everywhere. Studies on the impacts of selective logging on wildlife suggested that sun bears exist only in primary forest; none were found in logged forest (Wilson and Wilson 1975; Wilson and Johns 1982; Johns 1983). Duff et al. (1984) reported no sun bear in logged forests and commercial tree plantations in Sabah, but found sun bears in an island of unlogged habitat within a tree plantation. The reasons for low sightings of sun bear in logged forests were unclear (Wilson and Johns 1982), but may have been correlated with the lack of food in the plantations. In contrast, J. Payne (1988 in Servheen 1990) noted that signs of Malayan sun bear were found in logged forests and even in heavily logged areas. However, the impacts of logging on sun bears are little known. These impacts could include changes in abundance of bear foods, such as wild fruits, honeybees, termites, invertebrates, and disturbance by human activities.

The habitats of the sun bear are the lowland tropical hardwood forests of Southeast Asia. These forests are highly diverse and are valued for timber production. Timber harvest affects portions of the habitats of the sun bear. Malaysia and Indonesia are the world's leading exporters of tropical hardwoods, sawn-wood, and veneer (Laarman 1988), and much of this harvest originates in sun bears habitats. In Peninsula Malaysia, the proportion of the total land area under forest declined from 74 percent in 1958 to about 40 percent in 1990- a drop of 34 percent in 32 years (Aiken and Leigh 1992). Another source reported that 48 percent, about 64,000 km^2 of forestlands in

Peninsula Malaysia were cleared or will be developed for agriculture (Abidin et al. 1991). In Sumatra, it is estimated that between 65 and 80 percent of the lowland forest have already been lost (Whitten et al. 1984). By 1988, the remaining lowland forest had further decreased to only 10 percent of the land area of Sumatra (Santaipillai and Santiapillai 1996). According to the World Bank, the deforestation rate in Borneo reached 7,000 km^2/year in 1988 (Davis and Ackermann 1988). Other data indicated that Kalimantan, Indonesian Borneo, lost more than 100,000 km^2 of forest between 1984 and 1990 (Meijaard 1999b). In Sabah, forest harvest almost tripled from 1,570 km^2/year in 1980 to 4,263 km^2/year in 1990 (Meijaard 1999b), and in Sarawak, forest harvest increased from 1,400 km^2 to 4,500 km^2/year (Rijksen and Meijaard 1999). Between 1960 and 1990, 30-60% of suitable sun bear habitat was estimated to have been reduced in Borneo (Collins et al. 1991; Meijaard 1999b; Rijksen and Meijaard 1999). Meijaard (2001) predicted that some 14,000 – 28,000 sun bear will lose their habitat in Kalimantan, and most likely die in the next 5-10 years, due to the disappearance of suitable sun bear habitat across its distribution range, together with hunting pressures.

In a report by Caldecott (1988) on hunting activities in Sarawak, sun bear were most often thought to be in rapid decline. His survey revealed that 77% of 48 long-houses (traditional communal house in Sarawak and Kalimantan) reported a serious decline in the number of Malayan sun bears. Based on the information provided by Caldecott (1988) (approximately 1 bear/50 hunting family was killed each year), Cleary and Eaton (1992) (estimated of 105,000 hunting families), Colins et al. (1991) and Meijaard (1999a) (93,000 km^2 of potential sun bear habitat), and Davies and Payne (1982) (estimated bear density of 1 bear/4 km^2), Meijaard (1999b) estimated that 10% of the sun bear population in Sarawak was shot in 1988. Additional threats to the sun bear populations in the wild include the uses of sun bear parts for traditional ceremonies, the international and regional trade in sun bears and bear parts, and keeping sun bears as pets (Santiapillai and Santiapillai 1996; Meijaard 1999b).

Despite threats from habitat loss and hunting, Malayan sun bear remains one of the most neglected large mammal species in Southeast Asia, and the least known bear species in the world (Servheen 1999). Even basic biological attributes such as food habits, home range size, and reproductive biology are unknown. Until recently, little research had been conducted on sun bear ecology, and there have been no organized surveys of its distribution and population densities (Meijaard 1997). The lack of biological information on the sun bear is a serious limitation to conservation efforts (Servheen 1999). Basic research on sun bears is the highest priority research need for any of bear species worldwide (Servheen 1999). Because so little information exist on their biology and numbers, sun bears are classified as "Data Deficient" in the 2001 IUCN *Red List of Threatened Animals* (IUCN 2001).

The scarcity of biological and ecological information of Malayan sun bear can be largely attribute to the animals' secretive behavior, low density, uncommonly seen, spear distribution, and hostile environment in which it lives. Because of its shy, secretive nature, and because it lives in dense tropical forest, it is impossible to study this species from direct observation. Thus, radio-telemetry, together with remote sensing automatic cameras, are useful tools to study its ecology. My study is one of the first successful and in-depth attempts using radio-telemetry to gather information on sun bear food habits, home range, movement patterns, activity patterns, population density, use of day beds, among other topics. This study also documented a famine period during a prolonged non-fruiting season where we observed signs of starvation among sun bears and bearded pigs (*Sus barbatus*) in the forest. Field works were undertaken during the summer of 1998, and between January 1999 and December 2000.

Few important reasons that make this study plausible and successful, among others, were the permission to conduct this study approved by Economic Planning Unit of the Malaysian Federal Government, Danum Valley Management Committee, and approval and collaboration with Sabah Wildlife Department. The study would also not have been successful without the facilities, warm hospitability, and help provided by staffs from Danum Valley Field Center and Sabah Wildlife Department.

Study area location

The Danum Valley Field Center (DVFC), situated in the Ulu Segama Forest Reserve, provided one the best facility for researchers worldwide to conduct researches on the biotic and abiotic communities in the lowland tropical rainforest of Southeast Asia. The center located at the eastern border of Danum Valley Conservation Area, a 43,800 ha of totally protected primary forest, and surrounded by 972, 804 ha of logged or will be logged forests. It is an ideal location to study the ecology of wildlife in both pristine primary forests and in logged forests. Since we know so little about Malayan sun bears, I sought to gather as much data on all aspects of sun bear ecology as time and resources permitted. Although we attempted to collect data systematically and with pre-planned methods, the difficult logistics, unpredicted incidents and expenses, rugged terrain, and harsh climate greatly hampered our efforts when conducting this study. Very little information on methodology was available from predacessors because this study is one the first of its kind ever conducted. I learned new ideas from mistakes and experiences, and developed appropriate modification of study methods to solve the problems I faced.

Objectives

My overall objective was to determine the basic biological information on Malayan sun bears in both primary and logged lowland tropical rainforests of Sabah, Malaysian Borneo. This biological information included food habits, home range, movement patterns, activity patterns, population density, and use of day beds from radio-collared Malayan sun bears. We also collected data on fruit production in the forest to investigate the association between fruit availability and physical condition of sun bears.

Thesis Format

Chapter II presents the food habits of Malayan sun bears based on bears scats, feeding sites, and direct observations. Chapter III details the methods and results of home range, movement patterns, activity patterns, population densities, and the use of day bed of Malayan sun bears. Chapter IV documents and discusses a famine period in the study area where Malayan sun bears and bearded pigs were observed to starve. All of these chapters were formatted for submission and publication to various journals. Chapter 2 has already undergone peer review and has been accepted in the journal Ursus.

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CHAPTER II

FOOD HABITS OF MALAYAN SUN BEAR IN LOWLAND TROPICAL FORESTS OF BORNEO

ABSTRACT

Food habits of Malayan sun bears (*Helarctos malayanus*) in the Ulu Segama Forest Reserve, Sabah, Malaysia were studied from 1998-2000 by analyzing scats, examining feeding sites, and making direct observations. Invertebrates such as termites (Isoptera), beetles (Coleoptera), and beetle larvae (Coleoptera), were the predominant food items with 57% frequency of occurrence in scat samples. Figs (*Ficus* sp.) were the most common fruit consumed (61% frequency of occurrence) during the non mast fruiting season. Vertebrates were also consumed but less commonly. Most feeding sites (60%) were in decaying wood, where sun bears foraged for termites, beetles, and beetle larvae. Tree cavities with bee nests and decaying standing stumps were also recorded as feeding sites. We conclude that sun bears are opportunistic omnivores consuming a wide variety of food items.

Key words: sun bear, food habits, Malaysia, Sabah, *Helarctos malayanus*, tropical forest, Borneo

INTRODUCTION

The Malayan sun bear (*Helarctos malayanus*) is the smallest of the eight bear species. It remains the least known bear species in the world. Even basic biology such as food habits, home range size, and reproductive biology is unknown. Until recently, very little research has been devoted to investigating sun bear ecology, and there have been no organized surveys of its distribution and population densities (Meijaard 1997). The lack of biological information on the sun bear serious limits conservation efforts (Servheen 1999). Basic research on sun bears should be a high priority for bear biologists.

Food habits of Malayan sun bears are poorly documented, but have been briefly described by many authors (Shelford 1916; Bank 1931; Lekagul and McNeely 1977; Medway 1978; Tweedie 1978; Davies and Payne 1982; Payne *et al*. 1985; Domico 1988; Nowak 1991; Servheen 1993; MacKinnon *et al*. 1996; Kanchanasakha *et al*. 1998; Lim 1998; Sheng *et al.* 1998; Yasuma and Andau 2000; Fredriksson 2001). Their diet is described as bee nests, termites, earthworms, small rodents, small birds, lizards, animal carcasses, fruits, and the 'heart' of coconut palms. Documentation of sun bears as seed dispersers by Leighton (1990), and McConkey and Galetti (1999), were the only two scientific reports published to date regarding food habits.

We present data on food habits of Malayan sun bears in Ulu Segama Forest Reserve, Sabah. Data were collected during a three-year field study designed to gain basic information on the biology and ecology of the sun bear.

STUDY AREA

The study was conducted between May 1998 and December 2000 at the Ulu Segama Forest Reserve situated on the eastern side of the Malaysian state of Sabah, island of Borneo (Figure 1) (4°57'40"N, 117°48'00''E, 100-1200 m elevation). The reserve encompasses both selectively logged forest conceded to the Sabah Foundation on a 100-year timber license, and primary forest including the 43,800 ha Danum Valley Conservation Area (Marsh and Greer 1992). Lowland, evergreen dipterocarp forest comprises about 91% of the conservation area and the remaining area is lower montane forest (Marsh and Greer 1992). Lower montane forest extends from 750-1500 m and differs from lowland rainforest in having a lower canopy, with fewer, smaller emergent trees (Whitmore 1984). Approximately 88% of the total volume of large trees in the conservation area are dipterocarps (Marsh and Greer 1992).

The conservation area is surrounded by approximately one million hectares of selectively logged forest. Logging follows the monocyclic Unit System (MUS) (Poore 1989) with a 60-year rotation, in which all saleable timber is logged during the first cut and natural regeneration takes place thereafter. Both conventional tractor logging and cable yarding or highlead techniques are used on moderate terrain and on steeper slopes. Timber extraction rates have ranged from 73-166 m^3/hectare since the 1960s (Marsh & Greer 1992). If compared to other selectively logged forests in Southeast Asia, these logged forests can be considered as "good quality" logged forest because of rapid forest regeneration and reduced human disturbance after logging is complete. Many large mammals are present in the study area such as clouded leopards (*Neofelis nebulosa*), Asian elephants (*Elaphus maximus*), and orangutans (*Pongo pygmaeus*). Soils in the reserve include ultisols, inceptisols and alfisols (Marsh and Greer 1992; Newbery *et al*. 1992).

The climate of Ulu Segama Forest Reserve is weakly influenced by two monsoons (Marsh and Greer 1992). Annual rainfall at Danum Valley Field Center (located within Ulu Segama Forest Reserve and the center of the field effort) averages 2700 mm (unpubl. station records 1986-2000), with the wettest period between November and March, and the dry period between July and September. Mean daily temperature at the field center during 1999-2000 was 26.7^{o} C.

The study was concentrated in approximately 15,000 ha of both logged and unlogged forest adjacent to the Danum Valley Field Center. Primary forest existed in the conservation area and the water catchment area of the field center. Logged forest surrounded this conservation area and consisted of different logging coupes or cutting units, from which timber was extracted between 1981 and 1991.

METHODS

Sun bears were captured in culvert traps as per the methods described in Jonkel (1993). Trapping operations started on February 24, 1999 and ended on December 11, 2000. Trapping success was extremely low (1 bear / 396 trap nights) probably due to low density of sun bears in the study area and their wariness of entering traps. Monitoring and tracking of the bears' activity and movement began soon after bears were released. Bears were fitted with MOD-400 radio-collar transmitters (Telonics, Inc., Mesa, AZ, U.S.A.). We located radioed bears using standard methods of ground-based triangulation (White and Garrott 1990). Each location was taken from at least 2 directional fixes at approximately 90-degree angles from the bear's position within 30 minutes, or was simultaneously taken by 2 people in 2-way radio contact. Bear locations were visited within 2-4 hours after coordinates were taken. Radioed bears were located daily using ground triangulation. A total of 343 locations of five radioed bears were collected in the study. Bears were also tracked on foot when possible at a distance so as not to disturb the bear but to visit locations of activity soon after the bear left an activity site. At each activity site, we looked for any feeding evidence, such as bear scats, feeding sites, or claw marks on trees. Thirty-two bear encounters in the forest within 300 m of triangulated radio locations reinforced our confidence in tracking accuracy. In 8 cases, bears were observed feeding and foraging.

Scats were collected on the forest floor at radiolocation sites, when tracking radioed bears, and by chance. Bear scats usually do not remain in the field for a long period due to the moist and soft texture of bear scats that causes the scat to dissolve in the frequent heavy rain, and the efficiency of dung beetles (Order Coleoptera, Fam. Scarabaeidae) that find and utilize feces in a short time. Thus, we believe that collected scats were usually very fresh (< 24 hours old). A possible exception is scats containing mostly figs (*Ficus* spp.), which are not commonly attractive to dung beetles.

We also collected feeding evidence and scats from non-radioed bears when possible. Some bears were known to feed at the Danum garbage dump during the study period. To avoid reporting food habits results from such garbage dump use, human-related food items such as rice, pumpkin or watermelon seeds, chicken bones, or garbage items were eliminated from scats prior to analysis. Four of 56 scats (7%) had some evidence of human-related foods.

Collected scats were placed in plastic bags and frozen before laboratory analysis. Scats were weighed wet, and then oven dried for 24 hours at 70^0 C and reweighed. Dried scats were then soaked in water for 1-3 hours, washed through 0.7 and 0.3 mm-mesh sieves, and dried again in an oven for 24 hours at 70^0 C. Dried materials from scat samples were sorted by using either a hand lens or a binocular dissecting scope (2x ~8x). Taxonomic classes of organisms (e.g. termites, ants, beetles) were sorted and grouped for further identification. Many scats were contaminated with items such as live ants, live dung beetles, live maggots, and dead leaves and twigs (sometimes attached to scat samples when collected from the forest floor). These materials were removed from the scat samples during analysis. Other items such as bear hair were not included in the analysis.

We present results of scat analysis as frequency of occurrence of an item within all samples. Frequency of occurrence is defined as the total number of times a specific food item appeared in a scat sample. “Percent frequency of occurrence” defines the total number of times a specific food item appeared in scats of the sample group divided by total number of scats collected. We did not analyze food habits by season or month due to limited sample size. However, seasonal data are presented on Table 1 for reference. 53 of the 56 scat samples were collected between May 2000 and December

2000 from Bear #122 and Bear #120. We did not compare the results between these two bears due to limits on sample size and non-random scat collection.

We attempted to get as close as possible to radioed bears but not to disturb them while tracking them in the forest. Nevertheless, it was extremely difficult to get close to these bears. In addition, the density of undergrowth in the study made it impossible to observe radioed bears from a long distance. Visual sightings of radioed bears occurred on rare occasions when bears failed to detect our presence within 2 to 20 m on the ground (n=13), or a greater distance (> 30 m) (n=4) when bears were resting or feeding in trees. After the bear left the feeding site, we looked for uneaten food items, examined the feeding site for possible foods, and collected samples. A sample unit was considered a feeding episode, which we defined as a site where a bear was feeding (i.e., decayed wood in a log, where a termite nest was found, or below a fruiting tree).

Only confirmed feeding sites known to be from a sun bear were recorded. Other mammals (e.g., bearded pig [*Sus barbatus*], pangolin [*Manis javanica*], and Malay badger [*Mydaus javanensis*]) were also known to create similar feeding evidence when they fed on termites, earthworms, and other invertebrates from decayed wood or soil (Payne *et al*. 1985; Yasuma and Andau 2000). To ensure that feeding sites were indeed sun bear feeding sites, we recorded only very fresh feeding sites where radioed bears were close by, or where we found bear claw marks and sun bear tracks. At such feeding sites, we also collected uneaten food items for identification .

Malayan sun bears are well known for their arboreal behavior. They climb trees in order to harvest ripe fruit and bee nests, to seek shelter, and to escape danger (Payne *et al*. 1985; Lim 1998; Yasuma and Andau 2000). At such trees, they leave distinct claw marks on the tree. This tree-climbing behavior provided us indirect evidence of sun bear feeding behavior. When we came across trees with sun bear claw marks, we attempted to identify tree species, recorded fruiting condition of the tree, and tree height and size.

RESULTS

Analysis of scats - Six Malayan sun bears (5 males and 1 females) were captured between June 1999 and October 2000 (Table 2). Fifty-six scats were collected from June 1999 to December 2000 during 760 field days (1 scat / 13.6 days). Scat collection was most successful during November 2000 (n=29), moderately successful during July, August, September 2000, and least successful during the rest of the time. Scat searching effort was the same each month except from November 1999 to April 2000 when there was no radioed bear in the study. Table 1 summarizes the monthly frequency of occurrence of food items found in Malayan sun bear scats. The average scat weight was 329 g (range 73 -1,119 g). Malayan sun bears were omnivorous, consuming both animal and plant items. Animal food consisted of 13 genera of termites (Isoptera), 8 families of beetles (Coleoptera), one genus of stingless bee (Apidae), two genera of ants (Formicidae), one genus of wasp (Vespidae), three other orders of insects, two other classes of arthropods, and small amount of reptiles, birds, and small mammals (Appendix 1). Among termite genera found in sun bear scats*, Bulbitermes, Coptotermes, Dicuspiditermes, Nasutitermes*, and *Schedorhinotermes* had > 37% of occurrence rate in the scat samples collected (Table 3). *Bulbitermes* and *Nasutitermes* (both wood-feeding Nasutitermitinae) had the highest above ground biomass densities at the study area (Eggleton *et al*. 2000). Plant food items mainly consisted of figs, 4 known species of fruits, and at least 14 species of unknown fruits (Appendix 1). Ten percent of scats contained only one food item, 23% contained 2 food items, and the remainder contained multiple food items. Among different major types of foods, invertebrates had the highest frequency of occurrence (57%), followed by plant origin food items (29%), and vertebrates (11%).

Beetles were the most common food and the most common invertebrates in the scat samples. Overall, 63% of the scat samples collected contained beetles, 56% contained beetle larvae, 50% termites, and 25% ants. Other invertebrates found in scats included bees and wasps (10%), forest cockroaches (6%), and scorpions (<5%) (Table 4). Figs were the second most important food item accounting for 61% of frequency of occurrence. Other fruits found in scats but with lower frequencies included *Santiria* spp. (Burceraceae), *Polyalthia sumatrana* (Annonaceae), and *Lithocarpus* spp. (Fagaceae). Vertebrate food items were uncommon (11% of scats). Vertebrates included Burmese brown tortoise (*Manouria emys*), pheasants, reptiles, birds, eggs, and fish.

Analysis of feeding sites - We found 82 confirmed sun bear feeding sites from June 1999 to December 2000. All feeding sites were very fresh, which we estimated within a few hours to a day old. Seven types of sun bear feeding sites were found in the study area: 1) decayed standing tree stumps (usually with broken tops), 2) decayed wood or decayed logs on forest floor, 3) fruiting trees, 4) underground termite nests, 5) many different kinds of termite mounds, 6) tree cavities with bee nests, and 7) tree root cavity (Figure 2). Decayed wood was the most common feeding site recorded (n=49). Other types of feeding sites were less common with 1 to 10 sites found (Figure 2).

A total of 105 food items were collected from these 82 feeding sites. The most common food items collected were termites (48%). Earthworms and beetle larvae (both 14%), bees (10%), beetles (7%), figs (3%) and other invertebrates were less common (3%).

Foraging observations – We made 32 direct observations of radioed bears during the entire study; 8 of which were feeding observations. We observed feeding on termites from termite mounds on three occasions. We twice saw sun bears breaking open decayed wood, in search of termites, beetle larvae, and earthworms. On two occasions, Bear #122 was observed harvesting figs from fruiting fig trees. On 6 August 2000, Bear

#122 was found feeding on a Burmese brown tortoise carcass inside a tree cavity for several minutes. These observations lasted a few seconds to a few minutes, but on one rare occasion, radioed bears were observed up to 45 minutes without noticing the presence of field crews.

On 10 June 2000, STW observed Bear #122 resting on a tree branch of a large mengaris tree (*Koompassia excelsa*) about 50 m above the ground. He was lying with his belly on the tree branch, with all legs hanging down. The mengaris tree was a host tree for a strangling fig tree (*Ficus* sp.) with many fruits. He was observed resting for 40 minutes. He then climbed down to another smaller branch opposite the previous branch to eat figs. He used his right paw to reach the end branches of the fig tree and to bring the figs into his mouth. Figs were consumed as whole fruits. He continued feeding on figs for another 5 min, until the observer was forced to leave the scene when a female orangutan with infant began throwing twigs at him. Other frugivores, such as a binturong (*Arctictis binturong*) with its young, two helmeted hornbills (*Buceros vigil*) and many other birds, were also seen feeding at the same fruiting fig tree at the same time.

On 10 October 2000, STW observed Bear #122 feeding for 1 minute on 2 termite mounds of *Dicuspiditermes sp.* in a secondary forest with very dense undergrowth. The bear used its claws and teeth to break the standing termite mound into a few pieces and quickly licked and sucked the contents from the exposed mound. He later sat down on the ground with his body straight up, and held one of the broken mounds with his front paws and licked the termites from the surface of the mounds. Figure 3 shows a bear feeding at similar termites mound with similar posture. After the bear left the area, we found many termite eggs, alates (winged reproductive stages), and a few soldiers at the feeding site.

Trees with bear claw mark- Of 190 trees with sun bear claw marks, 69 trees were climbed repeatedly, as indicated by healed scars and overlapping claw marks on tree bark. This suggested that sun bears are attracted to certain resources from these trees, such as fruits, bee nests, or bedding sites. From 91 trees we were able to identify, *Lithocarpus* spp. (33 trees) and *Ficus* spp. (13 trees) were the two most frequently climbed (Table 5). Except for *Shorea* spp., the first six tree genera listed in Table 5 have fruits that may be important food for sun bears, especially acorns and figs produced by *Lithocarpus* spp. and *Ficus* spp., respectively. In addition, we found 10 trees with bear claw marks that had a tree cavity (probably containing bee nests) with a shattered entrance. Large dipterocarps, such as *Shorea* spp. provide comfortable and safe bedding sites for sun bears, rather than offering fruits. On 14 June 2000 at 1000, STW observed Bear #122 roosting on the first branch of a *Shorea johorensis*, about 30 m above the ground, for 20 minutes. The tree was about 50 m from a busy logging road, and measured 40 m in height and 156 cm DBH. Bear #122 was laying on the branch, with his four legs hanging down. He lifted his head occasionally to observe passing vehicles without paying much attention to them.

DISCUSSION

Food items of Malayan sun bear reported in this study (Appendix 1) are limited and represent a small proportion of the total diet eaten by wild sun bears. Fredriksson (2001) reported that Malayan sun bears have been recorded to feed on more than 50 plant species and more than 100 species of insects in the Sugai Wain Protection Forest, East Kalimantan, Indonesian Borneo. Low numbers of food items presented here were due to the small sample size of bear scats collected and limited number of feeding observations. Low numbers of fruit items in sun bear diets were probably due to the lack of a normal mass fruiting season during the study period (Chapter 4).

Figs are a keystone resource for tropical frugivorous species, especially birds, primates, and bats (Janzen 1979; Leighton and Leighton 1983; Kalko *et al*. 1996;

Kinnaird *et al*. 1999). In this study, figs were the most important fruit eaten by Malayan sun bears. Although we were aware of the possible over-estimate of the importance of figs in sun bear diets that resulted from non-random scat collection (many scats were collected under fruiting fig trees, and 17 scat samples were collected around a bear roosting site on 7 November 2000), the importance of figs could be seen from the relative amount of figs that a bear consumed. Four bear scats with fig seeds collected in the study contained 30, 47, 64, and 84 countable buds of figs. This indicated that bears were able to consume figs in large amounts. Additional evidence that sun bears could consume figs in large amounts at one time came from the amount of scat with fig seeds collected (wet weight=1.43 kg) inside a trap, where an adult female bear (Bear #121, body weight =20 kg) was caught in this study. The scats collected in the trap represent > 7% of the bear's body weight. Two direct observations of sun bears feeding on fig trees and bear claw marks on fig trees (Table 5) provide direct and indirect evidence of sun bear feeding on figs. Leighton (1990) showed a photograph of "a sun bear resting in a *Ficus dubia* tree, after eating the large dark red-purple figs" (Leighton 1990, p 23). The importance of figs in diets of sun bears is poorly documented. Only Leighton (1990), and McConkey and Galetti (1999) report sun bears feeding on figs. Spectacled bears (*Tremarctos ornatus*) in Peru, and sloth bears (*Melursus ursinus*) in Nepal, are also known to feed on figs in the wild (Peyton 1980; Joshi *et al*. 1997). Table 6 summarizes fruit species consumed by Malayan sun bear reported by other sources.

Other fruits that sun bears consumed (as indicated by scat analysis) include *Lithocarpus* spp., *Polyalthia sumatrana*, *Eugenia* spp., and *Santiria* spp. (Appendix 1). All of these trees were also found to have claw marks of sun bear, except *Santiria* spp. In addition, of 33 *Lithocarpus* spp. trees with sun bear claw marks, at least 11 trees had been climbed repeatedly over the years, (recognized from the different sets of claw marks of difference ages) suggesting that sun bears harvest acorns from *Lithocarpus* spp. trees. Although hard shells of acorns from the Fagaceae family only occurred once in the scat analysis, Davies and Payne (1982) stated that the sun bears feed on large quantities of the hard seeds of the Fagaceae family. The low encounter rate of Fagaceae's shells in our study was likely due to extremely low fruit production during the study period. Other species of bears, such as Asiatic black bear (*Ursus thibetanus*) and brown bear (*Ursus arctos*), are also known to consume acorns from this family (both *Lithocarpus* spp. and *Quercus* spp.) (Nozaki *et al*. 1983; Schaller *et. al* 1989; Clevenger *et al*. 1992). Table 7 and Table 8 show the relative abundance of the top 15 tree genera in primary forest plot and logged forest plot, respectively, in the study area reported by Hussin (1994).

In our study, invertebrates were the most important food items for Malayan sun bear in Ulu Segama Forest Reserve. Termites, beetle larvae, and beetles occurred in more than half of all scat samples. In addition, 60% of sun bear feeding sites found were in decayed wood on the forest floor housing termites, beetles, and larvae (Figure 2). Unlike fruit production that fluctuated throughout the year, numbers invertebrates were available year round with little fluctuation (Burghouts *et al*. 1992). Due to the fact that most invertebrates are small (except beetle larvae of *Cholcosoma* spp. which measured up to 10 cm in length and 3 cm in diameter), sun bears had to spend more effort in search of invertebrate food items to meet their energy requirements. This is in contrast to consumption of fruit where bears can consume a large quantity with minimal effort.

Presence of many termite wings from reproductive individuals (alates), and termite eggs, and beetle larvae in scat samples indicates sun bears do eat individual invertebrates that contain high levels of nutrients. For example, ant alate, termite alate, and large beetle larva contain more body fat (44%, 42%, and 40%, respectively), than adult ant worker, termite worker, and adult beetles (13%, 11%, and 10%, respectively) (Phelps *et al*. 1975; Redford and Dorea 1984; Rawlins 1997). The sun bear feeding site with termite eggs and alate we found on 10 October 2000 was a typical feeding site of a sun bear or of other myrmecophages (specialized termite- and ant-eating mammals), where these mammals consume mostly termite eggs, larvae, and alates with higher body fat and discard termite solders and workers (Lubin and Montgomery 1981; Redford and Dorea 1984).

Earthworms are an important food of sun bears (Shelford 1916; Lekagul and McNeely 1977; Tweedie 1978; Davies and Payne 1982; Domico 1988; Lim 1998; Sheng *et al*. 1998), although none of these authors ever studied ecology of sun bears. We failed to find any remains of earthworms during the scat analysis. Since earthworms only have soft tissue and do not possess an exoskeleton, they are probably digested completely. We believe that earthworms could be an important food item for sun bears, based on our frequent observation of earthworms at sun bear feeding sites (14%). Earthworms are found not only in soil, but also found in decayed wood, together with beetles, beetle larvae, termites and other invertebrates. Interestingly, two captive Malayan sun bears from Woodland Park Zoo, Seattle, USA, rejected earthworms when offered them (C. Frederick, Woodland Park Zoo, Seattle, USA, pers. comm.).

The Malayan sun bear is also know as “honey bear” which refers to its voracious appetite for honeycombs and honey. Thus, bees, beehives, and honey, are another important food item (Lekagul and McNeely 1977; Medway 1978; Payne *et al*. 1985). We found sun bears occasionally feed on wild bees, especially the stingless bee (*Trigona* spp.). Sun bears are known to tear open trees with their long, sharp claws and teeth in search of wild bees (*Apis dorsata, A. indica*, and *Trigona* spp.) and leave behind shattered tree trunks (MacKinnon *et al*. 1996; Lim 1998; G. Fredriksson in Meijaard 1999; Meijaard 1999). We found 10 similar foraging sites with shattered tree trunks in tropical hardwoods. G. Fredriksson (pers. comm., 2000) reported seeing Borneo ironwood trees (*Eusideroxylon zwageri*) with tree trunks shattered from sun bear foraging. Meijaard (1999) suggested this feeding habit explained why most older sun bears have damaged teeth, such as the canines being broken off. This may explain why the three adult sun bears we captured all had canines worn down or broken to the gum line.

Malayan sun bears are typical omnivores and opportunist feeders that utilize a broad range of resources in the ecological niche they occupy. Bank (1931) stated that almost anything served as bear food. Besides fruits and invertebrates, Malayan sun bears also are reported to feed on variety of vertebrates, animal carcasses, small animals, rodents, small birds, and reptiles (Shelford 1916; Bank 1931; Medway 1978; Tweedie 1978; Davies and Payne 1982; Payne *et al*. 1985; Domico 1988; MacKinnon *et al*. 1996; Lim 1998; Kanchanasakha *et al*. 1998; Sheng *et al*. 1998; Yasuma and Andau 2000). Lim (1998) reported only a desperately hungry bear would prey on vertebrates, such as pheasants, civets, cats, and rodents. However, fragments of bones, claws, scales, feathers and egg shells found in scat analysis suggest sun bears opportunistically prey upon small vertebrates in the study area.

Many reports state that sun bears eat the heart of coconut palm (*Cocos nucifera*), and may do serious damage to coconut plantations (Lekagul and McNeely 1977; Domico 1988; Payne et al. 1985; Servheen 1993; Yasuma and Andau 2000). N. Fuyuki (Hokkaido University, Sapporo, Japan, pers. comm., 1999) reported radioed sun bears captured at the edge of an oil palm (*Elaeis quineensis)* plantation next to Tabin Wildlife Reserve, Sabah, foraged in the oil palm plantation at night and spent their daytime in the reserve forest. Rapid conversion of lowland tropical rainforest into large-scale oil palm plantations in Sabah and other parts of Southeast Asia has caused many bears to access plantations to became pests and nuisance animals. This would be expected from an opportunistic omnivore when food diversity is reduced as forests are converted to monoculture plantation agriculture.

Wilson and Wilson (1975) and Wilson and Johns (1982) suggested that sun bears exist only in primary forest (they found none in logged forests. We showed that Malayan sun bears do exist in logged forest. Although our data are limited to assess the specific impacts of selective logging on the food availability of Malayan sun bears, Hussin (1994) reported that the number of fruit trees, especially fig trees, were significantly lower in logged forests in the study area. Burghouts *et al*. (1992) also reported that the abundance of invertebrates within our study area was higher in primary forest with a significantly higher abundance of termites. However, the proportion of beetles, millipedes, and cockroaches was higher in the logged forest than the primary forest (Burghouts *et al*. 1992). These data show that the food items of sun bears are found in the mixture of logged and unlogged forests. However, the complexities of food webs capable of supporting sun bears in tropical forests dominated by Dipterocaraceae are more complex than just whether the habitat is logged, unlogged or a plantation (Curran et al. 1999). Forest managers should consider the extent and distribution of logging for both human benefits and wildlife needs when managing the forests. These management implications should include careful maintenance and adequate distribution of unlogged areas to provide habitat diversity, well-designed logging practices using environmentally friendly methods such as practicing reduced impact logging, prohibitions on damaging mature fig trees and maintaining buffer zones around fig trees, and controlling poaching activities that often accelerate with the increased access resulting from logging roads.

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Table 1. Frequency of occurrence of monthly food items in Malayan sun bear scats at Ulu Segama Forest Reserve, Sabah, Malaysia. August 1999- December 2001 (n=56)

Foot items	*Apr*	%	Jun	%	Jul	%	Aug	%	Sep	%	Oct	%	Nov	%	Dec	%
Termites	1	16.7	1	20	2	10.5	9	19.6	4	14.3	2	10	8	12.12	1	25
Ants	1	16.7	1	20	1	5.26	4	8.7	2	7.14			2	3.03	1	25
Beetles	1	16.7	1	20	2	10.5	6	13	4	14.3	2	10	14	21.21	1	25
Beetle larvae	1	16.7	1	20	1	5.26	7	15.2	4	14.3	3	15	11	16.67		
Bees and wasps			1	20			1	2.17			1	5	2	3.03		
Forest Cockroach							1	2.17	1	3.57						
Other arthropods	1	16.7					2	4.35	1	3.57			2	3.03		
Turtle					1	5.26			2	7.14						
Reptiles							1	2.17			1	5				
Small vertebrates					1	5.26	2	4.35	3	10.7	3	15	2	3.03		
Birds' eggs											1	5				
Unidentified animals					2	10.5	2	4.35					2	3.03		
Figs					6	31.6	3	6.52	2	7.14	1	5	18	27.27		
Fruits					1	5.26	4	8.7	4	14.3	3	15	3	4.545		
Flowers							1	2.17								
Acorns							1	2.17								
Unidentified Plants	1	16.7			2	10.5	2	4.35	1	3.57	3	15	2	3.03	1	25
Number of scat (n)	2		1		7		7		6		3		29		1	

Table 2. Sexes and monitoring duration of the six captured Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia.

		1999							2000											
Bear #	Sex	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
125	M	---	---	---	---															
124	M		---	---	---															
123	M			---	---															
122	M										---	---	---	---	---	---	---	---	---	---
121	F																-			
120	M																	---	---	---

Table 3. Frequency of occurrence of termite species found in sun bear scats in Ulu Segama Forest Reserve, Sabah, Malaysia. (n=24)

Family	Subfamily	Species	Frequency of occurrence	%
Rhinotermitidae	Coptotermitinae	*Coptotermes curvignathus*	5	20.83
Rhinotermitidae	Coptotermitinae	*Coptotermes sp 1*	10	41.67
Rhinotermitidae	Rhinotermitinae	*Schedorhinotermes*	9	37.50
Termitidae	Termitinae	*Globitermes globosus*	1	4.17
Termitidae	Macrotermitinae	*Hypotermes xenotermitis*	4	16.67
Termitidae	Macrotermitinae	*Macrotermes*	11	45.83
Termitidae	Macrotermitinae	*Odontotermes* sp	2	8.33
Termitidae	Nasutitermitinae	*Bulbitermes sp*	10	41.67
Termitidae	Nasutitermitinae	*Lacessititermes*	1	4.17
Termitidae	Nasutitermitinae	*Nasutitermes*	11	45.83
Termitidae	Nasutitermitinae	*Nasutitermes longinasus*	2	8.33
Termitidae	Termitinae	*Dicuspiditermes*	10	41.67
Termitidae	Termitinae	*Homallotermes* sp	3	12.50
Termitidae	Termitinae	*Microcerotermes dubius*	1	4.17
Termitidae	Termitinae	*Microcerotermes* sp	1	4.17
Termitidae	Termitinae	*Pericapritermes*	1	4.17

Table 4. Frequency of occurrence and percentage of food items found in 56 Malayan sun bear scats in Ulu Segama Forest Reserve, Sabah, Malaysia, 1999-2000.

Foot items	Frequency of occurrence	Percent frequency of occurrence
Invertebrates	***116***	***57.14***
Termites	26	50.00
Ants	13	25.00
Beetles	33	63.46
Beetle larvae	29	55.77
Bees and wasps	5	9.62
Forest Cockroach	3	5.77
Other arthropods	7	13.46
Vertebrates	***23***	***11.16***
Turtle	3	5.77
Reptiles	2	3.85
Small vertebrates	11	21.15
Birds' eggs	1	1.92
Unidentified animals	6	11.54
Plants	***61***	***29.61***
Figs	32	61.54
Fruits	15	28.85
Flowers	1	1.92
Acorns	1	1.92
Unidentified Plants	12	23.08
Non-organic	***3***	***0.14***
Resin[a]	3	5.77

(a) : Resin is nesting material from stingless bee (*Trigona* spp.) nests. It was consumed when sun bears feed on a bee nest.

Table 5. Frequencies of tree species with Malayan sun bear claw marks in Ulu Segama Forest reserve, Sabah, Malaysia. 1999-2000 (n=190)

Tree species	Number of trees with claw marks	% of tree species with claw marks	% of tree species (known species only)
Unknown tree species	99	52.11	
Lithocarpus spp.	33	17.37	35.48
Ficus spp.	13	6.84	13.98
Shorea spp.	7	3.68	7.53
Polyalthia sumatrana	5	2.63	5.38
Duabanga moluccana	4	2.11	4.30
Eugenia spp.	4	2.11	4.30
Dryobalanops spp.	3	1.58	3.23
Lauraceae	3	1.58	3.23
Macaranga hypoleuca	3	1.58	3.23
Scorodocarpus borneensis	2	1.05	2.15
Stemonurus scorpioides	2	1.05	2.15
Aglaia spp.	1	0.53	1.08
Alangium javanicum	1	0.53	1.08
Baccaurea spp.	1	0.53	1.08
Dillenia spp.	1	0.53	1.08
Durio spp.	1	0.53	1.08
Hopea dryobalanoides	1	0.53	1.08
Intsia palembanica	1	0.53	1.08
Neolamarckia cadamba	1	0.53	1.08
Octomeles sumatrana	1	0.53	1.08
Paranephelium xestophyllum	1	0.53	1.08
Fam. Leguminosae	1	0.53	1.08
Fam. Myristicaceae	1	0.53	1.08

Table 6. Fruit items in Malayan sun bear diets as reported in the literature.

Family	*Genus*	*Species*	Source
Bombacaceae	*Durio*	*zibethinus*	Ridley (1930) in McConkey and Galetti (1999)
Burseraceae	*Canarium*	*pilosum*	McConkey and Galetti (1999)
Burser aceae	*Santiria*	*spp.*	Leighton (1990)
Convolvulaceae	*Erycibe*	*Maingayi*	McConkey and Galetti (1999)
Fagaceae	*Lithocarpus*	*spp.*	Davies and Payne (1982)
Lauraceae	*Litsea*	*spp.*	Leighton (1990)
Moraceae	*Ficus*	*consociata*	McConkey and Galetti (1999)
Moraceae	*Ficus*	*stupenda*	S. Harrison in McConkey and Galetti (1999)
Moraceae	*Ficus*	*dubia*	Leighton (1990)
Palmae	*Cocos*	*nucifera*	Domico (1988); Lekagul and McNeely (1977); Payne at el. (1985); Servheen (1993); Yasuma and Andau (2000)
Palmae	*Elaeis*	*Guineensis*	F.Nomura (Hokkaido University, Japan, personal communication, 1999)
Rhizophoraceae	*Carallia*	*spp.*	Leighton (1990)
Sapindaceae	*Nephelium*	*spp.*	Leighton (1990)

Table 7. Frequency, percentage and ranking of the top 15 tree genera in a 4-ha primary forest plot in Ulu Segama Forest Reserve, Sabah, Malaysia.

Genus	Frequency	%	Rank
Shorea (Dipterocarpaceae)	227	10.34	1
Mallotus (Euphorbiaceae)	142	6.47	2
Aglaia (Meliaceae)	131	5.97	3
Ryparosa (Flacourtiaceae)	93	4.24	4
Litsea (Lauraceae)	89	4.06	5
Polyalthia (Annonaceae)	87	3.96	6
Eugenia (Myrtaceae)	86	3.92	7
Chisocheton (Meliaceae)	84	3.83	8
Aporusa (Euphorbiaceae)	81	3.69	9
Parashorea (Dipterocarpaceae)	78	3.55	10
Lithocarpus (Fagaceae)	66	3.01	11
Canarium (Burseraceae)	59	2.69	12
Alangium (Alangiaceae)	55	2.51	13
Diospyros (Ebenaceae)	55	2.51	13
Madhuca (Sapotaceae)	53	2.42	15
Total	1386	63.17	

Source: Hussin (1994)

Table 8. Frequency, percentage and ranking of the top 15 tree genera in a 4-ha logged forest plot in Ulu Segama Forest Reserve, Sabah, Malaysia.

Genus	Frequency	%	Rank
Shorea (Dipterocarpaceae)	153	9.57	1
Aglaia (Meliaceae)	92	5.75	2
Eugenia (Myrtaceae)	86	5.38	3
Litsea (Lauraceae)	77	4.82	4
Polyalthia (Annonaceae)	74	4.63	5
Xanthophyllum (Polygalaceae)	71	4.44	6
Lithocarpus (Fagaceae)	67	4.19	7
Mallotus (Euphorbiaceae)	63	3.94	8
Aporusa (Euphorbiaceae)	59	3.69	9
Alangium (Alangiaceae)	53	3.31	10
Parashorea (Dipterocarpaceae)	49	3.06	11
Microcos (Tiliaceae)	38	2.38	12
Diospyros (Ebenaceae)	37	2.31	13
Knema (Myristicaceae)	35	2.19	14
Canarium (Burseraceae)	35	2.19	14
Total	989	61.85	

Source: Hussin (1994)

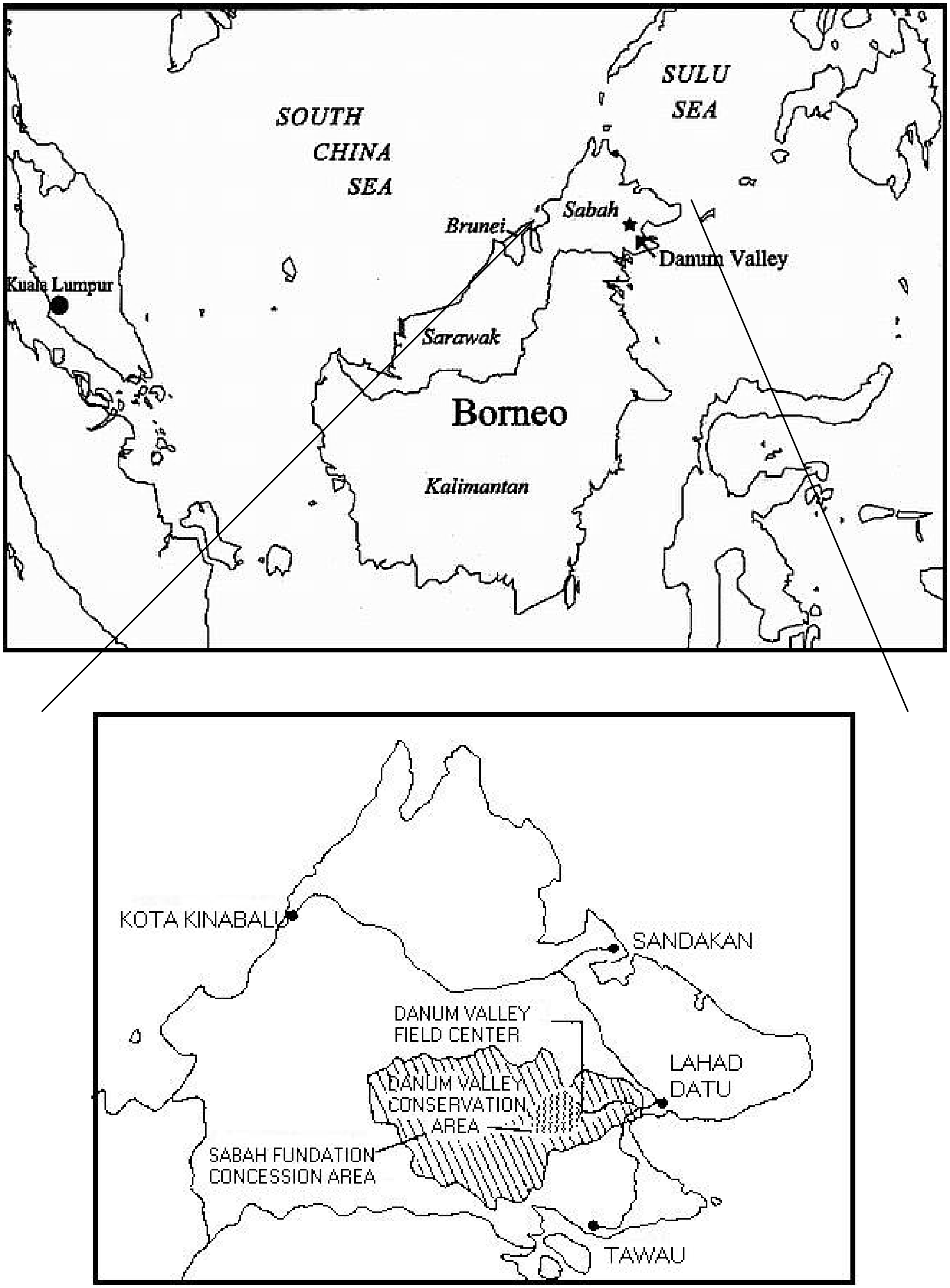

Figure 1. Location of the study area, based at Danum Valley Field Center at the state of Sabah, Malaysia, Northern Borneo.

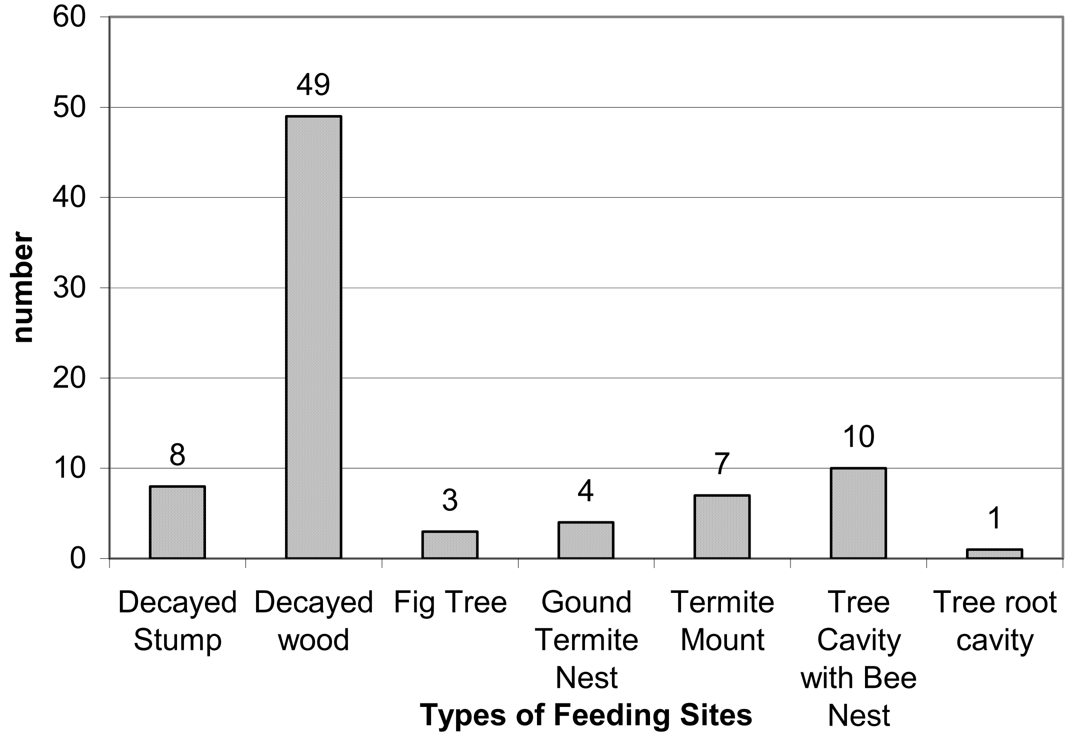

Figure 2. Frequency of feeding sites of Malayan sun bear feeding sites in Ulu Segama Forest Reserve, Sabah, Malaysia. 1999-2000 (n=82)

Figure 3. Photograph of a Malayan sun bear feeding on termite (*Dicuspiditermes* spp.) mounds taken by the remote sensing automatic camera at Ulu Segama Forest Reserve, Sabah, Malaysia.

Appendix 1. List of food items of Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia. 1999-2000

Class	Order	Family	Sub-Family	Species
Animal origin				
Arachnida	Scorpionida			
Insecta	Coleoptera	Carabidae or Tenebrionidae		
Insecta	Coleoptera	Chelonariidae		
Insecta	Coleoptera	Chrysomelidae		
Insecta	Coleoptera	Dytiscidae		
Insecta	Coleoptera	Histeridae		
Insecta	Coleoptera	Passalidae		*Aceraius spp.*
Insecta	Coleoptera	Scarabaeidae		*Chalcosoma spp.*
Insecta	Coleoptera	Tenebrionidae		
Insecta	Dictyoptera	Blattidae		*Panesthia spp.*
Insecta	Hymenoptera	Apidae		*Trigona collina*
Insecta	Hymenoptera	Apidae		*Trigona spp.*
Insecta	Hymenoptera	Apoidea		
Insecta	Hymenoptera	Formicidae		*Camponotus gigas*
Insecta	Hymenoptera	Formicidae		*Ccamponotus species*
Insecta	Hymenoptera	Formicidae		*Gnamptogenys menadensis*
Insecta	Hymenoptera	Vespidae		*Polistine spp.*
Insecta	Isoptera	Rhinotermitidae	Coptotermitinae	*Coptotermes curvignathus*
Insecta	Isoptera	Rhinotermitidae	Coptotermitinae	*Coptotermes sp1*
Insecta	Isoptera	Rhinotermitidae	Rhinotermitinae	*Schedorhinotermes*
Insecta	Isoptera	Termitidae	Termitinae	*Globitermes globosus*
Insecta	Isoptera	Termitidae	Macrotermitinae	*Hypotermes xenotermitis*
Insecta	Isoptera	Termitidae	Macrotermitinae	*Macrotermes*
Insecta	Isoptera	Termitidae	Macrotermitinae	*Odontotermes* sp
Insecta	Isoptera	Termitidae	Nasutitermitinae	*Bulbitermes sp*
Insecta	Isoptera	Termitidae	Nasutitermitinae	*Lacessititermes*
Insecta	Isoptera	Termitidae	Nasutitermitinae	*Nasutitermes*
Insecta	Isoptera	Termitidae	Nasutitermitinae	*Nasutitermes longinasus*
Insecta	Isoptera	Termitidae	Termitinae	*Dicuspiditermes*
Insecta	Isoptera	Termitidae	Termitinae	*Homallotermes* sp
Insecta	Isoptera	Termitidae	Termitinae	*Microcerotermes dubius*
Insecta	Isoptera	Termitidae	Termitinae	*Microcerotermes* sp
Insecta	Isoptera	Termitidae	Termitinae	*Pericapritermes*
Insecta	Lepidoptera			
Insecta	Orthoptera	Gryllotalpidae		
Mammalia	Rodentia			
Osteichtyes		Cyprinidae		
Reptilai	Chelonia	Testudinidae		*Manouria emys*
Reptilai	Chelonia			
Chordata	Reptilai	Squamata		

Class	Order	Family	Sub-Family	Species
Plant Origin				
		Annonaceae		*Polyalthia sumatrana*
		Burseraceae		*Santiria sp.*
		Fagaceae		*Lithocarpus spp.*
		Moraceae		*Ficus spp.*
		Myrtaceae		*Eugenia sp.*

CHAPTER III

HOME RANGE, ACTIVITY PATTERNS, AND HABITAT RELATIONS OF MALAYAN SUN BEARS IN THE LOWLAND TROPICAL RAINFOREST OF SABAH, MALAYSIAN BORNEO

ABSTRACT

Six Malayan sun bears (*Helarctos malayanus*) were captured and radio-collared from June 1999 to December 2001 in Ulu Segama Forest Reserve, Sabah, Malaysia to study home-range characteristics, movement patterns, activity patterns, population density, and bedding sites. A total of 343 locations were recorded. Home range sizes, calculated by the 95% adaptive kernel method, averaged 14.8 $\pm$ 6.1 (SD) km^2, and were found in both primary and logged forests. Daily movement distances from these bears averaged 1.45 $\pm$ 0.24 (SD) km, and were affected by food availability, especially availability of figs (*Ficus* spp.). Male Malayan sun bears were primarily diurnal, but a few individuals were active at night for short periods. The first peak of activity occurred early morning, the second started 1300 h, and activity remained high until dusk. A total of 26 sun bear bedding sites were found in the study area. The majority of the bedding sites consisted of fallen hollow logs. Other bedding sites included standing trees with cavities, cavities underneath fallen logs or tree roots, and tree branches high above ground.

INTRODUCTION

The Malayan sun bear (*Helarctos malayanus*) is the smallest of the eight living bear species. Adults are about 120 to 150 cm long and weigh 27 to 65 kg (Stirling

1993). It was originally found in the dense forests of Bangladesh, Myanmar, Thailand, Laos, Kampuchea, Vietnam, Southern China, Peninsular Malaysia, and the islands of Sumatra and Borneo (Stirling 1993). It remains the least known bear species in the world and one of the most neglected large mammal species in Southeast Asia (Servheen 1999). Even basic biological facts such as food habits, home range size, and reproductive biology are unknown. Until recently, little research has been conducted to investigate sun bear ecology, and no organized surveys of the bear's distribution and population densities have been conducted (Meijaard 1997). The lack of biological information on the sun bear is a serious limitation to conservation efforts (Servheen 1999). Therefore, basic research on sun bears is the highest priority need of any bear species worldwide (Servheen 1999).

Davies and Payne (1982) reported that sun bears are found throughout dipterocarp and the lower montane forests of Sabah, Malaysia from 0 to 1350 m in elevation, but are common nowhere. In the past few decades, these forests have been greatly reduced. Malaysia and Indonesia are the world's leading exporters of tropical hardwoods, which originate in sun bear habitat. Although some forests were selectively logged, many forests were being cleared permanently for human developments and agriculture, such as rubber and oil palm plantations. Malaysia has become the world's largest producer and exporter of palm oil (World Rainforest Movement 2001). This large-scale forest conversion into monoculture plantations has led to the reduction of sun bear habitat. Wilson and Wilson (1975), Wilson and Johns (1982), and Johns (1983a) suggested that sun bears exist only in primary forest (they found none in logged forests). With the rapid disappearance of suitable sun bear habitat, the conservation and survival of the Malayan sun bear in Southeast Asia has become both challenging and questionable. Wise conservation planning for Malayan sun bears requires information on the biological needs of this species. We present information on home range size, movement patterns, activity patterns, population densities, and bedding sites of Malayan sun bears in Ulu Segama Forest Reserve, Sabah. These data were collected during a 3-year field study designed to gather biological and ecological information about the Malayan sun bear in the lowland tropical forests of Borneo.

STUDY AREA

This study was conducted between May 1998 and December 2000 at the Ulu Segama Forest Reserve situated on the eastern side of the Malaysian state of Sabah, island of Borneo (Figure 1) ($4^0$57'40"N $117^0$48'00E, 100-1200 m elevation). The reserve encompasses both forests that were selectively logged by the Sabah Foundation on a 100-year timber license, and primary forest including the 43,800 ha Danum Valley Conservation Area (Marsh and Greer 1992). The area has been used as a research site since 1985 to study the ecology of tropical forest flora and fauna and the effects of logging on various ecosystem components (Marsh and Greer 1992). Lowland, evergreen dipterocarp forest comprises about 91% of the conservation area; the remaining area is lower montane forest (Marsh and Greer 1992). Lower montane forest extends from 750 to 1500 m and differs from lowland rainforest in that it has a lower canopy with fewer, smaller emergent trees (Whitmore 1984). Approximately 88% of the total volume of large trees in the conservation area are dipterocarps (Marsh and Greer 1992).

The Danum Valley Conservation Area is surrounded by approximately one million hectares of selectively logged forest. Logging follows the Monocyclic Unit System (Poore 1989) with a 60-year rotation. It involves harvesting all healthy, commercially valuable tree species with a diameter at breast height (dbh) > 60 cm occurring on slope of < 20^o (Marsh 1995). Both conventional tractor logging and overhead cable techniques are used on moderate terrain and steeper slopes. Studies on the impacts of this logging method show that a harvesting of 3-7% of the trees with > 60 cm dbh (translates to 8-18 trees ha^{-1}) destroys over 50% of the trees > 30 cm dbh by logging and road building processes (Wilson and Wilson 1975; Johns 1985, 1988, 1992). Timber extraction rates in the Ulu Segama Forest Reserve are typically high, averaging 118 m^3ha^{-1} over the period 1970-90, with a range of 73-166 m^3ha^{-1} between different logging areas (Marsh and Greer 1992) (this compares to the extraction level of 8.4 and 13.5 m^3ha^{-1} in Neotropical and African rainforests: Yeom 1984). This number represents the removal of about 8 trees ha^{-1} during the logging operation: less than the average extraction rate of 12-15 trees ha^{-1} typical in the rest of Malaysia (Marsh 1995). Compared with other selectively logged forests in Sabah and Malaysia, some parts of the logged forests in the study area can be considered as "good quality" forest, due to relatively lower extraction rates and less human disturbance (such as illegal logging).

When logging is complete in an area, a mosaic of vegetation types remaining, from relatively undisturbed forest, through forested area dominated by pioneer trees, such as *Macaranga, Octomeles, Neolamarkia* and *Duabanga*, to more open area of grasses, ferns, vines, and climbing bamboo (*Dinochloa* spp.), and finally to exposed and compacted mineral soil with little or no vegetation (Willott 2000). These successional forest mosaics have a tendency to increase total biodiversity. In a 1 ha study on floristic composition and forest structure of both primary and logged forest in the study area, Ahmad (2001) found a higher species richness at the family, genus, and species level in a 10-year old logged forest than in primary forest (Table 1). Another similar floristic composition of 4 ha of primary and 10-year old logged forest in the study area revealed higher species richness in primary sites than logged forest sites (291 for primary forest and 274 for logged forest) (Hussin 1994). In general, primary forests are characterized by a taller (45 m compared to 15 m), more well-developed, and less open upper canopy (5.3% compared to 10.7%) than logged forest (Ahmad 2001; Willott 2000). Logged forests, on the other hand, are usually covered by dominant species of certain trees like *Macaranga* and *Mallotus* with abundant vine covers, climbers, and herbs, notably *Melastomata*, *Piper*, and many ginger species (Ahmad 2001). Hussin (1994) reported that the total fruiting frequency of all trees in primary forest was significantly higher than in logged forest. During a mass fruiting in the study area in September 1990, fruit production was clearly higher in the primary forest than in the logged forest (Hussin 1994). Numbers of fig trees, which are an important food source for Malayan sun bear (Wong *et al*. in press.), are higher in primary forest than logged forest in Ulu Segama Forest Reserve (Hussin 1994) and Sungai Tekan Forest Concession, West Malaysia (Johns 1983b). Despite these post-logging changes, many species of large mammals including clouded leopards (*Neofelis nebulosa*), Asian elephants (*Elaphus maximus*), orangutans (*Pongo pymeous*), and Malayan sun bears, were still found in the logged forest during our study.

The climate of Ulu Segama Forest Reserve is weakly influenced by two monsoons (Marsh and Greer 1992). Annual rainfall at Danum Valley Field Center (DVFC) (located within Ulu Segama Forest Reserve and the center of the field effort) is on average of 2700 mm (unpubl. station records 1986-2000), with the wettest period from October to January and the dry period between July and September (Figure 2). Mean daily temperature at the field center during 1999-2000 was 26.7^{o} C. Soils in the reserve include ultisols, inceptisols and alfisols (Newbery *et al*. 1992; Marsh and Greer 1992).

The study area was concentrated in approximately 150 km^2 of both logged (60%) and unlogged forest (40%) adjacent to the DVFC (Figure 3). Primary forest could be found in the 438 km^2 conservation area and the water catchment area of the field center. Logged forest consisted of different logging coupes or cutting units, from which timber was extracted between 1981 and 1991. The elevation in this forest block ranged between 150 m and 600 m.

Three human settlements are found inside this 150 km^2-forest block. DVFC located east of Segama River, was the base station for this study. The development of DVFC began in 1984 and was completed in 1986 to provide facilities for scientific research, education, and conservation. About fifty local staff members and their families were stationed there year-round, with additional seasonal researchers and visiting scholars staying in DVFC at various time of the year. The FACE (Forests Absorbing Carbon-dioxide Emissions) nursery was first set up in 1992 as a base camp and nursery site for an enrichment planting project to rehabilitate 250 km^2 of degraded, logged-over forests with indigenous dipterocarps, fast growing pioneers, and forest fruit trees (Yap et al. 1996). The project is funded mainly by the FACE Foundation of the Netherlands, an organization set up by the Dutch Electricity Generating Board to promote the planting of forests to absorb CO_2 from the atmosphere to offset that produced during power generation. This nursery is located at the center of the study area and houses about eighty permanent staff members and their families year-round. The third human settlement is Takala logging camp, located at the northwest corner of the study area. Takala was the first human settlement in this area with approximately 100 forest workers and family members. Most of them work as contract-workers for the FACE project or logging road maintenance workers. Hunting is strictly prohibited by law in the study forest or adjacent forests. However, poaching activities were still reported during the study period.

METHODS

The study was divided into two phases. Phase I was conducted from June to August 1998, and Phase II went from January 1999 to December 2000. Phase I involved a preliminary survey of sun bear presence in both logged and unlogged forests and a search for baits attractive to bears. The techniques in Phase I were necessary for the completion of Phase II. Phase II involved collecting information on the basic biology of sun bears through the capture and radio-tracking of animals in the forests.

Animal Capture

We used an aluminum culvert trap (Teton Welding and Machine, Choteau, MT, U.S.A.) and three locally made 55-gal. barrel traps to capture sun bears. We also built four wooden log traps to capture bears, but abandoned this method later in the study after two captured bears chewed through the wooden wall of the trap and escaped. Trapping operations started on February 24, 1999 and ended on December 11, 2000. Each trap was equipped with a radio-transmitter that would begin transmitting signals once the trap's door was closed. Signals from the traps' transmitters were monitored several times each day. We checked the traps immediately after receiving these signals to minimize the holding time of captured animals. A variety of baits were used for trapping, but chicken entrails proved to be the most effective. Captured bears were immobilized with Zoletil (tiletamine HCL/ zolazepam HCL) (4 mg/kg of estimated body mass) (Virbac Laboratories, Carros, France), delivered with a jab stick. Each bear was fitted with a non-time delay motion sensitive radio transmitter collar (MOD-400; Telonics Incorporated, Mesa, Arizona, U.S.A.), operating in the 150-151 MHz frequency range. Each collar weighed about 300 g, less than 2% of the bear's body mass, and was designed for 18 months of battery life. Each radio transmitter was equipped with a mercury-tip switch that changed the pulse rate from fast to slow, depending upon the position of the bear's head. The amplitude of radio signals received also changed when the animals traveled in the forest as the signals passed through obstacles like trees and rocks. Animal handling procedures followed the approved University of Montana animal welfare protocol.

Home Range

We located radioed bears using standard methods of ground-based triangulation (White and Garrott 1990) with a TR-4 receivers (Telonics Incorporated, Mesa, AZ, U.S.A.) and a hand held RA-14K rubber-ducky “H” directional antenna (Telonics Incorporated, Mesa, Arizona, U.S.A.). Each location was taken from at least 2 locations at approximately 90-degree angles from the bear’s position within 30 minutes, or simultaneously taken by 2 people from different locations in 2-way radio contact. All telemetry locations were taken from 0900 h to 1100 h daily, if possible. Thirty-two bear encounters in the forest within 300 m of the triangulated locations of radioed bears reinforced our confidence in accuracy. The locations of radioed bears was also obtained from recaptures, sightings by field crews, and photographs taken by camera traps. We attempted to locate Bear #122 and Bear #120 twice a month from January 2001 to July 2001. All locations were plotted on 1: 25,000 topographic maps and assigned grid coordinates based on the Universal Transverse Mercator (UTM) system. Home range size was calculated using the Adaptive Kernel method (Worton 1989; Worton 1995), with ArcView GIS 3.2a (Environmental Systems Research Institute, ESRI, Redlands, California, U.S.A.). We calculated the home range core areas of radioed bears using the Adaptive Kernel method with ArcView GIS 3.2a (Environmental Systems Research Institute, ESRI, Redlands, California, U.S.A.). The home range core areas are known as the areas used most intensively by, and most important to, the animals (Burt 1943; Samuel and Green 1988; Powell 2000). The home range core area in this study was defined as the smallest areas enclosing 25% of total use by any given animal (Powell 2000).

Movement Patterns

Location data were used to measure sun bear daily movements and their association to other radioed bears and habitat characteristics. Linear distances between animal locations on consecutive days provided an index of how far animals traveled in a day. We used ArcView GIS 3.2a (Environmental Systems Research Institute, ESRI, Redlands, California, U.S.A.) to calculate average daily travel distance and to plot movement patterns on a map that was digitized manually from a 1:25,000 topographic map.

Activity Patterns

Activity patterns of radioed bears were recorded manually through 24-hour continuous monitoring once a week from a fire observation tower at Bukit Atur (Atur Hill), located at the center of the study area. Using criteria by Beier and McCullough (1988), the signal strength and pulse was scored manually as active (1) or inactive (0) in 10-minute intervals, providing 144 readings per day. Activity rate was calculated by dividing the number of active times by the total number of times for each bear for the time period of interest. Monthly activity was calculated by averaging the percent activity of each 24-hour monitoring period. Only the data from one bear were sufficient to analyze monthly activity from May to November 2000.

Activity of bears was also collected from camera traps. Ten camera traps were used from June 1998 to December 2000. Each camera unit consisted of a fully automatic (auto focus/advance/flash), weather-proof, point-and-shoot 35- mm Pentax 606 camera combined with a passive infrared motion and heat sensor designed specifically for detecting animals in the wild (Wildlife Research Laboratory, Department of Wildlife Conservation, National Pingtung University of Science and Technology, Taiwan R. O. C.). Sites for cameras were carefully chosen near areas of potential wildlife use such as animal trails, water pools, mud wallows, and trap sites. Each camera unit was relocated every 6-10 weeks. A variety of baits such as chicken entrails, meat scraps, fish, fruit, liver-oil, fruit extracts, honey, air refresher, etc. were used in most camera stations to attract animals. Each photograph was printed with the date and time the picture was taken. We assumed that the numbers of photographs taken at various times were correlated to activity periods of bears. In other words, the number of photographs with bears taken in a particular hour represents their relative activity patterns. Time periods were pooled to hours due to small sample size. We compared the activity pattern obtained from the radio signals with the activity data from camera traps by looking at the time period where the animals were active.

Bedding Sites

Bear locations were visited within 2-4 hours after the coordinates were taken to look for any feeding evidence, such as bear scats, feeding sites, or claw marks on trees, and other activities. We also attempted to track radioed bears on foot when possible at a distance so as not to disturb the bear but to visit locations of activity soon after the bear left activity sites. In some cases, bears were observed directly foraging, traveling, and resting. When we found bears resting at bedding sites, we waited close-by quietly until the bears awoke and left the area. After the bears left the area, we recorded details of the microhabitat of the area, took measurements of the bedding sites, and collected scats and hairs.

RESULTS

A total of six bears (5 male, 1 female) were trapped during 2,372 trap nights. Trapping success was extremely low (1 bear/ 396 trap nights), probably due to the low density of sun bears in the study area and their wariness. Physical parameters and other capture information for all captured bears are in Table 2. The results presented below are based on 4 male bears (Bear #125, 124, 122, 120). Data from Bear #123 were not included in the analysis due to the low number of locations and short monitoring period. We failed to collect any data from Bear #121 due to a suspected malfunction of her radio-transmitter within 24 hours after her release.

Home range

Between June 1999 and July 2001, 344 locations of 4 radio-collared male bears were collected. About 80% of these location data came from radio telemetry while the remaining data were collected from trapping, camera traps, and sightings by field crews (Table 3). Bear #125 and Bear #124 were monitored for approximately 4 months and 2 months, respectively, in 1999; Bear #122 and Bear #120 were monitored for approximately 14 months and 10 months, respectively, in 2000 and 2001. The number of locations from which home range was estimated varied from 43 to 176 (mean= 85.7, n=4). From June 22, 1999 to December 31, 2000, the mean interval between locations of individual bears was 1.6 days. Estimation of annual home range was not possible due to the limited monitoring period of radioed bears, except Bear #122, which was monitored for more than 14 months. In this paper, we report the home range sizes of bear tracked, regardless of the duration of monitoring period. Only 1 location per day per bear was used to estimate home range.

The home ranges of 4 male Malayan sun bears in Ulu Segama Forest Reserve ranged between 6.2 km^2 and 20.6 km^2 (Table 3). Average home range size for these bears was 14.8 km^2 (n=4, SD= 6.1 km^2). The home range size of Bear #125 for four months was 16.8 km^2 and incorporated both primary forest (40%) and secondary forest that had been logged in 1988, south of Danum Road (Figure 4). The home range size of

Bear #124 after two months of radio tracking was 6.2 km^2 and was directly north of Bear #125's range. But unlike Bear #125, a logging road located at the center of Bear #124's home range. The home range of Bear #124 only occupied logged forest, which was also selectively logged in 1988. Using a 95% adaptive kernel estimator, the home ranges of Bear #125 and Bear # 124 overlapped by 0.54 km^2.

The number of locations of Bear #122 was the highest among the four bears in our study. His locations were taken almost daily from the time of his capture to December 2000. After that, his locations were taken once every two weeks until June 2001. However, his home range size (20.6 km^2) remained stable after the first four months of locations and did not increase proportionally with the number of locations collected. Bear #122's range originated in logged forest that had been logged in both 1988 and 1989, and incorporated the main logging road and Danum Road (Figure 5). The home range size of Bear #120 was 15.56 km^2 and was found only in logged forest that was logged in 1989. However, Bear #120 probably has a larger home range size because there were several occasions when we failed to locate Bear #120, despite intensive efforts to search for his radio signal. The home range of Bear #120 was located west of Bear #122's range. The home range of Bear #122 and Bear #120 overlapped 3.45 km^2.

Even though the 95% adaptive kernel home range of these bears overlapped, the 25% core areas did not overlap (Figure 6 & 7). Bear #125 and Bear #124 developed one core area within their home ranges, while Bears #122 and #120 developed two core areas within their home ranges. These core areas ranged between 0.32 km^2 and 1.10 km^2 (mean= 0.68 km^2, SD= 0.32 km^2, n= 4) (Table 3).

Movement Patterns

We did not observe radioed Malayan sun bears completing long distance movements or seasonal migrations, probably due to the constant tropical environment where such behaviors are not necessary, or simply perhaps because of the short monitoring period. The daily movement distance for the animals mentioned ranged from 141 m to 5660 m. The mean daily movement distance of the four radioed bears was 1454.5 $\pm$ 240.2 m (Table 4). The use area of Bear #125 was concentrated south of Danum Road (Figure 8). He often traveled back and forth between the primary forest, about one kilometer west of DVFC, where he was captured, and the logged forest at the west end of his range, where his core area was found.

We divided the movement patterns of Bear #122 into two different time periods: May – August 2000, and September – December 2000, because we noticed a shift of area used after the first three months of radio-tracking. During the first period, Bear #122 moved primarily in an east –west direction, north of the main logging road (Figure 9). He developed one core area north of the road, where he found at least four fruiting fig trees and always stayed close to the fig resources until the total depletion of the crop. On 25 July 2000, we tracked Bear #122 on foot in the forest and found him feeding on a fruiting fig tree. Bear #122 remained very close to that fruiting fig tree for the next five days. On 13 October 2000, we recorded him near a garbage dump for the first time since his capture. The dumpsite was located at the most southern tip of his home range and about 3.5 km south from his core area at the northern part of his range. He remained in the vicinity of the garbage dump that became his second core area most of the time until June 2001. He would periodically travel north to his old core area where the fig trees were. Bear #122 crossed the main logging road many times even during daytime.

The home range of Bear #120 located in between Bear #122's range on the east and the Segama River on the west. Bear #120 generally concentrated his movements near his core areas where he was captured and later found a fruiting fig tree (Figure 10). Although the movement patterns of Bear #122 and Bear #120 showed minor overlap, we never found these two bears close to one another. The daily movement distance of Bear #120 were among the longest with a mean of 1810 m. The maximum travel distance of a sun bear in 24 hours was recorded for Bear #120, which was about 5.5 km.

Activity Patterns

24-hours monitoring- a total of 792 h of continuous monitoring for daily activity was obtained in 1999 and 2000 that resulted in 5,687 readings of activity. These included ten days (1,206 readings) of monitoring of Bear #125, nine days (1,104 readings) of Bear #124, three days (238 readings) of Bear #123, and 23 days (3,139 readings) of Bear #122. The analysis was based only on the 24-hour monitoring samples (n=45), and excluded activity data recorded from the brief period of radio monitoring to locate the bears.

Male Malayan sun bears exhibited unimodal activity, where activity occurred mostly in the daytime (Figure 11). Activity started at dawn, before sunrise, at 0530 and increased abruptly 30 minutes later. The activity reached a peak (>80% probability of activity) between 0640 and 0800 and decreased slightly between 0910 and 0940 (53% probability of activity), probably due to the morning resting period. Activity then slowly increased and reached the highest peak at 1230 and remained high until a sharp drop of activity at 1640 and immediately rose to a third peak an hour later. Decreasing activity in general occurred after 1800 in the evening and slowly decreased as dusk approached, with sunset at 1830. Due to a dense canopy layer of the forest, the forest floor becomes dark in the forest immediately after sunset at 1830. After 2100, the activity of the sun bears reached its lowest level with < 20% probability of activity and remained at this level until the next morning at dawn. However, we did find variation among bears. For instance, Bear #125 was a strictly diurnal animal. On the other hand, Bear #124 had two major resting periods at 0800 and 1400 shortly after two activity peaks. Bear #124 also had two activity peaks, which reached about 60% probability of activity at 2000 and 0030. Despite these variations in general, male Malayan sun bears at Ulu Segama Forest Reserve were basically diurnal animals.

The monthly percentage of activity for Bear #122 fluctuated between 40% and 70% from May to November 2000; with 52% mean monthly activity level. The bear was most active in September (70%) and least active in July 2000 (Figure 12).

Camera traps- a total of 49 camera trap stations were set up in the forest that accumulated 858 camera/nights (19,418 working hours). These cameras took 2,667 photographs, of which 1,957 were effective photographs that contained at least one animal (73.45% success rate). A total of 198 photographs of Malayan sun bears were taken. However, many of these photographs were of same bear taken continuously by the camera when the bear wandered around the camera station. To make the analysis meaningful, we analyzed the data only from the initial picture, if a series of continuous photographs were taken of the same bear within a 10 minute period. Only 63 photographs fulfilled this criterion and were used for the analysis of activity.

If photographs are used as a measure of activity of Malayan sun bears, the results from camera traps show different activity patterns than the radio monitoring. Photographs of Malayan sun bears were taken predominantly during nighttime, especially at dawn and dusk (Figure 13). Up to 20 photographs (32%) and 9 photographs (14%) were taken at dusk and dawn respectively, in contrast to only 4 photos between 0700 and 1700. Numbers of photographs taken at night ranged from 2 – 4 photos every hour. The Malayan sun bears were more active during the crepuscular period.

Bedding Sites

We found 26 bedding sites for Malayan sun bears. Bedding sites consisted of twelve cavities of hollowed-fallen logs (46%), six on tree branches (23%), five cavities in standing trees (19%), two cavities underneath tree roots (8%), and one cavity underneath a fallen log (4%) (Tables 5 and 6). We sighted radioed bears using seventeen of these bedding sites: either they were resting in/on the bedding sites or coming out/down from them. Other bedding sites were determined from tracking radioed bears on foot and from radio signals transmitted from a hollowed log or cavity. Due to dense undergrowth, we sometimes failed to observe bears when they left bedding sites, but did know the bear left the area from fading radio signals.

We categorized bedding sites of Malayan sun bears into five types: a) cavities in hollowed fallen logs, b) tree branches, c) cavities at the base of standing trees, d) cavities underneath tree root systems, and e) cavities underneath fallen logs. The first type of bedding site was the most common and was frequently found in the study area. These were cavities in large hollowed tree trunks that may measure up to 49 m long, or large hollowed tree branches. They were in trees that either naturally fell, or in trees purposely felled during logging operations, but apparently discarded due to their hollow trunk (Figure 14). They usually have two entrances, one bigger entrance at the base of the tree and one smaller at the far end of the log. These logs were from large sized trees with diameter > 100 cm. (Table 6). The family and species of these tree logs were usually unidentifiable due to the highly decayed condition. However, based on their large size and being purposely felled, we suspected that many of the logs were also members of family Dipterocarpaceae. Like in the standing tree cavities, the floor of hollowed-fallen logs was dry, soft, and sometimes a depression with 80 cm in diameter.

On May 1999, a forest worker sighted two Malayan sun bear cubs, probably at the age of two to three months, emerge from a 40 m hollowed-fallen log (RC 18) and vanish into the dense vegetation. We revisited RC 18 many times and set up a camera trap in front of the cavity entrance to monitor bear activity but failed to detect any bear presence. Instead, the 20-m-deep cavity was occupied by two thick-spined porcupines (*Thecurus crassispinis*) for up to eight months. These types of bedding sites may serve as important dens for females to raise cubs.

The third type of bedding site was a standing tree with a cavity inside the main trunk. We sighted radioed bears using all of the six standing tree cavities (Table 5) as bedding sites for > 2 hours, except RC 1. RC 1 was a tree cavity where we found the remaining skeleton and radio-collar of Bear #123. Bear #123 was suspected of dying from old age and malnutrition (see Chapter 4) and apparently was seeking safe cover. Some entrances of these cavities were cracks on the main tree trunk with relatively narrow width. Others, like RC 02, was actually a tunnel-shaped 170 cm deep cavity from the tree's buttress, where Bear #125 was found deep inside the tunnel. The floor space of these bedding sites was roomy for a bear (Table 5), but the bear usually rested in a corner of the cavity. The floor of these cavities was matted with a thick layer of woody debris from the wall the tree trunk and was surprisingly dry and soft. We found no evidence of bears carrying bedding materials into these bedding sites. The majority tree species of this type of bedding site were from the family Dipterocarpaceae, the main timber species in Sabah.

In general, the forth type of bed was a dirt hole under a tree where parts of the root system were exposed either on flat ground or steep slopes. We sighted Bear #122 on two occasions where he rested inside cavities underneath a standing tree root. One of these sightings occurred on 6 August 2000 where Bear #122 was feeding on a Burmese giant tortoise (*Geochelone emys*).

Bedding sites of Malayan sun bears were not only confined to tree cavities, they also rested in tree branches, high above the ground and exposed. We sighted Bear #122 five times when he rested in a tree, and one sighting from a non-marked bear clinging to the branches of a tree. On June 10, 2000, STW sighted Bear #122 resting in a huge mengaris tree (*Koompassia excelsa)*, the tallest tree species in Borneo, about 50 m above the ground. Bear #122 was lying with his belly on the tree branch, and his four legs hanging down on the tree branch. The mengaris tree was a host tree for a fruiting strangling fig tree (*Ficus* sp.). Bear #122 was observed resting for 40 minutes, with some minor position changes once in a while. He later climbed down to another smaller branch opposite the previous branch to harvest figs. Another similar sighting was made on July 19, 2000 of Bear #122 resting and feeding in another tall mengaris tree, which was hosting a fruiting strangling fig tree. Other sightings included Bear #122 sitting straight up on a tree branch and clinging to the main trunk of a fruiting *Euginia sp*. (Fam. Myrtaceae), and lying on the first branch of a huge *Shorea johorensis* (Fam. Dipterocarpaceae), about 20 m above the ground.

DISCUSSION

This study is one of the first ecological studies ever conducted on wild Malayan sun bears, and there are no scientific reports available to make comparisons. As a result, we used ecological data from American black bears (*Ursus americanus*), Asiatic black bears (*U. thebetanus*), and, to a lesser extent, sloth bears (*Melursus ursinus*) to compare ecological parameters to those of Malayan sun bears. We are aware that the average body weights of these bears used for comparison (100 –115 kg) were more than twice the average body weight of sun bears (45 kg) (Brown 1993).

Home Range and Movement Patterns

Ursids other than Malayan sun bears usually live where there are distinct seasonal changes in food. These bears usually have seasonal home ranges. As mobile and opportunistic mammals, bears show changing home range use in accordance with changes in resource abundance (Hazumi and Maruyama 1987; Powell 1987; Nagy and Haroldson 1990; Smith and Pelton 1990; Reid et al. 1991; Mano 1994; Joshi et al. 1995). Malayan sun bears in the study area were active year round and lived in a relatively constant environment without clearly evident seasons other than in respect to rainfall and fruiting seasons. Analysis of limited scat samples in the study area showed no evidence of shifts in diet (Wong et al. in press). It may be that shifting seasonal home ranges by Malayan sun bears is unnecessary.

Compared to adult male Asiatic black bears and sloth bears that have an average annual home range of 12.5 km^2 and 14.4 km^2, respectively (Hazumi and Maruyama 1987; Joshi et al. 1995), the home range of male Malayan sun bears in this study was slightly larger than that size (mean= 14.8 km^2). However, home ranges of male sun bears were much smaller than the home ranges of male American black bears that range from 79 km^2 to 1,721 km^2 in various states in North America (Amstrup and Beechum 1976; Hugie 1982; Wooding and Hardisky 1994; Warburton and Powell 1985; Smith and Pelton 1990; except for a few studies reporting a smaller annual home range size for male black bears- Garshelis and Pelton 1981; Hellgren and Vaughan 1986; Lindzey and Meslow 1977).

Harestad and Bunnell (1979) evaluated the relationship between North America mammal home ranges and body weights, and postulated that the home range (in ha) (H) of omnivores can be related empirically to body weight (in grams) (W) by the formula $H = 0.059W^{0.92}$. Using this formula, Malayan sun bears with body weights of 40 kg would have home range of approximately 10.1 km^2. If home range size is a reflection of the quality, abundance and distribution of food (Harestad and Bunell 1979; Gittleman and Harvey 1982; Hixon 1987; Gompper and Gittleman 1991), then the large home range size of sun bears in this study may imply low quality, abundance and distribution of food in the study area.

Tropical rainforests usually give an impression of high food abundance throughout the year due to high biodiversity, constant environment, and optimum growing conditions. However, our phenology data (Chapter 4) documented prolonged low fruit production in the forest during the entire study period. This is a typical "non-fruiting period" observed in tropical dipterocarp forest in Borneo and western Malesia. These forests have a striking feature known as "mass flowering" followed by "mass fruiting" (episodic synchronous reproduction interspersed with periods of little or no seed production) (Janzen 1974; Chan and Appanah 1980; Appanah 1985; Ashton et al. 1988; Curran and Leighton 2000). The low fruit production observed during study was most extreme between August 1999 and September 2000 when we observed various stages of starvation among all six radioed bears and bearded pigs (*Sus barbatus*) (Chapter 4). We suspect that two of the monitored bears and several bearded pigs died from starvation during this time (Chapter 4).

We documented two core areas for Bear #122, and both of these core areas were important feeding sites. We saw Bear #122 feeding at a fruiting fig tree in one of the core areas, where he remained close to the fruiting fig tree for weeks until the fig resource was depleted (usually in about two weeks). Bear #122 still came back to check these areas frequently after the fruiting period had ceased. In mid-October 2000, Bear #122 moved southward to a garbage dump that was actively used by the Danum Valley Field Center and FACE nursery. This dumpsite later became the most important core use area after fig sites. We speculated that because of the lack of natural food in the forest, Bear #122 learned to exploit human food at this dump. His physical condition was extremely poor by August and September 2000, and we anticipated he would soon die from starvation. His condition improved significantly after he found the dumpsite. We speculated that the lack of natural foods would have resulted in his death by starvation if not for the dumpsite.

For decades, bears throughout the world have been known for exploiting human food at garbage dumps. Many of these bears became nuisance animals (Howard and Marsh 1972; Herrero 1983; Rogers 1989; Eberhardt and Knight 1996; Thomas 1999). On October 2001, a nuisance Malayan sun bear was captured in DVFC and detained by Sabah Wildlife Department. This adult male bear appeared in the vicinity of the field center in early August to feed on garbage. It also broke into the staff kitchens to steal human food (Senthilvel K.K.S. Nathan, veterinarian, Sabah Wildlife Department, Sepilok Orangutan Rehabilitation Center, Sabah, Malaysia, personal communication, 2001). Due to strict prohibitions on poaching in the vicinity of the field center, this bear was very lucky to be alive. In other areas, nuisance sun bears that ruin oil palm plantations and agriculture are usually killed by angry stockmen and farmers (Servheen 1993a; Santiapillai and Santiapillai 1996; Meijaard 1999b). Fredriksson (1998) reported three out of five ex-captive sun bears that were radio-collared and released into the wild were eaten, shot, and/or killed for the sale of their body parts, as they wandered close to human settlements. Servheen (1993b) noted that one of the primary bear conservation needs is for people who live in bear habitat to properly dispose of their garbage.

Movement Patterns

Many studies on the movement patterns of American black bears (Amstrup and Beechum 1976; Garshelis and Pelton 1981; Kasbohm et al. 1998) and brown bears or grizzly bears (Clevenger et al. 1990; McLoughlin et al. 1998) conclude that food availability was the most important factor that influenced bear movements. No distinct fruiting period where bear food became abundant occurred during the entire study period. Thus, it was not possible to compare daily movement distances between fruiting season and non-fruiting season. Amstrup and Beecham (1976) reported that the daily movements of American black bears were greater (mean = 1.5 km) in 1973 when food was sparse, than in 1974 (mean = 1.1 km), when food was diverse and abundant. Similarly, Pelton (1989) reported American black bears in Tennessee moved 2-4 times farther in poor acorn years than in good ones, and Rogers (1977) documented increased numbers of bears moving during scarce food years (in Kasbohm et al. 1998).

Malayan sun bears during our study fed mainly on invertebrates, such as termites (Isoptera), beetles (Coleoptera) and beetle larvae (Coleoptera), and figs, if available (Wong et al. in press). Our observations of sun bears in the study area indicated that bears were constantly searching for food while walking with their head pointing down the ground and nose sniffing debris on forest floor. The low fruit production between June 1999 and December 2000 has caused the bears to be constantly in search of food.

In our study, figs were the most important fruit eaten by Malayan sun bears especially because figs were available in large quantities at certain sites (Wong et al. in press). Figs are a keystone resource for tropical frugivorous species, especially birds, primates and bats (Janzen 1979; Leighton and Leighton 1983; Terborgh 1983; Kalko et al. 1996; Kinnaird et al. 1999). The attractiveness of figs for wildlife has been attributed to their asynchronous fruiting patterns, the tendency to produce large crops of 10,000 – 60,000 fruits that ripen synchronously per tree, and low interannual variation in fruit production (Janzen 1979; Leighton 1990). In 1999, we failed to find any fruiting fig trees in the home ranges of Bear #125 and Bear #124 and thus have limited information on the use of figs by these bears. However in 2000, we found five fruiting fig trees inside the home ranges of Bear #122 and Bear #120, and three other fruiting fig trees outside their range with fresh sun bear claw marks on the tree trunks. On two occasions, we either sighted or photographed (from camera traps) up to three different bears, both marked and unmarked, visiting the same fruiting fig trees. Similar sightings also were reported in Barito Ulu Research Area, Central Kalimantan, where at least three sun bears were present in the 430-ha forest during a fruiting peak in May 1997 (McConkey and Galetti 1999). We strongly believe that food availability, especially figs, has a strong influence on movement patterns of sun bears.

Activity Patterns

Activity patterns of animals are considered an adaptation to seasonal and diurnal variation of environmental factors (Cloudsley-Thompson 1961; Nielsen 1983). Aschoff (1964) stated that the daily activity pattern of an animal results from a complex compromise between optimal foraging time, social activities, and environmental constraints. In our study, male Malayan sun bears exhibited a definite diurnal pattern of activity based on 24-hour monitoring. Diurnal behavior of Malayan sun bears was also reported by Lim (1999) and MacKinnon et al. (1996). Based on camera traps and some direct observations, Yasuma (1994) stated that the sun bear is nocturnal. Other reports that support the latter included Lekagul and McNeely (1977), Tweedie (1978), Medway (1978), Domico (1988), Nowak (1991), and Sheng et al. (1998). Other references, however, considered sun bears as active mainly at nighttime, but also sometimes during the day (Davies and Payne 1982; Kanchanasakha et al. 1998), and periodically active during day and night (Payne et al. 1995; Yasuma and Andau 2000). A behavioral study of captive Malayan sun bears at zoos showed a naptime between 1000 h and 1100 h, and a highest peak of social activity between 1430 h and 1500 h (Hewish and Zainal-Zahari 1995). Another study of captive sun bears reported activity concentrated during morning and evening, and resting occurring during most of the daytime (Feng and Wang 1991). However, this behavior was related to the feeding time in captivity and this artificial setting has likely resulted in the diurnal behavior of the captive sun bears. J. Holden's (researcher FFI, Sungai Penuh, Indonesia) reported photographs of sun bears taken by camera traps in Sumatra, Indonesia, were often made between 1200 and 1500 hrs (in Meijaard 1999b), suggesting bears in that area move about considerably at midday. van Schaik and Griffiths (1996) showed that the Malayan sun bears were active both day and night.

The majority of sun bear photographs taken by camera traps in our study were made during the crepuscular period (dusk and dawn) and nighttime, with very few photographs taken during the daytime (Figure 13). The results were contradictory to our 24-h monitoring data, if the relative number of photographs taken at different time periods implies bear activities. This phenomenon can be explained by the disproportional sampling efforts and strata when setting up camera traps. Usually these camera-traps were set up 1.3 m above the ground and were targeted more on terrestrial animals then arboreal animals. Malayan sun bears are known for their arboreal activities like foraging, resting, and nest building in trees (Fetherstonhaugh 1940; Medway 1978; Payne et al. 1985; Domico 1988; Kanchanasakha et al. 1998; Lim 1998; Meijaard 1999b; Wong et al. in press). Of 32 sightings of sun bears in the study, we sighted sun bears in trees on seven of these occasions. Nevertheless, this number may be misleading because sun bears are difficult to sight in the wild due to thick undergrowth. It would be even harder to sight them in trees simply because of the thicker and multi-layer canopy in tropical rainforest (S.T. Wong, personal observation).

The contradictory results between activity data collected from different methods were also reported by Pei (1998). He compared the activity pattern data of Formosan macaques (*Macaca cyclopsis*) gathered from field observation and camera traps. These differences in activity pattern may stem from the fact that these data were collected from different strata. Data from Wu and Lin (1993) were mainly collected from observing Formosan macaques from the forest canopy, whereas the data from Pei (1998) was mainly collected from camera trapping that was set up on the forest floor. Knowing the specific niche occupied by the study animals and setting up the camera traps at appropriate forest strata to reduce bias can overcome this problem.

Another possibility for this contradictory results may simply caused by the wariness of sun bears to human scents found at the camera stations. These bears may avoid these camera sites during the daytime and would only approach during the nighttime.

In North America, behavior of bears is apparently associated with human-induced modifications to the environment (Ayres et al. 1986). This may explain the nocturnal behavior of American bear species, such as grizzly bears and American black bears feeding in orchards, garbage dumps, and campgrounds (Waddell and Brown 1984; Ayres et al. 1986). Diurnal activity in bears and other wildlife is usually considered as a result of low human activity (Roth and Huber 1986; Griffiths and van Schaik 1993a). A similar idea was also suggested by I. Singleton (Leuser Development Project, Medan, Indonesia): in heavily disturbed areas sun bears may have undergone a change from predominantly diurnal to nocturnal activity to avoid confrontation with humans (in Meijaard 1999b).

Griffiths and van Schaik (1993b) provided support for the variability of sun bear daily activity patterns in relation to human disturbance. By using camera trapping, they compared sun bear activity and density in two study areas in northern Sumatra, i.e., a heavily human-traveled area (Ketambe, 0.728 human passes/camera week) and a pristine site (Bengkung, 0.003 human passes/camera week), with similar vegetation and topography. Their data indicated 100% of nocturnal activity in Ketambe, while only 18%

of nocturnal activity in Bengkung (Griffiths and van Schaik 1993b). These observations indicate that human traffic in a tropical rainforest can, in itself, alter the activity period of Malayan sun bears, even if unaccompanied by any disturbing activities such as logging, hunting and fire making (Meijaard 1999b). The low level of human activities in the home range of Bear #125 and Bear #123 may have resulted their diurnal activity patterns, if this was true. In contrast, the home range of Bear #124 and Bear #122 included a 20-m wide logging road with intense human use (quantitative measures not available). The home range of these two bears also occur in a large-scale enrichment-planting project to rehabilitate logged forests, where forest workers visited these forests several time a year to maintain planting strips and to survey the survival rates of seedlings planted (Yap et al. 1996; Yap and Simmons 2000). These human activities may have caused Bear #124 and Bear #122 to have more nocturnal activities. In fact, the majority photographs taken by camera traps were from Bear #124 and Bear #122 (71% nocturnal activity), while none were taken of Bear #125 and Bear #123.

Nocturnal behavior of sun bears to avoid human confrontation may pose another threat to their survival. We found several wounds from shotgun pellets on Bear #124's back when he was first captured. After two months of radio-tracking and intensive monitoring, his signals disappeared and he was never seen or photographed in the study area again, despite intensive search efforts. We suspect that this bear was shot along roads from a vehicle with spotlights at night. This method is widely used in Sabah and Sarawak, Malaysia, where opportunistic poachers shoot almost all animals encountered, including ungulates, primates, clouded leopards, and Malayan sun bears (Caldecott 1986; Bennett and Dahaban 1995; Bennett et al. 2000). Conversely, we had never heard of poaching from vehicles during daytime anywhere in Sabah, at least. If poaching pressure were high on bears whose home range incorporated roads that allowed access to the forest interior, this nocturnal behavior would have adverse impacts to the survival of these animals. Eight months after the disappearance of Bear #124, we radio-collared Bear #122, which took over the home range of Bear #124 until the end of the study. Bear #122 used forests adjacent to the busy logging road and frequently crossed it, even during daytime. On June 14, 2000, at 1000 h, STW observed Bear #122 resting on the lowest branch of a huge *Shorea johorensis*, about 50 m north of the logging road, for 20 minutes. Bear#122 was on a big tree branch, about 20 m above the ground. His front legs were placed on the branch with his chin on top of his paws. He raised his head every time a vehicle passed by, but the vehicles did not seem to disturb him. Further investigations on the effect of human activities to daily activity patterns and the negative impacts of logging roads would promote understanding the trade-off between diurnal and nocturnal behavior.

The variation in the monthly percentage of activity for Bear#122 could result from food availability, especially with the availability of fruiting fig trees that caused the low monthly activity on July 2000 (40% activity). When sun bears found fruiting fig trees, they tended to stay close to the fruit crop with little activity. On July 18, 2000, we found Bear #122 feeding on a fruiting fig tree (Fig tree #2) and he stayed at the vicinity for the next five continuous days until the fruit resource was almost depleted. Two days later, on July 25, we found Bear #122 feeding on another fruiting fig tree (Fig tree #3) and remained close to the fig tree for another five days. We revisited Fig tree #3 on July 26 to monitor the activities of the fruiting fig tree and found Bear #122 remaining inactive $\leq$ 30 m from the tree. From 0900 h to 1800 h, we recorded three short activity periods of Bear #122 that lasted between 20 – 35 min, and he remained inactive the rest of the time. In contrast to the low percentage of monthly activity resulting from the availability of fruiting trees, the increased monthly percentage of activity in September (70%) (Figure 12) may be explained by the intense stress of hunger (see Chapter 4). In addition to the lack of evidence showing that Bear #122 consumed figs, photographs from camera traps taken on late August revealed an extremely emaciated Bear #122. He has protruding vertebra, ribs, and hipbones, with sparse fur and most of the hair on his face is gone (Figure 15). Additional evidence of the condition of Bear #122 came from the fact that he was recaptured seven times from August 19 to October 3, 2000. Each time he was recaptured, Bear#122 had consumed all available bait and stayed quietly inside the trap until we released him hours later. This "trap-happy" behavior can be explained by food desperation, which had overcome his wariness to capture. Limited information is available on hunger stress directly increasing activity of bears, but this phenomenon has been documented on other mammalian species. Smythe et al. (1982) reported that two large caviomorph rodents, the agouti (*Dasyprocta punctata*), and the paca (*Cuniculus paca*), foraged longer during the season of fruit shortage on Barro Colorado Island, Panama.

Bedding sites

Malayan sun bears used several kinds of day beds or bedding sites. However, during our study, we never found a tree nest. The use of "tree nests", or small "platforms" by sun bears, has been reported by Fetherstonhaugh (1940), Lekagul and McNeely (1977), Domico (1988), Piether (in Santiapillai and Santiapillai 1996), Kanchanasakha et al. (1998), Lim (1999), and McConkey and Galetti (1999). Domico (1988) and Brown (1993) described that sun bears make their beds in small platforms from broken branches, 2 to 7 m high in a tree, and this bed looks similar to the nests of orangutan, but are usually nearer to the tree trunk and more loosely made. Fetherstonhaugh (1940:17) described the nest building process by a six-month-old captive female sun bear.

> "She would shinny up a tree, climb out upon a limb until she reached a convenient fork where there were small leafy branches handy, and proceed to pull the twigs and leaves underneath her belly, lying upon them with her chin in the fork of the limb, her body along its length and all four legs hanging down. If overtaken by rain the procedure was the same and it was ludicrous to see her literally scuttle up the nearest tree and work against time to get a mat of leaves and twigs under her belly while leaving her back to the mercy of the elements; there she would stay with a look of patient misery on her face and not even hunger would get her down until the shower was over".

Similar nest-building techniques for the sun bears were also reported by hunters from North Sumatra, Indoensia (Meijaard 1999b). I. Singleton (in Meijaard 1999b) photographed a sun bear using an old nest, which was thought to have been constructed by an orangutan. Given the possibility that sun bears may use old orangutan nests, we checked for bear claw marks on > 100 of trees with orangutan nests during the study. We failed to find any trees with both an orangutan nest and bear claw marks. Interestingly, Pieters (in Santiapillai and Santiapillai 1996) observed sun bears in disturbed habitats and states that it is mostly in secondary forest that stick nests are used. This observation was confirmed by G. Fredericksson (in Meijaard 1999b) who observed 14 nests in plantations and gardens and none in the forest area during 3 years of survey work. McConkey and Galetti (1999) found three distinguishable sun bear nests in the tree canopy of a fruiting *Canarium pilosum* in the forest at Barito Ulu Research Area, a 430-ha forest located in Central Kalimantan, Indonesia, where orangutans are absent. Although no information about human disturbance in the forest is provided by McConkey and Galetti, the small forest size implies potential disturbance from the surrounding environment. Nest building might only occur in areas with significant human disturbance, where safe resting places are rare (Meijaard 1999b). In addition, the presence of big cats that share the same habitat with sun bears in Sumatra and the Asia Mainland, such as tigers (*Panthera tigris*) and leopards (*Pantrera pardus*), may cause sun bears to seek safer ground for bedding. Although the interaction between these species has rarely been reported, these big cats pose a significant threat to the life of this small bear. Lim (1998) suggested that the only likely enemies of the sun bear are a hungry tiger or panther (leopard). Van Balen (1914) (in Meijaard 1999b) reported a fight between a Sumatran tiger (*P.t. sumatrae*) and a sun bear in southern Sumatra. This kind of interaction may explain why reports of nest building behavior of sun bears in the forests (except plantation and gardens) were often from Sumatra and Asian Mainland, but not Borneo where these two large cats are absent. Clouded leopards are present in Borneo but this is a smaller cat and may be less of a threat to sun bears. Two other bear species that are reported to construct day-nests in trees are the South American spectacled bear (*Tremarctos ornatus*) (Peyton 1980; Domico 1988; Weinhardt 1993) and Asiatic black bear (Osteen 1966; Matthiessen 1978; Domico 1988; Schaller et al. 1989; Brown 1993). Asiatic black bears also construct day beds on the ground with bamboo and tree saplings (Schaller et al. 1989).

In contrast to the common reports of sun bears using tree nests as day beds, the use of tree cavities by sun bears has never being reported. These cavities in hollowed trees are commonly found in the study area. Other bear species such as Asiatic black bears (Lekagul and McNeely 1977; Wang 1988; Li et al. 1994), American black bears (Hayes and Pelton 1994; Weaver and Pelton 1994; White et al. 2001), and giant panda (Schaller et al. 1989) also utilize similar hollow tree cavities, not as day beds, but as denning sites for female bears giving birth to young. We believe that these tree cavities can also be denning sites for pregnant female sun bears. The sighting on May 1999 of two sun bear cubs coming out of a hollow log (RC18) helps further prove the potential function of such logs as dens for both female sun bears and cubs.

Johnson and Pelton (1983) reported that bear scats (mean = 2.5, range = 1-4) were found in all 25 summer beds of American black bears in Tennessee, USA. We found only five bedding sites (3 tree cavities, and 2 tree roosts) with scats near the beds, out of a total of 26 bedding sites found. One of these bedding sites, RC20, used by Bear #120, had 17 scats of various age. Radio tracking data indicate that the bear stayed in that area for at least four days, and harvested figs from a fruiting strangling fig tree about 250 m away. All of the scats contained primarily fig seeds, and with very few exoskeletons of termites and beetles.

CONCLUSION

Before the project started on May 1998, the Malayan sun bear was the least known bear in the world and the least studied large mammal in Southeast Asia. The lack of studies stemmed from the fact that sun bears are rare, seldom seen, compete for conservation attention with other species of higher conservation interest (i.e. tigers, orangutans, and rhinos), and live in a relatively harsh environment. This project has taken twenty-seven months of intensive field study to begin to describe the basic ecological aspects of this elusive bear in the Borneo rainforest. We learned that the Malayan sun bear requires a large home range, moves considerably in search of food, and uses old and large trees as bedding and denning sites. Food apparently varies significantly throughout the year, and in some areas bears may starve due to natural fluctuations in abundance of food. These findings also contradict several former studies on the impacts of selective logging on wildlife, which suggested that sun bears exist only in primary forest and that few are found in logged forests (Johns 1983a; Wilson and Wilson 1975; Wilson and Johns 1982). Our study clearly showed that Malayan sun bears do exist in logged forest. The importance of primary forest to the survival of the sun bear is unclear. More study is needed to understand the specific impacts of logging on the disturbance and survival of sun bears. Well designed logging practices, or environmentally friendly logging methods, such as reduced impact logging, should be considered by forest managers to benefit both human and wildlife needs. Other implications for forest managers include maintaining of large trees that lack commercial value (e.g., trees with cavities, hollow trees), prohibitions on damaging fig trees and the creation of buffer zones around fig trees, strict control of poaching activities, closing of logging roads after logging is completed, and education of local communities on the importance of the maintenance of forests and wildlife. Our results can generally be extrapolated to other part of Southeast Asia where the sun bear still exists in similar environments. Today, with the rapid disappearance of suitable sun bear habitat from logging, forest fire, and conversion of tropical rainforests into plantations and human settlements, the future of this little-known bear is far from secure. Well-planned conservation programs for Malayan sun bears should be a top priority for government authorities, non-government organizations (NGOs), and the scientific community. This conservation program should work closely with the various agencies, involve law enforcement agencies, the general public, and local communities who live and work in sun bear habitat. The program will hopefully gain national and international attention and recognition similar to conservation programs for Southeast Asian elephants, Sumatran rhinoceros (*Dicerorhinus sumatrensis*), tigers, and orangutans.

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Table 1. Tree biodiversity inventory of lowland tropical rain forest distributed in 1 ha of sampling area each in primary forest and logged forest sites at Ulu Segama Forest Reserve, Sabah, Malaysia.

PARAMETER	Primary forest	Logged forest	Total
Species richness	106	136	185
Number of families	39	41	46
Number of genera	70	89	111
Most speciose family	Dipterocarpaceae (13 sp.)	Euphorbiaceae (23 sp.)	
No.Dipterocarp species	13	20	
Most common Dipterocarp	*Parashorea tomentella* (n=21)	*Shorea johorensis* (n=19)	*P. tomentella* (n=31)
Tree species with highest number (ha^{-1})	*Diospyros* sp. (n=23)	*Shorea johorensis* (n=19)	*Sygygium* sp. (n=35)
Number of tree species with only one individual in 1 ha	41 species (8.8%)	13 species (2.9%)	70 sp. (7.7%)
Dipterocarp: Non-dipt. Ratio	1 : 5.5	1 : 2.8	

Source: Ahmad (2001)

Table 2. Physical parameters and capture information for radio-collared Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia.

ID #	Sex	Capture Date	Date Last Monitored	Age Class	Body Condition	Wt (kg)	TL (cm)	SL (cm)
125	M	22 June 99	12 Oct 99	Old	Fair	44	121	20
124	M	10 Jul 99	20 Sep 99	Old	Fair	40	124	24
123	M	7 Aug 99	10 Sep 99	Old	Poor	34	124	20
122	M	4 May 00	25 Jul 01	Sub-Ad	Poor	30	117	
121	F	24 Sep 00	25 Sep 00	Adult	Very poor	20	110	20
120	M	11 Oct 00	11 Jun 01	Adult	Fair	40	123	21

Age – Based on tooth wear, tooth color, body size, and overall condition

Body condition – Based on fat level, fur condition, and general appearance. Divided into 5 categories: range from “very poor”, “poor”, “fair”, “good” and “very good”.

Wt – Body weight, during first captured

TL – Total body length.

SL – shank length

Table 3. The number of locations of each bear collected from radio-telemetry, capture, camera trap, and sighting used in home range estimation.

Bear #	Capture Date	Date Last Monitored	Radio-telemetry	Capture	Camera trap	Sighting	Total # of locations	95% adaptive kernel home range	*Core area	Forest type
125	22 June 99	12 Oct 99	60	1	0	5	66	16.8 km^2	1.10 km^2	Primary & Logged
124	10 Jul 99	20 Sep 99	28	2	12	1	43	6.2 km^2	0.32 km^2	Logged
122	4 May 99	25 Jul 01	143	9	9	15	176	20.6 km^2	0.65 km^2	Logged
120	11 Oct 00	11 Jun 01	44	2	10	2	58	15.5 km^2	0.65 km^2	Logged
Total			275	14	31	23	343	Mean= 14.8 km^2	Mean= 0.68km^2	

*The home range core area was defined as the smallest areas enclosing 25% adaptive kernel home range of total use by any given animal.

Table 4. Linear distance (m) between consecutive daily locations (approximately 24 h apart) of Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia.

Bear ID	n	Mean	SD	Minimum	Maximum
125	36	1286	962	250	4890
124	17	1382	930	320	3150
122	88	1340	826	141	3667
120	24	1810	1294	316	5660
Total		1454 ± 240		256 ±83	4341±1142

Table 5. Dimensions of cavities of standing trees that served as bedding sites for Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia

Site No.	Slope	Tree spp.	Est. tree height	DBH	Size of entrance (Greatest width x height)	Floor space (Greatest length x width)	Remarks
RC01	20 degree	*Shorea sp.*	40 m (broken top)	160 cm	30 x 30 cm	100 x 100	live tree
RC03	10 degree	*Shorea sp.*	20 m (broken top)	190 cm	40 x 60 cm	120 x 150 cm	Dead tree
RC04	15 degree	*Dryobalanops lanceolata*	25 m	120 cm	19 x 120 cm	120 x 100 cm	Dead tree
RC09	Flat	Unknown	35 m	58 cm	27 x 33 cm	not measured	live tree, underneath tree root cavity
RC11	30 degree	Fam. Dipterocarpaceae	35 m	115 cm	16 x 137 cm	90 x 90 cm	live tree
RC02	Flat	Fam. Dipterocarpaceae	20 m	145 cm	50 x 26 cm	170 x 40 cm	Dead tree, cavity in the buttress
RC13	45 degree	*Macaranga hypoleuca*	10 m	35 cm	80 x 38 cm	2.1 m depth	cavity underneath the root system

Table 6. Dimensions of hollow logs on the forest floor that served as bedding sites for Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia.

Site No.	Slope	Tree spp.	Length of log	Diameter	Size of entrance (Greatest width x height)	Depth of cavity	Remarks
RC05	flat	Fam. Dipterocarpaceae	9.3 m	136 cm	136 x 120 cm	9.3 m	Chain-sawed
RC06	10 degree	*Shorea johorensis*	11.0 m	78 cm	45 x 50 cm	11.0 m	
RC07	flat	unknown	23.3 m	120 cm	90 x 90 cm	23.3 m	
RC08	40 degree	Fam. Dipterocarpaceae	26.0 m	124 cm	50 x 44 cm	9.3 m	
RC10	30 degree	unknown	4.8 m	136 cm	175 x 50 cm	4.8 m	Chain-sawed
RC12	flat	unknown	15.0 m	110 cm	62 x 40 cm	14 m	Chain-sawed
RC14	30 degree	unknown	49.3 m	104 cm	40 x 37 cm	6.0 m	
RC15	flat	unknown	6.3 m	110 cm	40 x 60 cm	4.0 m	
RC16	12 degree	Fam. Dipterocarpaceae	22.0 m	97cm	60 x 37 cm	4.9 m	
RC17	12 degree	Unknown	7.1 m	77 cm	70 x 54 cm	2.3 m	
RC18	15 degree	Unknown	40.0 m	130 cm	100 x 70 cm	20.0 m	
RC20	18 degree	unknown	11.3 m	113 cm	63 x 53 cm	11 m	Chain-sawed
RC19	30 degree	Unknown					Chain-sawed; cavity underneath the log

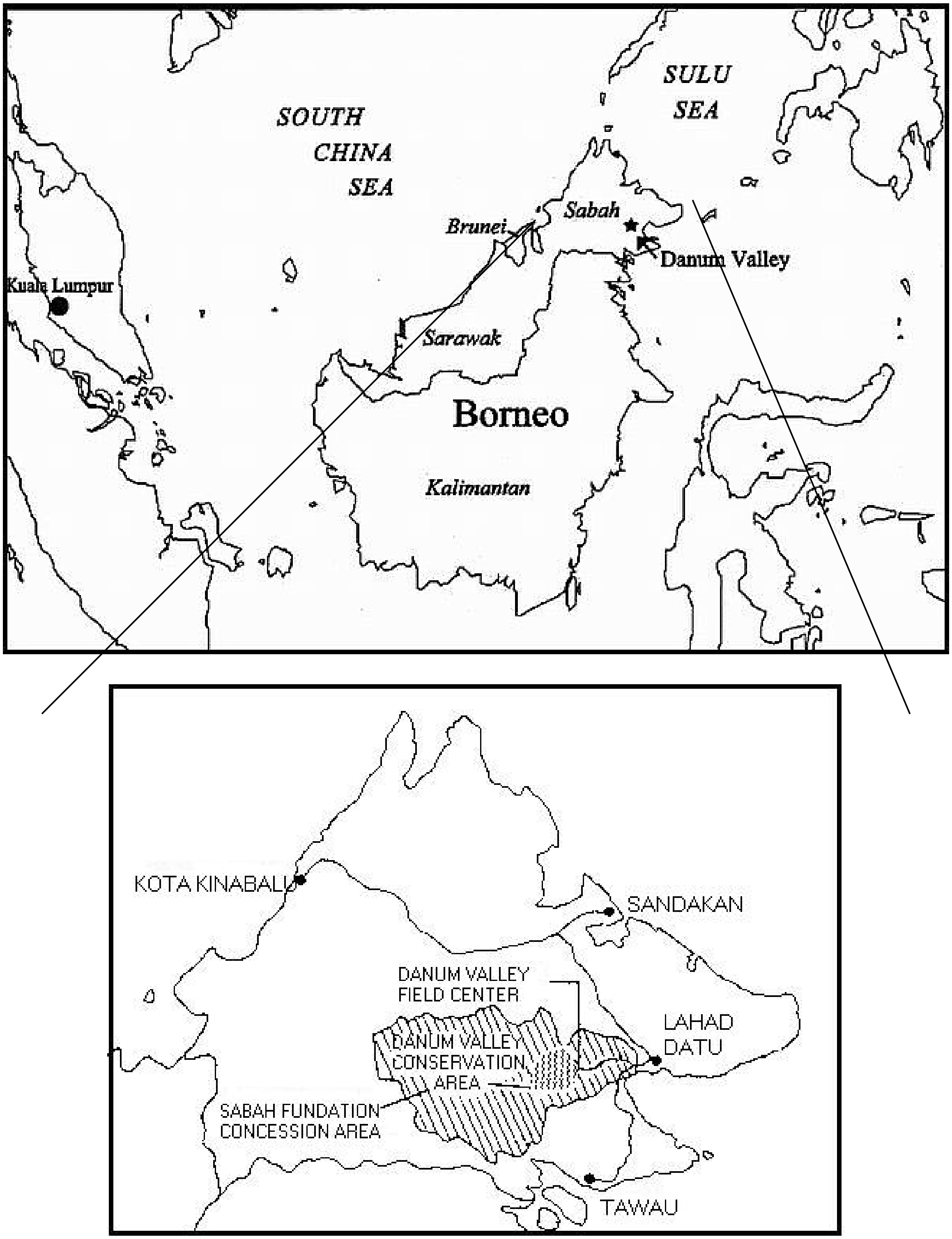

Figure 1. Location of the study area at Danum Valley Field Center at the state of Sabah, Northern Borneo.

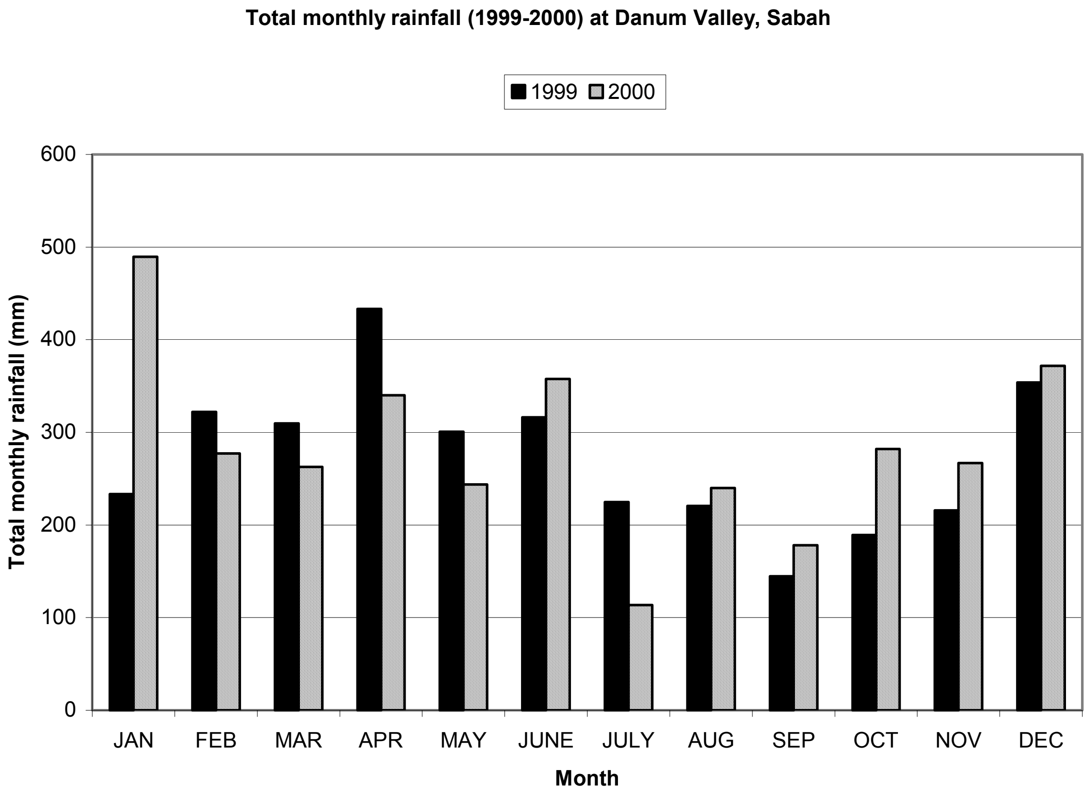

Figure 2. Total monthly rainfall in Danum Valley Field Center, Ulu Segama Forest Reserve, Sabah, Malaysia from 1999-2000.

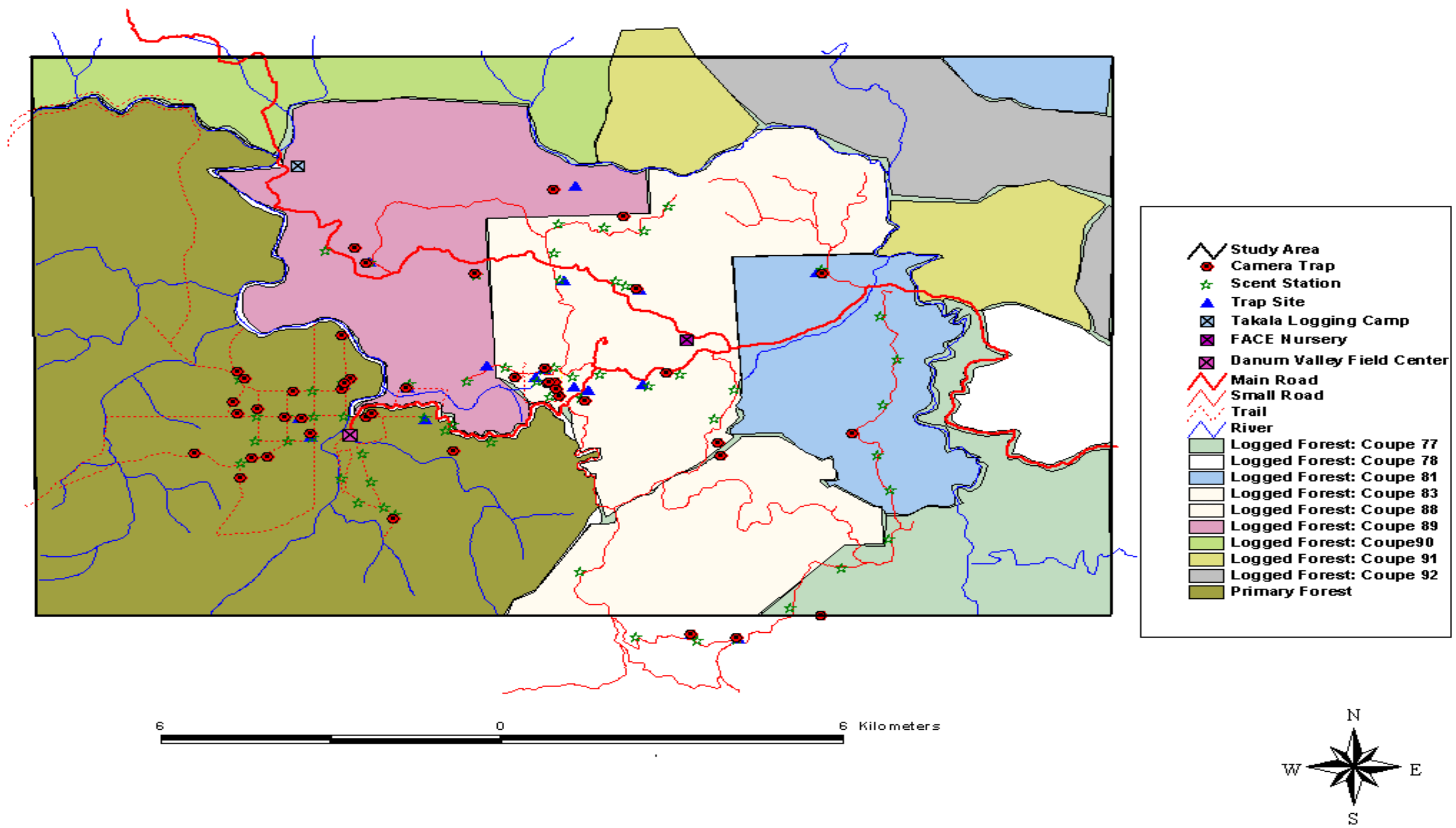

Figure 3. Traps sites, camera locations, scent stations, and logging history in the study area on approximately 150 km^2 within and adjacent to the Danum Valley Field Center

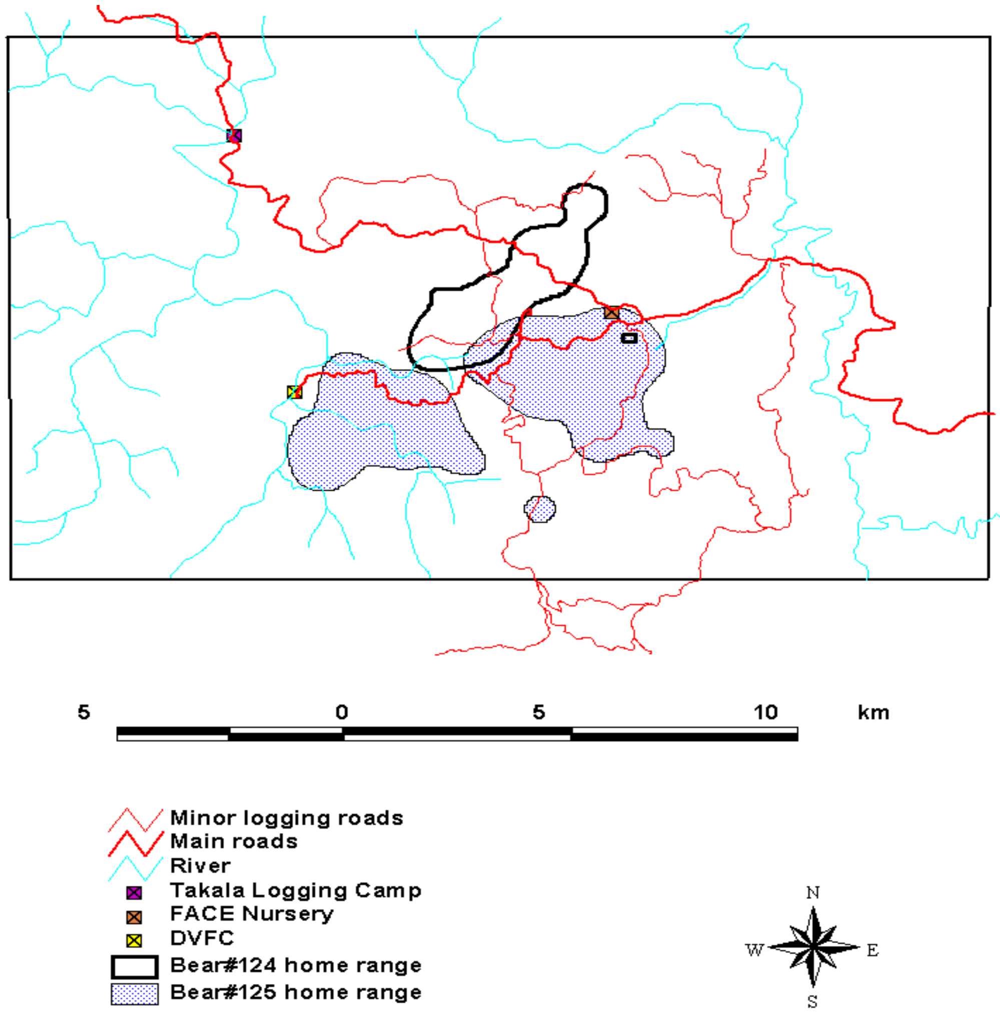

Figure 4. 95% adaptive kernel home range of Bear #125 and Bear #124 in Ulu Segama Forest Reserve, Sabah, Malaysia, from June – October 1999.

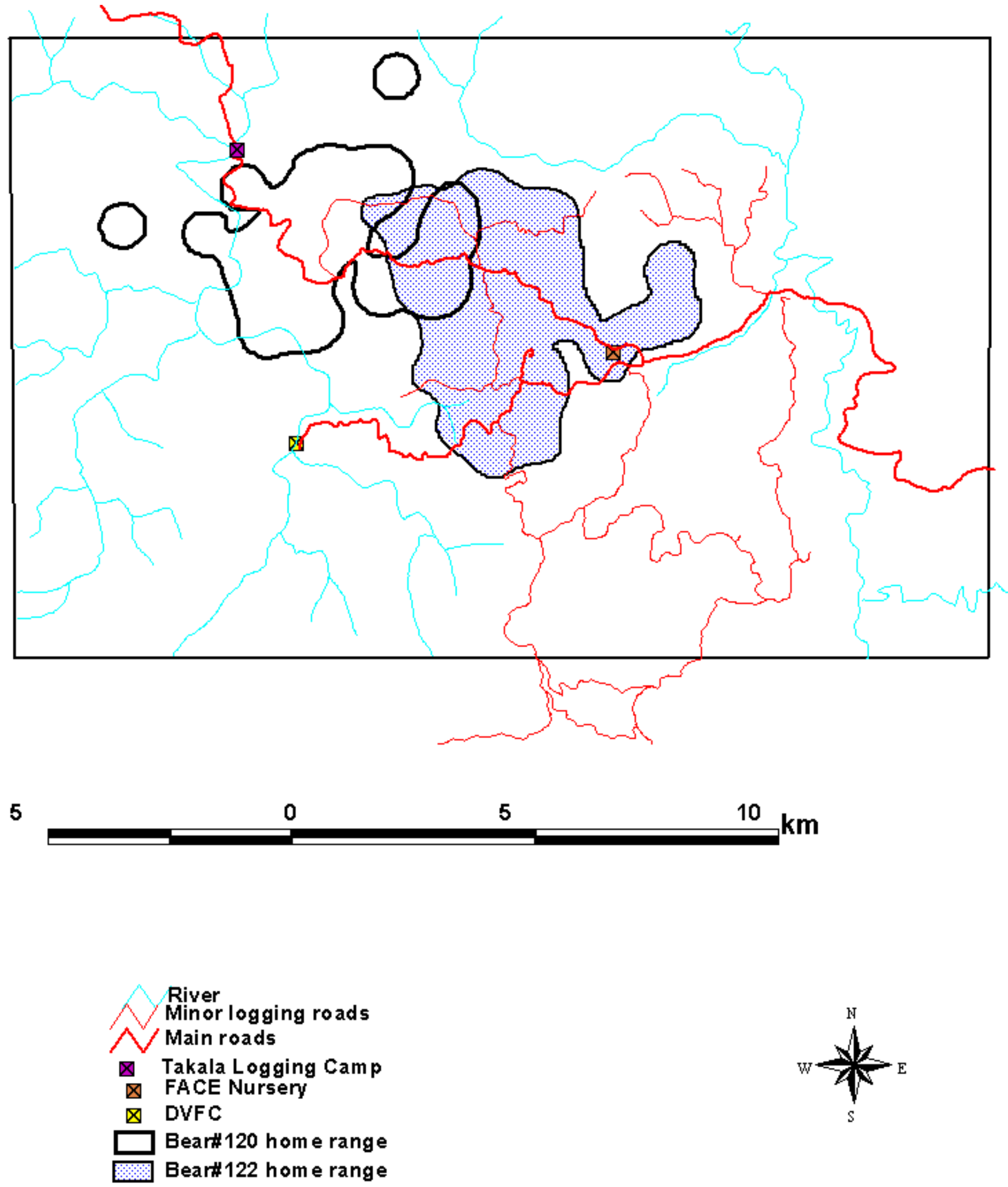

Figure 5. 95% adaptive kernel home range of Bear #122 and Bear #120 in Ulu Segama Forest Reserve, Sabah, Malaysia, from May 2000 – July 2001.

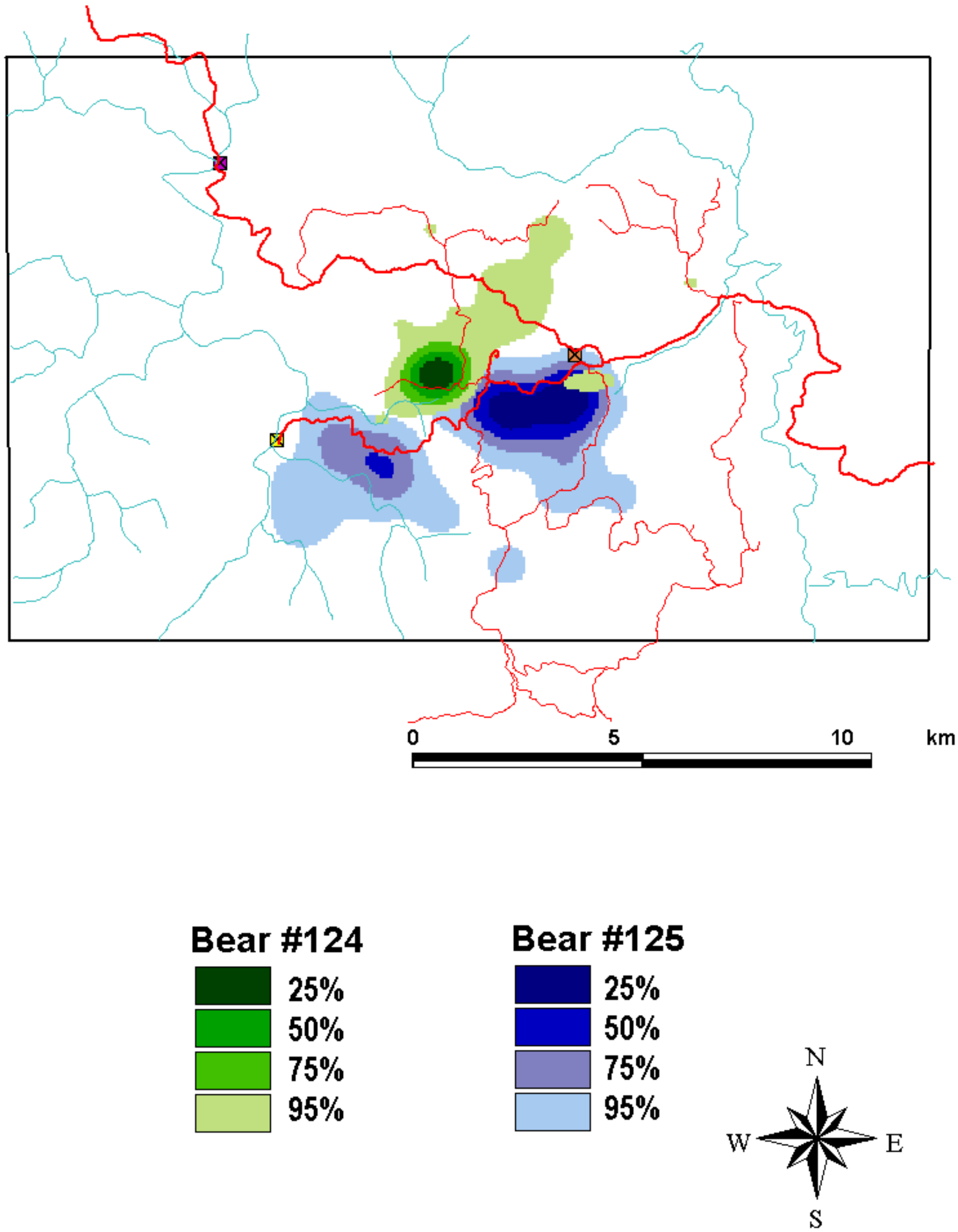

Figure 6. Adaptive kernel home range for Bear #125 and Bear #124 in Ulu Segama Forest Reserve, Sabah, Malaysia, during 1999 showing various utilization isoclines (in percent) and core areas.

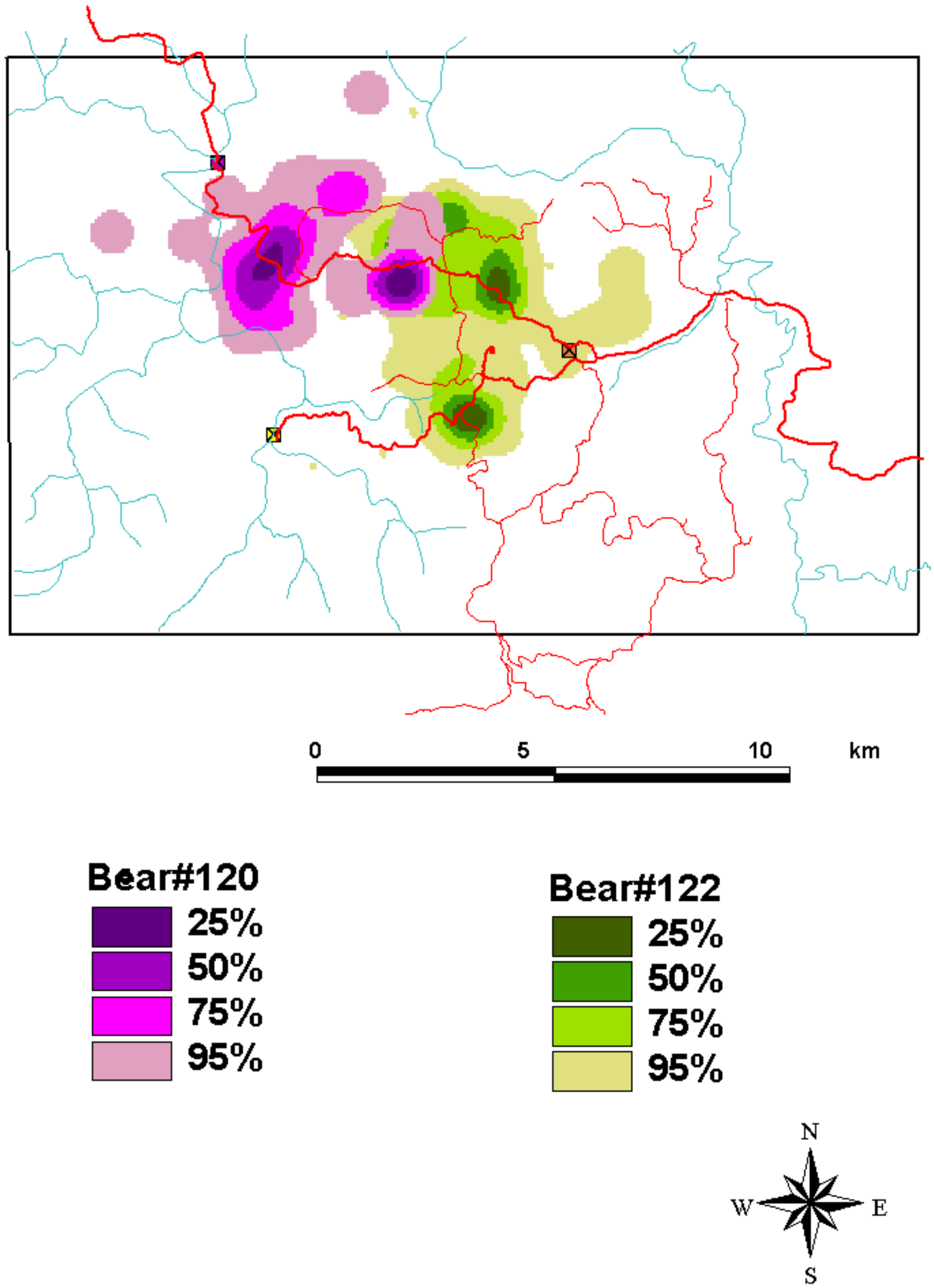

Figure 7. Adaptive kernel home range for Bear #122 and Bear #120 in Ulu Segama Forest Reserve, Sabah, Malaysia, during 2000 showing various utilization isoclines (in percent) and core areas.

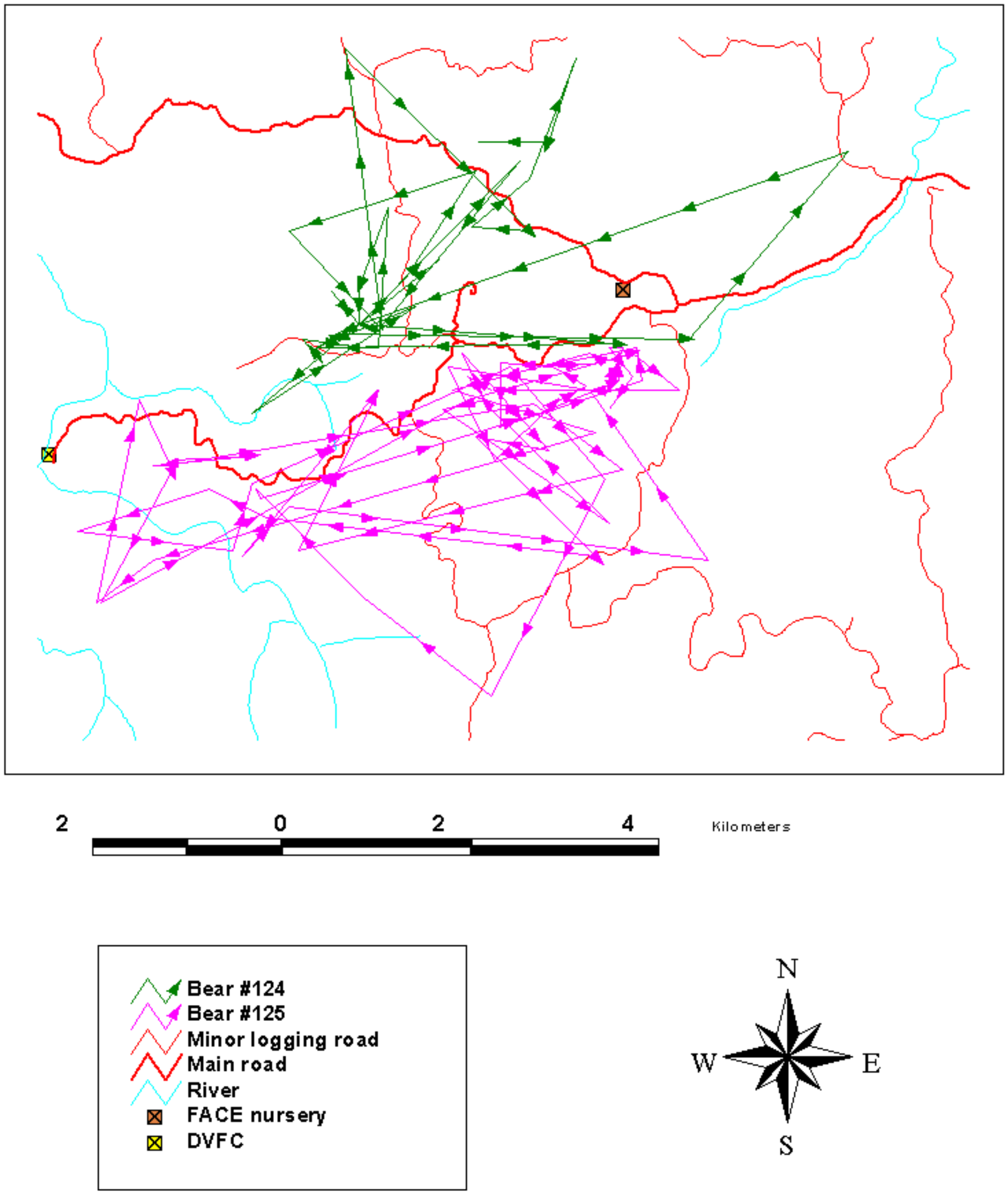

Figure 8. Movement patterns of Bear #125 and Bear #124 in Ulu Segama Forest Reserve, Sabah, Malaysia, from June to October 1999.

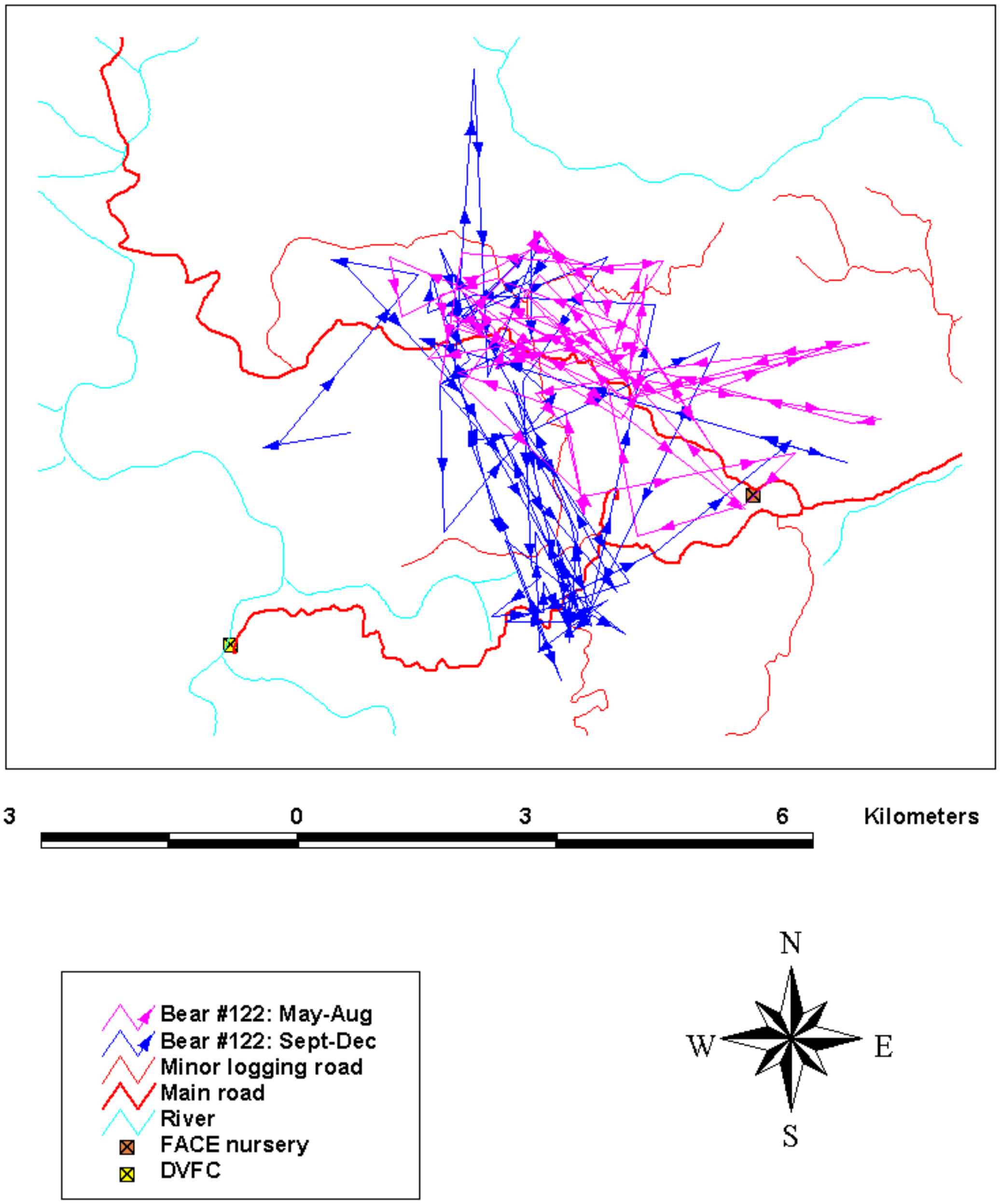

Figure 9. Movement patterns of Bear #122 between May – August 2000, and September – December 2000 in Ulu Segama Forest Reserve, Sabah, Malaysia.

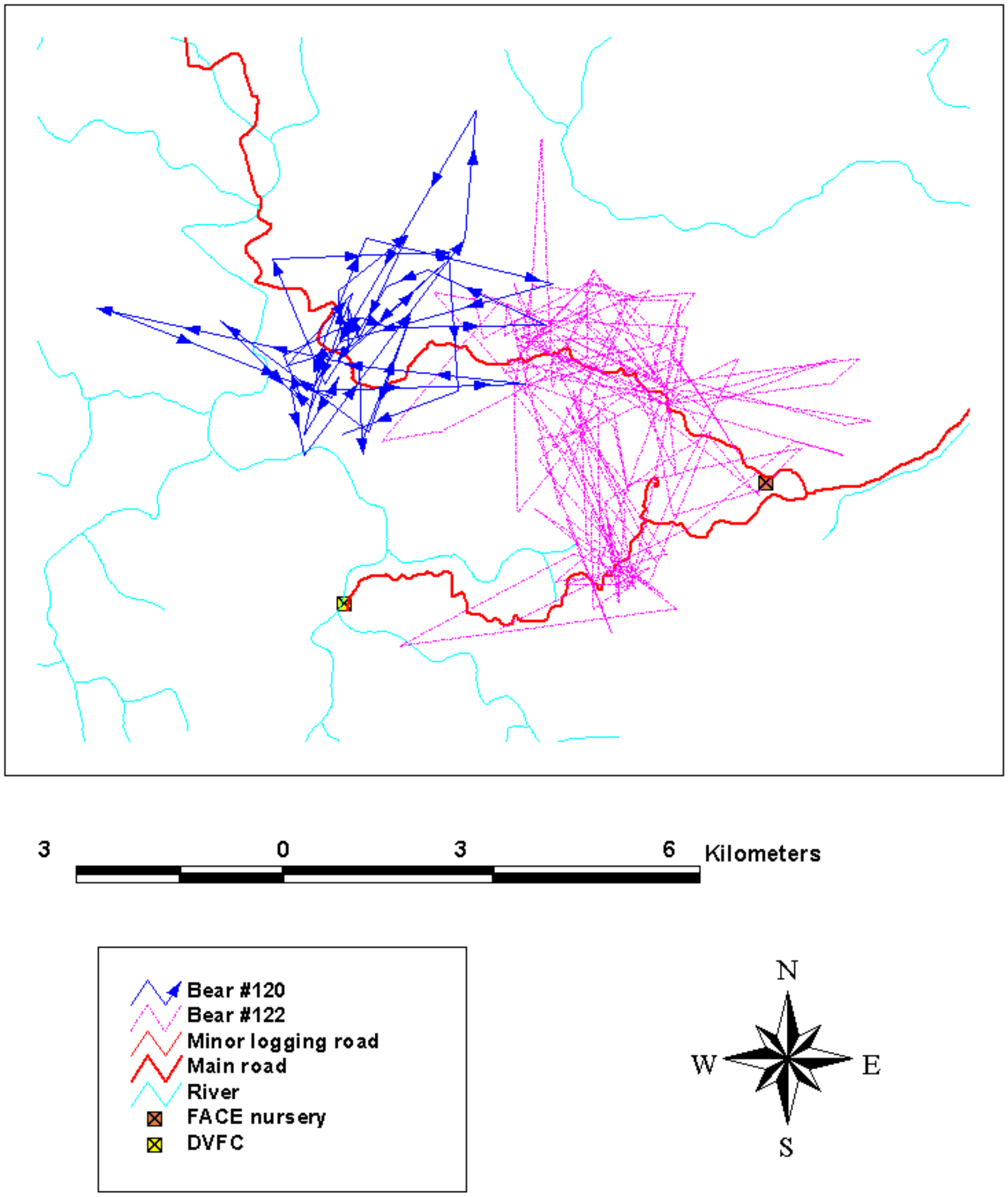

Figure 10. Movement patterns of Bear #122 and Bear #120 in Ulu Segama Forest Reserve, Sabah, Malaysia, from May to December 2000.

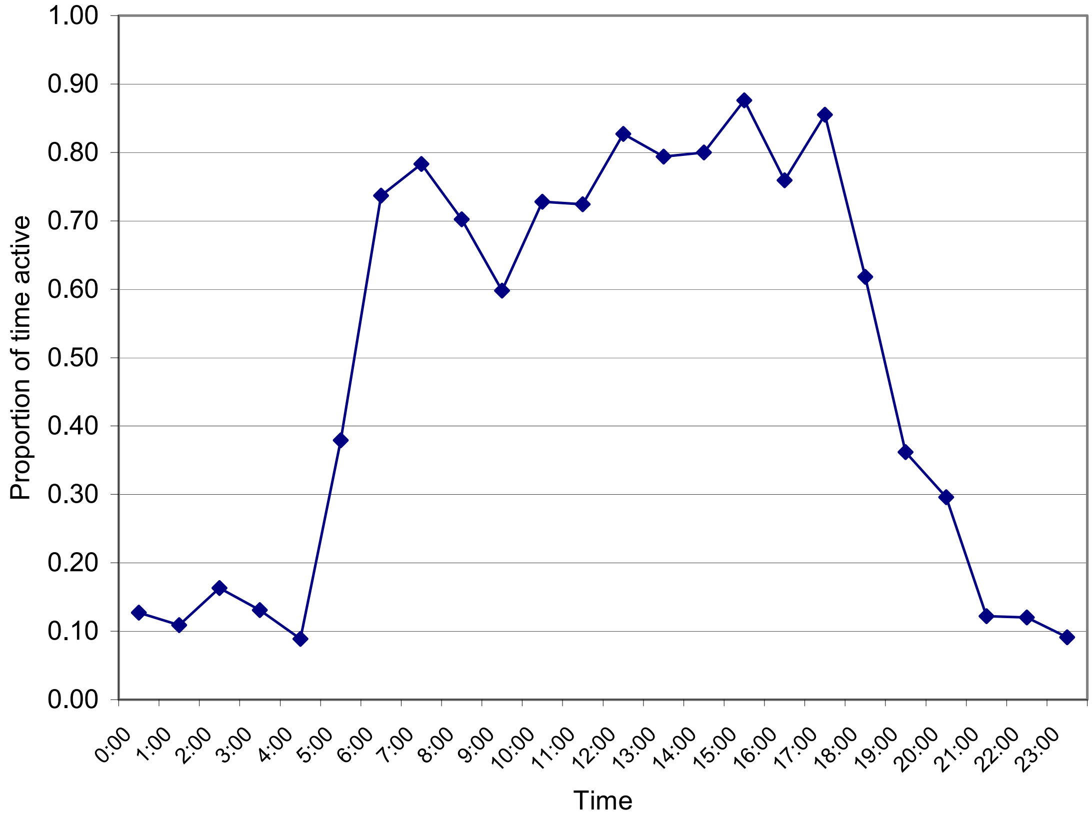

Figure 11. Combined 24-hour activity patterns of 4 male Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia (n = 5687) from June 1999 to December 2000.

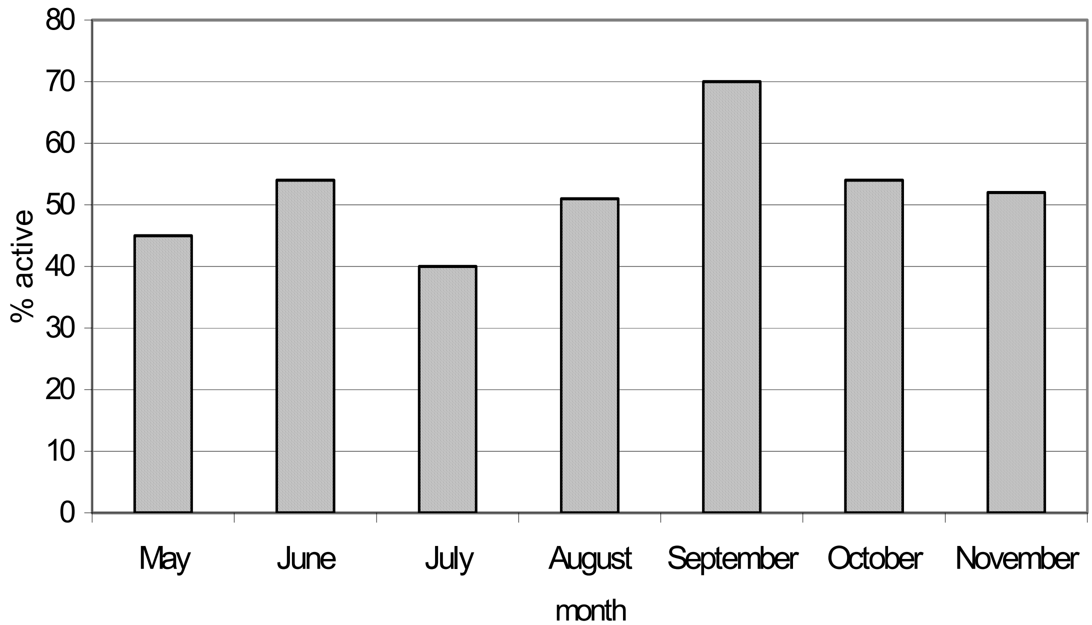

Figure 12. Mean monthly activity of Bear #122 in Ulu Segama Forest Reserve, Sabah, Malaysia, 2000.

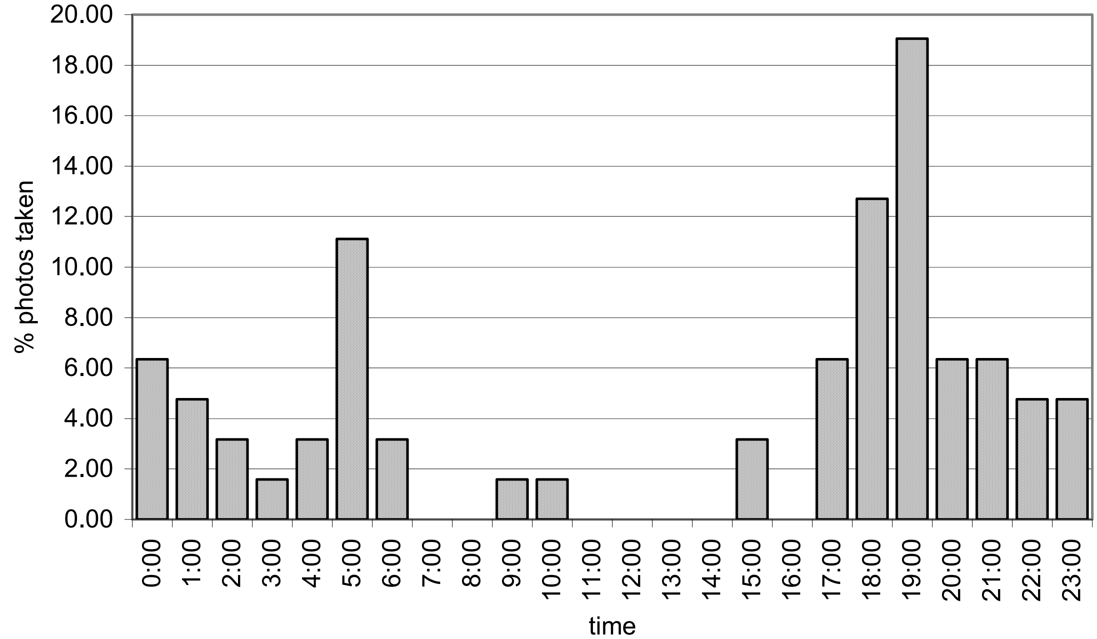

Figure 13. Frequency distribution of Malayan sun bear photographs taken by camera traps in Ulu Segama Forest reserve, Sabah, Malaysia (n= 63).

Figure 14. A typical hollow log in the study area used by sun bears as a daybed. This log was felled during a logging operation, but apparently discarded due to its hollow trunk.

Figure 15. Bear #122 photographed on August 2000, revealing his “very poor” physical condition. He has an emaciated body, sparse hair, and loose skin that indicate starvation and malnutrition.

CHAPTER IV

THE EFFECTS OF FAMINE ON MALAYAN SUN BEARS AND BEARDED PIGS IN LOWLAND TROPICAL FOREST OF SABAH, MALAYSIAN BORNEO

ABSTRACT

We observed a period of famine in the lowland tropical rainforest of Sabah, Malaysia from August 1999 to October 2000. All six Malayan sun bears that were captured and radio-collared were in poor physical condition, and two were later found dead. The physical condition of bearded pigs that were captured, observed, or photographed by camera traps also revealed that the pigs were in various stages of emaciation and starvation. We surmise that the famine resulted from prolonged scarcity of mass fruiting in the study area. The phenomena of emaciated animals and fruit scarcity have also been reported from other areas of Borneo. Lowland tropical rainforest trees of Borneo display supra-annual synchronized mass fruiting. We believe that the starvation we observed and the generally low density of large animals in Borneo forests is a consequence of a history of prolonged food scarcity during non-mass fruiting years.

INTRODUCTION

The Malayan sun bear (*Helarctos malayanus*) is the smallest of the eight living bear species. Adults are about 120 to 150 cm long and weigh 27 to 65 kg (Stirling 1993). They were originally found in the dense forest of Bangladesh, Myanmar, Thailand, Laos, Kampuchea, Vietnam, Southern China, Peninsular Malaysia, and the islands of Sumatra and Borneo (Stirling 1993). They remain the least known bear species in the world and one of the most neglected large mammal species in Southeast Asia (Servheen 1999). Even basic biological facts such as food habits, home range size, and reproductive biology are poorly known. The diet of Malayan sun bears includes beetles, beetle larvae, termites, bees' nests and wild fruits (Wong et al. in press). Davies and Payne (1982) report that sun bears are found throughout dipterocarp and lower montane forests of Sabah, Malaysia from 0 to 1350 m in elevation, but are common nowhere.

In contrast to sun bears, the bearded pig (*Sus barbatus*) is still widespread throughout Borneo but is declining (Caldecott et al. 1993). Adults are 120 cm to 152 cm long and usually weigh 57-83 kg, or up to 120 kg or more when in good condition (Payne et al. 1985). Although they occur in Peninsula Malaysia, Sumatra, Borneo, Palawan and neighboring islands, and in the Philippines (Payne et al. 1985), the species is rare except in Borneo (Caldecott et al. 1993). Bearded pigs are known to migrate over considerable distances in Sarawak and East Kalimantan to follow the harvest of illipe nuts (*Shorea* spp.) (Caldecott and Caldecott 1985; Caldecott 1988). The diet of bearded pigs includes fallen fruits and seeds, roots, herbs and other plant material, earthworms and other small animals (Payne et al. 1985). Bearded pigs are considered to be potential ecosystem "engineers," playing important roles as seed dispersers, seed predators, and agents of physical disturbance (Ickes and DeWalt 1999; Curran and Leighton 2000).

Malayan sun bears and bearded pigs are sympatric in the tropical rainforests of Borneo; these forests are well recognized as one of the most diverse ecosystems on earth. For instance, P. Ashton found 700 species of trees in 10 selected 1-ha plots in Borneo (in Wilson 1988), and Proctor et al. (1983) reported the above ground biomass from 1-ha plot of tropical forest in Mulu, Sarawak reached more than 500,000 kg/ha. This high biodiversity and biomass results from a stable climate, with high solar radiation, temperature, rainfall, and humidity (Huston 1994; Richards 1996). Unlike temperate and artic regions with distinct growing seasons for plants, the rainforests of Borneo lack distinct seasonality and thus give a general superficial impression of constant food abundance and even surplus for wildlife communities that live in the forest. However, many tropical rainforests experience seasonally variable fruit production that influences mammalian frugivore and granivore communities dependent on such forests. These influences range from reduction in numbers and population size (Kaufmann 1962; Milton 1982; Milton 1990; Wright et al. 1999), changes in home range size (Judas and Henry 1999), seasonal movement and nomadic behavior (Kiltie and Terborgh 1983; Caldecott and Caldecott 1985; Caldecott 1988; Bodmer 1990), and to extreme cases, mass starvation, extreme famine, and even mass mortality (Kaufmann 1962; Foster 1982; Milton 1982; Wright et al. 1999).

In this paper, we report on a famine period in a lowland tropical rainforest of Borneo where we observed emaciated and dying Malayan sun bears and bearded pigs during a three-year field study on the biology and ecology of the Malayan sun bear. Information on bearded pigs was collected as peripheral data during this sun bear project.

STUDY AREA

This study was conducted between May 1998 and December 2000 at the Ulu Segama Forest Reserve situated on the eastern side of the Malaysian state of Sabah, island of Borneo (Figure 1) ($4^0$57'40"N $117^0$48'00E, 100-1200 m elevation). The reserve encompasses both forests that were selectively logged by the Sabah Foundation on a 100-year timber license, and primary forest including the 43,800 ha Danum Valley Conservation Area (Marsh and Greer 1992). The area has been used as a research site since 1985 to study the ecology of tropical forest flora and fauna and the effects of logging on various ecosystem components (Marsh and Greer 1992). Lowland, evergreen dipterocarp forest comprises about 91% of the conservation area; the remaining area is lower montane forest (Marsh and Greer 1992). Lower montane forest extends from 750 to 1500 m and differs from lowland rainforest in that it has a lower canopy with fewer, smaller emergent trees (Whitmore 1984). Approximately 88% of the total volume of large trees in the conservation area are dipterocarps (Marsh and Greer 1992).

The Danum Valley Conservation Area is surrounded by approximately one million hectares of selectively logged forest. Logging follows the Monocyclic Unit System (Poore 1989) with a 60-year rotation. It involves harvesting all healthy, commercially valuable tree species with a diameter at breast height (dbh) > 60 cm occurring on slope of < 20^{o} (Marsh 1995). Both conventional tractor logging and overhead cable techniques are used on moderate terrain and steeper slopes. Studies on the impacts of this logging method show that a harvesting of 3-7% of the trees with > 60 cm dbh (translates to 8-18 trees ha^{-1}) destroys over 50% of the trees > 30 cm dbh by logging and road building processes (Wilson and Wilson 1975; Johns 1985, 1988, 1992). Timber extraction rates in the Ulu Segama Forest Reserve are typically high, averaging 118 m^3ha^{-1} over the period 1970-90, with a range of 73-166 m^3ha^{-1} between different logging areas (Marsh and Greer 1992) (this compares to the extraction level of 8.4 and 13.5 m^3ha^{-1} in Neotropical and African rainforests: Yeom 1984). This number represents the removal of about 8 trees ha^{-1} during the logging operation: less than the average extraction rate of 12-15 trees ha^{-1} typical in the rest of Malaysia (Marsh 1995). Compared with other selectively logged forests in Sabah and Malaysia, some parts of the logged forests in the study area can be considered as “good quality” forest, due to relatively lower extraction rates and less human disturbance (such as illegal logging).

When logging is complete in an area, a mosaic of vegetation types remaining, from relatively undisturbed forest, through forested area dominated by pioneer trees, such as *Macaranga, Octomeles, Neolamarkia* and *Duabanga*, to more open area of grasses, ferns, vines, and climbing bamboo (*Dinochloa* spp.), and finally to exposed and compacted mineral soil with little or no vegetation (Willott 2000). These successional forest mosaics have a tendency to increase total biodiversity. In a 1 ha study on floristic composition and forest structure of both primary and logged forest in the study area, Ahmad (2001) found a higher species richness at the family, genus, and species level in a 10-year old logged forest than in primary forest. Another similar floristic composition of 4 ha of primary and 10-year old logged forest in the study area revealed higher species richness in primary sites than logged forest sites (291 for primary forest and 274 for logged forest) (Hussin 1994). In general, primary forests are characterized by a taller (45 m compared to 15 m), more well-developed, and less open upper canopy (5.3% compared to 10.7%) than logged forest (Ahmad 2001; Willott 2000). Logged forests, on the other hand, are usually covered by dominant species of certain trees like *Macaranga* and *Mallotus* with abundant vine covers, climbers, and herbs, notably *Melastomata*, *Piper*, and many ginger species (Ahmad 2001). Hussin (1994) reported that the total fruiting frequency of all trees in primary forest was significantly higher than in logged forest. During a mass fruiting in the study area in September 1990, fruit production was clearly higher in the primary forest than in the logged forest (Hussin 1994).

Fig trees are not a synchronous mass fruiting species and can fruit at any time during the year. There are more fig trees in primary forests than logged forests in Ulu Segama Forest Reserve (3 individuals/ha in primary forest compared to 1.75 individuals/ha in logged forest) (Hussin 1994) and Sungai Tekan Forest Concession, West Malaysia (Johns 1983). Figs are an important food source of Malayan sun bear and bearded pigs (Wong et al. in press).

The climate of Ulu Segama Forest Reserve is weakly influenced by two monsoons (Marsh and Greer 1992), but influenced by the El Nino Southern Oscillation (ENSO) events that were recorded during 1986-87, 1991-92, and 1997-98. Annual rainfall and monthly rainfall at Danum Valley Field Center (DVFC) (located within Ulu

Segama Forest Reserve and the center of the field effort) is, on average 2700 mm and 230 mm, respectively (unpubl. station records 1986-2000 by Royal Society SE Asia Rainforest Research Program: Hydrology Project [University of Manchester, University of Wales Swansea, University of Lancaster, University Malaysia Sabah]), with the wettest period between October and January and the dry period between July and September. Figure 2, Figure 3 and Figure 4 shows total monthly rainfall from 1997 to 2000, total monthly rainfall from 1986-2001, and annual rainfall from 1986 to 2000, respectively. Mean daily temperature at the field center during 1999-2000 was 26.7^{o} C. Soils in the reserve include ultisols, inceptisols and alfisols (Newbery *et al*. 1992; Marsh and Greer 1992).

The study area was concentrated in approximately 150 km^2 of approximately 60% logged and 40% unlogged forest adjacent to the DVFC (Figure 5). Primary unlogged forest could be found in the 48,000 ha conservation area and the water catchment area of the field center. Logged forest consisted of different logging coupes or cutting units, from which timber was extracted between 1981 and 1991. The elevation in the study area ranged between 150 m and 600 m.

METHODS

The study was divided into two phases. Phase I was conducted from June to August 1998, and Phase II from January 1999 to December 2000. Phase I involved a preliminary survey of sun bear presence in both logged and unlogged forests, and a search for baits attractive to bears. The techniques in Phase I were necessary for the completion of Phase II. Phase II involved collecting information on the basic biology of sun bears through the capture and radio-tracking of animals in the forests.

Animal Capture

Techniques of animals capture and use of automatic cameras can be found in Wong et al. (in press). We used an aluminum culvert trap (Teton Welding and Machine, Choteau, Montana, U.S.A.) and three locally made 55-gal. barrel traps to capture sun bears. Trapping operations started on February 24, 1999 and ended on December 11, 2000. Each trap was equipped with a radio-transmitter that would begin transmitting signals once the trap's door was closed. Signals from the traps' transmitters were monitored several times each day. We checked the traps immediately after receiving these signals to minimize the holding time of captured animals in the traps. A variety of baits were used for trapping, but chicken entrails proven to be the most effective. Captured bears were immobilized with Zoletil (tiletamine HCL/ zolazepam HCL) (4 mg/kg of estimated body mass) (Virbac Laboratories, Carros, France) delivered with a jab stick. Each bear was fitted with a MOD-400 radio-collar transmitter (Telonics, Inc., Mesa, Arizona, U.S.A.), operating in the 150-151 MHz frequency range. Each collar weighed about 300 g, less than 2% of the bear's body mass, and were designed for 18 months of battery life. Animal handling procedures followed the approved University of Montana animal welfare protocol. Captured bearded pigs were not handled because they were a non-target species; bearded pigs were released immediately.

We located radioed bears using standard methods of ground-based triangulation (White and Garrott 1990) with a TR-4 receiver (Telonics, Inc., Mesa, Arizona, U.S.A.) and a hand held RA-14K directional antenna (Telonics, Inc., Mesa, Arizona, U.S.A.). Each location was taken from at least 2 different locations at approximately 90 degree angles from the bear's position within 30 minutes, or simultaneously taken by 2 people in 2-way radio contact. Bear locations were visited within 2-4 hours after coordinates were taken. Bears were also tracked on foot when possible at a distance so as to not disturb the bear; we examine activity sites soon after the bear left. At each radiolocation site, we looked for any feeding evidence, such as bear scats, feeding sites, and claw marks on trees. Thirty-two bear encounters in the forest within 300 m of the triangulated locations of radioed bears reinforced our confidence in accuracy. Sightings were also valuable opportunities to observe physical conditions of radioed bears. Another opportunity to examine the condition of radioed bears was when animals were recaptured. Except on one occasion, recaptured bears were released immediately on site without handling.

Camera trapping

Camera trapping is an effective tool to document not only the presence of animals (Bull et al. 1992; Gysel et al. 1956; Kucera and Barrett 1993), but also their behavioral ecology (Savidge and Seibert 1988; Picman and Schriml 1994), and activity periods (Dodge and Snyder 1960; Carthew and Slater 1991; Pei 1995), as well as for population estimates (Mace et al. 1994). Camera trapping is also an ideal system to collect information on elusive species in dense forest, such as Malayan sun bears (Griffiths and van Schaik 1993a & b; van Schaik and Griffiths 1996; Mudappa 1998; Karanth 1999; Franklin et al. 1999). In our study, camera trapping also served as an effective tool to monitor the physical condition of bears and pigs as the physical condition of individual animals can be clearly revealed from the photographs taken. We used ten camera traps from June to August 1998, and May 1999 to December 2000. Each camera unit consisted of a fully automatic (auto focus/advance/flash), weather-proof, point-and-shoot 35-mm Pentax 606 camera combined with a passive infrared motion and heat sensor designed specifically for detecting animals in the wild (Wildlife Research Laboratory, Department of Wildlife Conservation, National Pingtung University of Science and Technology, Taiwan R. O. C.). Sites for cameras were carefully chosen near areas of potential wildlife use, such as animal trails, water pools, mud wallows, and trap sites. A variety of baits such as chicken entrails, meat scraps, fishes, fruit, liver-oil, fruit extracts, honey, air refresher, etc. were used at most camera stations to attract animals to the camera stations.

We visually rated photographed bears and pigs subjectively into five different categories of physical condition. These categories ranged from very poor, poor, fair, good, and very good, based on the physical appearances of the animals. Physical appearances such as fur color, relative size of neck, body fat and muscle appearance, protruding zygomatic arch, scapulae, vertebral columns, ribs, and hipbones, were considered (Table 1).

Forest fruit production

Long-term monitoring of tree productivity is very important and basic to the understanding of ecosystem function, and especially the relationship between producers and consumers (Ahmad 2001). Because we have little information on the exact species of fruit consumed by bears or pigs, the monitoring of fruit production of these specific food trees would be impossible. Nevertheless, we documented monthly production of fruits of non-dipterocarp trees in both primary forest and logged forest to understand the periods when wild fruits are available for the consumption by such as bears and pigs. We assumed that the fruit trees that the bears and pigs feed on would have similar fruiting patterns to the trees monitored. Ahmad (2001) in the study area and monitored the leafing, flowering, and fruiting activities of trees $\geq$ 10 cm dbh monthly from August 1997- May 1999 in primary and logged tropical rainforest. We continued monitoring the same trees for another 19 months from June 1999 to December 2000 after N. Ahmad had finished her study. The botanical plots were placed in primary forest 1 km south of DVFC, and the other about 1.5 km northeast of DVFC that was selectively logged in 1989. Each botanical plot consisted of five tree transects, each measuring 20 x 100 m, that were placed systematically along two km of trails in each forest type for tree inventory. Each tree transect was further divided into five sub-plots of 20 x 20 m. The total area sampled was 1 ha in each forest type (Ahmad 2001). Trees with $\geq$ 10 cm dbh inside the sub-plots were tagged, numbered, and identified species by qualified botanists from Forest Research Center, Sabah Forestry Department (Ahmad 2001).

RESULTS

A total of six bears (5 male, 1 female), and six bearded pigs (4 male, 2 female) were captured in 2,372 trap nights. Trapping success was extremely low (1 bear/ 396 trap nights, and 1 pig/ 396 trap nights) probably due to the wariness of bears and pigs entering traps, and also the low density of sun bears in the study area (Chapter 3). Table 2 and Table 3 lists the physical parameters for all captured bears and pigs.

Emaciated sun bears

We first noticed emaciated animals when Bear #124 was recaptured on August 3, 1999. We sedated and handled Bear #124 to check on his gun shot wounds, which were discovered during his first capture in July 10, 1999. Bear #124 lost 2 kg within 3 weeks and looked slightly emaciated. Two days later, we observed Bear #125 at close range, and noticed he also looked emaciated. We then suspected that the radio-collar might pose an adverse effect on the bears. However, the poor condition of bears became more obvious when Bear #123, an old male bear, was captured in primary forest on August 7, 1999. Although fully grown, Bear #123 weighted only 34 kg, and lacked the fit and muscular look of Bear #125 and Bear #124 captured earlier (Table 2). Bear #123 appeared skinny, with protruding hipbones, and he showed characters of malnutrition and old age. His fur was dried, slightly sparse, with many white hairs and loose skin. Bear #123 was found dead a month later inside a hollow tree trunk. The straight-line distance between the capture site and the location of the tree where Bear #123 found dead was 8 km. The causes of death of Bear #123 could be a combination of old age, starvation and to a lesser extent, stress from handling.

On October 7, 1999, we observed Bear #125 in extremely poor condition in a tree cavity. He was surprisingly shy, and allowed us to within a meter without showing any aggression. Besides having sparse hair, his protruding zygomatic arch, scapulae, ribs, vertebrae, hipbones and his loose skin clearly indicated his extreme malnutrition. Two days later, we found him in another tree cavity exhibiting similar behavior and condition. We suspected that Bear #125 was wounded by a poacher, just like Bear #124, as he had several silvery white spots that resembled shotgun pellet wounds scattered on his body. A decision was made to handle Bear #125 on October 11. What we thought to be shotgun pellet wounds turned out to be large, engorged female ticks. Bear #125 lost approximately 32% of his body weight since his first capture on June 22, 1999, and weighted only 30 kg (Figure 6). He was found dead the next day where we had left him to recover from sedation. His carcass was sent to Sabah Wildlife Department for necropsy to determine the causes of death. We found an infection on his mouth and a hemorrhage on his left ribs caused from severe impacts. Bear #125 could have been injured by other large animals, possibly pigs or bears. We concluded that Bear #125 died from a combination of malnutrition, old age, injured, mouth infections and probably stress from handling. A special report was submitted to the Danum Valley Management Committee to further discuss the death of Bear #125 and Bear #123 (Wong 2000).

Another emaciated sub-adult male bear (Bear #122) was captured on May 4, 2000. Although Bear #122 weighed 30 kg, his physical condition was not as poor as Bear #125 when he died. This was due to his smaller size and younger age. Bear #122 had dense black fur on his body with the exception of the belly. His physical condition was closely monitored for the next seven months from 21 sightings and 28 photographs after his first capture. His physical condition deteriorated gradually and was very poor in late August and September. Figure 7 taken on July 28, 2000 shows Bear #122 in “very poor” condition. Another four photographs taken a month later showed that the condition of Bear #122 became even worse. Bear #122 was recaptured for the first time on July 4 and later learned to exploit the bait (chicken entrails) in traps and became a “trap happy” bear, seeking the bait in traps repeatedly. Between August 19 and October 3, 2000, he was recaptured seven times. Each time he was recaptured, Bear #122 had consumed all available baits and sat quietly inside the trap until we released him. We suspect that this “trap happy” behavior was probably caused by his desperate need for food. In October, the home range of Bear #122 expanded south and incorporated a garbage dumpsite where garbage from the DVFC and the FACE nursery was disposed. He utilized the garbage and remained in the vicinity of the dumpsite until June 2001. His physical condition improved as indicated by another photograph of Bear #122 taken on October 29, 2000, at the dumpsite. Bear #122 looked healthier, having sleek black fur and a muscular body.

The only female bear in our study, captured on September 24, 2000, Bear #121, also showed signs of severe starvation, weighing only 20 kg as an adult. For comparison, three captive female Malayan sun bears kept in Sepilok Orangutan Rehabilitation Center weighed 33-40 kg (S.K.K.S. Nathan, Veterinarian, Sepilok Orangutan Rehabilitation Center, Sabah Wildlife Department, Sabah, Malaysia, personal communication 2000). Two wild, adult female sun bears captured in Sungai Wain Forest Reserve, East Kalimantan, Indonesia, by G. Frederiksson in mid 1999, which Frederiksson considered as “very skinny,” weighed 23 kg and 25 kg (G. Frederiksson, Tropenbos-Kalimantan, Indonesia, personal communication, 1999). Ten photographs of Bear #121 taken in late July before she was first captured also indicated her malnutrition.

Forty-two photographs of Bear #120 (adult male) were taken between early August and late September. These photos revealed his malnourished appearance before his capture on October 11, 2000. His emaciated body, sparse hair, and loose skin or what we described as a "wrinkled skin" condition, were an indication of starvation and malnutrition (Figure 8). Interestingly, the physical condition of Bear #120 improved significantly by the time he was captured on October 11, 2000. Although lacking body fat, his physical appearance was much more muscular and he was covered with sleek black fur. Another four photographs of Bear #120 taken in November also indicated similar good physical condition. On November 5, 2000, we observed at close range a full-grown, unmarked bear climbing down from a fruiting fig tree. This bear looked slim but healthy by having sleek black fur. Another two photographs taken at the same location on November 13 showed a healthy looking bear climbing down from the same fig tree (Figure 9). In summary, we observed emaciated sun bears from August 1999 to October 2000. However, we found two exceptions unmarked bears, photographed between March and May 2000 at the northeast and southeast corner of our study area, who appeared to be in somewhat better condition (Table 4).

Emaciated bearded pigs

Except for a fat bearded pig captured in a snare in early March 2000, all of the other 5 pigs captured in either culvert traps or barrel traps between February and July 2000 were in various stages of starvation. An adult pig captured in primary forest on April 27, 2000 was extremely skinny with most bones visible and little body muscle remaining (Figure 10). Another bearded pig in similar poor physical condition was captured in early June 2000 in logged forest. The other two smaller sized, female pigs captured on July 2000 also showed signs of starvation (Table 2). Although new tracks of pigs were encountered almost daily near traps, and photographs of pigs were often taken near trap sites, we rarely captured pigs. As a result, those pigs that were captured in traps were likely in desperate need of food. Starvation likely contributed to the capture of the most desperate animals.

However, evidence of starving pigs did not come only from captures. Further evidence of famine in the forest came from the emaciated bearded pigs that were sighted in the vicinity of DVFC, along logging roads, and in the forest. At least eight different emaciated bearded pigs were recorded foraging in garbage bins and kitchen waste at the vicinity of DVFC from January to September 2000. Several habituated, resident bearded pigs that stayed near DVFC often charged these new, non-resident pigs. It was unusual for those emaciated pigs to show up around DVFC because of the presence of resident, habituated pigs. These resident pigs showed strong territorial behavior even among themselves and some dominant boars would not tolerate their subordinates to use their favorite feeding sites (S.T. Wong, personal observation). The first extremely emaciated pig sighted during the entire study period was in January 2000. This sub-adult pig was found dead near DVFC a week after we took its photograph (Figure 11). On March 2000, a rotten carcass of a bearded pig was found beside a forest trail about 1 km west of DVFC. We suspected that the pig died from starvation, although the actual cause of death was unknown. Several anecdotal sightings of emaciated pigs by the field crews and staff from DVFC in 2000 provided additional evidence of this famine period. Several DVFC staff who sighted these pigs stated that they had never seen such extremely skinny animals, despite being in DVFC for more than 10 years.

During the entire study period, camera traps took 142 photographs of bearded pigs. After eliminating photographs taken continuously of the same pig, a total of 90 photographs were used to assess monthly physical condition of bearded pigs for 10 months from July 1998 to August 2000 (Figure 12). The missing data on Figure 12 resulted because: a) no cameras were set up between September 1998 and March

1999, and b) no photographs of pigs were taken from March - June, October -November 1999, January - March, and June 2000. The results showed that the majority of the bearded pigs with "good" physical condition were photographed before September 1999, and individual pigs with "poor" or "very poor" physical condition were mainly photographed after March 2000 (Figure 13). However, we did find a few exceptions. A pig with "very good" physical condition was photographed in April 2000, and two pigs with "poor" physical condition were photographed in August 1998.

Forest Fruit production

Ahmad (2001) sampled 904 trees greater than 10 cm dbh in two 1-ha plots, one in primary forest and one in logged forest. Tree density was 465 stems ha^{-1} for primary forest and 439 stems for logged forest. The inventory of trees revealed a total of 185 species, which belonged to 111 genera and 46 plant families. A total of 715 non-dipterocarp trees were monitored for monthly fruit production, of which 392 trees (92 species) were in primary forest, and 323 trees (116 species) were in logged forest (Ahmad 2001).

We combined the 19 months of forest fruit production data collected in our study with the 22 months of data collected by Ahmad (2001) to investigate fruiting patterns. In general, the 41 months of data collection revealed very low fruit production, with an average of 2 trees and 3 trees fruiting each month in primary forest and logged forest respectively (Figure 14 and Figure 15). Only one distinct fruiting peak was recorded on September and October 1998, with 28 (3.92%) and 14 (1.96%) trees fruiting in logged and primary forests, respectively. Fruiting trees in primary forest and logged forest seem evenly distributed, although the total number of fruiting trees in logged forest was slightly greater than in primary forest. Ahmad (2001) found that the flowering pattern in the primary forest differed significantly than that of logged forest (Kolmogorov-Smirnov, Z=

2.1106, $p<0.05$), while fruiting patterns did not (Kolmogorov-Smirnov, Z= 0.9045, $p>0.05$).

DISCUSSION

Physical condition of Malayan sun bears and bearded pigs is strongly influenced by the availability of both plant and animal foods in the forest. Unfortunately, limited information is available on the proportion of these two kinds of food in the diet of bears and pigs. We also lack information on the temporal scale of relative abundance of animal food items during the study period. Therefore, the influence of specific animal food items on the physical condition of bears and pigs was not accounted for in this study.

Two assumptions were made when we evaluated the relationship of fruit productivity to the physical condition of animals. First, we assumed that the majority of sun bear and bearded pig diets consisted of fruits when available. Frederiksson (2001) and Kusters (2001) reported that sun bears and bearded pigs feed on more than 50 and 83 plant species respectively. These fruits range from lipid-rich nuts and drupe (e.g., Fagaceae, Euphorbiaceae), sugar-rich pulp fruits (e.g., Ebenaceae, Sapindaceae), to low nutrient figs (Moraceae). Second, we assumed that the abundance of animal food items, such as termites, beetles, beetle larvae, and earthworms, remained relatively constant during the study period at low density. Burghouts et al. (1992) reported termite densities were much lower in the study area (ca. 100 m^{-2}) than in other rainforests in Asia and Africa (> 1000 m^{-2}). The low termite density may be related to the low organic matter content of the soil in the Ulu Segama Forest Reserve (Burghouts et al. 1992).

The lowland tropical rainforest trees of Borneo and western Malesia (Sumatra and Peninsula Malaysia) display a synchronized mass flowering event followed by a mass fruiting event (MacKinnon et al. 1996). This synchrony can be related to decreases in rainfall and prolonged periods of drought (Woods 1956; Janzen 1974; Appanah 1985;

Aston et al. 1988). At irregular intervals of two to ten years, most species of dipterocarp, together with members of the Burseraceae, Fagaceae, Myristicaceae, Polygalaceae, and Sapotaceae, fruit almost simultaneously (MacKinnon et al. 1996). Over a period of few weeks or months, nearly all dipterocarps, and up to 88% of all canopy species, can flower after a long period of no reproductive activity (Appanah 1981, 1985). Such mass fruiting is behaviorally very similar to the supra-annual sexual phenology displayed by many North American and European canopy-member trees, such as *Abies, Carya, Fagus, Pinus, Quercus* and *Tsuga* (Janzen 1974). This synchrony is not absolute however. Due to the high temperature and rainfall throughout the year within lowland rainforests in Borneo, some trees are flowering, fruiting, and leafing at any time of the year (MacKinnon et al. 1996).

Since 1985, three mass fruiting events have occurred in the study area in the Ulu Segama Forest Reserve in 1986, 1990, and 1996. Minor fruiting peaks were also recorded in the study area outside these mass fruiting events. Ahmad (2001) recorded one minor fruiting pick in September-October 1998, where 1.2% and 2.8% of trees fruited in primary and logged forests respectively. During 18 months of phenological study in the same forests, Hussin (1994) recorded a mass fruiting even in September 1990 and a minor fruiting event between July and August 1991 in the study area. He recorded 10.4% and 7.4% of trees fruited in primary and logged forest respectively in the 1990 fruiting event. However, during the minor fruiting event in August 1991, the percentage of fruiting trees in primary forest (5.7%) was slightly lower than that in logged forest (6.0%). In general, fruit production in the study area from August 1997 to December 2000 was comparatively low during non-mass fruiting years. A similar trend was also reported by Heydon (1994) in his studies on the ecology of fruigivorous ungulates in the study area.

Ahmad (2001) found minimum temperature was significantly and negatively related to the number of overstory trees that fruited in both primary and logged forest. According to her, minimum temperature during the dry spell before the onset of rain may have influenced how many trees fruited. Low minimum temperatures (LMT) were also reported to correspond to mass-flowering events that occurred roughly two months later in western Peninsula Malaysia in 1976, 1981, 1982, and 1985 (Aston et al. 1988). An analysis of meteorological records suggests that the induction is caused by a drop of roughly 2^{o} C or more in minimum nighttime temperature (< 20^{o} C) for three or more nights (Aston et al. 1988). T. Inoue (in Wright et al. 1999) reported that the LMT cued the development of reproductive buds during El Nino Southern Oscillation (ENSO) event in Sarawak in 1997-98. Similar mass fruiting tree response to low temperatures has also being documented in the moist evergreen forests in Uganda (Chapman et al. 1999) and Gabon (Tutin and Fernandez 1993).

On the other hand, other studies have related flowering and fruiting in Peninsula Malaysia and Borneo with a sharp increase in sunshine (Wycherley 1973; Ng 1977) and/or a dry period (a period of several rainless weeks), especially during ENSO events (Wood 1956; Ashton 1969; Medway 1972; Ng 1977, Appanah 1985; Curran et al. 1999; Curran and Leighton 2000). The major fruiting periods recorded by Hussin (1994) and Ahman (2001) occurred between August and October. These periods coincided with wet months and an extremely dry month (monthly rainfall = 11.3 to 24.4 mm, compared to mean monthly rainfall= 230 mm) five months before the fruiting peak. These fruiting patterns were similar with other studies reported by Medway (1972), Bennett (1983), and Johns (1983b), who demonstrated that the patterns of flowering and fruiting were affected by wet and dry seasons. In addition, Putz (1979) found no strong seasonality during his four year phenological study of lowland rainforest trees in Peninsula Malaysia, but he did find that more species of trees tended to flower and later bear fruits after dry spells regardless of whatever time of the year these occurred. In more seasonal forests, most flowering tends to occur at the end of the dry season (Mabberley 1983).

The influence of rainfall on fruiting in tropical rainforest was best documented on Barro Colorado Island, Panama. Foster (1982) and Wright et al. (1999) recorded four episodes of extreme famine, and ten episodes of mild famine in tropical rainforest of Barro Colorado Island, in a 51-year period. All of these famine episodes were associated with anomalously heavy rains in the later part of the dry season. These famine events resulted in a mass starvation of the vertebrate consumers. These terrestrial and arboreal mammals foraged longer, fed on novel foods, were emaciated, and died in unusual numbers.

The famine events on Barro Colorado Island were very similar to those observed in our study. Immediately after the ENSO (negative Southern Oscillation Index [SOI]) event in 1997-98 that caused a record low annual rainfall, the onset of La Nina (positive SOI) brought high precipitation to the study area (Figure 2). In fact, 1999 and 2000 marked the record high annual rainfall in 16 years of meteorological data at DVFC since 1986. Monthly rainfalls for 22 months from September 1998 to June 2000 all exceeded the mean monthly rainfall, with the exception of November 1998, and September to November 1999. It is likely that this heavy rainfall caused the “wet” dry-season and further disrupted the fruiting peak that should have occurred in August – October of 1999 and 2000. This situation was similar to Foster (1982) hypothesized that dry-season rains prevent many tree species from attaining the threshold levels of drought required to initiate flowering and then fruiting.

Wright and van Schaik (1994) reported that light-limited trees produce new leaves and flowers during the season of maximum irradiation. They found correlations between plant performance and irradiance suggesting that light limits many tropical forest trees, even in the canopy. Thus, above average radiation may stimulate fruit production during El Nino events (Wright et al. 1999). In contrast, during the La Nina events in the year following the ENSO, rainy weather and heavy clouds may reduce fruit production in tropical forest. This theory was supported by photosynthetic measurements suggesting that light limits many tropical trees (Wright and van Schaik 1994). Low photosynthetic photon flux densities (PPFD) associated with cloudy conditions frequently limited wet-season photosynthesis by the canopy emergent *Ceiba pentandra* in central Panama (G. Zotz and K. Winter in Weight and van Schaik 1994). Thus, the low rainfall in April 1990, March 1991(Hussin 1994), April 1998 (Ahmad 2001), and June 2001 in the study area may have cued the fruiting peak five months later on September 1990, August 1991, September 1998, and November 2001 respectively. Nevertheless, long-term meteorological records and phenological data are needed to fully evaluate the relationship between climatic factors and the variation in fruit production in the study area.

Apart from the examples from Barro Colorado Island, Van Schaik et al. (1993) reported that evidence of animal starvation in more humid tropical forests is lacking. They found no evidence of mass mortality in tropical forests, such as Cashu, Peru, and Ketambe, Sumatra, despite long-term observations. This may be due to the impact of large forest carnivores such as jaguars (*Panthera onca*), and pumas (*Puma concolor*) in the Neotropics, and leopards (*Panthera pardus*) and tigers (*Panthera tigris*) in old-world tropics keeping their prey species, the primary consumers, at low population levels. In contrast, both Barro Colorado Island and Borneo, including the study area, lack large predators that could effectively keep the population density of primary consumers at low levels. The two large predators that are known to prey on sun bears and bearded pigs are the reticulated python (*Python reticulatus*) (G. Frederiksson, Tropenbos-Kalimantan, Balikpapan, Indonesia, personal communication, 2000) and clouded leopard (*Neofelis nebulosa*) (Payne et al. 1985). Full-grown reticulated pythons (7 – 10 m in length) that are capable of preying on sun bears and pigs are extremely rare throughout Borneo. The clouded leopard is actually a medium-sized cat weighing 12-23 kg (Nowak 1991) and is only capable of preying on juvenile pigs or piglets, primates, and medium to small-sized forest ungulates. Thus, in the study area there is no regulation of primary fruit consumer density by large predators. It may be that, in lieu of predation, starvation may be the most important regulatory factor on the population density of primary consumers in the Borneo tropical ecosystem. The principal cause of starvation for consumers appears to be mass fruiting failures.

Similar observation of emaciated Malayan sun bears and bearded pigs have been reported by G. Frederiksson (Tropenbos-Kalimantan, Balikpapan, Indonesia, personal communication, 2000), Curran and Leighton (2000), and J. Payne (in litt., 22 Jul 2000). Two female adult sun bears captured by G.Frederiksson on July 1999 in Sungai Wain Forest Reserve, East Kalimantan, were in various stages of starvation weighing 23 and 25 kg. One of these bears was found dead on September 1999 in extremely poor physical condition, and the skeletons of the other found later in the year. Although the cause of death for the latter bear was difficult to determine, it was believed that this bear too suffered from starvation. Curran and Leighton (2000) reported numerous emaciated pigs ranged throughout their study area in Gunung Palung National Park, West Kalimantan, in early 1990, and many became destructive pests of their research camp. They also witnessed numerous battles among these emaciated pigs over food sources, and surviving adults had many tusk-shaped scars and wounds (Current and Leighton 2000). At least six large, adult pigs were found dead and many other large adult boars starved at their study site approximately three years after the last mass fruiting in 1987 and before the onset of the next mass fruiting in 1991 (Current and Leighton 2000). They believed, from these observations, that the length of the mass fruiting cycle seems sufficient to depress the populations of bearded pigs in this forest

(Curran and Leighton 2000). Coincidently, emaciated bears and pigs in our study area also occurred three to four years after the last mass fruiting in 1996 and a year before the onset of the 2001 mass fruiting.

Looking at historic information, J. Payne (pers commun.) reported that he often saw “quite thin” pigs many times that he believed were suffering from starvation during periods with low food availability. He also found a dead pig on a logging road near our study area that he thought had died of starvation. He also shows an illustration of this juvenile bearded pig during a period of low food abundance. (Payne et al. 1985, p 137)

It seems clear that the periods between mass fruiting years are periods of low food abundance for frugivores and omnivores in lowland tropical forests of Borneo. It seems possible that these periods of scarcity would be intensified and result in famine for frugivores and omnivores during any prolonged wet season that might disrupt a “minor” fruiting period.

During intervals between mass fruiting, it seems likely that Malayan sun bears survive by feeding on invertebrates, such as termites, beetles, beetles larvae, and asynchronously fruiting species, such as *Ficus* spp., *Eugenia* spp., *Lithocarpus* spp., and some vertebrates (Wong et al. in press). Bearded pigs may survive during these periods by feeding on a wide range of asynchronously fruiting species, such as *Lithocarpus* spp. and *Quercus* spp. in the montane zone, and *Tetramerista glabra* and *Palaquium leicarpum* in peat swamps, and by scavenging the forest floor for palm meristems and earthworms (Curran and Leighton 2000).

Bearded pigs in Sarawak and East Kalimantan are known for their irregular mass migratory behavior that seems to follow crops of illipe nuts (*tengkawang*) (*Shorea* spp.) (Caldecott and Caldecott 1985; Pfeffer and Caldecott 1986). In Sabah, there are no signs of such long-distance migration behavior by pigs, even in the early 1980’s when bearded pigs were common year-round in the study area and when forests were more contiguous in the lowlands and less fragmented by logging (J. Payne, in litt., 22 Jul 2000). For resident bearded pigs in the study area, the length of time between mass fruiting intervals may prevent many juveniles from reaching maturity and may increase mortality of old and weak individuals (Curran and Leighton 2000). Similarly for sun bears, the length of time between mass fruiting intervals likely contributes to increased mortality and lower densities, particularly for older, weaker, injured, and sick individuals.

Janzen (1974) suggests that in habitat with a climate favorable to animals, yet with low productivity due to bad soils, strong anti-herbivore plant defenses have evolved with leaves containing exceptionally high concentrations of defensive chemicals. This leads to low animal densities, enabling mass fruiting to work through satiation of the lowered number of seed predators in Malesian dipterocarp forest (Janzen 1974). This reduction in seed predator density serves to enhance seed and seedling survival when a mass fruiting occurs. Thus, long periods without fruit production are an indirect cause of low frugivore and omnivore numbers. This hypothesis remains generally untested due to few long-term studies necessary to evaluate the population fluctuation of frugivores and other mammals in the tropics (Wright et al. 1999).

General low wildlife population densities in tropical forests of Borneo were reported by Inger (1980), when he compared densities of floor-dwelling amphibians and reptiles in various sites in Southeast Asia and Central America. He related the low densities of floor-dwelling amphibians and reptiles in Borneo and Peninsular Malaysia to two distinctive features found in these forests: 1) high proportions of tree species in these forests are members from one single tree family, Dipterocarpaceae; and 2) dipterocarps are noted for their synchronized mass fruiting behavior, with intervals between fruiting from two to ten years (Woods 1956; Janzen 1974; Appanah 1985; Aston et al. 1988). Inger (1980) suspected that mass fruiting should result in lower abundance of arthropod primary consumers during non-mass fruiting years. This consequently reduces the total biomass of insect populations, with consequent reductions in numbers of insectivore secondary consumers, such as amphibians and reptiles (Scott 1976; Inger 1980). Other vertebrates, both frugivorous and insectivorous, should also be reduced as well (Inger 1980).

Fleming (1979) demonstrated a higher proportion of fruit, nectar, and plant feeders in Panama than Peninsula Malaysia, when trying to compare the trophic structure of tropical bats and non-volant mammals between these two regions. Karr (1972) and M. Wong (in Appanah 1985) also found the density of birds in Indo-Malaysian forests are significantly lower than those in African and Neotropical forests where mass fruiting does not occur. Our observations on emaciated bears and pigs in this study during a period of no mass fruiting provide additional evidence to support this hypothesis.

Inger (1980) suggested that low animal densities in Indo-Malayan rainforests are a consequence rather than the cause of mass fruiting. This is contrary to Janzen's (1974) suggestion that mass fruiting evolved in Indo-Malaya rainforests because of the low animal densities found here. Janzen (1974) suggested that satiation of seed predators during mass fruiting works successfully in dipterocarp forests only because there are fewer animals present resulting in lower levels of seed predation. Janzen (1974) assumed that mass fruiting was a mechanism of escape from seed predators that could not evolve successfully with high numbers of frugivores and omnivores. A unique feature of Malesian forests is the dominance by a single tree family with consequent fruiting synchrony. Such forest dominance by a single tree family is not found in other forests where mass fruiting does not occur, such as Africa or the Neotropics. Mass fruiting is only found in three tropical forest areas: Borneo, Sumatra, and Peninsular Malaysia. The synchrony of mass fruiting appears to be most pronounced in Borneo. This may explain why no large carnivores are able to exist in Borneo given the low prey densities there. This is in contrast to Sumatra and Peninsular Malaysia where large predators are able to exist. More long-term ecological studies are necessary to fully understand the ecological interactions between mass fruiting and animal communities in this region.

Regardless of whether low animal density is a consequence or cause of mass fruiting, the trophic interactions that determine distributions and abundances of organisms in the lowland tropical rainforest of Borneo are primarily controlled by resource availability at the bottom of the food chain. According to this bottom-up view, organisms on each trophic level are food limited (Power 1992). It is very likely that the low density of frugivores and omnivores such as the Malayan sun bears and bearded pigs in the study area and in other dipterocarp forests in Borneo is related to prolonged food scarcity and resulting starvation during non-mass fruiting years. Heydon (1994), and Heydon and Bulloh (1996), reported a significant increase of grazers and browsers such as sambar deers (*Cervus unicolor*) and common muntjacs (*Muntiacus muntjac*) in logged forests in the study area due to the sudden increase of foliage in these disturbed sites. Based on these findings, we surmise that the densities of grazers and browsers tend to be low in primary forests that once carpeted the entire island of Borneo. This is because these primary forests have limited openings and few disturbed sites that favor the growth of plants browsed by herbivores. The absence of large carnivores in Borneo is a consequence of this low density of frugivores, omnivores, and herbivores that, in turn, is related to the ecological effects of mass fruiting cycles and the structure of the forest itself.

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Table 1. Criteria of appearance that were used to rate the physical conditions of Malayan sun bears and bearded pigs in Ulu Segama Forest Reserve, Sabah, Malaysia.

Category	Fur condition	Neck size	Body fat and muscle	Scapulae, vertebral columns, ribs, hipbones
Very good	Sleek, dense	Think	Fat, muscular	Not visible
Good	Sleek, dense	Thick	Little fat, muscular	Not visible
Fair	Dense	Medium	Lack fat, muscular	Slightly visible
Poor	Dull	Narrow	Lack fat, slim	Visible ribs, less protruding bones
Very poor	Dull, spare	Narrow	Lack fat, little muscle remained	Protruding

Table 2. Physical parameters and capture information for radio-collared Malayan sun bears in Ulu Segama Forest Reserve, Sabah, Malaysia.

ID #	Sex	Capture Date	Date Last Monitored	Age Class	Body Condition	Wt (kg)	TL (cm)	SL (cm)
125	M	22 June 99	12 Oct 99	Old	Fair	44	121	20
124	M	10 Jul 99	20 Sep 99	Old	Fair	40	124	24
123	M	7 Aug 99	10 Sep 99	Old	Poor	34	124	20
122	M	4 May 00	25 Jul 01	Sub-Ad	Poor	30	117	
121	F	24 Sep 00	25 Sep 00	Adult	Very poor	20	110	20
120	M	11 Oct 00	11 Jun 01	Adult	Fair	40	123	21

Age – Based on tooth wear, tooth color, body size, and overall condition
Body condition – Based on fat level, fur condition, and general appearance. Divided into 5 categories: range from "very poor", "poor", "fair", "good" and "very good".
Wt – Body weight, during first captured
TL – Total body length.
SL – shank length

Table 3. Capture information of bearded pigs in Ulu Segama Forest Reserve, Sabah, Malaysia.

Sex	Capture Date	Age Class	Body Condition	Estimated weight*
M	8 Mar 99	Adult	Very good	150 kg
M	1 Feb 00	Sub- adult	Poor	20 kg
M	27 Apr 00	Adult	Very poor	35 kg
M	9 Jun 00	Adult	Very poor	35 kg
F	7 Jul 00	Sub-adult	Poor	15 kg
F	25 Jul 00	Juvenile	Poor	10 kg

Age – Based on body size, and overall condition
Body condition – Based on body fat level, and general appearance. Divided into 5 categories: range from “very poor”, “poor”, “fair”, “good” and “very good”.
*weight were estimated visually while the pigs were in the traps.

Table 4. Physical appearance of Malayan sun bears determined from photographs taken by camera traps at Ulu Segama Forest Reserve, Sabah, Malaysia (n=198).

Bear ID	N	Location	Chronological description of physical condition
124	56	Coupe 88	July 99: “fair”; Aug 99: “poor”
122	28	Coupe 88	May 00: “poor”; Jul- Aug 00: “very poor”; late October 00: “fair”
121	10	Coupe 89	July 00: “poor”
120	53	Coupe 89	Aug-Sep 00: “poor”; Nov 00: “fair”
Unmarked "A"	44	Coupe 83	Mar-May 00: “fair”
Unmarked "B"	2	Coupe 88	May 00: “fair”
Unmarked "C"	2	Coupe 89	Nov 00: “fair”
Unmarked "D"	2	Coupe 89	Jul 00: “poor”
Unmarked "E"	1	Coupe 89	Aug 00: “poor”

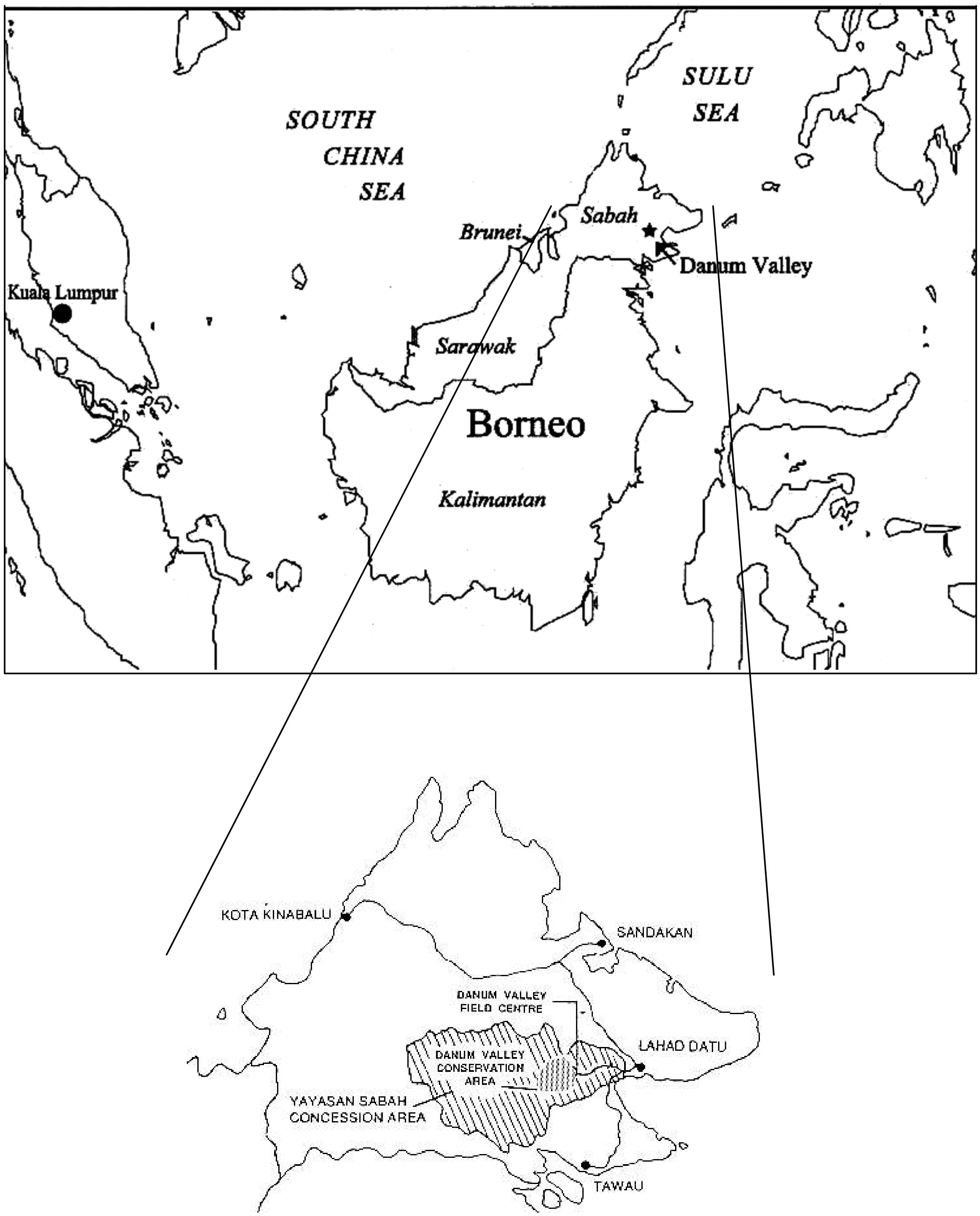

Figure 1. The location of the study area, based at Danum Valley Field Center at the state of Sabah, Northern Borneo.

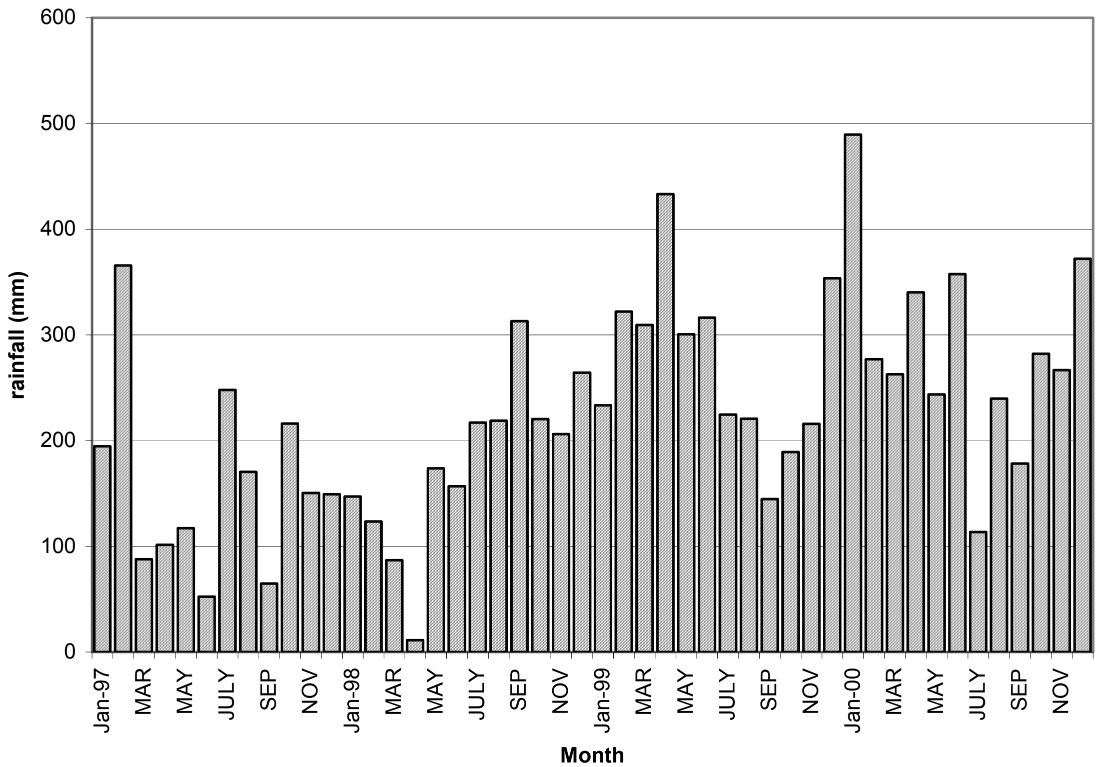

Figure 2. Monthly rainfall at Danum Valley Field Center, Ulu Segama Forest Reserve, Sabah, Malaysia, 1997-2000. Note the low rainfall during the 97-98 El Nino year in contrast to the high rainfall during 99-00 La Nina year.

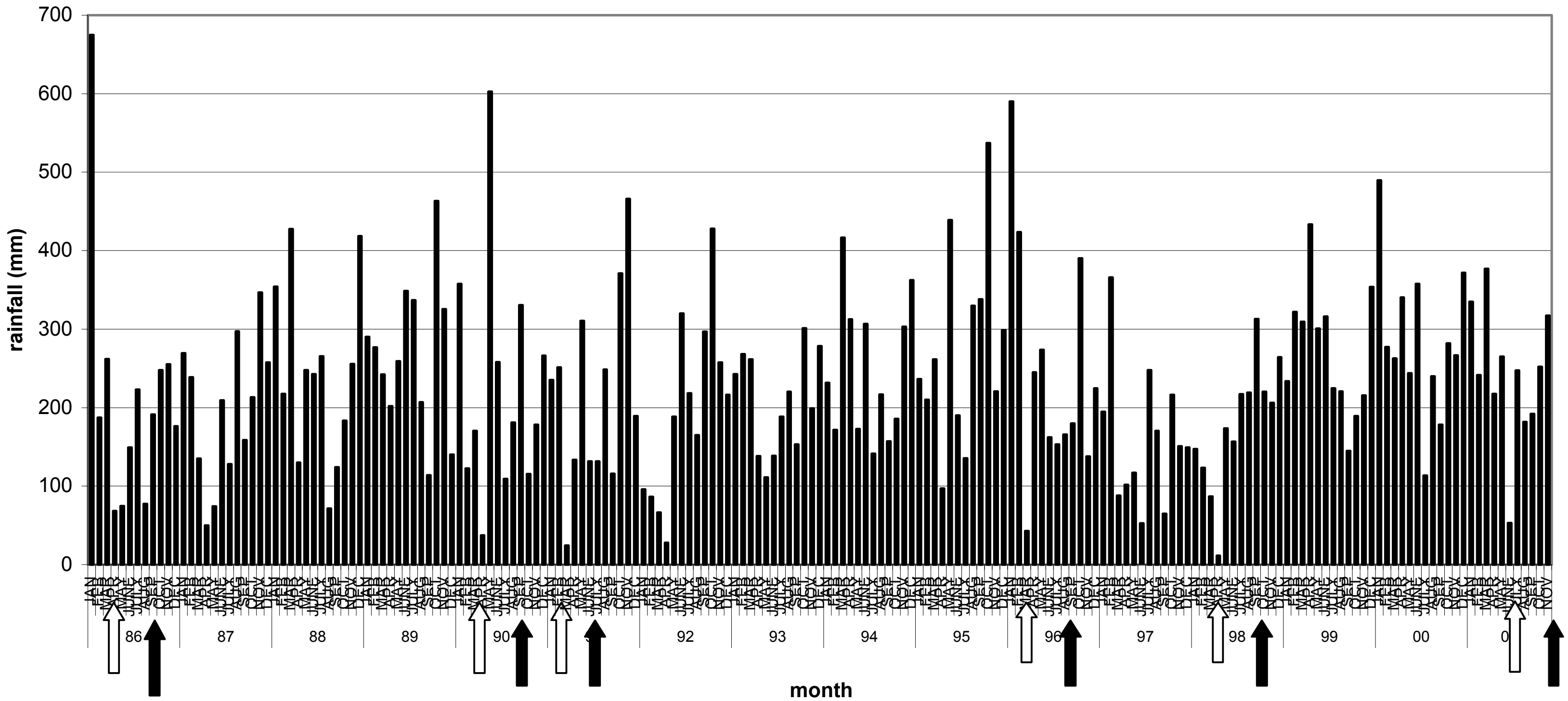

Figure 3. Monthly rainfall at Danum Valley Field Center, Ulu Segama Forest Reserve, Sabah, Malaysia, 1986-2000. Note the low rainfall (⇨) on April 1986, April 1990, March 1991, March 1996, April 1998, and June 2001 may correlated to the fruiting seasons (➡) five months after these low rain months, in which 1986, 1990, and 1996 fruiting seasons were mass fruiting. No phenological information available between 1986-90, and 1993-95.

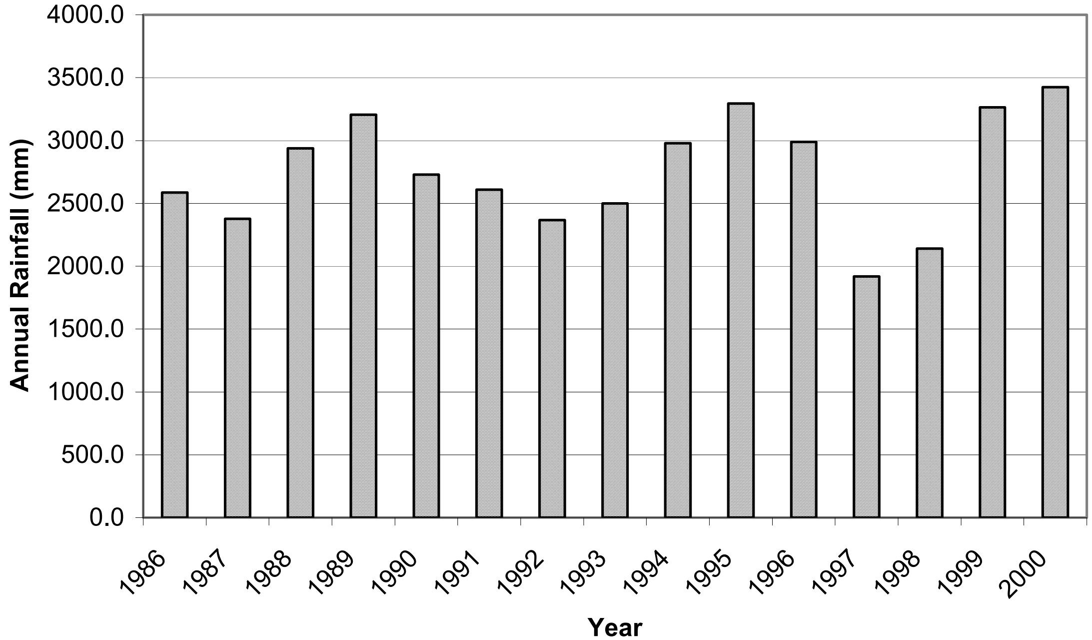

Figure 4. Annual rainfall at Danum Valley Field Center, Ulu Segama Forest Reserve, Sabah, Malaysia, 1986-2000. Note the low rainfall during the 97-98 El Nino years in contrast to the high rainfall during 99-00 La Nina years.

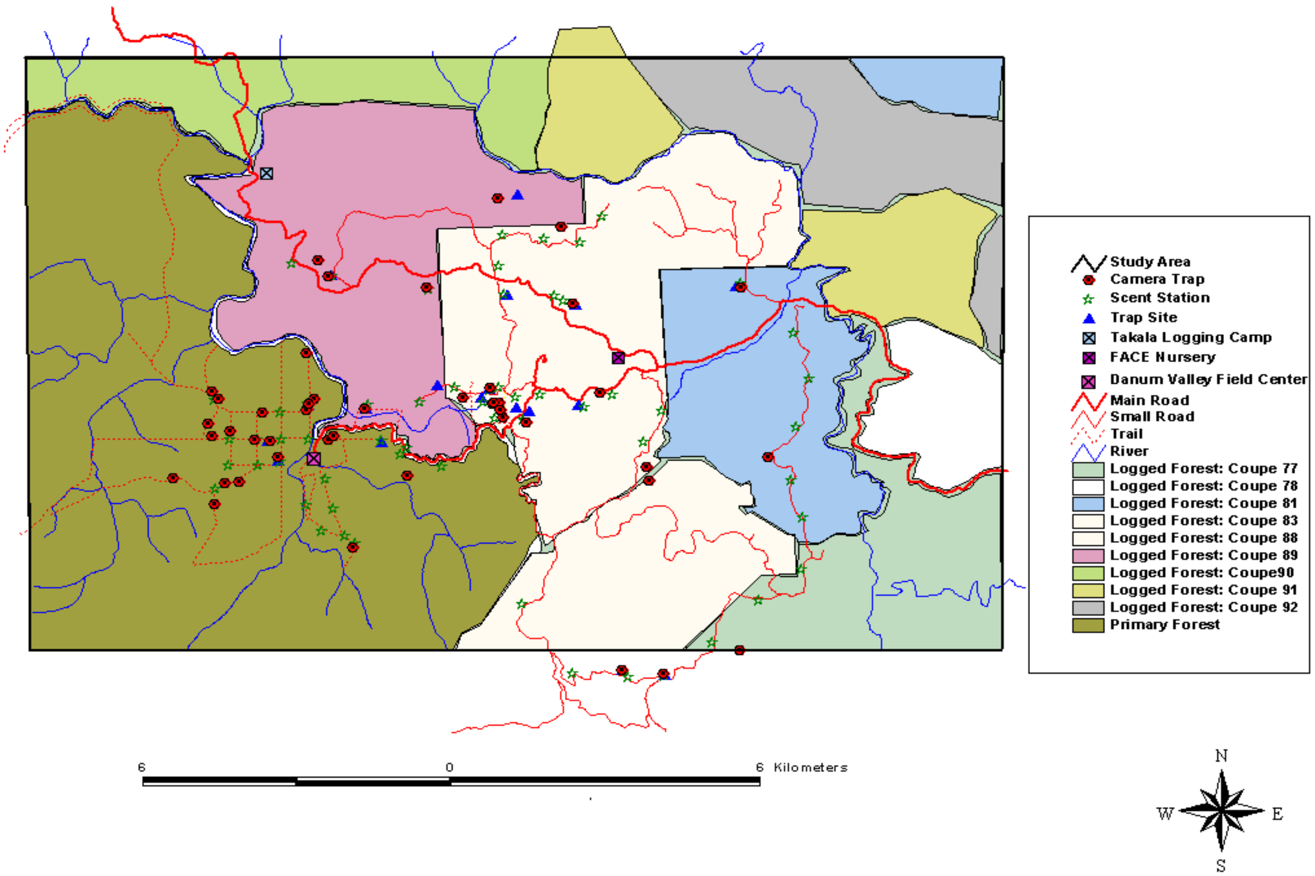

Figure 5. The study area covered approximately 150 km^2 of both logged and primary forest adjacent to the Danum Valley Field Center.

Figure 6. Bear #125 on October 11, 1999. The sparse hairs, protruding zygomatic arch, scapulae, ribs, vertebrae, and hipbones clearly indicated his extreme malnutrition. He lost approximately 32% of his body weight since his first captured by weighing only 30 kg.

Figure 7. Bear #122 photographed on July 28, 2000, revealed his “very poor” physical condition.

Figure 8. Bear #120 photographed on 23 August 2000 revealed his malnourished appearance before his captured on October 11, 2000. He has an emaciated body, sparse hairs, and loose skin that resulted in “wrinkle skin,” which were indications of starvation and malnutrition.

Figure 9. A healthy looking unmarked bear climbing down from a fruiting fig tree on November 13, 2000.

Figure 10. An adult pig captured in primary forest on April 27, 2000 was extremely skinny with most bones visible under its skin and little body muscle remained. The pig was capable of fleeing after we pushed him out of the trap.

Figure 11. The first extremely emaciated pig sighted on January 2000, at Danum Valley Field Center. This sub-adult pig was seen charged by resident pigs and found dead near our quarters a week later.

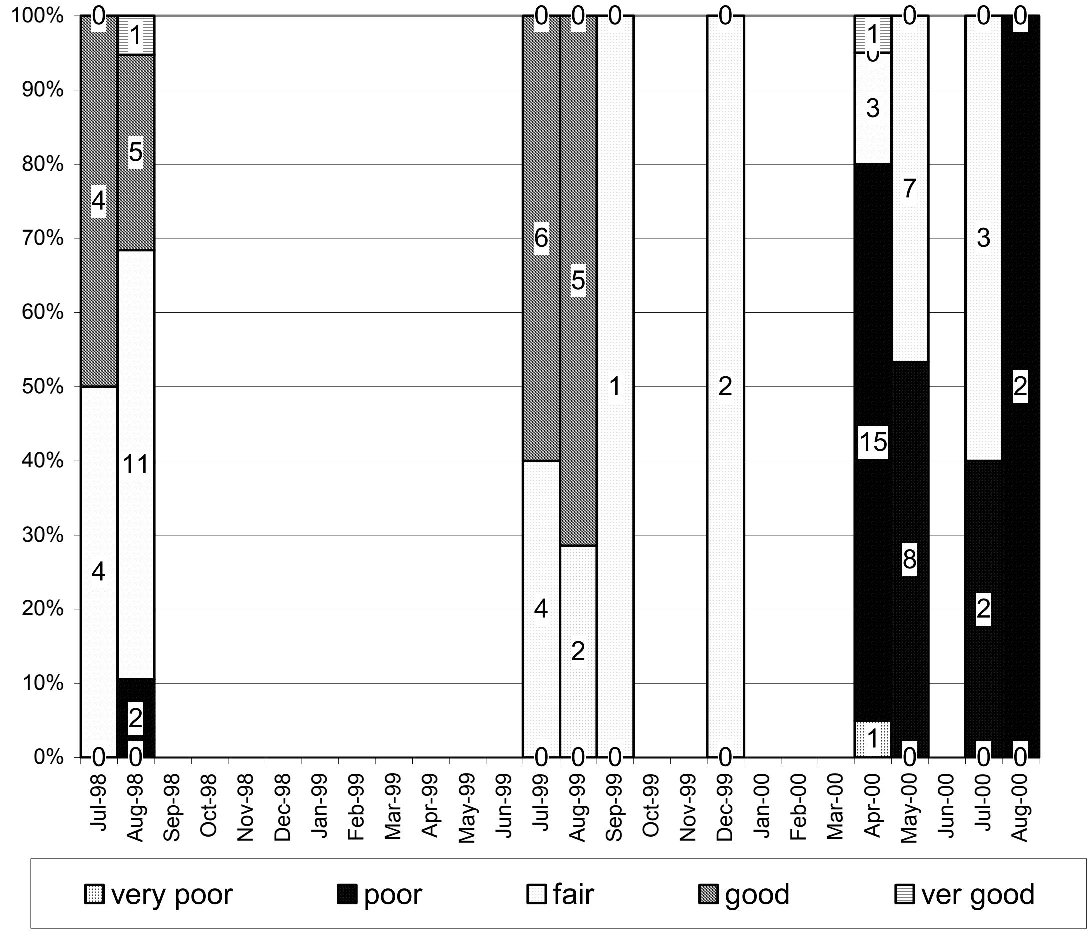

Figure 12. Physical condition of bearded pigs photographed in Ulu Segama Forest Reserve, Sabah, Malaysia (n=90). Numbers in bars indicate the number of photographs taken. The missing data resulted because no camera trap was set between September 1998 and June 1999, and no photographs of pigs were taken on October -November 1999, January - March, and June 2000.

Figure 13. Example of emaciated pig photographed on 6 April 2000 with camera trap in the study.

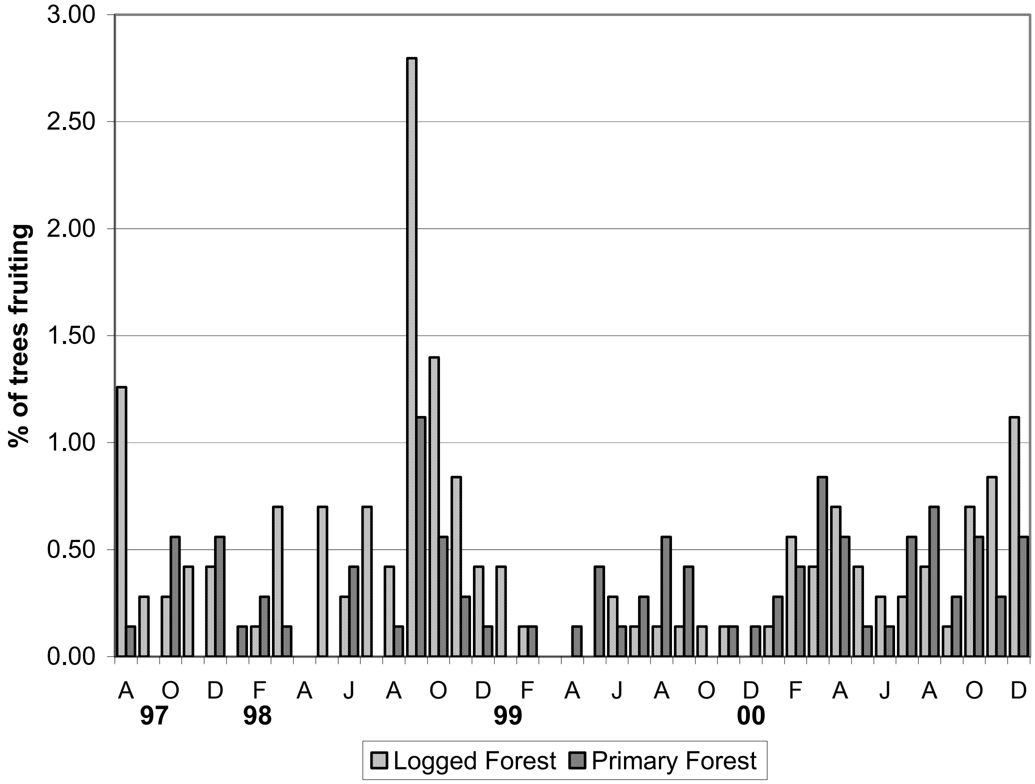

Figure 14. Fruiting frequency of trees in primary forest and logged forest from August 1997 to December 2000 at Ulu Segama Forest Reserve, Sabah, Malaysia (n=715).

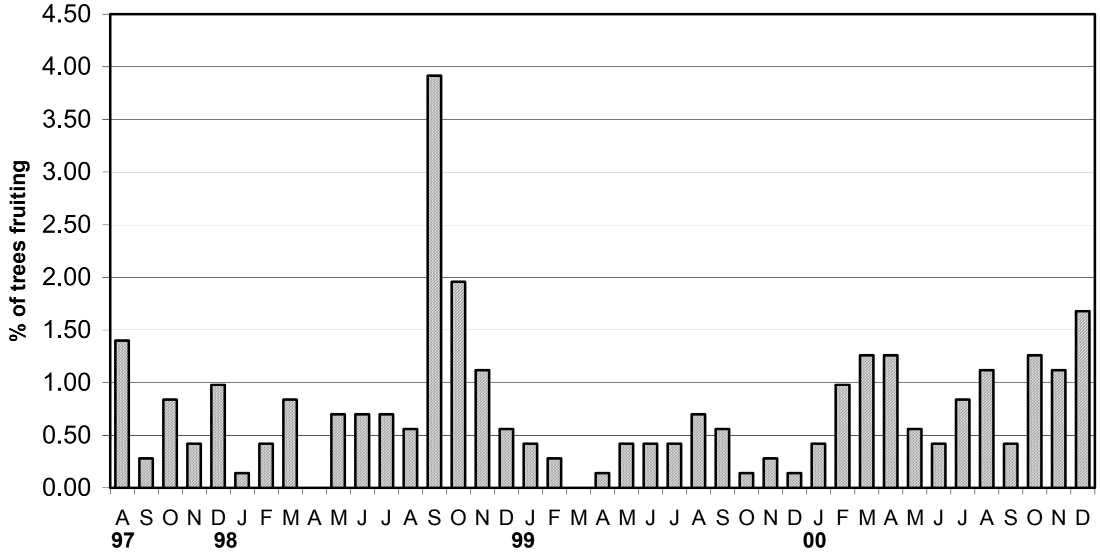

Figure 15. Percentage of total fruiting trees August 1997 to December 2000 at Ulu Segama Forest Reserve, Sabah, Malaysia (n=715).