THE POTENTIAL OF FRUIT FEEDING NYMPHALID BUTTERFLIES (PAPILIONOIDEA: NYMPHALIDAE) AS BIOLOGICAL INDICATORS FOR FOREST QUALITY

MOHD. FAIRUS B. JALIL

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POTENSI KUPU-KUPU NYMPHALID (PAPILIONOIDEA: NYMPHALIDAE) SEBAGAI PENUNJUK BIOLOGI UNTUK KUALITI HUTAN

MOHD. FAIRUS B. JALIL

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SEKOLAH SAINS DAN TEKNOLOGI
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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries, each of which have been fully acknowledged.

June 2000

MOHD. FAIRUS B. JALIL
PS98-005-006

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ABSTRACT

A study on fruit feeding Nymphalid butterflies at two sites (Deramakot Forest Reserve and Danum Valley Conservation Area) in Southeastern Sabah yielded 41 species over a period of two years. This study was used to evaluate the potential of the butterflies as indicator species to detect habitat degradation. In this study, the primary forest of Danum Valley Conservation Area acted as a comparative site to the secondary forest of Deramakot Forest Reserve. Three sites with different logging histories were compared with one site in Danum Valley Conservation Area. The parameters studied were the butterfly diversity (species richness, species diversity and evenness) and their faunal similarity. Tests-of-fitness on abundance model were also carried out. A test on the effectiveness of bait trapping for gathering species was also carried out. Estimators of four different kinds (ACE, ICE, Chao2 & MMMeans) were tested to evaluate the rate of species accumulation by bait trapping. Results showed that, at all sites, the studied community matched the log-series and log-normal distribution. Number of species and individuals recorded during the study also had the same positive relation with habitat quality. The diversity parameters α and λ were also positively related with habitat quality. The Shannon-Wiener index H' and Simpson, D, also had similar trends. The values decreased in more disturbed habitats. The use of similarity as estimates of β-diversity showed that all communities had similar species compositions even though there was difference in abundance relationship. Of various estimators of "total" species richness tested, Michaelis-Menten Means (MMMeans) generated the most reasonable of all species richness values. All the estimators provided similar trends to the observed species richness and this study also showed that bait trapping is highly reliable as more than 80% of the species estimates by the estimators have been collected during the study period. Collectively, these results demonstrated that recording fruit feeding Nymphalid butterflies provided data suitable for diversity assessment, however, a more rigorous study must be carried out before any conclusion can be made.

ABSTRAK

Satu kajian menggunakan kupu-kupu Nymphalid dari kumpulan pemakan buah dijalankan di dua tempat (Hutan Simpan Deramakot dan Kawasan Pemuliharaan Lembah Danum) di tenggara Sabah menghasilkan 41 spesies dalam jangkamasa dua tahun. Kajian ini bertujuan untuk menilai potensi kumpulan kupu-kupu ini sebagai pentunjuk biologi untuk mengesan degradasi habitat. Dalam kajian ini, hutan primer di Kawasan Pemuliharaan Lembah Danum bertindak sebagai kawasan bandingan kepada hutan sekunder di Hutan Simpan Deramakot. Tiga kawasan kajian dengan sejarah pembalakan yang berbeza dibandingkan dengan satu kawasan kajian di Kawasan Pemuliharaan Lembah Danum. Parameter yang dikaji adalah kepelbagaian kupu-kupu (kekayaan spesies, kepelbagaian spesies dan kesamarataan) dan kesamaan. Ujian kebagusan padanan model kelimpahan juga dijalankan. Satu ujian mengkaji keberkesanan perangkap berumpan untuk mengumpul spesies juga dijalankan. Empat jenis penggangar (ACE, ICE, Chao2 & MMMeans) digunakan untuk menilai kadar pengumpulan spesies oleh perangkap berumpan. Keputusan telah menunjukkan bagi semua kawasan kajian, komuniti adalah menepati dengan model log-normal dan log-series. Bilangan spesies dan individu yang di rekodkan sepanjang kajian mempunyai hubungan yang positif dengan kualiti habitat. Parameter kepelbagaian α dan λ juga menunjukkan hubungan positif dengan kualiti habitat. Indek Shannon-Wiener H' dan Simpson, D, juga mempunyai tren yang sama. Nilai semakin menurun dengan merosotnya kualiti habitat. Kegunaan indek kesamarataan sebagai penggangar kepelbagaian β menunjukkan semua komuniti mempunyai komposisi spesies yang sama walaupun terdapat perbezaan kelimpahan. Dari semua penggangar kekayaan spesies "sebenar" yang diuji, Michaelis-Menten Means (MMMeans) menghasilkan nilai yang paling munasabah antara semua nilai kekayaan spesies. Semua penggangar menghasilkan tren yang hampir sama dengan nilai kekayaan spesies yang di perhatikan. Kajian ini menunjukkan bahawa perangkap berumpan adalah sangat sesuai digunakan kerana lebih daripada 80% spesies telah dikutip sepanjang kajian dijalankan. Secara keseluruhan, hasil kajian menunjukkan yang pengumpulan kupu-kupu Nymphalid pemakan buah memberi data sesuai untuk tinjauan kepelbagaian. Namun kajian yang lebih terperinci mesti dijalankan sebelum sebarang kesimpulan dapat dibuat.

CONTENTS

LIST OF ABBREVIATIONS

FFNB	: Fruit feeding Nymphalid butterfly
DFR	: The Deramakot Forest Reserve
DVCA	: The Danum Valley Conservation Area
	: DVCA study plot, primary forest.
DFR85	: DFR study plot, logged in 1985
DFR86	: DFR study plot, logged in 1986
DFR90	: DFR study plot, logged in 1990
SRAM	: Species rank/abundance model
LNAM	: Log-normal abundance model
LSAM	: Log-serie abundance model
MMMeans	: A Michaelis-Menten Means asymptotic based estimator of species richness
Chao2	: An incidence-based estimator of species richness
ACE	: An abundance-based coverage estimator of species richness
ICE	: An incidence-based coverage estimator of species richness

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CHAPTER 1

INTRODUCTION

In the recent past, the lowland rainforests of Sabah, in northern Borneo, constituted an extensive wilderness, teeming with life, but rapid development during the last decades has reduced the once proud and extensive rainforest into degraded forest remnants (Keith, 1981; Phillipps, 1995; Wong & Phillips, 1996; Anon., 1998a). Today it is widely recognized that biodiversity is being lost rapidly on a local and global scale through degradation of ecosystems related to anthropogenic and economic pressures (Groombridge, 1992; Padoch & Peluso, 1996; Potter, 1996; John, 1997; Laurance & Bierregaard, 1997).

In the past the Malaysian state of Sabah relied heavily on timber as its major source of income (Anon., 1998a). At present, most of the lowland forests have already been converted to plantations and the extraction of timber is being controlled to ensure a sustainable timber supply. Reduced-impact logging methods are practiced as part of the sustainable forest management program. In Sabah, the Deramakot Forest Reserve has established some methods and is now a model for other forest reserves (Kleine & Heuveldop, 1993; Anjin & Kleine, 1997; Chai, 1997).

As this decrease in diversity is observed, through species extinction and habitat loss, cataloging what remains becomes increasingly critical (Groombridge, 1992; Speight *et al.*, 1999). Arthropod inventory can provide good indicators of biodiversity in relation to habitat quality because of their quick response to environmental changes (Kremen *et al.*, 1993; Speight *et al.*, 1999). The potential of butterflies as bioindicators lies in their sampling simplicity; it does not require complicated devices, and taxonomically, butterflies are much more stable than other groups of insects (DeVries, 1987; Otsuka, 1988; Corbet & Pendlebury, 1992; DeVries *et al.*, 1997).

The specific relationship of butterflies with plants is an added advantage. It has been generally known that butterflies only lay their eggs on a handful of food plants (e.g., Aristolochiaceae for *Troides*; Rutaceae for *Papilio*) (Corbet & Pendlebury, 1992; Igarashi & Fukuda, 1997). Due to this specificity, loss of a food plant (due to habitat loss) could result in loss of the species that utilize it. The most famous case is the Xerces Blue butterfly, *Glaucopsyche xerces* (Boisduval, 1852), of Baja Peninsula, California. It once thrived in coastal sand dunes near San Francisco, California and was last seen in 1941. The species is now extinct, being a victim of habitat loss caused by urban development (Chicago Field Museum, 1998).

This study is focused on using butterflies of the fruit feeding understorey guild as potential biological indicators to understand the effect of forest disturbance on their diversity and community structure. The change in butterfly community is related to the degree of habitat alteration. The fruit feeding Nymphalid butterflies (in short, FFNB) are defined as butterflies (adult/imago) whose nutritional needs are obtained strictly from rotting fruits and plant sap. In Malaysia, these groups are species of the subfamilies Satyrinae, Morphinae, Charaxinae and Nymphalinae (Corbet & Pendlebury, 1992).

In this study, habitat quality is defined in relation to the impact of selective logging and disturbance of habitat based on the number of years since it was logged. The major study sites were within the secondary forest of the Deramakot Forest Reserve (DFR). These sites in the DFR were pre-selected as study sites. Two of the three sites were slightly disturbed, while one site was a heavily disturbed forest. A site in the pristine primary forest of Danum Valley Conservation Area (DVCA) served as a comparison to the disturbed DFR sites.

The specific objectives of the study were:

1. To assess the effect of disturbance, that is selective logging, on the community structure of FFNB, by studying guild responses on species/abundance relationships.
2. To assess the effects of disturbance caused by selective logging on FFNB diversity, by comparing species richness and species diversity between disturbed DFR and undisturbed DVCA communities.
3. To determine whether similarity indices (as a measure of β-diversity) would describe a comparison of FFNB communities between disturbed (DFR) and undisturbed (DVCA) forests.
4. To access the suitability of bait trapping as a method of gathering information of species richness using estimates of diversity.

It is hoped that upon the completion of the study a clearer pattern of FFNB diversity could give an understanding of the effect of disturbance on forest butterfly community.

CHAPTER 2

LITERATURE REVIEW

2.1 INSECT DIVERSITY IN THE TROPICAL RAINFOREST

The tropic regions are defined as "*the areas which lie between the Tropic of Cancer (23.5^{o}N) and the Tropic of Capricorn (23.5^{o}S)*" (Otsuka, 1988; Reading *et al.*, 1995). The tropical rain forests cover a mere 7% of the total earth surface but contain more than half of the species known in the entire terrestrial ecosystem on earth (Groombridge, 1992; Wilson, 1992; Laurance & Bierregaard, 1997; Primack, 1998). Together with the coral reefs, they are the most biologically diverse ecosystem on earth (Wilson, 1992; Laurance & Bierregaard, 1997; Whitmore, 1998).

Insects form a very large and diverse group constituting more than half of the known species of living organisms (Groombridge, 1992; Wilson, 1992; Speight *et al.*, 1999) (Figure 2.1). In the tropical rainforest, insects are estimated to represent over 50% of the total species diversity and could be found in almost all microhabitat and niche available (Wilson, 1992; Speight *et al.*, 1999).

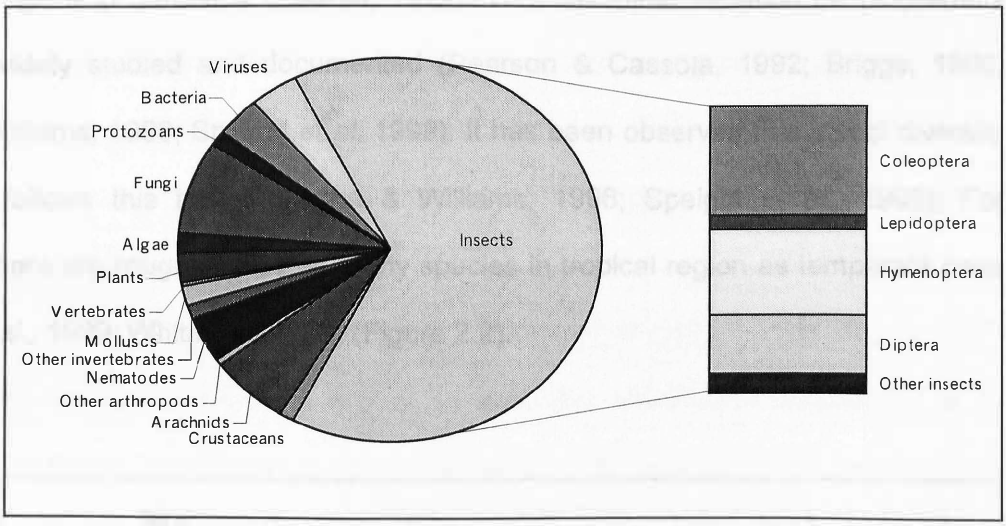

Figure 2.1. Estimated numbers of species of insects relative to all other kinds of organisms (after Groombridge, 1992).

The actual diversity of insects in a tropical rainforest is difficult to assess (due to stratification, niche, etc.) (Southwood, 1980; Romoser & Stoffolano, 1998; Speight *et al.*, 1999). Estimations are usually based on extrapolation of known species (Erwin, 1982; Stork, 1988; Groombridge, 1992; Colwell & Coddington, 1994). Erwin (1982), in an attempt to estimate the total number of arthropods, arrived at a figure close to 30 million species based on his work in a Panamian rain forest. Stork (1988) believes that Erwin (1982) oversimplified the estimates and, retracing the calculation, arrives at a figure ranging from 10 to 80 million species. Being highly speculative and debatedable, the estimates have given us some clue about the total number of species on earth and have stimulated numerous studies (Erwin, 1982; Stork, 1988; Basset *et al.* 1996).

There are less than 150 species of tiger beetles (Coleoptera: Cicindelidae) that have been recorded in the temperate region, but over 300 species have been recorded in tropical regions (Pearson & Cassola, 1992). This latitudinal variation on biodiversity has been widely studied and documented (Pearson & Cassola, 1992; Briggs, 1996; Gaston & Williams, 1996; Speight *et al.* 1999). It has been observed that insect diversity in general follows this trend (Gaston & Williams, 1996; Speight *et al.*, 1999). For butterflies there are roughly twice as many species in tropical region as temperate ones (Speight *et al.,* 1999; Whitmore, 1998) (Figure 2.2).

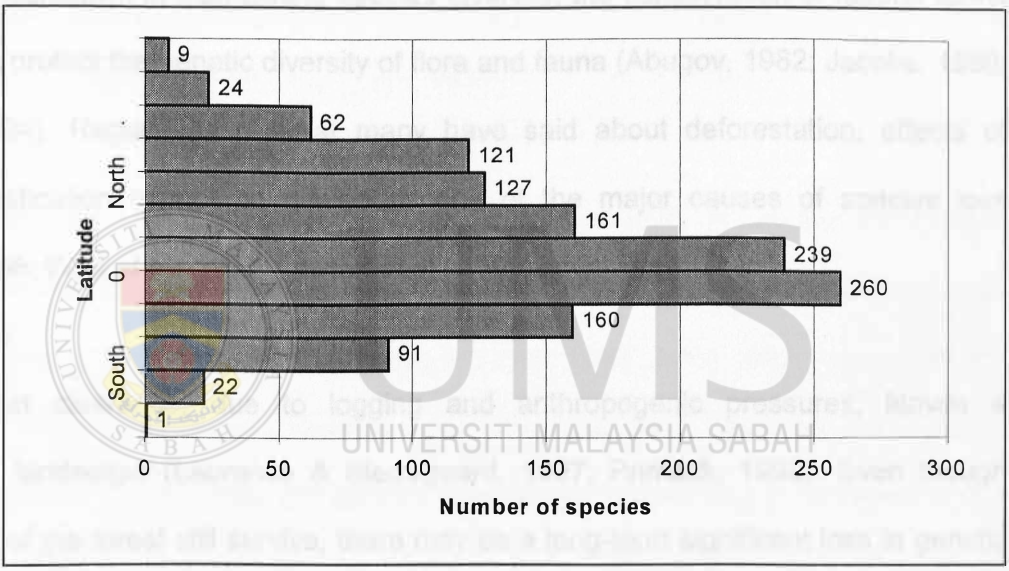

Figure 2.2. Latitudinal gradients of number of butterfly species (Papilionidae) from the north to the south (*after* Sutton & Collins (1991) *see* Speight *et al.*, 1999)

2.2 EFFECT OF FOREST DISTURBANCE ON INSECT DIVERSITY

Despite the extraordinary richness of the tropical rainforest, it is also the most fragile and is now extremely threatened by changes in land use (Whitmore & Sayer, 1992; Wilson, 1992; Laurance & Bierregaard, 1997; John, 1997; Primack, 1998; Whitmore, 1998). In recent years, the rate of deforestation has increased alarmingly, to the dismay of many scientists who are not only concerned with the loss of biodiversity but the integrity of the ecosystem as a whole (Whitmore & Sayer, 1992; Laurance & Bierregaard, 1997; Anon., 1998b). With the current rate of global destruction of tropical rainforests, the use of species diversity measurement has become critically important to understand tropical communities and their conservation needs (DeVries *et al.*, 1997; Watt *et al.,* 1997; Lawton *et al.,* 1998). Even though several studies have shown that disturbance is an important mechanism in maintaining species diversity, the conservation of natural forest is a must to protect the genetic diversity of flora and fauna (Abugov, 1982; Jacobs, 1988; Huston, 1994). Regardless of what many have said about deforestation, effects of habitat modification cannot be denied as one of the major causes of species loss (Turner, 1996; Watt *et al.,* 1997; Lawton *et al.,* 1998).

Forest clearance, due to logging and anthropogenic pressures, leaves a fragmented landscape (Laurance & Bierregaard, 1997; Primack, 1998). Even though some parts of the forest still survive, there may be a long-term significant loss in genetic variation in the remaining forest (Avise & Hamrick, 1996; John, 1997; Primack, 1998). Habitat fragmentation converts a previously continuous population into a metapopulation structure, with a series of isolated populations which run the risk of extinction (Turner, 1996; Wahlberg *et al.,* 1996), which could lead to the elimination of endemic and rare species (A.Lindberg, *pers. comm.*; Wahlberg *et al.*, 1996).

Forest plays an important role in recycling carbon dioxide and also provides a buffer zone to filter water and to hold soil in place (Richard, 1996; Whitmore, 1998). It sustains water and soil resources through recycling nutrients. Insects such as termites

(Eggleton *et al.*, 1995), ants (Holldöbler & Wilson,1990; 1995) and dung beetles (Davis, 1993; Davis & Sutton, 1998) are playing an important role in recycling and decomposing nutrients. In all these activities, insects process and return vast amounts of nutrients to the soil. Logging operations inevitably cause disturbance to the soil surface and to the remaining vegetation, which in turn affects hydrological cycles and can lead to erosion and sedimentation of the water systems (Whitmore & Sayer, 1992; Richard, 1996; John, 1997; Whitmore, 1998). Other effects on soil structure like scouring or compaction during the construction of access roads affect soil fauna (John, 1997). Insects that rely on this substratum would be greatly affected (John, 1997).

Unscrupulous logging mobilizes debris that not only finds its way into the streams and rivers but also into the marine environment, where it damages mangroves and coral reefs, sites crucial for aquatic life (Whitmore & Sayer, 1992; John, 1997; Anon., 1998b). Disturbance has significant impacts on structure and function of stream macroinvertebrate communities and has become an important focus in stream ecology (Resh, *et al.*,1988; 1995; 1996).

Logging practice also affects microclimate such as light intensity, temperature and humidity (Richard, 1996; John, 1997; Whitmore, 1998). The felling of trees usually causes the formation of gaps and major alterations on the forest canopy. Logging alters the once humid, dark and cool understorey into a drier, brighter and hotter understorey (John, 1997; Whitmore, 1998). It has been reported that the creation of gaps increases ground temperature, thus affecting the eggs and larvae of soil termites (Eggleton *et al.*, 1995). This would decrease the species richness of termites primarily due to the loss of soil feeder termites (Eggleton *et al.*, 1995; John, 1997)

Selective logging changes the forest in many forms. The forest structure may be lost during logging activities, changes in microclimate and other environmental conditions (Richard, 1996; Whitmore, 1998). For the forest insects, disturbance in the form of selective logging means the availability of resources in the forest is changed. Logging may increase or decrease the resources available depending on guilds feeding habits and behavior. Logging rarely eliminates species, however, it could limit the resources and thus reduce their population sizes, or increase the resource and thus increase their abundance. The mixed response of biodiversity should be interpreted carefully to really understand the forest dynamics after logging and the effect of forest disturbance on biodiversity (Whitmore & Sayer, 1992; John, 1997; Laurance & Bierregaard, 1997).

2.3 CONCEPT AND CRITERIA OF BIOLOGICAL INDICATORS

The pressures of current public and political decisions on habitat utilization are limiting the study on biodiversity. Due to such pressures, quantitative assessment must be able to represent biodiversity as a whole. The use of bioindicators for terrestrial ecosystems only gained popularity during the last few years (Kremen, 1992; Pearson, 1994; Kremen, 1994). It was derived from the concept of biological indication in aquatic ecosystem using macroinvertebrates (Jackson & Resh, 1988; Lenat, 1988; Resh *et al.*, 1988; 1995; 1996; Davis, 1995; Growns & David, 1991; McGeoch, 1998). However, when this concept is applied to terrestrial ecosystems, several problems arise: the complexity of terrestrial ecosystems compared to aquatic ecosystems and the difficulties to quantify the level of disturbance (Hellawell, 1991; McGeoch, 1998).

Moreover, the selection of an indicator taxon for biodiversity assessment has created a lot of confusion. Many have expressed their concern on the selection criteria of target taxa (Brown, 1991; Pearson, 1994; McGeoch, 1998). Brown (1991) has listed and evaluated insects as indicators of biodiversity by giving them scores for meeting each criterion. Pearson (1994) has advocated seven criteria to be tested before the selected taxa are used as biological indicators and McGeoch (1998) has listed fifteen criteria for the selection of bioindicators.

Browns (1991) has evaluated the potential of insects as indicators for biodiversity using twelve criteria and by giving a score on meeting each criterion. By having the highest scores, meaning the taxa/groups/guilds have proved to be an ideal taxon by virtue of having a desirable quality as indicator taxa/groups/guilds (Brown, 1991; Speight *et al.*, 1999). The twelve desirable qualities are, (i) taxonomically and ecologically highly diversified, (ii) species have high ecological fidelity, (iii) relatively sedentary, (iv) species narrowly endemic, or if widespread, well differentiated, (v) taxonomically well known, easy to identify, (vi) well studied, (vii) abundant, non-furtive and easy to find in the field, (viii) damped fluctuations (always present), (ix) easy to obtain large random samples of species and variation, (x) functionally important in ecosystem, (xi) response to disturbance, predictable, rapid, sensitive, analyzable and linear, (xii) associates closely with other species and specific resources (Brown, 1991; Speight *et al.*, 1999).

Pearson (1994) has urged that before selecting any indicator taxa for quantitative assessment of biodiversity, it must first pass seven criteria that enable the taxa to be claimed as ideal indicators. They are (i) well known and stable taxonomy, (ii) well known