INSECT SUCCESSION AND DIVERSITY ON CARRION IN DIFFERENT HABITATS AT KHAO YAI NATIONAL PARK

BUNTIKA AREEKUL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(ENVIRONMENTAL BIOLOGY)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2000

ISBN 974-664-493-9

Thesis

entitled

INSECT SUCCESSION AND DIVERSITY ON CARRION IN DIFFERENT HABITATS AT KHAO YAI NATIONAL PARK

Buntika Areekul
....
Miss Buntika Areekul
Candidate

V. Thirakhupt
....
Asst.Prof. Vacharobon Thirakhupt,
Ph.D.
Major-Advisor

....
Assoc.Prof. Sompoad Srikosamatara,
Ph.D.
Co-advisor

....
Prof. Liangchai Limlomwongse,
Ph.D.
Dean
Faculty of Graduate Studies

Praneet Damrongphol
....
Assoc.Prof. Praneet Damrongphol,
Ph.D.
Chairman
Master of Science Programme
in Environmental Biology
Faculty of Science

Thesis
entitled

INSECT SUCCESSION AND DIVERSITY ON CARRION IN DIFFERENT HABITATS AT KHAOYAI NATIONAL PARK

was submitted to the Faculty of Graduate Studies, Mahidol University for the degree of Master of Science (Environmental Biology)
on

July 28, 2000

Buntika Areekul
....
Ms. Buntika Areekul
Candidate

V. Thirakhupt
....
Asst.Prof. Vacharobon Thirakhupt,
Ph.D.
Chairman

....
Assoc.Prof. Sompoad Srikosamatara,
Ph.D.
Member

....
Mr. Sura Pimpasalee, M.Sc.
Member

....
Prof. Lianchai Limlomwongse,
Ph.D.
Dean
Faculty of Graduate Studies
Mahidol University

....
Prof. Amaret Bhumiratana,
Ph.D.
Dean
Faculty of Science
Mahidol University

4037168 SCEB/M: MAJOR: ENVIRONMENTAL BIOLOGY;
M.Sc. (ENVIRONMENTAL BIOLOGY)
KEY WORDS: INSECT SUCCESSION / DECOMPOSITION / DIPTERA / COLEOPTERA

BUNTIKA AREEKUL : INSECT SUCCESSION AND DIVERSITY ON CARRION IN DIFFERENT HABITATS AT KHAO YAI NATIONAL PARK. THESIS ADVISOR: VACHAROBON THIRAKHUPT, Ph.D., SOMPOAD SRIKOSAMATARA, Ph.D., SURA PIMPASALEE, M.Sc. 96 P. ISBN 974-664-493-9

A field study of insect succession on the carcasses of exposed household chicken and laboratory mice (*Mus musculatus*) was carried out in two different habitats—grassland and forest area at Khao Yai National Park, Thailand. The purposes of the study are to trace the insect succession pattern on the carcass, the rate of biomass removal during the decomposition process, the species diversity of carrion beetles on the carcass, and the impacts of physical environmental factors on the decomposition process. Six experiments, each lasting 35-40 days, were conducted at two-month intervals from January 1999 until December 1999.

In summer, during the first week of the experiment, the carcasses of both household chicken and laboratory mice decayed at a much faster rate than in the rainy season and winter (more than 70% of total biomass of both animal carcasses was removed in summer, 40% in rainy season and 20% in winter). Diptera and Coleoptera were the dominant groups of insects found on the carcasses. Dipteran larvae of the Family Calliphoridae were responsible at the beginning of the carrion degradation process followed by coleopterans. Twenty-one species of Coleoptera were found on carcasses. The diversity of Coleoptera was greater on carcasses in the forest area (H′ = 2.261) than those in the grassland (H′ = 2.114). In grassland, the diversity of Coleoptera was highest in summer followed by that in the rainy season and winter. Whereas in the forest, Coleoptera has the greatest diversity in the rainy season followed by that in thesummer and during winter. The similarity coefficient between Coleoptera found on the mice carcasses in the grassland and that in the forest area was 0.83. Approximately 50 insect species were found on carcasses throughout the study.

4037168 SCEB/M : สาขาวิชา : ชีววิทยาสภาวะแวดล้อม ; วท.ม. (ชีววิทยาสภาวะแวดล้อม)

บัณฑิกา อารีย์กุล : การศึกษาลำดับการเข้ากินซากและความหลากหลายของแมลงกินซากในที่อยู่อาศัยต่างชนิด ณ. อุทยานแห่งชาติเขาใหญ่ (INSECT SUCCESSION AND DIVERSITY ON CARRION IN DIFFERENT HABITATS AT KHAO YAI NATIONAL PARK). คณะกรรมการควบคุมวิทยานิพนธ์ : วัชโรบล ธีรคุปต์, Ph.D., สมโภชน์ ศรีโกสามาตร, Ph.D., สุระ พิมพะสาลี, M.Sc. 96 หน้า. ISBN 974-664-493-9

การศึกษาแมลงกินซากโดยใช้ซากหนูและไก่เป็นเหยื่อล่อในสิ่งแวดล้อมที่ต่างกันคือ บริเวณทุ่งหญ้าและบริเวณป่า ณ อุทยานแห่งชาติเขาใหญ่ มีวัตถุประสงค์เพื่อ ศึกษาลำดับการเข้ากินซาก, อัตราการย่อยสลายซากที่เกิดจากแมลงกินซาก, ความหลากหลายของกลุ่มแมลงปีกแข็งที่พบบนซาก และผลของปัจจัยสิ่งแวดล้อมต่อกระบวนการย่อยสลายซาก แต่ละการทดลองใช้เวลาประมาณ 35-40 วัน หรือจนกว่าซากจะย่อยสลายหมด รวมตลอดปีทำการศึกษาทั้งหมด 6 ครั้ง

ในช่วงสัปดาห์แรกของกระบวนการย่อยสลายซากของสัตว์ทั้งสองชนิด มีอัตราการย่อยสลายสูงสุดในฤดูร้อน (มากกว่า 70% ของน้ำหนักตัว), ฤดูฝน (40% ของน้ำหนักตัว) และฤดูหนาว (20% ของน้ำหนักตัว) ตามลำดับ พบแมลงในอันดับ Diptera และ Coleoptera มากบนซากสัตว์ทั้งสองชนิด หนอนแมลงวันหัวเขียว มีบทบาทสำคัญต่อการย่อยสลายซาก รองลงมาคือกลุ่มแมลงปีกแข็ง พบแมลงปีกแข็งทั้งหมด 21 สปีชีส์ จากซากของสัตว์ทั้งสองชนิด ความหลากหลายของแมลงปีกแข็งที่พบจากซากที่อยู่ในป่า ($H' = 2.261$) สูงกว่าที่พบจากซากที่อยู่ในทุ่งหญ้า ($H' = 2.114$) ณ บริเวณทุ่งหญ้า พบความหลากหลายของแมลงปีกแข็งสูงสุดในฤดูร้อน, ฤดูฝน และฤดูหนาว ตามลำดับ ในขณะที่ ณ บริเวณป่า พบความหลากหลายของแมลงปีกแข็งสูงสุดในฤดูฝน, ฤดูร้อน และฤดูหนาว ตามลำดับ แมลงปีกแข็งที่พบจากซากหนู ณ บริเวณทุ่งหญ้าและป่ามีสัมประสิทธิ์ความคล้าย (Similarity coefficient) เท่ากับ 0.83 จากการศึกษาครั้งนี้ พบแมลงทั้งหมดประมาณ 50 สปีชีส์

List of Contents

List of Contents (cont.)

List of Tables

List of Figures

List of Figures (cont.)

List of Figures (cont.)

List of Figures (cont.)

List of Figures (cont.)

List of Figures (cont.)

CHAPTER I

Introduction

Decomposition is a natural and necessary process responsible for the return of organic materials, such as dead plants or animal matters, to the ecosystem. Carrion or dead animal, represents a temporary and changing food source for a varied and distinct community of organisms. Arthropods, especially insects, are the major component of this community and are the primary element involved in the decomposition process, especially in the absence of vertebrate scavengers (1).

Insect succession is the orderly progression of insects inhabiting/utilizing the decomposing remains. The progress of insects invading a corpse is reasonably predictable (2). The general pattern of the insect succession is the rapid invasion of carcasses by adult Diptera (especially calliphorids and sarcophagids), the presence of dipterous larvae and adult coleopterans during which the insect diversity reaches its maximum, and the distinct decline in insect richness and dispersal from the carcasses (3).

The insects found in animal carcasses are classified into several ecological categories: necrophages (carrion-feeding), parasites and predators of the necrophagous species, omnivores and incidental or adventives (4). Insects of the Orders Diptera and Coleoptera comprise 60% of the total carrion fauna, and the dipteran Families Calliphoridae, Sarcophagidae and Muscidae are considered the most important decomposers (5) followed by the coleopteran Families Dermestidae, Silphidae and Cleridae (6). While silphids are usually considered the dominant form of carrion beetles, other types of beetles are also commonly found in carrion. Several genera of carrion-feeding Scarabaeidae frequent decomposing carrion during the early stages of decays (7). Parasites and predators are represented by the members of Coleoptera (Staphylinidae and Histeridae), Hymenoptera and several kinds of mites. Incidentals are the final group of arthropods. They include those associated with the corpse merely because it represents an environment similar to what they consider to be their normal habitat (i.e. moist, humid, rotting). Representatives of this division are the collembolans, spiders, centipedes, pillbugs, and some other mites (2).

The fauna succession on carrion is linked to the natural changes which take place in a corpse following death and also to the conditions surrounding the corpse. The availability of a body to the normal fauna succession of arthropods will strongly affect the rate of decomposition and the arthropod fauna found on the body (8). The carrion decomposition rate and arthropod succession are influenced by many factors, especially temperature, humidity, rainfall, abundance of insects (9) and carrion characteristics (10). The seasonal arthropod succession on carrion provides a dynamic profile of seasonal abundance of individual carrion species and a perspective on the shifting species composition of the carrion community with changing seasons (3).

Since the study on the ecology and successional pattern of carrion insects have not been recorded in Thailand even though these groups of insects are very important in the decomposition process. The objectives of this study will focus on

1. The pattern of insect succession on carrion in different habitats.
2. The comparison of biomass removal of the carrion between two habitats.
3. The impacts of environmental factors to the successional pattern of carrion insects.
4. The comparison of the species diversity and coefficient of similarity of carrion beetles (Coleoptera) between the two habitats. Species diversity and similarity coefficient will be calculated by using Shannon-Weiner function and coefficient of Sorensen, respectively.

CHAPTER II

Literature Review

The fauna succession on carrion is linked to the natural changes which take place in a corpse following death and also to the conditions surrounding the corpse. The availability of a carcass to the normal faunal succession of arthropods will strongly affect the rate of decomposition and the arthropod fauna found on the carcass (8). Insects perform a valuable recycling of organic matter in an ecosystem. The progression of insect diversity is somewhat predictable because certain insects are attracted to a cadaver only after certain levels of decay have occurred (7).

The insect succession on cadaver is a non-seasonal, directional and continuous sequential pattern of populations of species colonizing and being eliminated as the carrion decay progresses. The nature and timing of the succession depends upon the size of the corpse, seasonal and ambient climatic conditions, and the surrounding physical environment such as soil type. The organisms involved in the succession vary according to whether they are upon or within the carrion. Furthermore, each succession in different geographic areas will comprise different species of the carrion insects, even in places with similar climates. This is because very few species are widespread in distribution and each biogeographic area usually has its own specialized carrion fauna. However, the broad taxonomic categories of cadaver specialist are similar worldwide (11).

The first stage in carrion decomposition, "initial decay", involves only micro-organisms already present in the body, but within a few days the second stage called "putrefaction" begins. About two weeks later, amidst strong odors of decay, the third "black putrefaction" stage begins, followed by a fourth, "butyric fermentation" stage, in which the cheesy odor of butyric acid is present. This terminates in an almost "dry carcass" and in the fifth stage slow dry decay completes the process leaving only bones (11).

The typical sequence of corpse necrophages, saprophages and their parasites is often referred to as following "waves" of colonization. The first wave involves certain blow flies (Diptera: Calliphoridae) and house flies (Muscidae) that arrive within hours or few days at most. The second wave is of sarcophagids and additional muscids and calliphorids that follow shortly thereafter, as the corpse develops an odor. All these flies either lay eggs or larviposit on the corpse. The principal predators on the insects of the corpse fauna are staphylinid, silphid and histerid beetles, and hymenopteran parasitoids may be entomophagous on all the above hosts. At this stage blow flies' activity ceases as their larvae leave the corpse and pupate in the ground. When the fat of the corpse turn rancid, a third wave of species enter this modified substrate, notably more dipterans such as certain Phoridae and Drosophilidae. As the corpse becomes butyric, a forth wave of cheese skippers (Diptera: Piophilidae) and related flies use the body. A fifth wave occurs as the ammonia-smelling carrion dries out, and adults and larvae of the Families Dermestidae and Cleridae (Coleoptera) become abundant and begin feeding on keratin. In the final stages of dry decay, some tineid larvae (cloth moths) feed on any remnant hair (11).

These are examples of insects that are normally found on carrion.

Diptera:

1. Calliphoridae (blow flies). The blow flies constitute a large group, and are to be found practically everywhere. Many species are of considerable economic importance. Most blow flies are about the size of a house fly or a little larger, and many are metallic blue or green. Most blow flies are scavengers with larvae living in carrion, excrement, and similar materials. The most common species are those which breed in carrion. These species lay their eggs on bodies of dead animals, and the larvae feed on the decaying tissues of the animal. The larvae of some of the species that breed in carrion, particularly *Lucilia sericata* (Meigen) and *Phormia regina* (Meigen), when reared under aseptic conditions, have been used in the treatment of such disease in man as osteomyelitis. On the other hand, many of these flies may act as mechanical vectors of various disease, i.e. dysentery, frequently accompanies high blow fly populations (12).

2. Sarcophagidae (flesh flies). Flesh flies are very similar to blow flies in appearance and habits are generally quite common. The species which breed in carrion usually give birth to young larvae. Most flesh flies are scavengers in the larval stage, but a few are parasitic on other insects, snails, earthworms, or other invertebrate animals (12).

3. Muscidae. The family Muscidae includes the house fly, stable fly, horn fly, tsetse fly, and many other species. House flies are one of the most familiar and widely distributed of all insects. Besides being a nuisance, it is a prime carrier of disease. Its entire body swarms with millions of bacteria which are often transmitted to the food we

eat. Typhus, dysentery, tuberculosis and poliomyelitis are only a few of the illnesses for which it is a vector. House flies multiply at an enormous rate; it takes roughly two weeks from the time a female is hatched until she is able to lay eggs of her own. Favorite breeding sites are dung heaps, exposed human feces, all sorts of droppings, rotting garbage and carrion.

4. Phoridae (hump-backed flies). They are small or minute flies that are easily recognized by the hump-backed appearance, the characteristic venation, and laterally-flattened hind femora. The adults are fairly common in many habitats, but are most abundant about decaying vegetation. The habits of the larvae rather varied; some occur in decaying animal or vegetable matter, some occur in fungi; some are internal parasites of various other insects, and some occur as parasites or commensals in the nests of ants or termites. A few of the species occuring in ant or termite nests have the wings reduced or lacking (12).

Coleoptera:

Carrion beetles are a member of beetles in various Families that are frequently found in a close feeding association with vertebrate remains. They include the beetles in the Families Staphylinidae (rove beetles), Histeridae (hister beetles), Dermestidae (skin beetles), and numerous members of the Scarabaeidae (scarabs) (7).

1. Histeridae (hister beetles). These are small, broadly oval beetles that are usually shining black in color; the elytra are cut off square at the apex, exposing one or two apical abdominal segments. The antennae are elbowed and clubbed. These beetles are usually found in or near decaying organic matter, such as dung, fungi, and carrion, but are apparently predaceous on other small insects living in these materials, primarily maggots.

When disturbed, the hister beetles usually draw in their legs and antennae and become motionless. This enables them to usually avoid being seen and subsequently eaten by larger insect-feeding animals. The appendages fit so snugly into shallow grooves on the ventral side of the body that it is often difficult to see them, even with considerable magnification (7,12).

2. Staphylinidae (rove beetles). The body is slender and elongate, and can usually be recognized by the very short elytra. The elytra are usually not much longer than their apices. The hind wings are well developed and at rest are folded under the short elytra. Rove beetles are active insects which run or fly rapidly. When running, they frequently raise the tip of the abdomen like scorpions do. The mandibles are very long, slender, and sharp and usually cross in front of the head. Some of the larger rove beetles can inflict a painful bite when handled. Most of these beetles are black or brown in color. The color pattern of many species gives them a wasp-like appearance, and their penchant for curling the abdomen upwards when alarmed heightens this effect. Their wasp-like mimicry and ability to emit foul or caustic odors frequently protect them from other large, insect-eating predators. They vary considerably in size, but the largest are about an inch in length. Rove beetles occur principally in and about decaying animal or vegetable matter, particularly dung and carrion. Most species appear to be predaceous on other insects which occur in these materials (7,12).

3. Dermestidae (skin beetles). This group contains a number of very destructive and economically important species. The dermestids are mostly scavengers and feed on a great variety of plant and animal products including leather, furs, skins, museum

specimens, woolen or silk materials, rugs, stored food materials and carrion. Most of the damage is done by the larvae. Adult dermestids are small, oval, convex beetles with short clubbed antennae, and they vary in length from 2 to 10 or 12 millimeters. They are usually hairy and covered with scales. They may be found in the materials mentioned above and many feed on flowers. Some are black or dull colored, but many have a characteristic color pattern. The larvae are usually brownish, and are covered with long hairs (12).

4. Scarabaeidae (scarab). *Trox* species are scarab beetles that resemble small clumps of dirt because of their dirty gray or black color, lumpy shape, and frequent presence of encrustations and debris adhering to their bodies. Trogids, like hister beetles, are very adept at playing death when alarmed and so become extremely difficult to see because of their cryptic form and lack of movement. They too, like dermestids, are found scavenging in old, dry animal carcasses where the adults and larvae feed on anything that is left except bone. They seem to fulfill much the same role as dermestid beetles. Many other trogids live in mammal burrows or bird nests where they feed on fur, feathers, and other animal derived debris (7).

Hanski (13) studied the distribution ecology of 66 species of dung and carrion-feeding beetles (Scarabaeidae) in a forest type in the Gunung Mula National Park, Sarawak, a virgin forest area of 540 km^2 in Northern Borneo. He found that species richness was highest in the lowland forest and began to decrease with increasing altitude at 200 m above sea level, and no species were found at summit of Mt. Mulu (2376 m). The community in the lower montane rain forest was transitional between the lowland and upper montane communities, which were distinct in their species composition, some species are habitat specialists, this suggests tight species packing along the altitudinal gradient. The density of Scarabaeidae was high in the upper montane forest, in spite of low species richness, and density was exceptionally high in the limestone forest, where only onespecies was exceedingly abundant because the soil in the limestone forest is suggested to be unsuitable for the burrowing species of Scarabaeidae.

The pattern of insect succession as well as effects of environmental factors on the successional process and on carrion insects have been studied by a number of entomologists. Payne (14) distinguished six successional stages in the decomposition of the baby pig, *Sus scrofa*, as: fresh, bloated, active decay, advanced decay, dry and remains. The carrion free of insects decomposed slowly and retained its form for many months, whereas 90% of the carrion accessible to insects was removed in six days. This clearly shows that, in the absence of vertebrate scavengers, the succession in carrion is driven by insects, and population may be food-limited. His study supported the studies by Deonier (15) that the dominant insect guild is calliphorids. Their activity raises carrion temperature higher than soil and even air temperatures. The temperature of carcasses varies according to climatic conditions and immediate environment. A carcass in the shade usually cools to nearer air temperature than one exposed to the sun. The surfaces of carcasses warmed by the sun accumulate heat, a portion of which is retained overnight. Carcasses in the shade did not show a higher temperature until the larval development occurred. The natural body orifices usually become infested first, but if moisture conditions are favorable, flies oviposit readily on any parts of the body. When most of the

skin of the carcass is dry, conditions are often favorable for the oviposition in parts of the carcass that come in contact with the soil. After the eggs have hatched and the larvae have penetrated the tissues and begun development, enough heat is generated by the larvae, when added to that absorbed from the sun, to keep the carcass temperature high enough for continued larval development even when the minimum atmospheric temperature drops to 50° F. or lower. The insect activity on carrion has the effect of speeding up succession, both because insect activity is increased and because bacteria activity, which facilitates carrion feeders' digestion, is promoted by increased temperature.

Richer (8) studied the impact of circumstances surrounding death and decomposition whether a corpse is lying in the sun or the shade will affect its temperature and also the insects that are attracted to it. Some insects prefer bright sunlight and others prefer shady conditions. She found that calliphorid flies prefer shady condition while sarcophagid flies prefer sunny condition.

Megnin (8) and Motter (8) were the first to discover that exhumed cadavers had their own peculiar insect faunas and later work by Schmitz (8) and Leclercq (8) confirmed their findings. Burial hinders the decay process by excluding airborne bacteria and the normal fauna succession of invertebrates. A limited and somewhat different fauna is able to reach the corpse, but it varies with the nature and depth of the burial. Blow flies can be excluded from access to buried remains by as little as one inch of covering, but sarcophagid flies have been found on much deeper remains. Because of the decreased accessibility, the most significant feature of buried carrion is the longer time taken for its reduction compared to exposed carrion.

Wall and Warnes (16) reported the results of studies designed to explain the behavioral responses of sheep blowfly (*Lucilia sericata*; Diptera: Calliphoridae) to odor, initially through an examination of the effects of carrion odors and carbon dioxide on flight in the laboratory and, subsequently, on the responses of *L. sericata* to carrion-bait in the field. They found that the linear velocity was reduced and the sinuosity of flight increased in the presence of carrion odor. The response to carrion odor depends on previous exposure to proteinaceous materials. Protein-deprived females showed kinetic responses to carrion odor which were similar to these of gravid females. No such changes were observed in protein-fed females. No responses to CO_2 were observed. In the field, the importance of olfactory cues in bait location was demonstrated by the absence of *L. sericata* from sticky targets lacking an odor bait. The increased bait concentration did not affect the age, sex ratio or the ratio of *L. sericata* to other *Lucilia* spp. caught, but did increase the number caught. The analysis of the reproductive status of females caught indicated that a greater number of gravid females were caught than expected, while a lower number of females in the final stages of vitellogenesis were caught than expected. The results show that the responses of *L. sericata* to odors are complex, and are dependent on both exogenous and endogenous stimuli, the latter including the stage of ovarian development.

Many forensic entomologists study the patterns of carrion arthropod succession because the succession follows a predictable pattern. Different species will appear in different places at different times of the year and under different circumstances. Tantawi *et al* (3) described the decomposition process and arthropod succession patterns from seasonal field studies on exposed rabbit carcasses which were conducted in Alexandria, Egypt in 1988 and 1989. Eleven carrion-breeding dipterans were found to coexist in the study site. This coexist was facilitated by temporal separation by season and succession. The flies are *Calliphora vicina*, *Lucilia sericata*, *Chrysomya albiceps* (Calliphoridae); *Sarcophaga argyrostoma*, *S. aegyptica* and *W. nuba* (Sarcophagidae); *Synthesiomyia nudiseta*, *Muscina stabulans*, *M. prolapsa* and *Ophyra ignava* (Muscidae); and *Fannia leucosticta* (Fanniidae).

Calliphora vicina and *L. sericata* were primary species. *Calliphora vicina* was well represented in carrion in winter only, indicative of a preference for cooler temperatures. Greenberg and Povolny (17) stated that *Calliphora vicina* occurs in winter in the subtropics and in spring and fall in the temperate zone. Greenberg (5) noted that while higher temperatures ≈30°C accelerate the development of feeding instars of *Calliphora vicina*, the post feeding larvae fail to pupate and subsequently die. *Lucilia sericata* was able to breed successfully in carrion in fall, winter, and spring. *Chrysomya albiceps* was a secondary species in carrion summer, fall, and spring (3).

Wohlfahrtia nuba invaded rabbit carcasses only in summer and fall. Adults were absent in winter and spring. In summer, the larvae of *W. nuba* developed faster and pupate earlier than those of *Chrysomya albiceps*, but the pupariation period of the former species was longer. Denno and Cothran (18) stated that although the total life history of sarcophagids is longer than that of calliphorids, the feeding larvae of sarcophagids develop were rapidly. *Sarcophaga argyrostoma* and *S. aegyptica* bred successfully in carrion only in fall. In summer, high temperatures suppress the breeding activity and in winter the flies are hardly seen (3).

Seven muscid species were collected on rabbit carcasses in their study, of which 4, *Synthesiomyia nudiseta*, *Muscina stabulans*, *M. prolapsa* and *Ophyra ignava* breed in carcass in the cooler seasons. *S. nudiseta* was a secondary invader of slow-decaying carcasses in fall. *Ophyra ignava* was a tertiary fly in fall and winter carcasses. Larvae of this species appeared later in succession, and after those of calliphorids, sarcophagids, and other muscids. *Muscina stabulans* and *M. prolapsa* were secondary invaders of carrion in winter only (3).

Fanniidae was represented by *Fannia leucosticta* and *F. canicularis* in the cooler seasons. Only *Fannia leucosticta* bred as a tertiary fly in some fall and all winter carcasses. Larvae of this species appeared in carrion after those of *Ophyra ignava.* Larvae were on the upper side or on remaining scraps along the edges of carcasses. They were abundant compared with other fly larvae (3).

Adults of smaller Diptera of the Families Psychodidae, Scatopsidae, Sciaridae, Phoridae, Carnidae, Sepsidae, and Sphaeroceridae frequented carcasses in cooler seasons, especially winter. Psychodids, sciarids, and phorids were present only in winter carcasses. These flies observed feeding on the moistened carcasses as well as on the fluid seeping into the soil under and around carcasses during the decay stage. Sphaerocerids, phorids and scatopsids were the predominant adult dipterans present in the latter part of the decay stage after the departure of calliphorids and sarcophagids (3).

The staphylinines *Creophilus maxillosus*, hairy rove beetle, *P. longicornis* and *P. sordidus* and the aleocharine *Boreophilia* sp. were found to be the prevalent staphylinids present on carrion. Adults were observed preying heavily on dipterous larvae and probably an ectoparasite of dipterous pupa in its larval stage. In summer, only *P. longicornis* was present. In fall, only *Boreophilia* sp. frequented slower decaying carcasses. This species arrived late on day 50 and remained under carcasses associated with *C. albiceps* puparia until the end of observation. In winter, staphylinidae were well represented by *Creophilus maxillosus*, *P. discoideus*, *P. sordidus*, *longicornis* and *Boreophilia* sp. (3).

Histerids frequented carcasses in the decay stage and their feeding was confined to dipterous larvae. They may be significant in reducing dipterous larvae in carrion. In summer, *Saprinus chalcites* visited carcasses. Despite its small size, it was observed frequently devouring moderate- and large- sized maggots of *W. nuba* and *C. albiceps*. In winter, the Family was well represented by *Saprinus subnitescens* and *S. chalcites* (3).

Scarabaeidae was represented by *Aphodius granarius* in fall. This species was scantier in winter and absent in summer and spring. Scarabaeids are mainly coprophagous and are attracted to herbivore carcasses to feed on rumen contents (Tantawi *et al* 1996).

Two tenebrionid species were collected, *Blaps sulcata* and *Gonocephalum* sp. Adults of the former were observed on carcasses at night only, preying heavily upon fly maggots. In summer, *Blaps sulcata* was present on carrion in the bloated and decay stages, and in fall it was observed only in the bloated stage. *Gonocephalum* sp. was present only in winter and spring under carcasses in the later part of the decay stage and in the dry stage. There were no observations of carrion or maggot feeding (3).

In their study, a total of at least 100 arthropod species belonging to 16 orders and 48 families was recorded on rabbit carrion; many species were incidental visitors, not involved in the decomposition process. Diptera and Coleoptera dominated the carrion fauna. Diptera represented 37% and Coleoptera comprising 27% of the total number of arthropod species collected. The same pattern of dominance occurred throughout the year.

Richards and Goff (1) also studied arthropod succession patterns on exposed carrion (domestic pig carcasses) in three contrasting tropical habitats on Hawaii Island, Hawaii. In Richards and Goff (1), they extend the sampling range (previously limited to Oahu) to include 3 very different habitats found on the island of Hawaii—upland forest and woodland (1877m), rainforest (1169m), and midelevation woodlands (646m)—and make comparison of the nature of decomposition on Oahu and Hawaii.

Comparison decomposition studies between the island of Oahu and Hawaii have found that they have basic similarities of decomposition. Diptera were the first to oviposit on the carcasses. This trend has been documented in other successional studies conducted in tropical and temperate climates around the world. Some differences exist in the decay process between these two islands. These differences are related to variation in temperature, rainfall, and vegetation, which in turn, affect the species composition of carrion-community at each site (1).

Environmental factors—temperature, humidity and rainfall—have impacts on carrion decomposition rate and arthropod community. De Souza and Linhares (6) studied the effect of natural environmental conditions to the species of Diptera that visit and breed in carrion for each season. It was found that several fly species showed a definite seasonal pattern. Calliphoridae breed more frequently during the warmer months of the year, and the Sarcophagidae prefer the cooler periods.

The knowledge of the species that use carrion for breeding as well as their successional pattern, are of great importance in forensic medicine, for it may provide crucial information on the cause and circumstances of death. Several studies that use the knowledge of the composition and successional pattern of carrion insects for forensic purposes have been done in temperate parts of the world but very little known for tropical region (6). In Thailand, very few studies have been done about forensic entomology (19).

CHAPTER III

Materials and Methods

Study Sites :

During January 1999 to December 1999, field studies on chicken and mouse decomposition and their associated insect fauna were conducted at the Khao Yai National Park. The Park is located about 200 km northeast of Bangkok. It lies between 14° 15′ to 101° 50′ E. The size is 2,168 km^2, covering four provinces: Nakorn Ratchasima, Saraburi, Prachinburi, and Nakhon Nayok.

The Park was established as the first national park of Thailand in 1962. The main parts of the park are the mountain range "Phanom Dongrak" which lies between about 250 and 1,351 m above sea level. There are six dominant mountain peaks: Khao Laem (1,326 m) in the north; Khao Rom (1,351 m) and Khao Khieo (1,292 m) near the park's center; Khao Kamphaeng (875 m) in the northeast; and Khao Sam Yot (1,142 m) and Khao Fa Pha (1,078 m) in the northwest. Three major rivers that originate in the park are; the Lam Takhong River, flowing northeast; the Nakhon Nayok River, flowing south; and the Sai Yai River, flowing southeast. Smaller rivers that also originate in the park include Huai Muak Lek, Mae Nam Prachantakham, and Mae Nam Hanuman.

The annual precipitation at the Park is about 2,000-3,000 mm and is influenced by the southwest monsoon from the Indian Ocean during May and October. The relatively dry conditions begin from November until April. The driest months are

December and January with average precipitation of 15 mm per month. The temperature ranges between 5°C and 30°C over the year. The average annual temperature is 23°C. Average temperatures are highest in April and May, and lowest in December and January. The average humidity is about 86 percent. The vegetation types were grouped and described by Smitinand (1968) into 5 types as follows:

1. Dry Mixed Deciduous Forest occurs along some northern slopes at the elevations between 400-600 m. Typical tree species include *Afzelia xylocarpa*, *Zylia kerrii*, and *Lagerstroemia calyculata*. *Bambusa arundinacea* is the major understory species as well as various grasses.

2. Dry Evergreen Forest occurs along the lowland eastern border of Nakhon Ratchasima and Prachinburi at the elevations of 100-200 m. *Dipterocarpus alatus*, *Shorea roxburghii*, *Hopea odorata*, *Hydnocarpus ilicifolius* and *Aglaia* sp. are typical tree species that occur in this vegetation type.

3. Tropical Rain Forest occurs as the main parts of the park at the elevations between 500-1000 m. Important canopy species include *Dipterocarpus alatus*, *D. gracilis*, *D. costatus* and *Schima wallichii*. Understory species include *Lithocarpus annamensis*, *Castanopsis acuminatissima* and *Quercus fleuryi*.

4. Hill Evergreen Forest occurs at the elevations above 1,000 m and on the ridges of high mountains. *Podocarpus* spp., *Dacrydium elatum*, *Lithocarpus* sp. and *Quercus* sp. are typical upperstory trees whereas *Olea maritima*, *Rhus succedanea* and *Adina polycephala* are typical understory species. Epiphytes are abundant in this type of habitat.

5. Grassland and Secondary Growth results from former inhabitants, about 35-80 years ago. Common grass species include *Imperata cylindrica*, *Neyraudia*

reynaudiana, *Saccharum spontaneum* and *Themeda arundinacea*. Some common secondary tree species are *Hibiscus macrophyllus* and *Trema orientalis* (20).

Two different types of habitats at and near the abandoned golf course were selected as the study sites—a grassland and a dry evergreen forest (figure 1). The area of the study site is approximately 1 km^2. These two habitats are connected to each other. Both areas have inhabited a large number of wild animal species such as deer, barking deer, tiger, hog and bird. The site selection was based on the following criteria: It must

1. facilitate the exposure of the designated carcasses to carrion insects.
2. permit observation of the carrion.
3. be an isolated area in order to prevent disturbance of the carcasses by unwanted animals and their activities including human.

Animal Models :

Laboratory mice (*Mus musculus*) with an average weight of 35 g and household chicken with an average weight of 1,320 g were used. The bodies of mice and chicken were obtained by using ether and by cutting a throat vein, respectively, just prior to the experiments.

Procedures :

In each area, two experiments were designed to collect data on the insect succession and the rate of biomass removal of the carcass. The traps were set in two different way to collect data—in order to weigh the carcass in the biomass removal trap and in order to collect insects in the succession experiment. Both traps were set next to each other at the distance of 10 cm apart (figure 2). The chicken and mouse carcasses were placed 20 m apart at each site. New traps were set at two-month interval. Thus, making six experiments in total. The dates of the trap setups are as follows:

1. January 15, 1999
2. March 12, 1999
3. May 20, 1999
4. July 9, 1999
5. September 17, 1999
6. November 12, 1999

Each trap consists of a plastic tub of 20 cm diameter buried 30 cm deep in the ground. The collecting cup (8.5 cm diameter, 13 cm tall) filled with 70% ethyl alcohol was placed inside the tub. A funnel was placed on top of the tub with the end tip on top of the collecting cup. A grill (2.5 by 2.5 cm mesh) rested on the funnel.

In order to obtain insect specimens, a dead mouse or chicken was placed on the grill of the funnel and were exposed to attract detritivorous insects. Hence, using them as baited trap. Each trap was covered with a wire mesh and zinc cover to avoid the removal of the bait by scavenging vertebrates whereas insects of all sizes were allowed free access to the carcasses.

Data Collection:

The insect collection and the weighing for the carcasses of biomass removal were made 7, 14, 21 and 35 days after the start of each experiment. After 35 days, the carrion was completely dried out and was no longer attractive to insects. The time of collection and weighing did not exceed 10 minutes in order to keep the disturbance of carcasses at a minimum and to maintain the integrity of the micro-community. At each visit, the physical conditions and the state of decay of each carcass were recorded.

Data on temperature, rainfall, and humidity at the Park during the period of the experiments were obtained from the rain gauge station and the meteorological station at Mor Sing To located at the Khao Yai National Park.

Insect Specimens :

The insect specimens collected were brought into the laboratory and the total counts of insects as well as other arthropods were made. The adult specimens were pinned and the larvae were preserved in 70% ethyl alcohol for further identification. Specimens were identified down to at least the Family level and some to the species level. Arthropods other than insects were excluded and were not identified.

Data Analysis :

Three measurements were used to indicate species diversity of Coleoptera and similarity coefficient of Coleoptera between two habitats.

Shannon-Weiner Function :

The Coleoptera species diversity was calculated using Shannon index, H', in Shannon-Weiner function. The number of species and the number of individuals in each species must be collected (21).

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$$

H' = Index of species diversity (bits/individuals)

S = Number of species

p_i = Proportion of total sample belonging to i^{th} species

It should be noted that any base of logarithms can be used for this index, since they are all convertible to one another by a constant multiplier:

H' (base 2 logs) = 3.321928 H' (base 10 logs)

H' (base e logs) = 2.302585 H' (base 10 logs)

The Shannon-Weiner measure H' increases with the number of species in the community and, in theory, can reach very large values. In practice, for biological communities H' does not seem to exceed 5.0 (22).

Evenness Measures or Equitability :

The most commonly used index of evenness in the literature is based on the Shannon-Weiner function

$$J' = H' / H'_{MAX}$$

J' = Evenness measure or equitability (range 0-1)

H' = Shannon-Weiner function

H'_{MAX} = Maximum value of $H' = \log_2 S$

A greater number of species increases species diversity, and a more even or equitable distribution among species will also increase species diversity measure by the Shannon-Weiner function (21).

Measurement of Similarity :

Coefficient of Sorensen

$$Ss = 2a / 2a + b + c$$

Ss = Sorensen's similarity coefficient

a = Number of species in sample A and sample B (joint occurrences)

b = Number of species in sample B but not in sample A

c = Number of species in sample A but not in B

The range of the similarity coefficient is supposed to be 0 (no similarity) to 1.0 (complete similarity) (21).

Figure 1. The study sites—a grassland and a forest area at the abandoned golf course.

Figure 2. A chicken-baited pitfall traps in the forest area.

CHAPTER IV

Results

1. Pattern of insect succession on carrions in different habitats

1.1 Mouse carcass in the grassland area

The most abundance of insects (380 individuals) was found during the first week of decomposition period and then slightly declined until no insects were found on the completely decomposed carcass (Figure 1, see Appendix B-1).

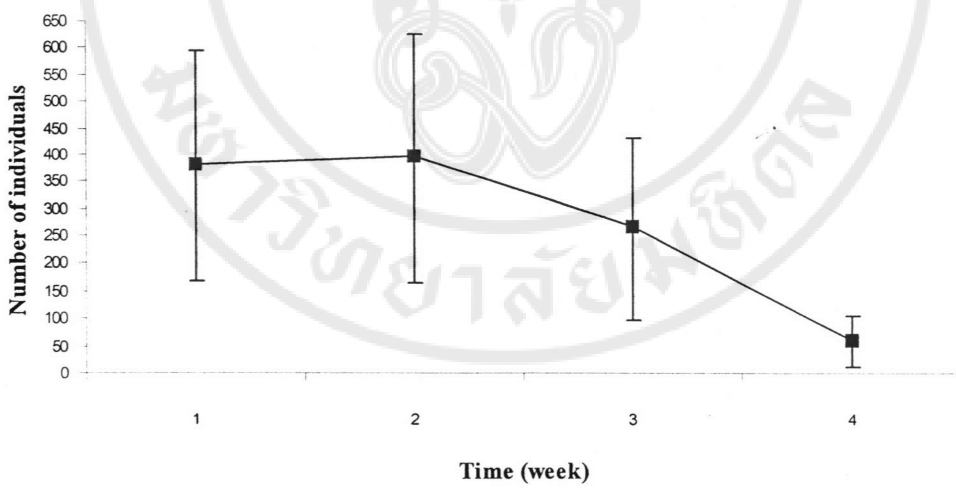

Figure 1. The average total number of insects per week on mouse carcass in grassland.

Figure 2 shows the relationship between the average number of maggots collected from traps during the decomposition period. The number of maggots was high (=154) during the first week of decomposition period. On the second week, the number of maggots declined very rapidly to 23 individuals. After two weeks, the number of maggots declined to zero because they completed their development (2) and carcasses were dried out, so they were not attractive to fly adults for the oviposition anymore.

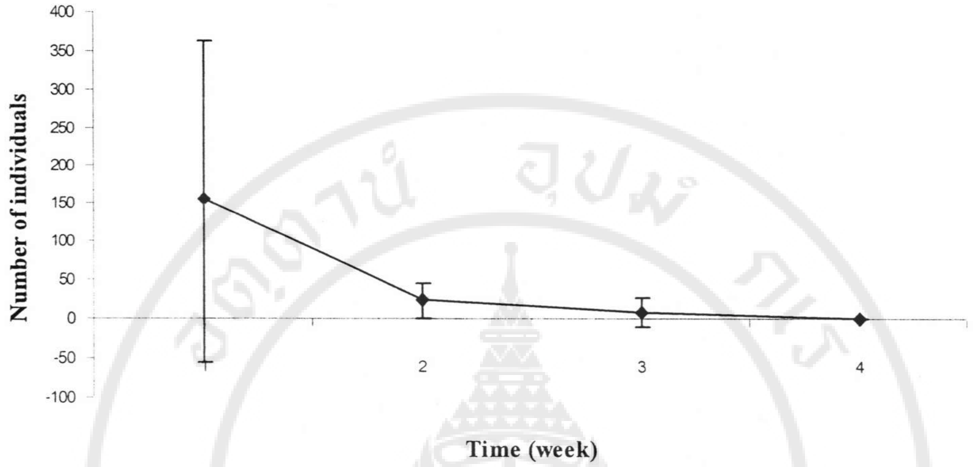

Figure 2. Average total number of maggots per week on mouse carcass in grassland.

Figure 3 represents the number of maggots on the mouse carcass in grassland during the decomposition process in three seasons. The number of maggots was found higher in rainy season (=235) than in winter (=136). In summer, the presence of maggots was extremely low (=5) because the number of ants was high in this trap (> 5000). Ants are the strong competitor of maggots and they also feed on maggots (23). Wells and Greenberg (24) reported that the red imported fire ant, *Solenopsis invicata* Buren, significantly affected the daily occurrence of post-feeding larvae of screwworm *Cochliomyia macellaria* (F.), in carrion-baited traps.

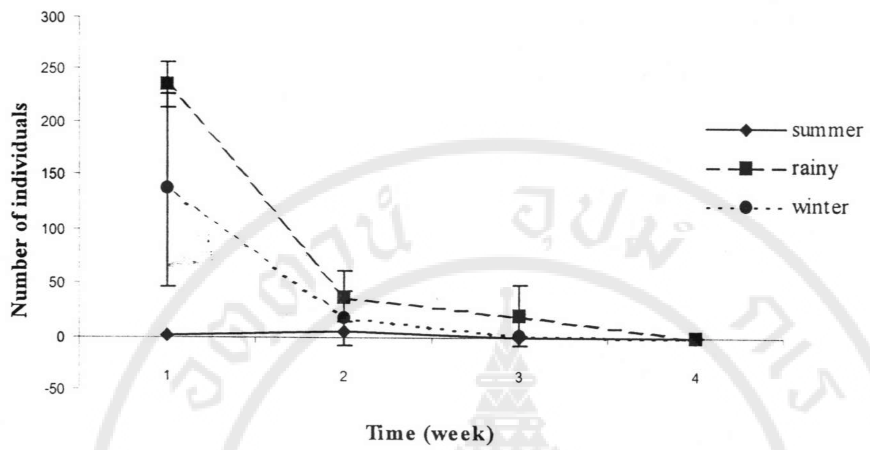

Figure 3. Comparison of the average total number of maggots per week on mouse carcass in grassland in summer, rainy season and winter.

Figures 4-6 show the abundance of Coleoptera species collected from the mouse carcass in grassland during the decomposition process in each season. The number of each species is shown in percentage of the total number collected. Three Families – Staphylinidae (rove beetles), Scarabaeidae (scarab beetles), and Histeridae (hister beetles)—were found on the carrion. Staphylinidae was the dominant group of beetles found in every trap during the year. Staphylinids are the predators of Diptera larvae (1).

In summer, eleven species of Coleoptera were found. Each species was found in a low number. Eight individuals of rove beetles sp. 4 from the average total number of beetles (=35) were found highly in the second week. In rainy season, twelve species of Coleoptera were found. Rove beetle sp. 3 was found in the greatest number (=70) in the second and third week. Rove beetle sp. 5 ranked the second in term of number. No beetles were found on the forth week. The average total number of beetles found in this season is 143 individuals. In winter, ten species of Coleoptera were found. Rove beetle sp. 3 were found in greatest number in the first and second week. The average total number of beetles found in this season is 156 individuals.

The diversity of Coleoptera species collected from mouse-baited pitfall traps in grassland has the greatest diversity in summer (H′ = 3.066, J′ = 0.886, see Appendix A-2) followed by in rainy season (H′ = 2.522, J′ = 0.631, see Appendix A-3) and in winter (H′ = 2.096, J′ = 0.606, see Appendix A-4), respectively.

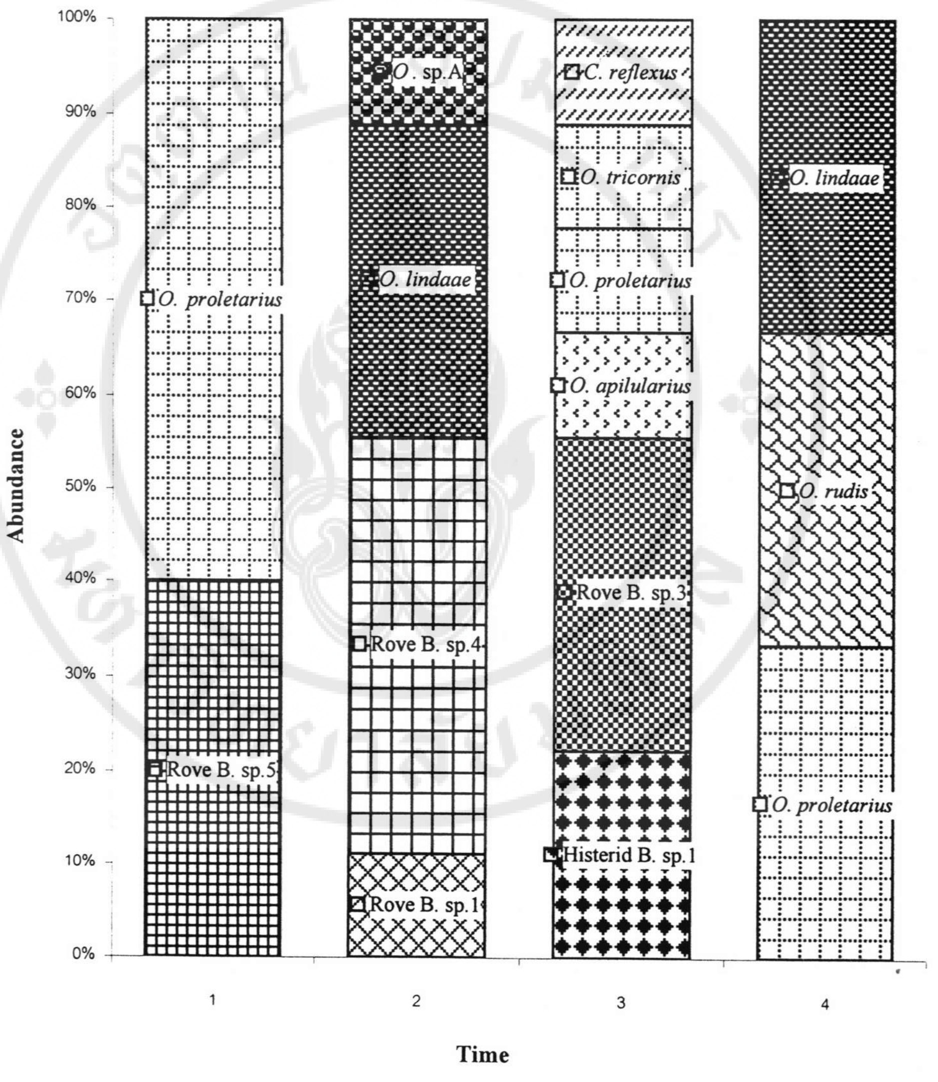

Figure 4. The percentage of Coleoptera species collected from the mouse carcass in grassland in summer (March-April 1999).

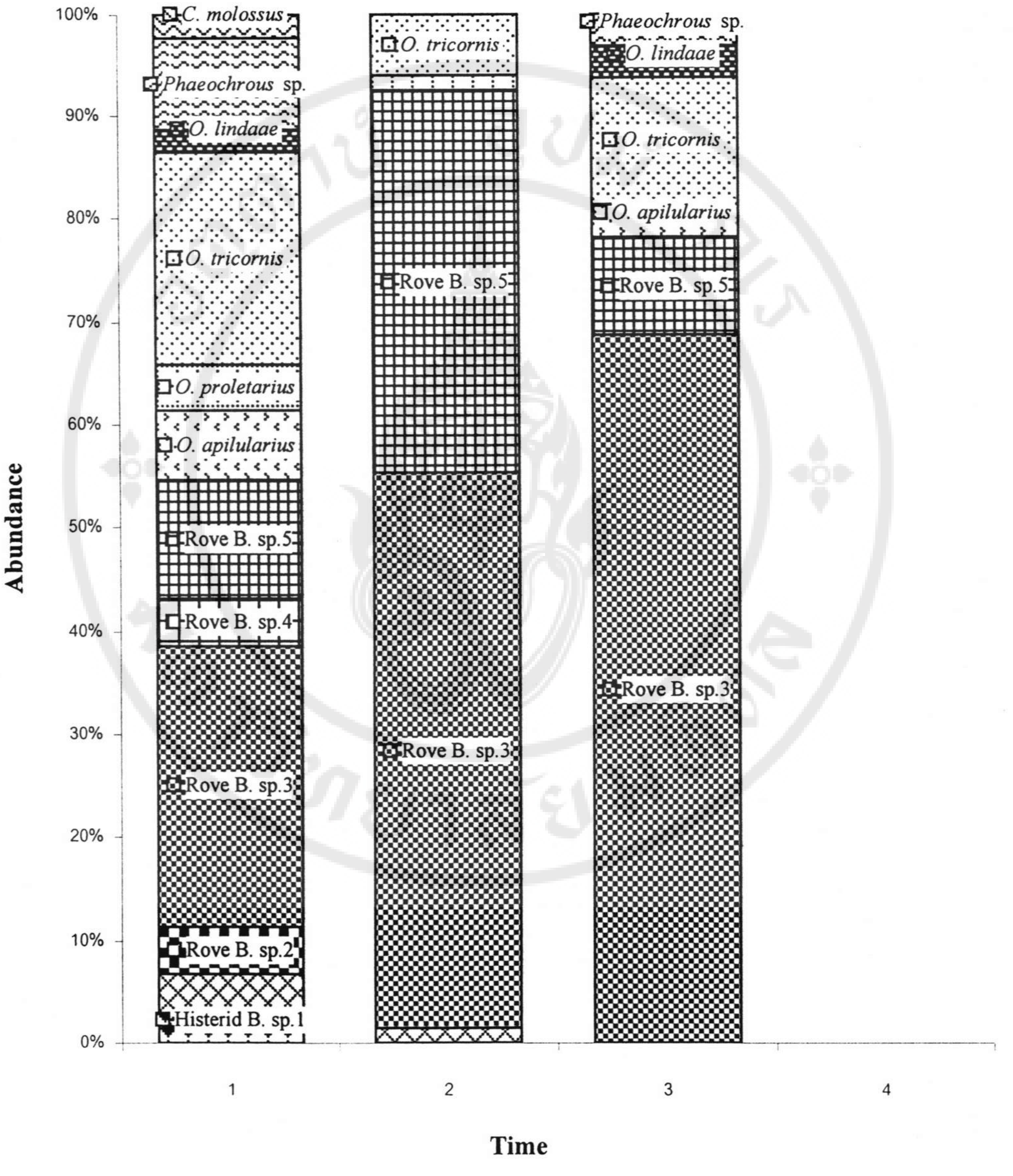

Figure 5. The percentage of Coleoptera species collected from the mouse carcass in grassland in rainy season (May-October 1999).

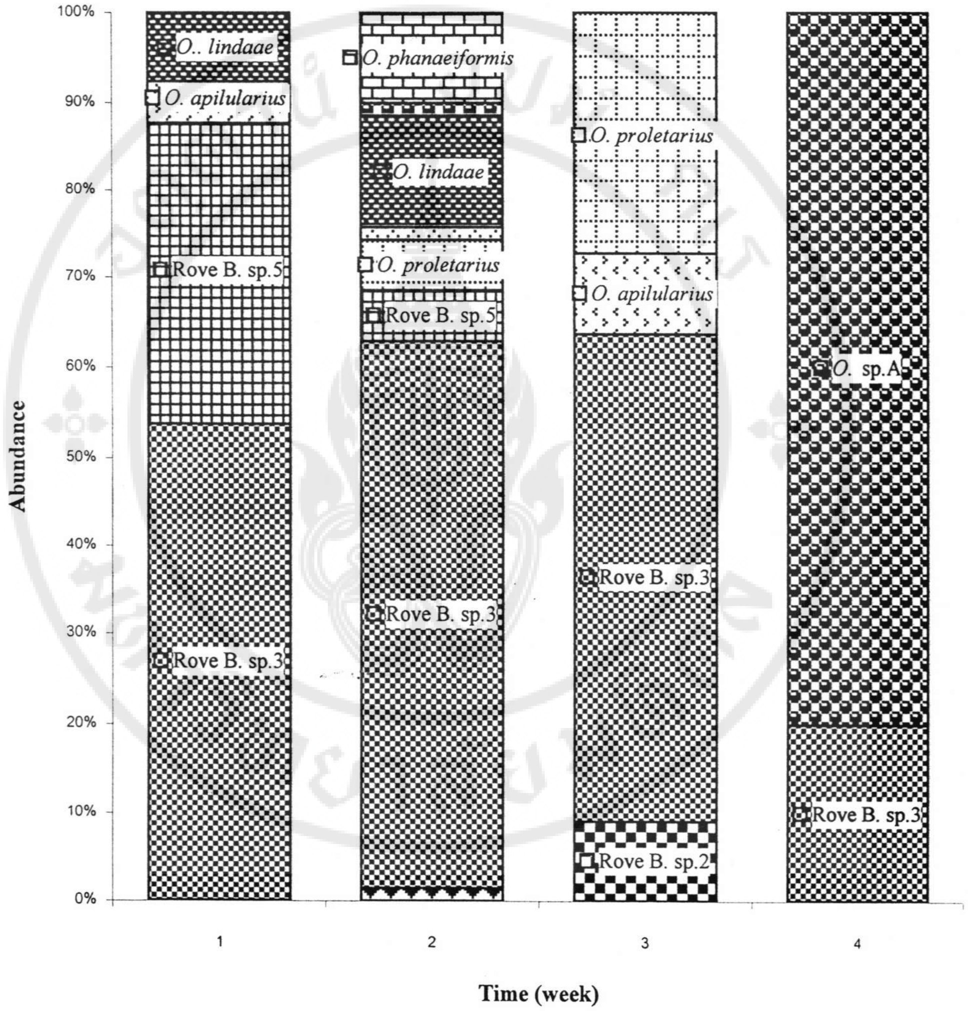

Figure 6. The percentage of Coleoptera species collected from mouse carcass in grassland in winter (January-February 1999 and November-December 1999).

The comparison of the average total number of maggots and beetles collected from mouse-baited pitfall traps in grassland in three seasons is shown in Figures 7-9.

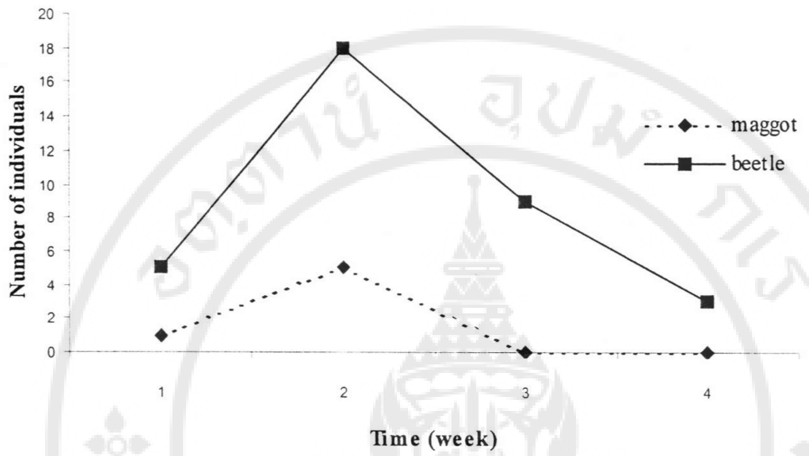

Figure 7. The comparison of the average total number of maggots and beetles per week collected from the mouse carcass in grassland in summer (March-April 1999).

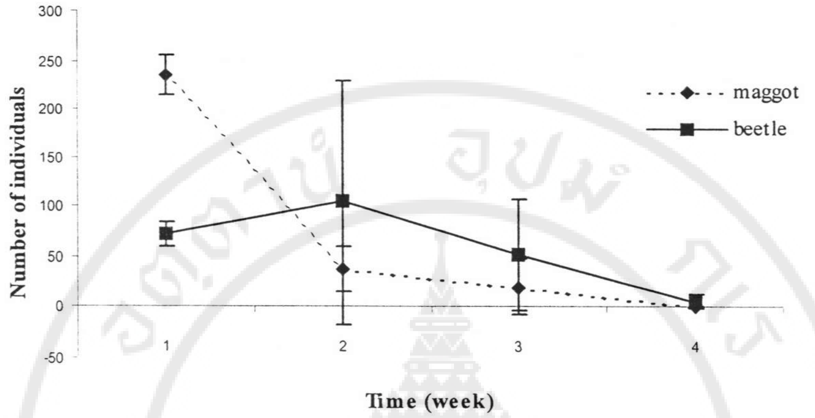

Figure 8. The comparison of the average total number of maggots and beetles per week collected from the mouse carcass in grassland in rainy season (May-October 1999).

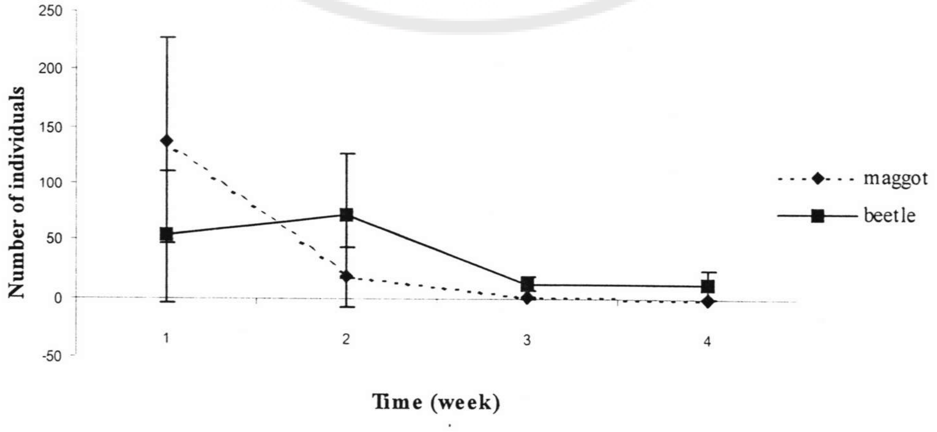

Figure 9. The comparison of the average total number of maggots and beetles per week collected from the mouse carcass in grassland in winter (January-February 1999 and November-December 1999).

1.2 Mouse carcass in the forest area

The average total number of insect per week collected from the mouse carcass in the forest area is shown in Figure 10. The highest average number of insects (= 1777) were found in the first week and rapidly declined in the second week (=508). On the third and fourth week, the average number of insects was very low (fewer than 100 individuals).

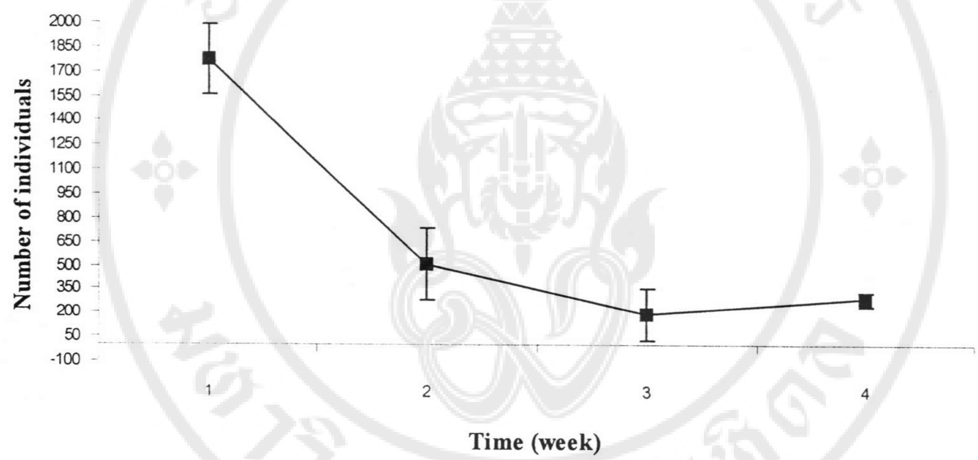

Figure 10. The average total number of insects per week on mouse carcass in the forest area.

Figure 11 shows the relationships between the average number of maggots collected from traps during the decomposition period. The number of maggots was high in the first week (=150). In the second week, the number of maggots slightly declined to 118 individuals, declined very rapidly to 10 individuals in the third week, and no maggots were found in the fourth week.

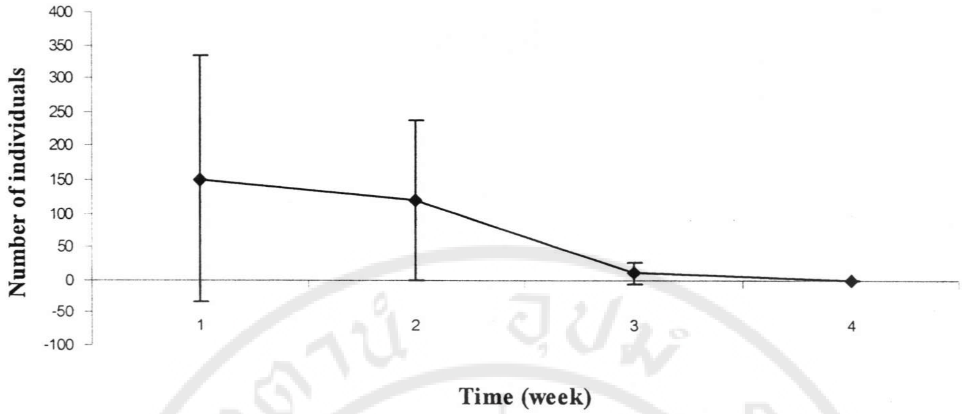

Figure 11. The average total number of maggots per week on mouse carcass in the forest area.

Figure 12 shows the number of maggots on the mouse carcass in forest during the decomposition process in three seasons. In summer and winter the general pattern of the number of maggots during the decomposition process is similar. In rainy season, the maximum number of maggots (= 293) occurred in the second week.

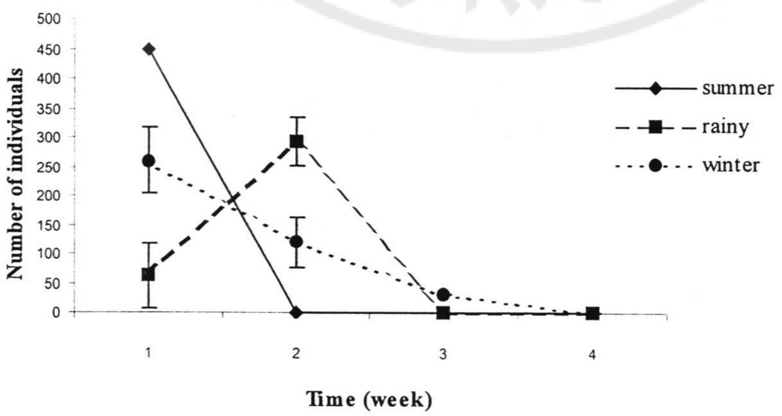

Figure 12. Comparison of the average total number of maggots per week on mouse carcass in the forest area in summer, rainy season and winter.

The number of Coleoptera species collected from the mouse carcass in forest area during the decomposition process in each season is shown in Figures 13-15 in term of the percentage of the total number collected. In summer, thirteen species of Coleoptera were found. Forty-six individuals of rove beetle sp.3 were found in this trap in the first and fourth week. The average total number of Coleoptera found in this season is 133 individuals. In rainy season, ten species of Coleoptera were found. Rove beetle sp. 3, *Onthophagus apilularius, Onthophagus proletarius* and *Onthophagus lindaae* were found in high number in the first and second week (39, 24, 22, 20 individuals, respectively). No beetles were found on the third and fourth week. The average total number of Coleoptera found in this season is 151 individuals. In winter, eleven species of Coleoptera were found. Rove beetle sp. 3 and 5 were found numerous in the second and the third week (113 and 103 individuals, respectively). The average total number of Coleoptera found in this season is 327 individuals.

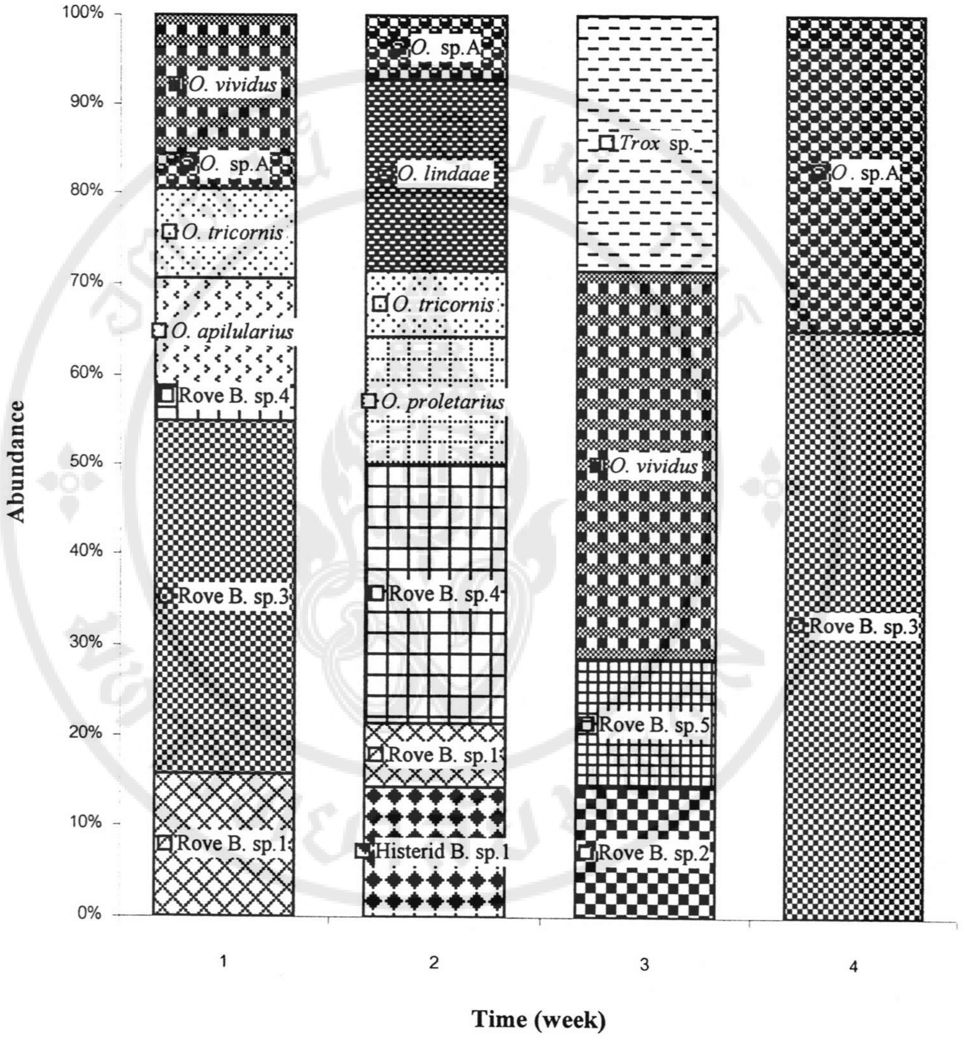

Figure 13. The percentage of Coleoptera species collected from mouse carcass in the forest area in summer (March-April 1999).

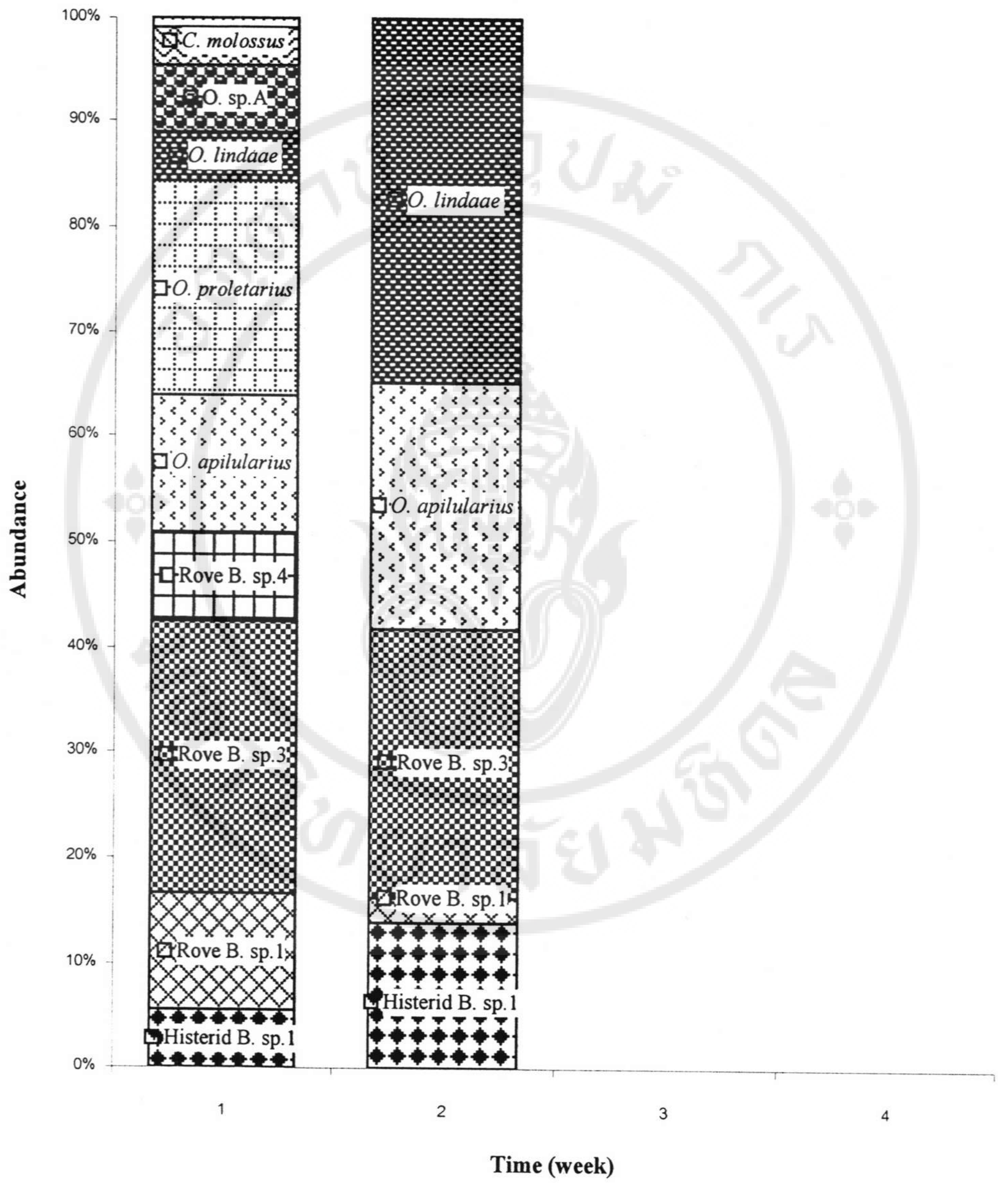

Figure 14. The percentage of Coleoptera species collected from mouse carcass in the forest area in rainy season (May-October 1999).

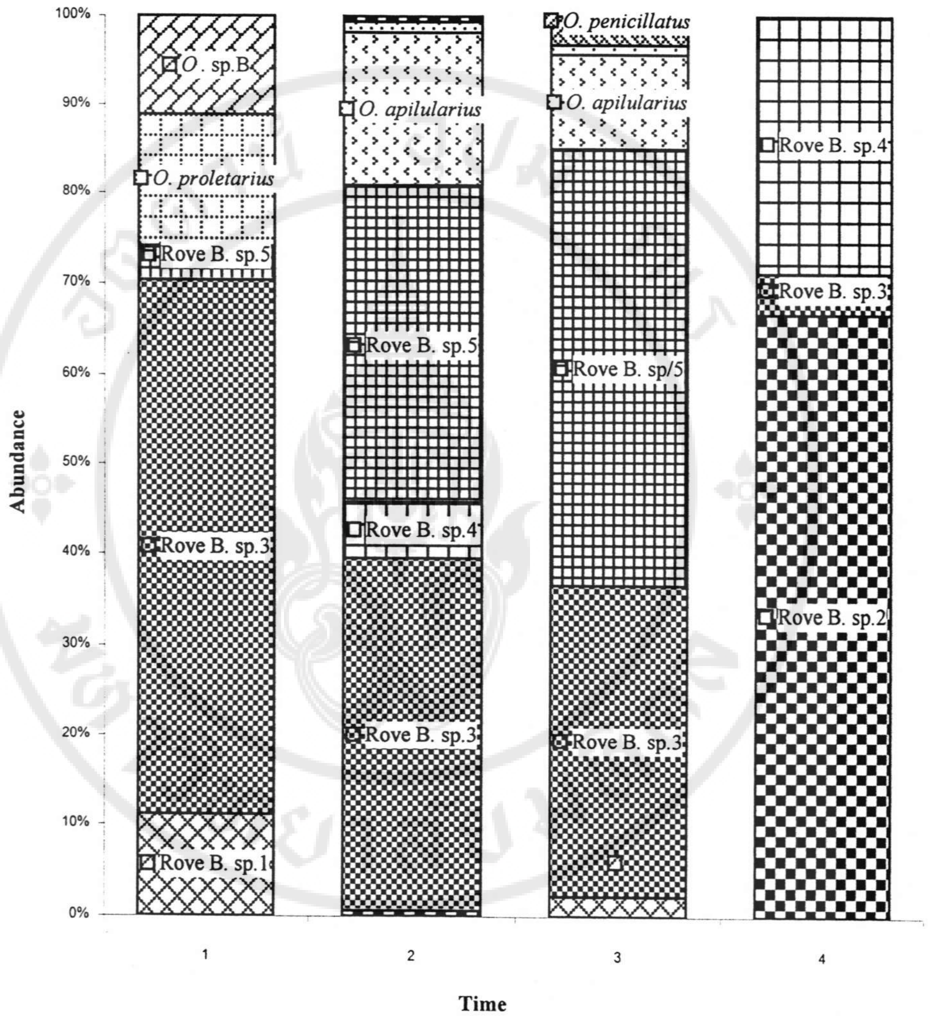

Figure 15. The percentage of Coleoptera species collected from mouse carcass in the forest area in winter (January-February 1999 and November-December 1999).

The diversity of Coleoptera species collected from mouse-baited pitfall trap throughout the study in the forest area is H′ = 2.863 (see Appendix A-5) and the evenness (J′) is 0.687 (see Appendix A-5). The diversity of Coleoptera collected from the forest area is higher than in grassland (H′ =2.648, J′ = 0.635).

The diversity of Coleoptera species collected from mouse-baited pitfall traps in the forest area has the greatest diversity in rainy season (H′ = 3.459, J′ = 0.865, see Appendix A-6) followed by in summer (H′ = 2.065, J′ = 0.765, see Appendix A-7) and in winter (H′ = 1.794, J′ = 0.54, see Appendix A-8), respectively.

Similarity Coefficient

Based on the Coefficient of Sorensen (21), the similarity of Coleoptera species collected from the mouse carcass in grassland and forest area is 0.83 (see Appendix A-9). This indicates the high similarity of the number of carrion beetle species in grassland and forest area.

The analysis of variance was used to compare the species diversity of Coleoptera collected from mouse-baited pitfall traps in different habitats. There is no significant difference in species diversity of Coleoptera between the two habitats ($p > 0.5$).

The comparisons between the average total number of maggots and beetles collected from mouse-baited pitfall traps in forest area in three seasons are shown is Figures 16-18.

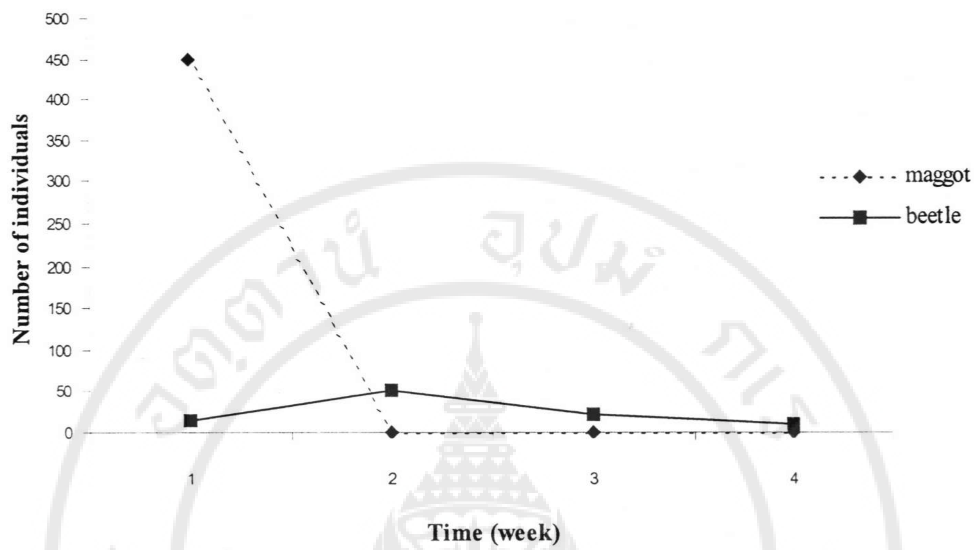

Figure 16. The comparison between the average total number of maggots and beetles per week collected from mouse carcass in the forest area in summer (March-April 1999).

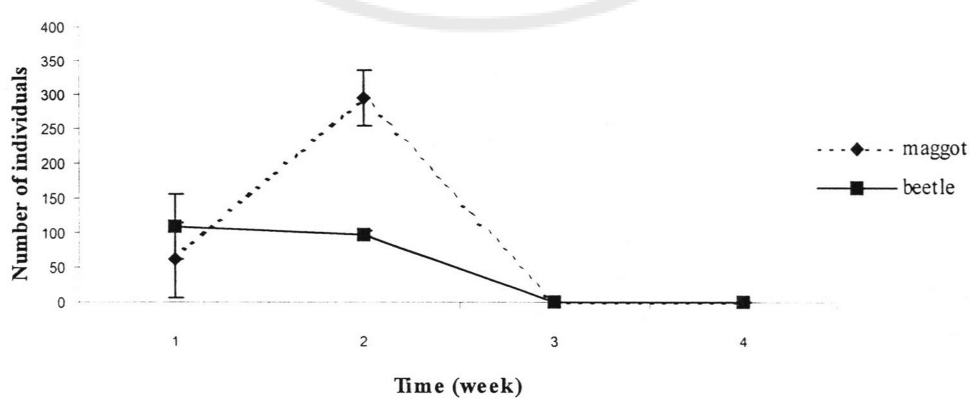

Figure 17. The comparison between the average total number of maggots and beetles per week collected from mouse carcass in the forest area in rainy season (May-October 1999).

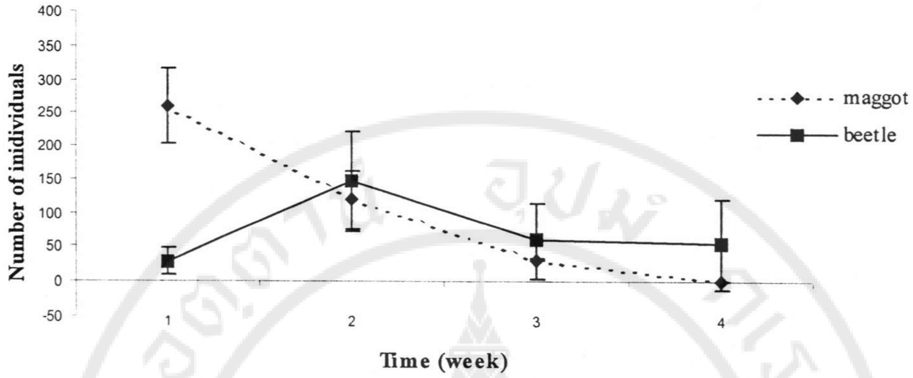

Figure 18. The comparison between the average total number of maggots and beetles per week collected from mouse carcass in forest area in winter (January-February 1999 and November-December 1999).

The relationships between the average total number of maggots and beetles per week collected from mouse carcass in grassland (Figures 7-9) and forest area (Figures 16-18) are similar.

1.3 Chicken carcass in grassland

Figure 19 shows the average total number of insects found on chicken carcass in grassland. The average total number of insects was highest in the second week (=603) and declined to 75 individuals in the third week (see Appendix B-2).

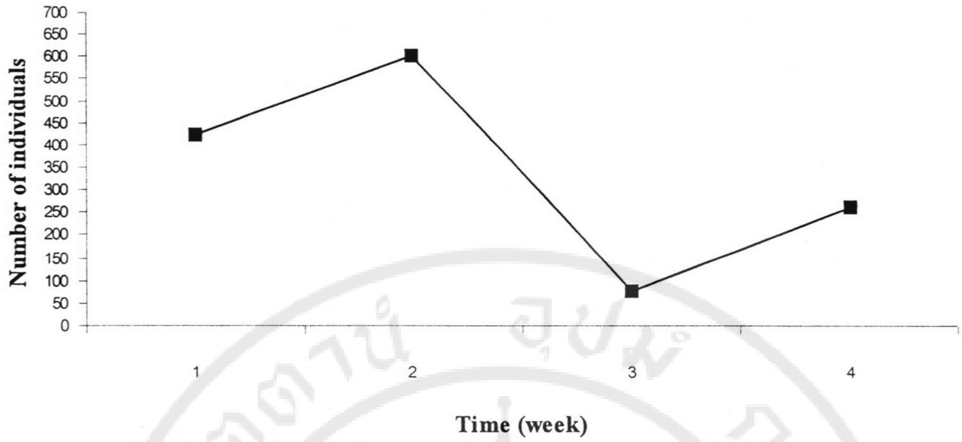

Figure 19. The average total number of insects per week on chicken carcass in grassland.

Figure 20 shows the relationship between the average number of maggots collected from trap during the decomposition period. The number of maggots was high (=535) in the second week and declined to 111 individuals in the third week. Only 35 individuals were found in the fourth week.

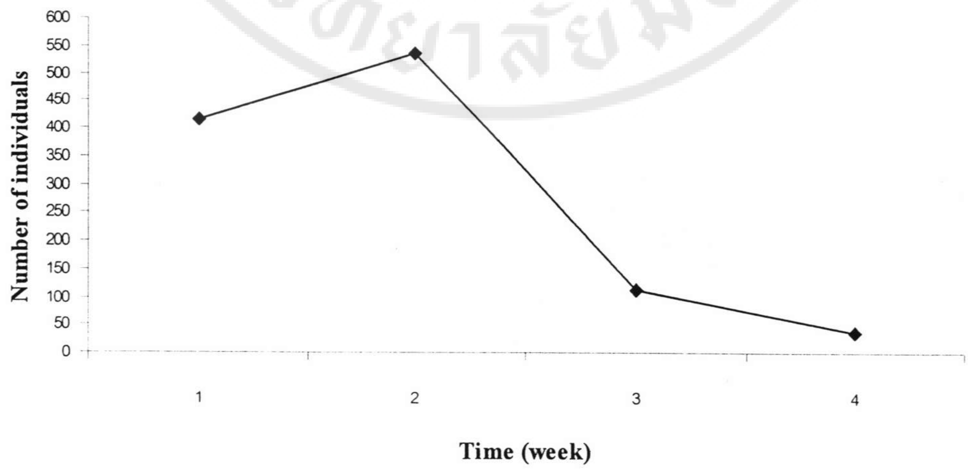

Figure 20. The average total number of maggots per week on chicken carcass in grassland.

The number of Coleoptera species collected from the chicken carcass in grassland during the decomposition process in summer is shown in Figure 21. The number of each species is shown in percentage of the total number collected. Eight species of Coleoptera were found. Rove beetle sp. 3 was found in highest number (=6) in the first week out of the total number of 14 beetles.

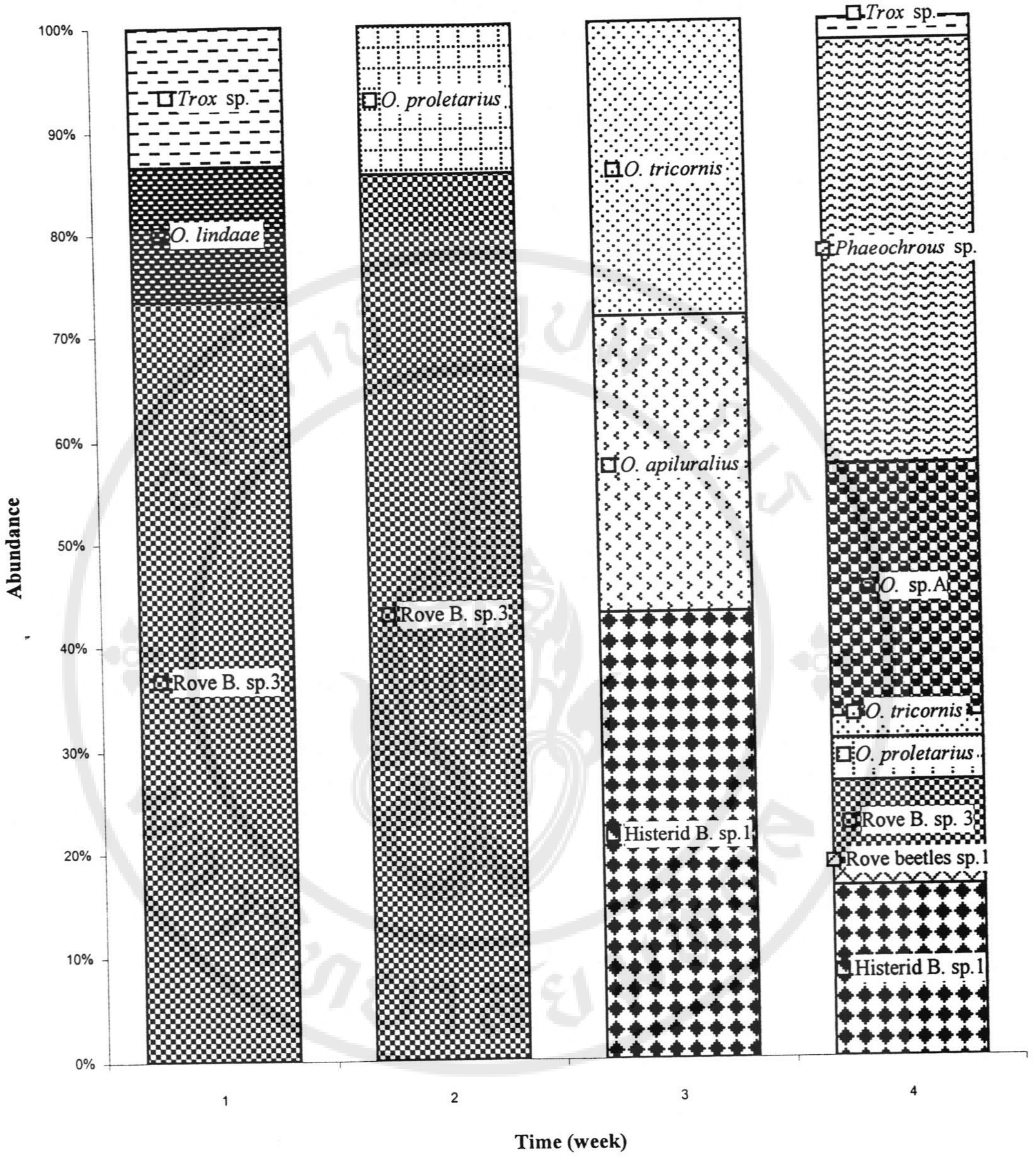

Figure 21. The percentage of Coleoptera species collected from chicken carcass in grassland in summer (March-April 1999).

The diversity of Coleoptera species collected from chicken-baited pitfall trap in the grassland is H′ = 2.114 and the evenness is J′ = 0.667 (see Appendix A-10).

1.4 Chicken carcass in the forest area

Figure 22 shows the average total number of insects found on chicken carcass in the forest area. The average total number of insects was highest in the first week (=1098) and declined rapidly to nearly zero in the second week.

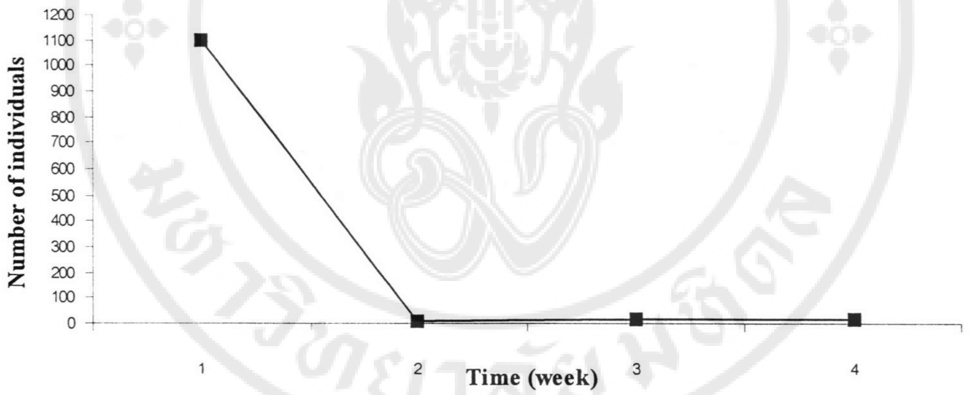

Figure 22. The average total number of insects per week on chicken carcass in the forest area.

Figure 23 shows the relationships between the average number of maggots collected from trap during the decomposition period. The number of maggots was high (=200) on the first week and rapidly declined to nearly zero on third week. No maggots were found in forth week.

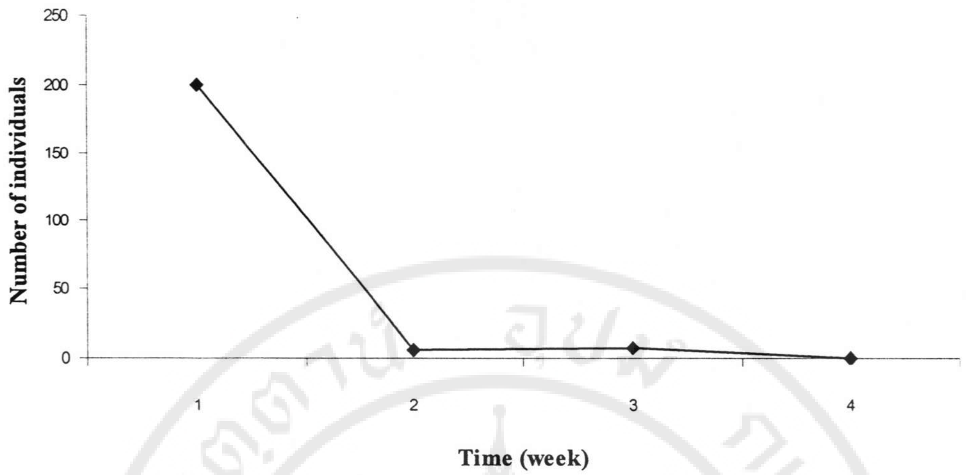

Figure 23. Average total number of maggots per week on chicken carcass in the forest area.

The number of Coleoptera species collected from the chicken carcass in the forest area during the decomposition process in summer is shown in Figures 24. The number of each species is shown in percentage of the total number collected. Ten species of Coleoptera were found. Rove beetle sp. 3 (=21) and *Phaeochrous* sp. (=20) were found highest in the first and fourth week, respectively, from the total number of 78 individuals.

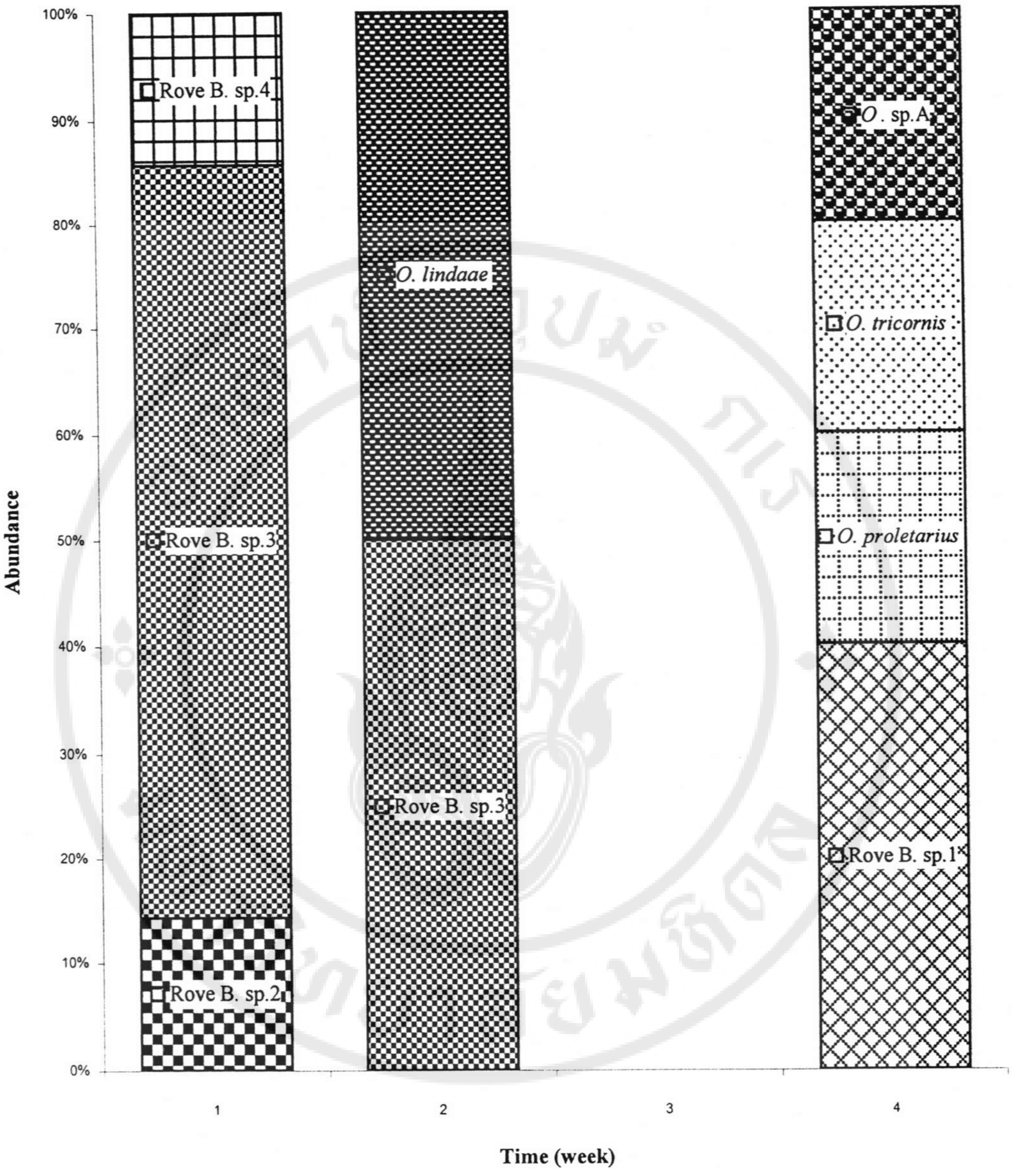

Figure 24. The percentage of Coleoptera species collected from chicken carcass in the forest area in summer (March-April 1999).

The diversity of Coleoptera species collected from chicken-baited pitfall trap in the forest area is H′ = 2.261 and the evenness (J′) is 0.805 (see Appendix A-11). The diversity of Coleoptera species collected from chicken carcass in forest area is higher than in grassland (H′ = 2.114, J′ = 0.667).

Similarity Coefficient

The similarity of Coleoptera species collected from the chicken carcass in grassland and forest area is 0.71 (see Appendix A-12). This indicates the high similarity of the number of carrion beetle species in grassland and forest area.

2. Biomass removal of the carrion in different habitats

2.1 Mouse carcass in the grassland area

Figure 25 shows the biomass removal (%) during the decomposition process of the mouse carcass in grassland.

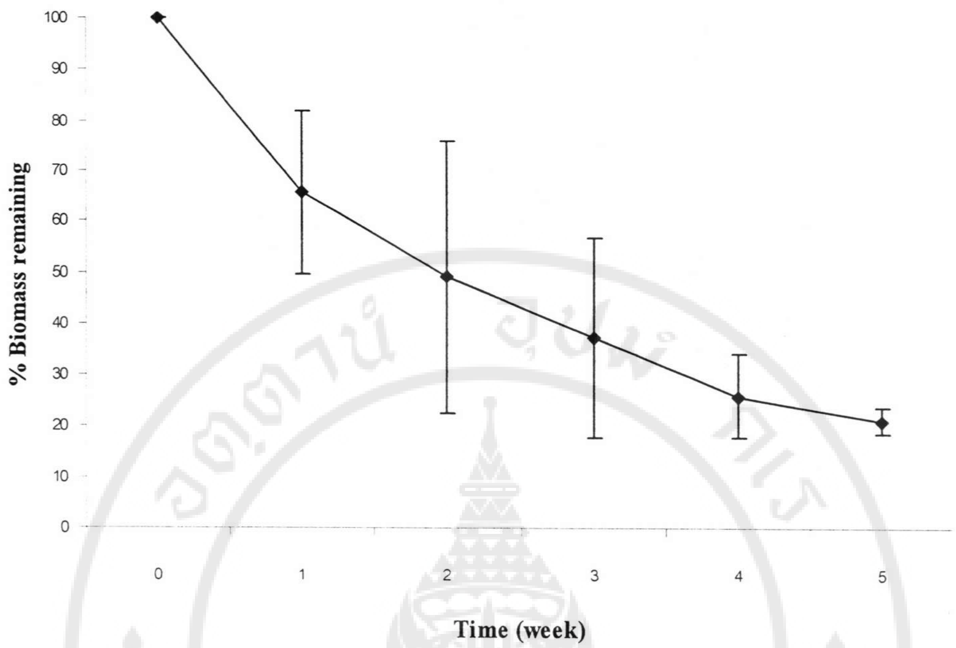

Figure 25. Biomass removal (%) per week on mouse carcass in grassland.

Figure 26 shows the comparison of the biomass removal (%) of the mouse carcass in grassland among seasons.

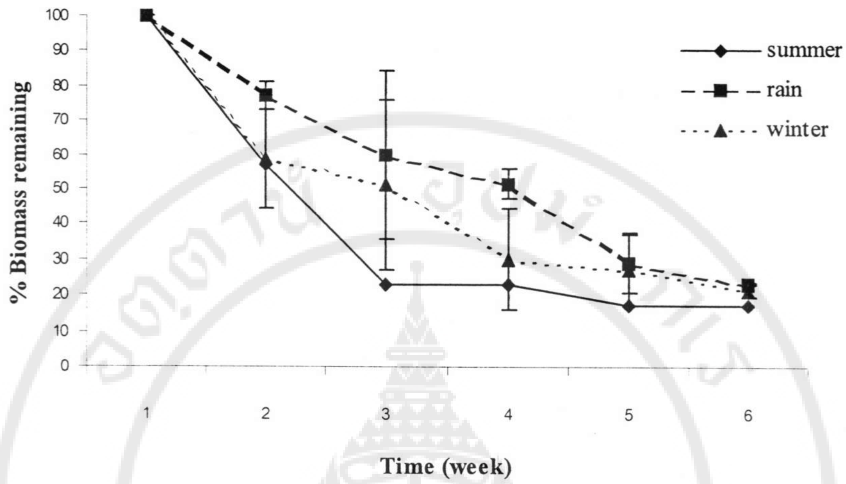

Figure 26. Comparison of the biomass removal (%) of mouse carcass in grassland during summer, rainy season and winter.

2.2 Mouse carcass in the forest area

Figure 27 shows the biomass removal (%) during the decomposition process of the mouse carcass in the forest area.

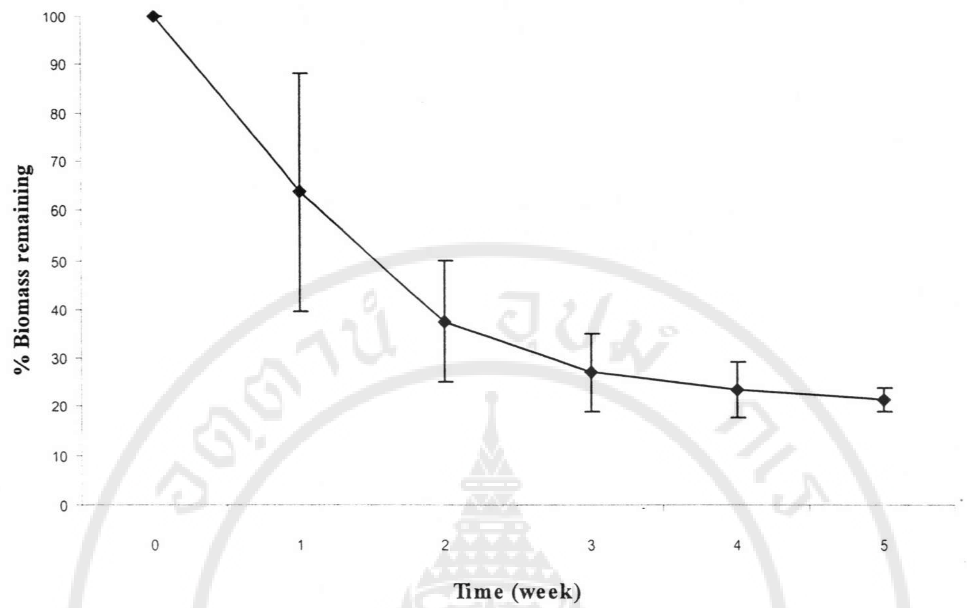

Figure 27. Biomass removal (%) per week on mouse carcass in the forest area.

Figure 28 shows the comparison of the biomass removal (%) of the mouse carcass in the forest area among seasons.

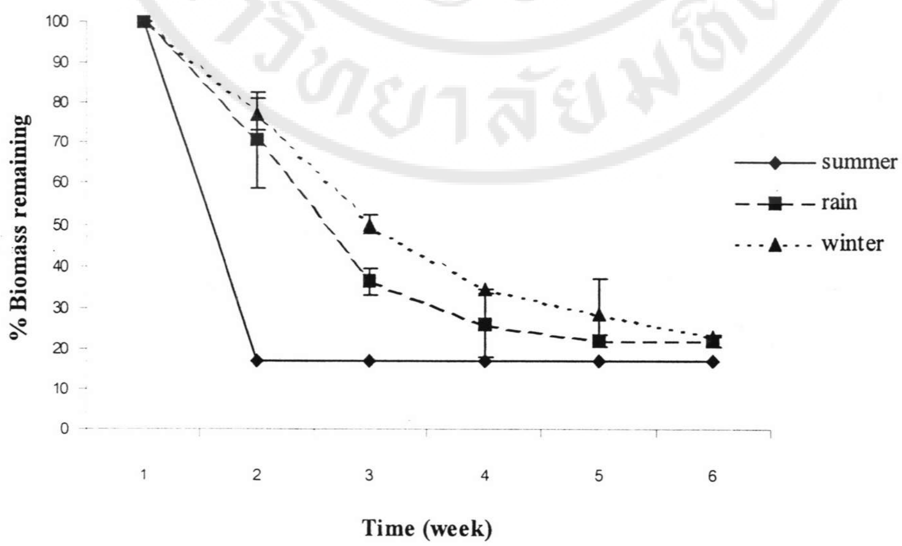

Figure 28. Comparison of the biomass removal (%) of mouse carcass in the forest area during summer, rainy season and winter.

The comparisons of the biomass removal (%) of mouse carcasses in grassland and forest area in each season are shown in Figures 29-31.

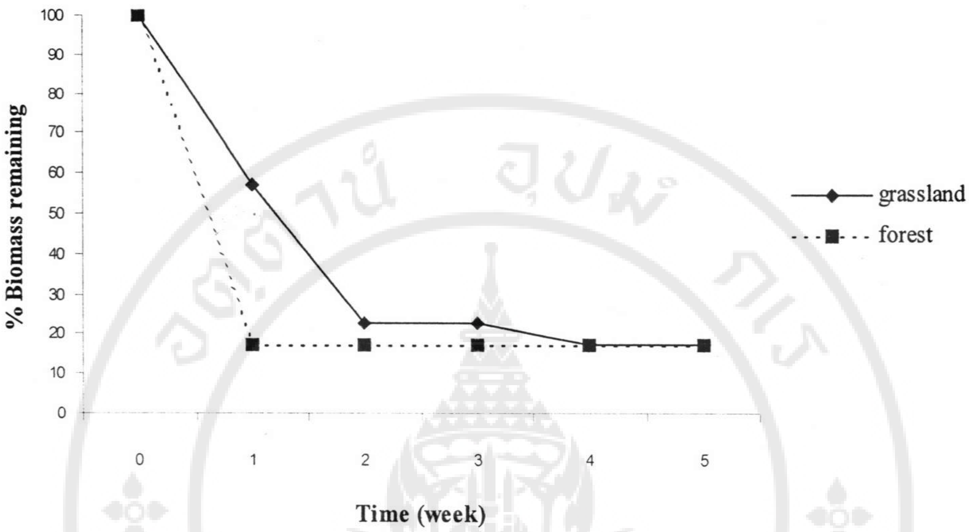

Figure 29. Comparison of the biomass removal (%) of mouse carcass in grassland and forest area in summer.

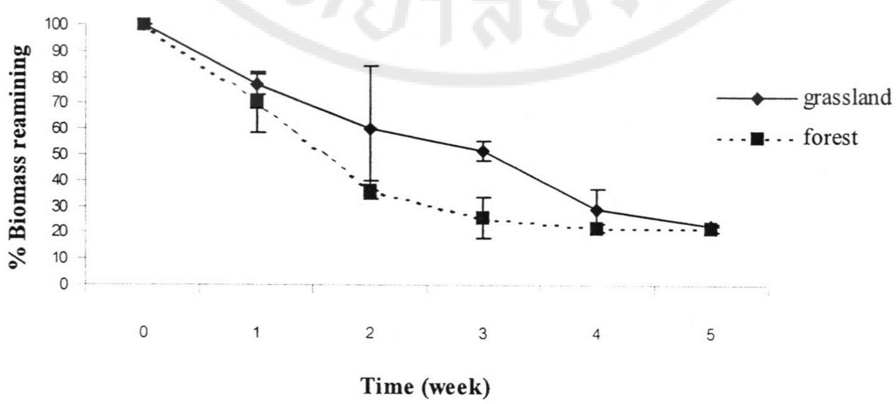

Figure 30. Comparison of the biomass removal (%) of mouse carcass in grassland and forest area in rainy season.

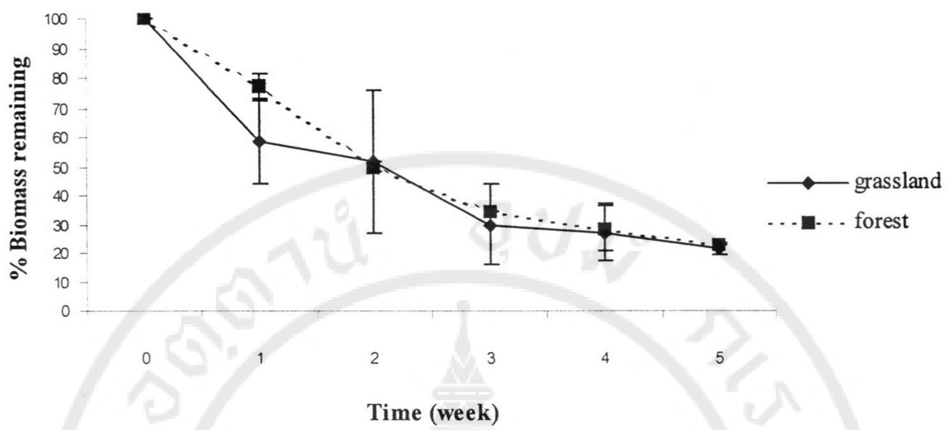

Figure 31. Comparison of the biomass removal (%) of mouse carcass in grassland and forest area in winter.

2.3 Chicken carcass in grassland

Figure 32 shows the biomass removal (%) during the decomposition process of the chicken carcass in grassland.

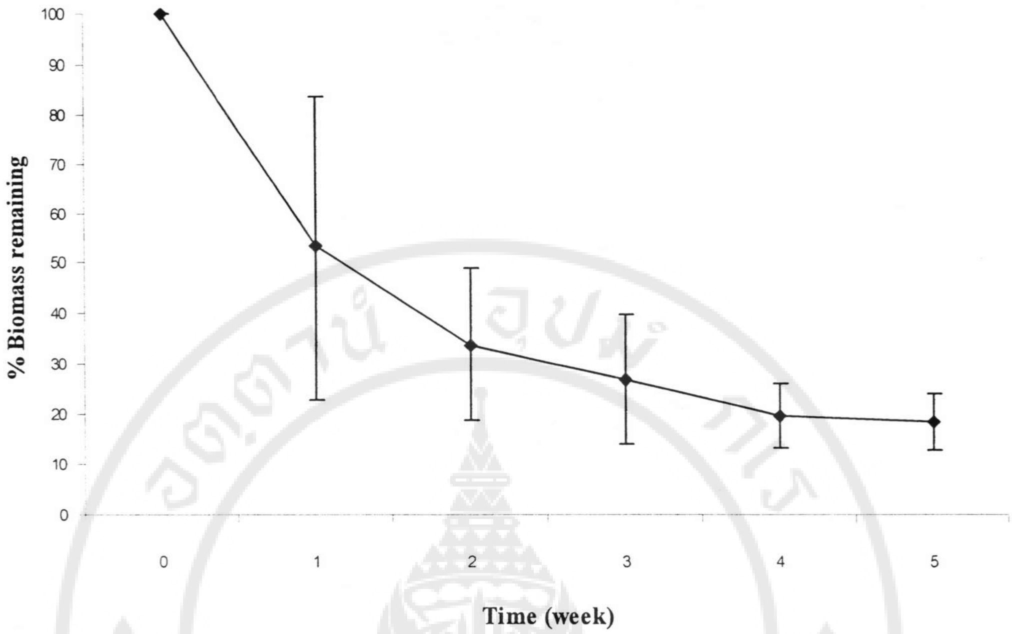

Figure 32. Biomass removal (%) per week of chicken carcass in grassland.

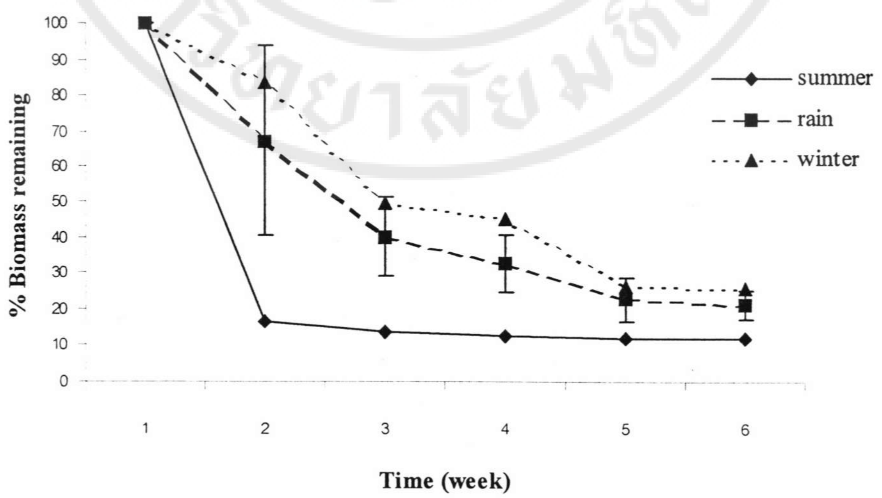

Figure 33. Comparison of the biomass removal (%) of chicken carcass in grassland during summer, rainy season and winter.

2.4 Chicken carcass in the forest area

Figure 34 shows the biomass removal (%) during the decomposition process of the chicken carcass in the forest area.

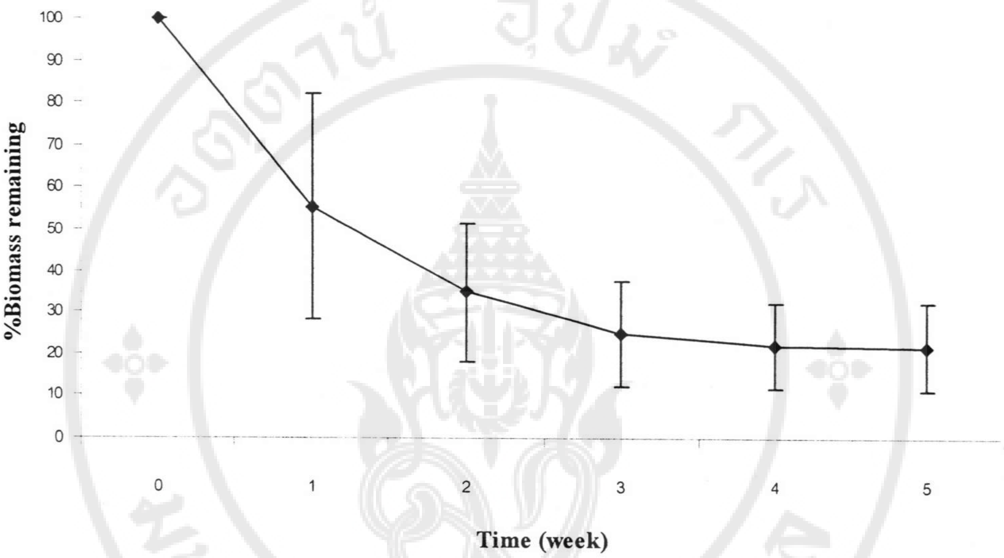

Figure 34. Biomass removal (%) per week on chicken carcass in the forest area.

Figure 35 shows the comparison of the biomass removal (%) of the chicken carcass in the forest area among seasons.

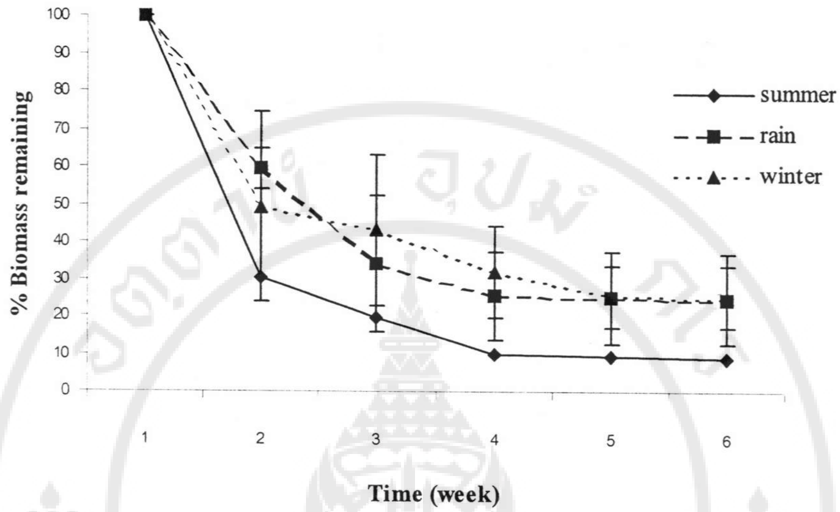

Figure 35. Comparison of the biomass removal (%) of chicken carcass in the forest area during summer, rainy season and winter.

The comparsions of the biomass removal (%) of chicken carcasses in grassland and forest area in each season are shown in Figures 36-38.

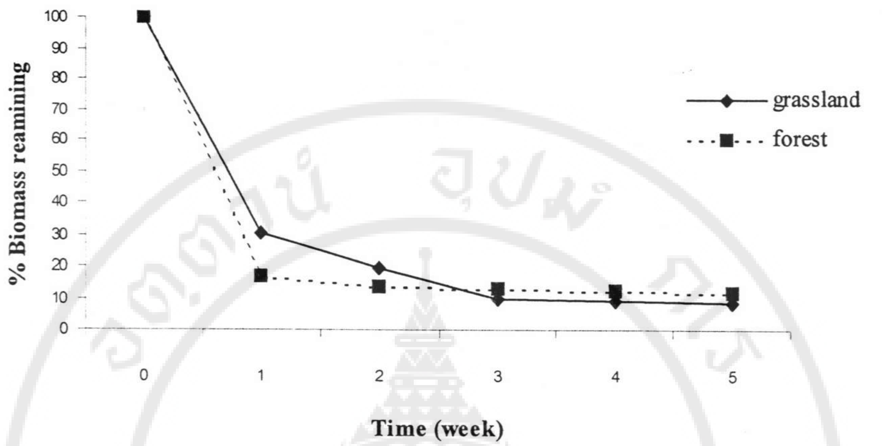

Figure 36. Comparison of the biomass removal (%) of chicken carcass in grassland and forest area in summer.

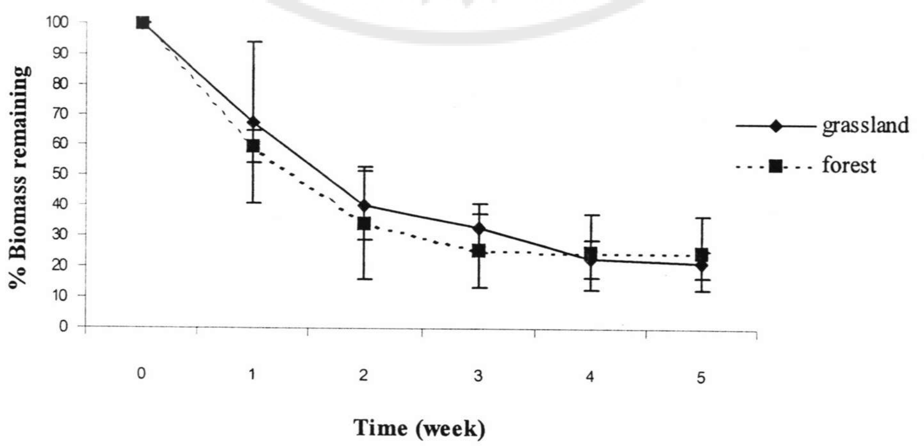

Figure 37. Comparison of the biomass removal (%) of chicken carcass in grassland and forest area in rainy season.

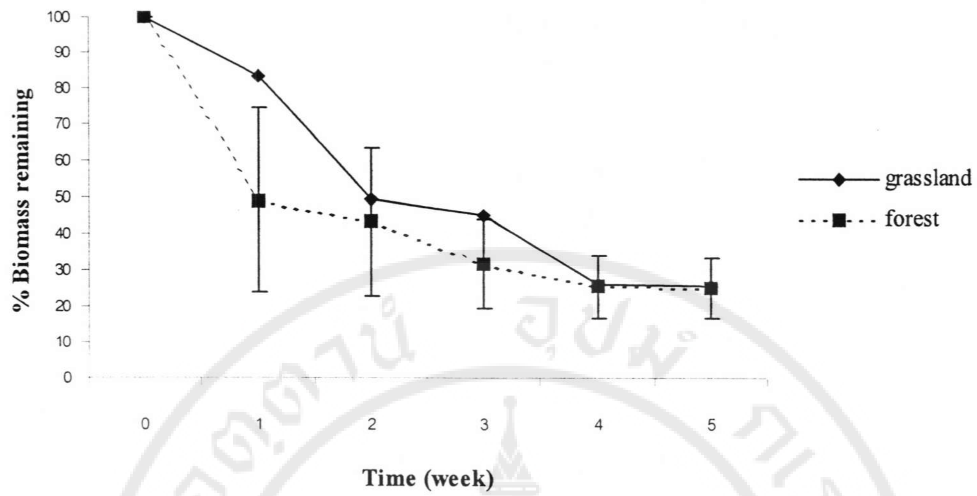

Figure 38. Comparison of the biomass removal (%) of chicken carcass in grassland and forest area in winter.

CHAPTER V

Discussion

Insect Activity:

The insect succession in this study follows the same general pattern found in previous studies (i.e. Payne (14), Tantawi *et al* (3), Richards and Goff (1)). Dipterans that initially invade the carcass are replaced by coleopterans that act as predators and dermatophages (14). The current studies are no exception. Dipterans and ants were found abundant on the carcasses. Diptera larvae were present dominantly during the first week. They fed on the carrion directly. Ants were found in a great number during all stages of carrion decomposition. They were observed carrying off maggots, capturing adult flies and beetles, and feeding on carrion themselves (3). Coleopterans in the Families Staphylinidae, Scarabaeidae and Histeridae are also important in the decomposition process. They preyed on maggots and some of them fed on the carrion directly. Arthropods such as spiders and mites were also found on the carrion. Spiders prey on the maggots and other insects on the carcass. Some mites are ectoparasites of Coleoptera and might prey on eggs of beetles (34). Many insects found in the traps were incidental visitors. These insects were associated with the corpse because the environment of the carrion was similar to their normal habitat (2). These groups of insects include cockroaches, grasshoppers, crickets, moths and termites.

A fresh carcass, when it expresses little to no odor, is immediately invaded by adult Diptera and ants which interact only with the surface of the corpse. Other insect species continue to arrive at the carcass at a rapid rate after one week. After leaving the trap for seven days, the presence of maggots and coleopterans along with other insects (incidental group) reaches its maximum. During this period, the decomposition and loss of the carcass weight begin to increase because of maggots' activity. After the maggots complete their development and left the carcass (after approximately two weeks), the number of insects on the carrion distinctively declined. In the fourth week, only a few insects were collected from the traps. Most of them are incidentals such as cockroaches and crickets.

The number of maggots was highest in the first week in summer and winter whereas in the rainy season, the maximum number of maggots occurred in the second week. This is probably because the heavy rain during the first week after setting the traps affects the oviposition of adult flies. This result agrees with Tantawi *et al* (3). They found that that the carcass exposed to the heavy rain when it was still at the peak of decay stage was actually prolonged the feeding period of *Chrysomya albiceps* (Wiedemann) (Calliphoridae) and *Ophyra ignava* (Harris) (Muscidae) larvae.

The number of maggots was higher than beetles in the first week, but in the second week, the number of beetles was high while the number of maggots was low. Thi is probably because

1. maggots completed their larval development and prepared to pupate. Post-feeding larvae dispersed from the carcass before pupation, so in the latter weeks (the third and fourth week), very few maggots were found in the traps. Greenberg (28) studied the behavior of post-feeding larvae of some Calliphoridae and Muscidae and found that the majority of calliphorid larvae disperse and dig into the soil before pupation. Ullyet's (29) data showed that the *Phaenicia sericata* themselves up to 11 cm deep in sand before pupation. The same burying behavior was observed among *Phaenicia eximia* (30), and *Phaenicia cuprina* (31). These larvae

have to bury themselves because adult staphylinids often attack calliphorid larvae when they leave the carcass (28). Larvae of *Calliphora vicina* suffered a predation rate of 66% in the field (32). Hence, leaving the carcass and digging deep into the soil may prevent Diptera larvae from their predators (28).

2. most of coleopterans found on the carcass are predators and only a few feed on carrion directly. This probably explains why these graphs show the similar pattern of relationship as in predator-prey relationship. When one species is a predator and another is a prey, the effect of predation is to reduce the number of the prey and increase the number of predators (33).
3. during the third week, the carrion was dried out, so it did not attract adult flies to oviposit anymore. In the fourth week, no insects were found on the carrion. The decomposition was finished off by bacteria and fungi (2).

The diversity of Coleoptera species collected from mouse carcasses in the forest area (H'= 2.863) is higher than in grassland (H'= 2.648) because of the differences in some environmental factors such as soil type and tree species. They may affect the species composition of Coleoptera in each habitat. This result agrees with Pinero (10). He studied the species diversity of carrion beetles between two habitats in Spain (Guadix and Baza) and found that the species diversity of carrion beetles was higher in Guadix (H'= 2.66) than in Baza (H'= 1.87). He attributed that the species diversity of carrion beetles which differ between sites is a main cause of variability in assemblage composition between sites.

The diversity of Coleoptera species collected from mouse-baited pitfall traps in grassland has the greatest diversity in summer followed by in rainy season and in winter. Rainfall and cold temperature in rainy season and winter may affect the activity of carrion beetles. This result agrees with Reed (25), Johnson (26), and Rodriguez and Bass (27) who found that the carrion fauna was richer in warmer than in cooler seasons because severe cold inhibits carrion arthropod activity.

The diversity of Coleoptera species collected from mouse-baited pitfall traps in the forest area has the greatest diversity in rainy season followed by in summer and winter. The delayed decomposition in rainy season was probably due to rainfall. It allowed a longer period of time for a large number of Coleoptera species to visit the carrion. Therefore, the species diversity of beetles in rainy season was higher than in summer. This result agrees with Tantawi *et al* (3). They found that succession in warmer seasons was driven by rapid resource depletion as the carcasses decayed faster because of high temperatures, therefore the total number of insect species collected on the carrion was less in summer than in rainy season. However, Reed (25), Johnson (26) and Rodriguez and Bass (27) found that the carrion fauna was in the highest number in summer. In this study, the diversity of Coleoptera species collected from mouse-baited pitfall traps in grassland agrees with Reed (25), Johnson (26) and Rodriguez and Bass (27).

In this study, a total of approximately 50 insect species belonging to 13 Orders and 16 Families was recorded on chicken and mouse carcasses (Table 1). Payne (14), in South Carolina, collected 522 animal species on fetal pig carcasses; 84% of these were insects. Goff *et al* (36) in Hawaii reported 140 arthropods taxa on fetal pig and cat carcasses, 83% of which were insects. Richards and Goff (1) reported 101 arthropod taxa, in 14 Orders and 61 Families associated with pig carcasses on the island of Hawaii and Tantawi *et al* (3) found at least 100 arthropod species associated with rabbit carrion in Egypt. In this study, the number of species was low in comparison with the above studies because arthropods other than insects were excluded and were not identified. Changes in carrion characteristics lead to different insect assemblages. The larger size of carrion, the greater diversity of insect species.

In this study, 13 species of Coleoptera in the Family Scarabaeidae was recorded. They are *Onthophagus tricornis* Wiedemanm, *Onthophagus apilularius* Masumoto, *Onthophagus proletarius* Harold, *Onthophagus rudis* Sharp, *Onthophagus lindaae* Masumoto, *Onthophagus vividus* Arrow, *Onthophagus penicillatus* Harold, *Onthophagus phanaeiformis* Boucomont, *Phaeochrous* sp., *Catharsius molossus* F., *Corpris reflexus* (F.), *Synapsis* sp. *and Trox* sp. Pinero (10) found only 3 species of Coleoptera in the Family Scarabaeidae. They are *Scarabaeus puncticollis* Latreille, *Onthophagus merdarius* Chevrolat and *Onthophagus furcatus* (F.) from baited-pitfall trap in the arid Guadix-Baza Basin in Spain. In comparison to the study in an arid area of Spain by Pinero (10), more species of beetles were found in this study. The forest area and the grassland at Khao Yai National Park have a greater diversity of flora and fauna species than in the arid Guadix-Baza Basin in Spain.

Table 1. List of insects taxa associated with decomposition at the Khao Yai National Park.

Order	Family	Genus and species
Collembola	Entomobryidae	
	Isotomidae	
	Sminthuridae	
Orthoptera	Blattidae	
	Gryllidae	
	Acrididae	
Isoptera		
Dermaptera		
Thysanoptera		
Mallophaga		
Hemiptera		
Homoptera		
Diptera	Calliphoridae	
	Sarcophagidae	
	Muscidae	
	Phoridae	
Coleoptera	Histeridae	
	Tenebrionidae	
	Staphylinidae	

Table 1 (cont.). List of insects taxa associated with decomposition at the Khao Yai National Park.

Order	Family	Genus and species
	Scarabaeidae	*Onthophagus tricornis* Wiedemanm
		Onthophagus apilularius Masumoto
		Onthophagus proletarius Harold
		Onthophagus rudis Sharp
		Onthophagus lindaae Masumoto
		Onthophagus vividus Arrow
		Onthophagus penicillatus Harold
		Onthophagus phanaeiformis Boucomont
		Phaeochrous sp.
		Catharsius molossus F.
		Corpris reflexus (F.)
		Synapsis sp.
		Trox sp.
Lepidoptera		
Hymenoptera	Formicidae	
	Ichneumonidae	

Biomass Removal :

The greatest percentage of biomass was removed during the first week as a result of the maggots' activities. Their activities totally dominated the pattern of decomposition during the decay stage (32). More than 30% of total biomass of mouse carcasses and 45% of total biomass of chicken carcasses was removed during this period.

In the first week, biomass removal of mouse and chicken carcasses in grassland and forest area was highest in summer (more than 70% of total biomass) followed by rainy season (40%) and winter (20%), respectively. Temperature is believed to be the most important environmental factor influencing the rate of a carcass decay (37). The developmental rate of Diptera larvae and oviposition depend on temperature (38, 5). From Table 2, summer has the highest average temperature (34°C) followed by rainy season (31°C) and winter (32°C). Hence, the decomposition occurred more rapidly in summer. In winter, the biomass removal was lowest because of cool weather. Deonier (15) reported that blowfly activity was greatly reduced by cool weather and carcasses frequently did not become infested for several days following death. In rainy season, heavy rains also reduce the rate of decomposition and prolong the feeding period of Diptera larvae. From Table 2, the average rainfall was high in rainy season (10 mm) whereas it was only 4.67 mm in summer and no rainfall was recorded in winter. These results agree with the study of Tantawi *et al* in 1996.

The biomass removal of chicken and mouse carcasses in forest area was higher than in grassland for every season (Figures 29-31 and 36-38). This is probably due to the abundance of maggots which was higher in the forest area than in grassland and also the abundance of other carrion insects invading the carcass in the forest area was greater than in grassland.

Climatic Data

Climatic data for the period of the study is shown in Table 2.

Table 2. Climatic data (daily average) recorded during the study period.

Season	Date	Ambient air Temp (°C)		Humidity (%)	Rainfall (mm)	
		Min ± SD	Max ± SD		Total	Average
Summer	12 March – 23 April	10.72 ± 0.76	34.54 ± 0.54	99.50	196.2	4.67
Rainy	20 May – 25 June	10.41 ± 0.77	30.53 ± 0.68	99.49	337.3	9.12
	9 July – 14 August	10.38 ± 0.93	31.05 ± 1.39	99.78	344.1	9.3
	17 Sept. – 23 October	10.24 ± 0.78	31.02 ± 0.70	99.35	371.5	10.04
Winter	15 Jan. – 20 February	10.32 ± 0.48	32.53 ± 1.48	98.58	7.4	0
	12 Nov. – 16 Dec.	9.51 ± 0.65	31.74 ± 1.08	98.71	6.4	0

CHAPTER VI

Conclusion and Recommendation

Conclusion

1. In this study, Diptera and Coleoptera dominated the carrion fauna. Diptera represented 34.12% and Coleoptera ranked 2nd, comprising 12.31 % of the total number of arthropod species collected. The same pattern occurred throughout the year. Many species were incidental visitors, not involved in the decomposition process. Springtails, cockroaches, crickets, termites and moths are the examples of incidental insects. Only Calliphoridae and, to a lesser extent, Sarcophagidae and Muscidae were responsible for carrion degradation. Coleoptera are the predators of maggots and some species are carrion-feeding beetles.
2. Insect succession follows a predictable pattern. Diptera initially made the rapid invasion of the carcass. Other species of insects continue to arrive at the carcass at a rapid rate within two weeks. The decomposition and loss of the carcass weight begin to increase at the time when maggots complete their development and leave the carcass. During this time, the presence of maggots and adult coleopterans—staphylinids, scarabs and hister beetles—which insect diversity reach it maximum, and distinct decline in insect diversity and dispersal from the carcass in the final stage of decomposition.

3. The highest percentage of biomass was removed during the decay stage (the first week) as a result of the maggot's activities. Their activities dominate the pattern of decomposition during this stage. Biomass removal was the highest in summer. Temperature is the most important factor influencing the rate of decomposition. Biomass removal in the forest was faster than in grassland because the numbers of maggots and other carrion insects were more abundant in the forest than in grassland.
4. The species diversity of Coleoptera in the forest area was greater than in grassland and the species diversity of Coleoptera collected from the mouse carcass was higher than from the chicken carcass. In grassland, the species richness of Coleoptera reached its highest in summer whereas it was in the rainy season in the forest area.

Recommendation

1. The stage of decomposition is a continuous process and discrete stages. If carrion insects could be observed and collected everyday, it might help to understand and describe the role of carrion insects in the decomposition process. Daily observation on carrion could help to discriminate stages of decomposition more clearly.
2. The study of the intraspecific and interspecific competition among carrion insects are interesting. If possible, the knowledge about the relative abundance of various species and the coexistence of carrion insects on carcasses could be achieved.

3. Not only blowflies, beetles and other terrestrial species associated with carrion, but also several species of aquatic insects are important in the decomposition process. The study of aquatic insects may help us to understand the decomposition process of carrion in water.

Nowadays, the knowledge of the insect species that use carrion for breeding, feeding, habituating as well as their succession pattern is of great importance in forensic science. It may provide information on the cause and circumstances of death. Many studies of forensic entomology have been done in the temperate part of the world and applied to solve many criminal problems. In Thailand, there are very few studies on carrion insects. Therefore it is worthwhile to study insect community on carrion, diversity, pattern of succession and impacts of environmental factors to the carrion insects and decomposition process.

References

1. Richards EN, Goff ML. Arthropod succession on exposed carrion in three Contrasting tropical habitats on Hawaii Island, Hawaii. J Med Entomol 1997;34(3):328-39.
2. Takano M. Arthropod succession and diversity [online]. University of Massachuset; 1998. Available from: http://www.umass.edu/ent/forensic/Miwa html [Accessed 1999 June 10].
3. Tantawi TI, El-Kady EM, Greenberg B, El-Ghaffar HA. Arthropod succession on Exposed rabbit carrion in Alexandria, Egypt. J Med Entomol 1996:33(4):566-80.
4. Catts EP, Goff ML. Forensic entomology in criminal investigations. Ann Rev Entomol 1992;37:253-72.
5. Greenberg B. Flies as forensic indicators. J Med Entomol 1991;28:565-77.
6. De souza AM, Linhares AX. Diptera and Coleoptera of potential forensic importance in Southeastern Brazil: relative abundance and seasonality. Med Vetern Entomol 1997;11:8-12.
7. Ratcliffe BC. A matter of taste or the natural history of carrion beetles. Museum Notes 1980 April 24.
8. Richer S. Impact of circumstances surrounding death and decomposition [online]. University of Massachuset;1998. Available from: http://www.umass.edu/ent/ Forensic/Sarah.html [Accessed 1999 June 10].
9. Shean BS, Messinger L, Papworth M. Observations of differential decomposition on sun exposed v. shaded pig carrion in Coastal Washington State. J Forensic

sci 1993;38:938-49.

10. Pinero FS. Analysis of spatial and seasonal variability of carrion beetle (Coleoptera) assemblages in two arid zones of Spain. Environ Entomol 1997; 28(4):805-14.

11. Gullan PJ, Cranston PS. The insects an outline of Entomology. London: Chapman&Hall;1994.

12. Borror DJ, Delong DM. An introduction to the study of insects. New York: Holt, Rinehart and Winston;1981.

13. Hanski I. Distribution ecology and abundance of dung and carrion-feeding beetles (Scarabaeidae) in tropical rain forests in Sarawak, Borneo. Acta zool Fenn 1983;167:1-45.

14. Payne JA. A summer carrion study of the baby pig *Sus scrofa* Linnaeus. Ecology 1965;46:592-02.

15. Deonier CC. Carcass temperatures and their relation to winter blowfly populations and activity in the Southwest. J Eco Entomol 1940;33(1):166-70.

16. Wall R, Warnes ML. Responses of sheep blowfly *Lucilia sericata* to carrion odour and carbondioxide. Entomologia Experimentalis et Applicata 1994;73:239-46.

17. Greenberg B. Flies and disease. Princton University: Princeton, NJ; 1971.

18. Denno RF, Cothran WR. Niche relationships of a guild of necrophagous flies. Ann Entomol Soc Am 1975;68:741-54.

19. อนุชิต ชินาจริยวงศ์. อาชญนิติเวชกีฏวิทยา. ว กีฏ สัตว 2542;2:120-31.

20. Udomlux S. Behavioral study of maturation of white-handed gibbons (*Hylobates Lar*) at Khao Yai National Park, Thailand [M.S. thesis in Environmental Biology]. Bangkok: Faculty of Graduate Studies, Mahidol University;1997.

21. Krebs CJ. Ecological methodology. New York: Harper&Row; 1989.

22. Washington HG. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystem. Water Res 1984;18:653-94.

23. Hanski I. Nutritional ecology of dung- and carrion-feeding insects. In: Slansky FJr, Rodriguez JG, editors. Nutrition ecology of insects, mites, spiders, and related Invertebrates. New York: Wiley; 1987. p.837-84.

24. Wells JD, Greenberg B. Effect of the red imported fire ant (Hymenoptera: Formicidae) and carcass type on the daily occurrence of post-feeding carrion Fly larvae (Diptera: Calliphoridae, Sarcophagidae). J Med Entomol 1994;31 (1):171-74.

25. Reed HB Jr. A study of dog carcass communities in Tennessee, with special Reference to the insect. Am Midl Nat 1958;59:213-45.

26. Johnson MD. Seasonal and microseral variation in the insect populations on Carrion. Am Midl Nat 1975;93:79-90.

27. Rodriguez WC, Bass WM. Insect activity and its relationship to decay rates of Human cadavers in East Tennessee. J Forensic Sci 1983;28:423-32.

28. Greenberg B. Behavior of post-feeding larvae of some Calliphoridae and a Muscid (Diptera). Ann Entomol Soc Am 1990;83(6):1210-14.

29. Ullyet GC. Pupation habits of sheep blowflies in relation to parasitism by *Mormoniella vitripennis* Wlk. (Hym., Pteromalid). Bull Entomol Res 1950;40 :533-37.

30. Madeira NG. Habito de pupacao de Caliiphoridae (Diptera) na natureza eo Encontro do parasitoide *Spalangia endius* (Hymenoptera:Pteromalidae). Rev Brasil Biol 1985;45:481-84.

31. Norris WC. The ecology of sheep blowflies in Australia. Mongr Biol 1959;8: 514-544.

32. Putman RJ. Dynamics of the blowfly, *Calliphora erythrocephala*, within carrion. J Anim Ecol 1977;46:853-66.

33. Hedrick PW. Population biology, the evolution and eccology of populations. Boston: Jones and Barlett:1984.

34. Blackman SW, Evans GO. Observations on a mite (*Poecilochirus darydovae*) Predatory on the eggs of burying beetles (*Nicrophorus vespilloides*) with a Review of its taxonomic status. J of zoology 1994;234:217-27.

35. Fuller ME. The insect inhabitants of carrion a study in animal ecology. Bull Counc Sci Ind Res Melbourne 1934;82:5-62.

36. Goff ML, Early M, Odom CB, Tullis K. A preliminary checklist of arthropods Associated with exposed carrion in the Hawaiian Islands. Proc Hawaii Entmol Soc 1986;26:53-7.

37. Spitz WU, Fisher RS. Medicolegal investigation of death; guidelines for the Application of pathology to crime investigations. Springfield, IL: Charles C. Thomas;1973.

38. Smith KGV. A manual of forensic entomology. London: British Museum;1986.

39. Yupa H, Sommai C, Sura P, Rowan WE, Kimio M. The dung beetle fauna (Coleoptera, Scarabaeidae) of Northeast Thailand. Elytra Tokyo 1999;27(2): 463-69.

Appendix

Appendix A-1. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in grassland through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2(pi)
Histerid sp.1	0.032	0.160
Rove B. sp.1	0.019	0.107
Rove B. sp.2	0.010	0.066
Rove B. sp.3	0.489	0.505
Rove B. sp.4	0.017	0.101
Rove B. sp.5	0.165	0.429
O. apilularius	0.021	0.117
O. proletarius	0.037	0.177
O. tricornis	0.072	0.273
O. rudis	0.001	0.012
O. lindaae	0.052	0.222
O. sp. A	0.029	0.146
O. vividus	0.001	0.012
O. penicillatus	0.004	0.030
O. sp. B	0.024	0.127
Phaeochrous sp.	0.022	0.122
C. molossus	0.004	0.030
C. reflexus	0.001	0.012
Total	1.000	2.648

$H' = 2.648$ $H'_{MAX} = \log_2 S = \log_2(18) = 4.170$

$J' = H'/ H'_{MAX} = 0.635$

Appendix A-2. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in grassland in summer (March-April 1999) through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp.1	0.063	0.250
Rove B. sp.1	0.063	0.250
Rove B. sp.4	0.250	0.500
Rove B. sp.5	0.063	0.250
O. apilularius	0.031	0.156
O. proletarius	0.156	0.418
O. tricornis	0.031	0.156
O. rudis	0.031	0.156
O. lindaae	0.188	0.453
O. sp. A	0.094	0.320
C. reflexus	0.031	0.156
total	1.000	3.066

$H' = 3.066$

$H'_{MAX} = \log_2 S = \log_2(11) = 2.459$

$J' = H'/ H'_{MAX} = 0.886$

Appendix A-3. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in grassland in rainy season (May-October 1999) through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp.1	0.048	0.211
Rove B. sp.1	0.023	0.125
Rove B. sp.2	0.013	0.079
Rove B. sp.3	0.461	0.515
Rove B. sp.4	0.013	0.079
Rove B. sp.5	0.210	0.473
O. apilularius	0.025	0.134
O. proletarius	0.021	0.117
O. tricornis	0.113	0.356
O. lindaae	0.013	0.079
O. sp. A	0.002	0.019
O. vividus	0.002	0.019
O. penicillatus	0.006	0.046
O. sp. B	0.006	0.046
Phaeochrous sp.	0.038	0.178
C. molossus	0.006	0.046
Total	1.000	2.522

$H' = 2.522$

$H'_{MAX} = \log_2 S = \log_2(16) = 4$

$J' = H'/ H'_{MAX} = 0.631$

Appendix A-4. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in grassland in winter (January-February and November - December1999) through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp.1	0.003	0.028
Rove B. sp.1	0.007	0.048
Rove B. sp.2	0.007	0.048
Rove B. sp.3	0.587	0.451
Rove B. sp.5	0.104	0.340
O. apilularius	0.013	0.083
O. proletarius	0.050	0.217
O. tricornis	0.010	0.067
O. lindaae	0.101	0.333
O. sp. A	0.064	0.253
O. sp. B	0.054	0.227
total	1.000	2.096

$H' = 2.096$

$H'_{MAX} = \log_2 S = \log_2(11) = 3.459$

$J' = H' / H'_{MAX} = 0.606$

Appendix A-5. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in the forest area through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp.1	0.021	0.115
Rove B. sp.1	0.047	0.209
Rove B. sp.3	0.384	0.530
Rove B. sp.4	0.217	0.478
Rove B. sp.5	0.040	0.187
O. apilularius	0.108	0.346
O. proletarius	0.034	0.166
O. tricornis	0.003	0.026
O. lindaae	0.040	0.184
O. sp. A	0.039	0.182
O vividus	0.023	0.125
O. penicillatus	0.012	0.076
O. phanaeiformis	0.005	0.037
O. sp. B	0.006	0.042
Phaeochrous sp.	0.007	0.051
C. molossus	0.009	0.064
Synapsis sp.	0.004	0.032
Trox sp.	0.002	0.015
total	1.000	2.863

$H' = 2.863$

$H'_{MAX} = \log_2 S = \log_2(18) = 4.170$

$J' = H' / H'_{MAX} = 0.687$

Appendix A-6. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in the forest area in rainy season (May-October 1999) through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp.1	0.058	0.239
Rove B. sp.1	0.087	0.307
Rove B. sp.3	0.217	0.478
Rove B. sp.4	0.056	0.233
Rove B. sp.5	0.105	0.342
O. apilularius	0.136	0.392
O. proletarius	0.067	0.262
O. tricornis	0.002	0.020
O. lindaae	0.112	0.353
O. sp. A	0.054	0.227
O vividus	0.018	0.104
O. penicillatus	0.016	0.094
O. phanaeiformis	0.013	0.083
Phaeochrous sp.	0.020	0.113
C. molossus	0.027	0.140
Synapsis sp.	0.011	0.073
total	1.000	3.459

$H' = 3.459$

$H'_{MAX=}$ $\log_2 S = \log_2(16) = 4$

$J' = H'/ H'_{MAX} = 0.805$

Appendix A-7. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in the forest area in summer (March-April 1999) through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Rove B. sp.1	0.067	0.260
Rove B. sp.3	0.483	0.507
Rove B. sp.4	0.017	0.098
Rove B. sp.5	0.033	0.164
O. proletarius	0.025	0.133
O. sp. A	0.208	0.471
O. vividus	0.167	0.431
Total	1.000	2.065

$H' = 2.065$

$H'_{MAX} = \log_2 S = \log_2(7) = 2.807$

$J' = H'/ H'_{MAX} = 0.765$

Appendix A-8. Calculation of species diversity and equitability of Coleoptera from the mouse carcass in the forest area in winter (January-February and november-December) through the use of Shannon-Weiner function

species	propotional abundance (pi)	(-pi)(log2pi)
Rove B. sp.1	0.019	0.107
Rove B. sp.3	0.475	0.510
Rove B. sp.4	0.354	0.530
O. apilularius	0.108	0.346
O. proletarius	0.014	0.088
O. tricornis	0.004	0.034
O. vividus	0.001	0.014
O. penicillatus	0.011	0.074
O. sp. B	0.010	0.067
Trox sp.	0.003	0.024
total	1.000	1.794

$H' = 1.749$

$H'_{MAX =}\ \log_2 S = \log_2(10) = 3.322$

$J' = H'/\ H'_{MAX} = 0.54$

Appendix A-9. Similarity coefficient of Coleoptera species collected from Mouse carcass in grassland and forest

From the equation:

$$Ss = 2a / 2a + b + c$$

$a = 15, \quad b = 17, \quad c = 19$

$$2(15) \ / \ 2(15)+17+19 = 0.83$$

Appendix A-10. Calculation of species diversity and equitability of Coleoptera from the chicken carcass in grassland through the use of Shannon-Weiner function

species	proportional aboundance (pi)	(-pi) (log2pi)
Histerid sp.1	0.096	0.324
Rove B. sp.1	0.007	0.049
Rove B. sp.3	0.555	0.472
O. proletarius	0.068	0.265
O. tricornis	0.021	0.115
O. lindaae	0.014	0.085
O. sp. A	0.082	0.296
Phaeochrous sp.	0.137	0.393
Trox sp.	0.021	0.115
Total	1	2.114

$H' = 2.114$

$H'_{MAX} = \log_2 S = \log_2(9) = 3.17$

$J' = H' / H'_{MAX} = 0.667$

Appendix A-11. Calculation of species diversity and equitability of Coleoptera from the chicken carcass in grassland through the use of Shannon-Weiner function

species	proportional abundance (pi)	(-pi)(log2pi)
Histerid sp. 1	0.071	0.272
Rove B. sp.1	0.143	0.401
Rove B. sp.3	0.500	0.500
O. proletarius	0.071	0.272
O. tricornis	0.071	0.272
O. lindaae	0.071	0.272
O. sp. A	0.071	0.272
Total	1.000	2.261

$H' = 2.261$

$H'_{MAX} = \log_2 S = \log_2(7) = 2.807$

$J' = H'/H'_{MAX} = 0.805$

Appendix A-12. Similarity coefficient of Coleoptera species collected from chicken carcass in grassland and forest

From the equation:

$$Ss = 2a / 2a + b + c$$

a = 7, b = 9, c = 11

$$2(7) / 2(7)+9+11 = 0.71$$

Appendix B-1. A mouse-baited pitfall trap

1.1 The mouse carcass in the first week.

1.2 The mouse-baited carcass in the fourth week.

Appendix B-2. A chicken-baited pitfall trap

2.1 The chicken carcass in the first week.

2.2 The chicken carcass in the fourth week.

Appendix B-3. Adults of some Diptera and Coleoptera found on the carcasses

3.1 Calliphoridae: Diptera

3.2 Sarcophagidae: Diptera

3.3 Histeridae: Coleoptera

Appendix B-3 (cont.). Adults of some Diptera and Coleoptera found on the carcasses

3.4 Rove beetle sp. 1

3.5 Rove beetle sp. 4

3.6 *Onthophagus tricornis* Wiedemanm

Appendix B-3 (cont.). Adults of some Diptera and Coleoptera found on the carcasses

3.7 *Onthophagus apilularius* Masumoto

3.8 *Onthophagus rudis* Sharp

3.9 *Onthophagus vividus* Arrow

Appendix B-3 (cont.). Adults of some Diptera and Coleoptera found on the carcasses

3.10 *Onthophagus penicillatus* Harold

3.11 *Onthophagus phanaeiformis* Boucomont

3.12 *Onthophagus* sp. B

Appendix B-3 (cont.). Adults of some Diptera and Coleoptera found on the carcasses

3.13 *Phaeochrous* sp.

3.14 *Catharsius molossus* F.

3.15 *Trox* sp.

Appendix B-3 (cont.). Adults of some Diptera and Coleoptera found on the carcasses

3.16 *Synapsis* sp.

BIOGRAPHY

NAME Ms. Buntika Areekul

DATE OF BIRTH 28 June 1977

PLACE OF BIRTH Bangkok, Thailand

INSTITUTIONS ATTENDED Mahidol University, 1994-1997:

Bachelor of Science (Biology)