

# **Effect of Inter-Habitat Matrix on Tropical Evergreen Forest Remnants: An Empirical Test of Matrix -Tolerance Hypothesis on Butterflies**

*Dissertation Submitted to Saurashtra University, Rajkot  
in Partial Fulfillment of the Master's Degree  
in Wildlife Science*

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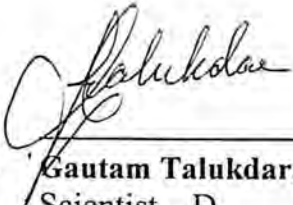


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## CERTIFICATE

This is to certify that **Mr. Deepak C. K.** has carried out original research titled "*Effect of Inter-Habitat Matrix on Tropical Evergreen Forest Remnants: An Empirical Test of Matrix – Tolerance Hypothesis on Butterflies*" in partial fulfilment of **Master's Degree in Wildlife Science from Saurashtra University, Rajkot.** The study was carried out under our supervision from December 2012 to June 2013. We hereby certify that this work has not been submitted for any other degree to any other university.



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## SUMMARY

Recent studies on habitat fragmentation has highlighted the importance of inter-habitat matrix and the need for a shift from traditional binary perspective to a 'matrix composition' perspective for understanding species diversity patterns in human modified landscapes. Matrix-tolerance model provides a simple framework for understanding the sensitivity of species to fragmentation by simultaneous study of native forest patches and surrounding matrix. According to this model, abundance of a species in the matrix is inversely proportional to its vulnerability to fragmentation. This study tested the matrix-tolerance hypothesis on butterflies of tropical evergreen forest remnants, surrounded by a matrix of coffee plantation and paddy field in Kodagu region of Western Ghats. Western Ghats is rich in butterfly fauna represented by 333 species of which 33 are endemic to the biogeographic region. The region is also characteristic in having human modified habitats with relatively large proportion of native forest patches which calls for a landscape level approach for conservation.

In order to test the matrix tolerance hypothesis sampling was carried out in 16 sites which included 7 in fragments (sacred groves), 7 in matrix (5 in coffee plantations, 2 in paddy field) and 2 in large contiguous forest (Reserve Forest). For abundance estimation of butterflies, time constrained surveys were carried out 3 times in each site between January 10 and April 8, 2013. An index related to fragmentation vulnerability was generated for each species using abundance data obtained from time-constrained surveys. The Fragmentation Vulnerability Index, FVI was defined as the ratio between average abundance of the species in the fragments and average abundance in the continuous patch. Spearman's rank correlation was then used to test the association between rank FVI and rank matrix abundance. Various microclimatic and habitat variables were measured in matrix sites and Generalized Linear Models (GLMs) were constructed to test their association with estimated species richness. Analyses were carried out using SPSS 16 and R (version 3.0.1, R core team 2013) software.

The present study shows that the relation between abundance of species in the inter-habitat matrix and its vulnerability to fragmentation is positive and significant ( $r_s = 0.514$ ,  $p = 0.001$ ,  $N = 37$ ). Species which are capable of tolerating the matrix are found to be less vulnerable to fragmentation. Some species deviate from the expected model in their response to habitat fragmentation which could possibly be explained by examining species specific traits. Fragment size didn't have a significant effect on relation between matrix abundance and fragmentation vulnerability index ( $F=0.758$ ,  $p=0.387$ ,  $df=1$ ), unlike expected from previous studies. This could either be due to smaller range of fragment sizes in the present study or due to confounding factors like patch isolation and patch quality which can mask the effect of patch size. Among various habitat and microclimatic variables, canopy cover was found to be important predictor of estimated species richness in matrix sites (weight = 0.8,  $\beta = 0.8$ ,  $p = 0.008$ ). Coffee plantations generally have a moderate level of canopy cover which is favorable for most butterfly species. But compared to paddy field, the canopy cover is higher in coffee plantations and this could be the reason for increase in species richness with increasing canopy cover in matrix sites. The matrix-tolerance model has several implications to conservation and management of biodiversity and its scope can be broadened by incorporating life history traits important in determining sensitivity of species to fragmentation.

## CHAPTER 1

### Introduction, Literature Review, Study Area, Hypotheses

#### Introduction

The spatial pattern in which habitats are distributed and its effects on population and community dynamics is of central interest to ecologists (Ricketts 2001). Increasing human pressure on forested landscapes has led to habitat loss and fragmentation. It is important to understand these phenomena and its implications to better inform conservation and management of native biota. The study of fragmented landscapes has been dominated by two classical paradigms, namely island biogeography theory (MacArthur & Wilson 1967) and metapopulation dynamics (Hanski 1998). Both these paradigms view an organism's environment as a set of habitat patches within a uniform non-habitat "matrix" (area surrounding the native forest patches of interest) like islands in ocean (Ricketts 2001). Earlier studies have focused on habitat patches and characters associated with them such as patch size and patch isolation as determinants of species richness and abundance (Bender et al. 2005). But most of the human-fragmented landscapes maintain some degree of terrestrial connectivity via the matrix of modified habitats surrounding fragments (Gascon et al. 1999). In this scenario a more realistic approach would be to view matrix as a heterogeneous mosaic containing a range of habitats that can serve as alternative habitat for species or can present different permeability to their movement or may serve as a source for exotic species (Gascon et al. 1999, Dixo et al. 2010). This approach recognizes the importance of matrix in determining species diversity patterns in fragments.

The species which are capable of tolerating the matrix are found to be less vulnerable to habitat fragmentation. This finding lead to the formulation of "matrix tolerance hypothesis", according to which, the abundance of a species in the matrix is inversely proportional to its vulnerability to fragmentation (Gascon et al. 1999). This forms a simple framework to understand sensitivity of species to habitat fragmentation by simultaneous study of native forest patches and surrounding human modified matrix. The land committed for production of food and other resources occupies a substantial portion of terrestrial environment throughout the world which is only going to increase in future (Houghton 1994, Bennet et

al. 2006). In this scenario, understanding the structure and composition of inter-habitat matrix and ways by which it influences species diversity and distribution is of prime importance for both scientific and conservation purposes (Ricketts 2001, Bender et al 2005).

The Western Ghats landscape is characteristic in having highly heterogeneous and structurally complex human modified habitats while retaining a large proportion of native forest (Anand et al. 2010). The spatial configuration of native forest patches juxtaposed with human modified habitats calls for a landscape level approach to study species diversity patterns in which inter-habitat matrix form an important component. But little effort has gone into this direction. Natural forests cover about one third of the area of Western Ghats. The land use practices in the remaining areas include artificial reservoirs, open agriculture such as paddy (*Oryza* spp.), vegetables, and plantations of coffee (*Coffea* spp.), tea (*Camellia sinensis*), rubber (*Hevea brasiliensis*), cardamom (*Elettaria cardamomum*) and other cash crops (Daniels et al. 1990, Anand et al. 2010). Coffee plantations cover over 3000 sq. km (Coffee Board of India 2009) and contain different proportion of native and exotic shade trees. The tree covered nature of coffee plantations may reduce species loss from fragmented patches embedded in it at least for some taxonomic groups (Bhagwat et al. 2005). Paddy cultivation is another important land use type in Western Ghats but unlike coffee plantation it differs drastically from native forest patches in terms of habitat structure.

Western Ghats harbors 333 species of butterflies which includes 33 endemic species and 8 species shared only with Sri Lanka (Kunte 2008). Species belonging to 6 families namely Hesperidae, Papilionidae, Pieridae, Lycaenidae, Nymphalidae and Riodinidae are found in the Western Ghats. Butterflies are considered to be good indicators of overall biodiversity and changes in environment. They are well studied group with comparably good knowledge on taxonomy and ecology (Ockinger et al. 2010). In spite of this there are no studies on butterflies from Western Ghats dealing with questions of habitat loss and fragmentation.

This study aims to test the matrix tolerance hypothesis on butterflies in Kodagu, Karnataka where coffee plantation and paddy field form the dominant matrix within which fragmented evergreen forest patches are embedded. The matrix tolerance hypothesis has never been tested on an invertebrate taxon except ants (Gascon et al. 1999). The Coorg-Nilgiris zoogeographic section is one of the most biodiversity rich areas in Western Ghats (Daniels

et al. 1991, Kunte 2008). In Kodagu, coffee is a prominent land use type occupying about 29% of land area (Elauord 2000, Page 2007) and paddy is the second major land use type covering nearly 9% of total land area.

## **Literature Review**

Though the importance of inter-habitat matrix have been realized much earlier, most of the studies empirically testing the effects of matrix structure, composition and differential response of species towards it came up during last one and a half decade. Gascon et al (1999) found that the response to inter habitat matrix varies from species to species and this is reflected in their vulnerability to fragmentation. To predict these responses, they suggested a model, namely matrix tolerance model, according to which the vulnerability of a species to fragmentation is inversely proportional to its abundance in the matrix. In a study conducted by Ricketts (2001) the structure of matrix was found to have a strong influence on effective isolation of patches. The response to matrix varied with butterfly taxa and type of matrix. Bender et al (2005) showed that matrix structure obscures the relationship between inter patch movement and patch size and isolation. Their simulation studies and empirical results showed that patch size and isolation can be poor predictors of inter patch movement when the matrix is heterogeneous and is in a coarse grained pattern. It also showed that generalist species respond less predictably to patch size and isolation than specialists. Bennett et al (2006) reviewed studies involving comparison of multiple landscapes to identify the influence of three categories of emergent properties of mosaic structure: the extent of habitat, composition of the mosaic and spatial configuration of elements on biota. They found extent of habitat and composition of mosaic to have a strong influence on species composition in the land mosaic compared to spatial configuration of elements which had less influence on biota. Laurance et al (2007) identified matrix structure and composition as a major factor influencing edge effect in their empirical study. Difference in matrix vegetation was found to have impact on dynamics of floristic change and faunal assemblages in the nearby fragments. Following Gascon et al (1999), Dixo et al (2010) tested the matrix tolerance hypothesis on frogs in Atlantic forests of Brazil. The pattern expected from matrix tolerance model was observed but strength of the relationship was weak. Fragment size and species traits were found to have strong influence on matrix-

tolerance model. The relationship between vulnerability to fragmentation and matrix abundance was stronger for small sized fragments compared to large fragments. Dixo et al (2010) proposed the inclusion of fragment characteristics and individual species traits into the simplistic model suggested by Gascon et al (1999).

A large number of studies related to habitat fragmentation and metapopulation dynamics has centered on butterflies owing to their value as indicator species and also due to fairly good amount of information available on their ecology (Ockinger et al. 2007). Benedick et al. (2006) found a significant correlation between butterfly species richness and patch characteristics in rainforest remnants of Northern Borneo. Patch size was positively correlated and patch isolation negatively correlated with species richness and diversity. Species traits such as adult body size and larval host plant specificity were found to be significant in determining response of individual species to habitat fragmentation. Results of a study from experimentally fragmented landscape in the Central Amazon indicate that butterfly communities in fragmented tropical forests are more variable than those in intact forest and that the natural variability of butterflies was not a buffer against effects of fragmentation on community dynamics (Leidner et al. 2010). Ockinger et al. (2010) demonstrated the importance of considering life history traits in fragmentation studies. This study shows that the effect of habitat loss was pronounced on species with low mobility, narrow feeding niche and low reproduction.

There are no recent published studies from Western Ghats which has looked into effect of habitat fragmentation on Lepidopteran diversity. Most of the fragmentation studies from Western Ghats are on vertebrate fauna (but see Kapoor 2006) and they rarely depart from traditional "island-ocean" approach. Studies which compare biodiversity in native forest and a human land use type are of little use in understanding fragmentation vulnerability of species and effects of inter-habitat matrix on it. But they may provide insight into conservation value of a particular human land use type (Dolia et al. 2007). One study which accounts for a landscape level approach for understanding effects of habitat fragmentation is of Bhagwat et al (2005) which looked into influence of landscape structure on tree, bird and macrofungi diversity in fragmented patches. They found that the tree covered nature of

surrounding matrix (coffee plantation) had a positive influence on biodiversity in the fragments.

## STUDY AREA

### Western Ghats

The Western Ghats stretches along the western coast of peninsular India from Surat, Dangs in southern Gujarat to southwestern Tamil Nadu (8–20°N), covering an area of ~160,000 sq. km and ranging in elevation from sea level to ~2700 m. The northern parts and extreme southern tip are less moist, while the central and southern Western Ghats receive heavy annual precipitation of up to 6000 mm, which supports dense evergreen forests rich in species diversity and endemism. Western Ghats is one among the 34 global biodiversity hotspots of the world owing to high levels of endemism and the necessity to conserve endangered flora and fauna (Myers *et al.* 2000). The two most biodiverse areas of the Western Ghats, i.e. Coorg–Nilgiris and southern Western Ghats, are separated by the Palghat Gap, giving rise to local endemism and increasing overall diversity in the area.

### Kodagu

The district Kodagu is located on the eastern slopes of Western Ghats in the state of Karnataka extending from 75°25'–76°14' E and 12°15'–12°45' N. The altitude of the district ranges between 300m to 1734m above the sea level. The district has a large number of forest types in a comparatively smaller area (4106 sq km). Pascal *et al* (1986) broadly classified the forests into following vegetation types.

#### I. Wet evergreen forests

Wet evergreen forests are found mainly in the western boundary of the district. This forest type receives high rainfall and is characterized by high species richness. It is further divided into the following types based on elevation and species composition:

- a.) Low elevation (upto 800m) *Dipterocarpus indicus*-*Kingiodendron pinnatum*- *Humboldtia brunonis* type
- b.) Medium elevation (650m-1400m) *Mesua ferrea*-*Palaquium ellipticum* type

c.) High elevation (1400m-1800m) *Schefflera* spp.-*Gordonia obtuse*-*Meliosma arnotiana* type

## II. Moist deciduous forests

Moist deciduous forests are situated along the central-eastern plains of the district and receive relatively lower rainfall (1500-2000mm). These forests are dominated by tree species like *Alstonia scholaris*, *Vitex altissima*, *Dillenia pentagyna* and *Stereospermum personatum*

## III. Dry deciduous forests

Dry deciduous forests are found mainly on the eastern side of the district. These forests receive an annual rainfall of 750-1500mm and are characterized by tree species like *Tectona grandis*, *Terminalia sp.*, *Anoegissus latifolia* etc.

The intensive study sites include reserve forest (continuous forest), sacred grove (fragment), coffee plantation and paddy field (matrix) in the Virajpet taluka of Kodagu district (fig. 1). The study sites are restricted to Medium elevation *Mesua ferea*-*Palaquium ellipticum* vegetation type. Virajpet lies in the southern part of the district and is the largest among three talukas (Madikeri and Somvarpet being the other two) with an area of 1646 sq km. Details of the study sites are given in Table 1.

The mean temperature of the coldest month in the study arearanges between 16 and 23 degrees centigrade and rainfall between 2000 and 5000 mm per year with four months dry (Pascal et al. 1986). The main rock formations belong to the most ancient Archaean system; the basement rock is composed of peninsular gneiss, gneissic granites and banded gneiss (Akbar Sha 1987, Bhagwat 2002). The soils in the study area are classified as red loamy soils, which have mature profiles, although the surface soils have been eroded from the site of formation in many places, making them generally poor in plant nutrients (Akbar Sha 1987, Bhagwat 2002).

### **Reserve Forest (Continuous forest)**

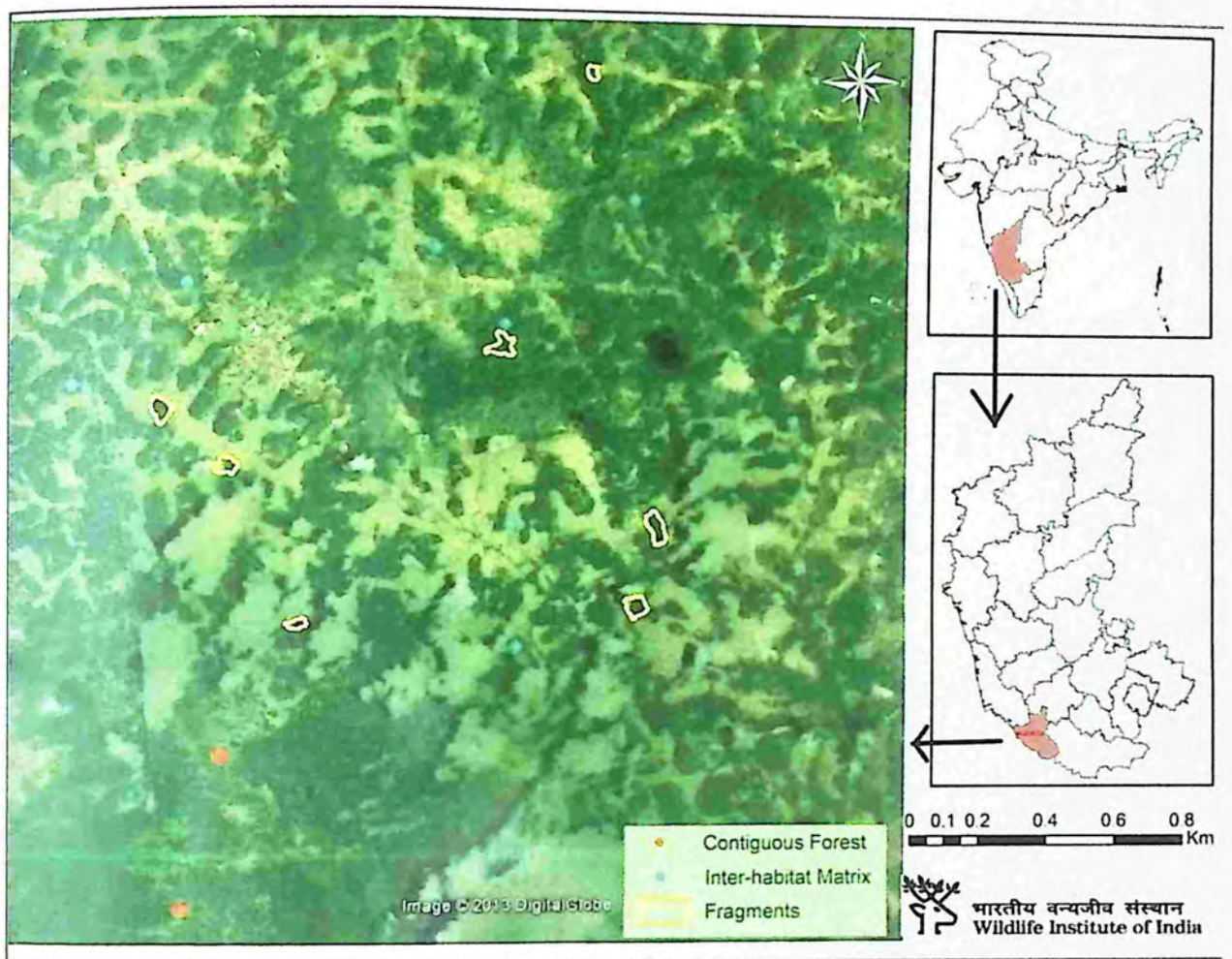
Of the 46% of total area of the district under forest cover, 30% is under Reserve Forest (RF). About 70% of the RF is represented by wet evergreen forests which lie along the western boundary of the district. Most of the dense and undisturbed forests are now found in the Reserve Forests. The RFs are contiguous with Brahmagiri, Talakaveri, and Pushpagiri Wildlife Sanctuaries (Elouard et al 2000, Page et al 2007).

### **Sacred Groves (Fragments)**

In Kodagu, remnant forest patches are managed as sacred groves by local communities. Traditional conservation practices have played an important role in protection and conservation of biodiversity in India. Protecting patches of forests in cultivated landscapes for religious purpose is one such practice followed in different parts of the country. In Kodagu these patches are locally referred to as Devarakadus which means “God’s forest”. According to Brandis (1897) these practices existed in India even before the advent of British rule. Currently, sacred forests in Kodagu are owned by Government and managed by local village committees (Bhagwat 2002). There are 1214 sacred groves in Kodagu covering an area of 2550 ha of the district. Out of these 508 are in Virajpet taluka. Their sizes range from fraction of a hectare to few tens of hectares. Virajpet taluka is recognized as a ‘global hotspot’ because of the high density of sacred groves (Kushalappa et al. 2001). Local beliefs and religious taboos prevent people from using and extracting resources from these “sacred forests”.

### **Coffee plantation and Paddy field (Matrix)**

Kodavas, the present occupiers of Kodagu, are believed to have arrived just before the beginning of the first millennium (Ponnappa 1997). They took up agriculture as their main occupation and cultivated most of the valley bottoms with paddy. During pre-colonial period most areas at medium elevation (900 to 1250 m) were under tree cover, while the lowlying ground was under paddy cultivation and the high mountain slopes under shifting cultivation. During British rule there was a marked increase in the area under coffee cultivation which resulted in loss and fragmentation of native forests. However, due to the structural complexity and floristic diversity of trees, shaded coffee plantations are known to resemble the original forest and thereby have relatively high biodiversity (e.g. Perfecto *et al.* 1996, Bhagwat 2002). Today coffee plantation is one of the most prominent land use type in the area. The canopy cover in most of the plantations consists of native forest species and exotic species like Silver oak (*Grevillea robusta*) and *Erythrina* sp. Paddy cultivation is the second major land use type in the area. The matrix surrounding the native forest patches is dominated by these two land use types.



**Fig. 1** Intensive study area (Western part of Virajpet taluka of Kodagu district in Karnataka)

**Table 1** Description of Study Sites

S. No	Site	Village	Status	Area (Ha)	Altitude (M)	Latitude (DMS)	Longitude (DMS)	Matrix
1	Arji- Bhagyati devarakadu	Arji	Sacred grove	6.6	905	N 12° 10' 50.9"	E 075° 47' 48.8"	Paddy, Road-Forest, Coffee
2	Balagodu – Kandimakki devarakadu	Balagodu	Sacred grove	3.41	915	N 12° 09' 32.7"	E 075° 48' 13.0"	Coffee, Road-Coffee
3	Bettoli-Bhadrakali devarakadu	Bettoli	Sacred grove	8.61	890	N 12° 11' 18.3"	E 075° 47' 14.7"	Paddy (largely), Road-Coffee
4	Kolathodu – Ayyappa devarakadu	Kolathodu Bygodu	Sacred grove	10.13	847	N 12° 10' 07.4"	E 075° 51' 34.1"	Coffee
5	Rudraguppe – Ayyappa devarakadu	Rudraguppe	Sacred grove	8.48	932	N 12° 09' 19.4"	E 075° 51' 17.1"	Paddy, Coffee
6	Karmadu – Ayyappa devarakadu	Karmadu	Sacred grove	3.04	935	N 12° 13' 56.6"	E 075° 51' 12.1"	Coffee, Road-Coffee
7	Nalvatoklu – Ayyappa devarakadu	Nalvatoklu	Sacred grove	8.98	1017	N 12° 11' 34.2"	E 075° 50' 19.5"	Coffee
8	Bilugunda	Bilugunda	Coffee plantation	-	969	N 12° 12' 49.4"	E 075° 51' 32.2"	-
9	Kukloor	Kukloor	Coffee plantation	-	915	N 12° 12' 27.2"	E 075° 47' 36.1"	-
10	Kottoli	Kottoli	Coffee plantation	-	923	N 12° 11' 41.0"	E 075° 46' 33.7"	-
11	Nalvatoklu	Nalvatoklu	Coffee plantation	-	1010	N 12° 11' 52.8"	E 075° 50' 18.6"	-
12	Rudraguppe	Rudraguppe	Coffee plantation	-	853	N 12° 09' 10.4"	E 075° 50' 11.9"	-
13	Aimangala	Aimangala	Paddy field	-	924	N 12° 12' 33.8"	E 075° 49' 44.7"	-
14	Bittangala	Bittangala	Paddy field	-	835	N 12° 10' 12.6"	E 075° 50' 13.4"	-
15	Perumbady		Reserve forest	-	909	N 12° 08' 29.0"	E 075° 47' 32.8"	-
16	Waterkolly		Reserve forest	-	704	N 12° 07' 10.7"	E 075° 47' 04.0"	-

## **Hypotheses**

**1) The abundance of butterfly species in the inter-habitat matrix is inversely proportional to its vulnerability to habitat fragmentation (Matrix tolerance hypothesis).**

For each species an index related to its vulnerability to fragmentation will be generated. This is defined as the ratio between average abundance of the species in the fragments to average abundance in the continuous patch (a lower value of the index will indicate high vulnerability). The fragmentation vulnerability indices will then be correlated with species abundance in matrix. According to matrix tolerance hypothesis a positive correlation is expected.

### **1.1) *Patch size influences matrix tolerance hypothesis.***

Compared to larger patches, persistence of species in smaller patches depends to a greater extent on their ability to tolerate matrix. Hence a stronger positive correlation between fragmentation vulnerability index and matrix abundance is expected for smaller patches compared to larger patches.

**2) The species richness in inter-habitat matrix can be predicted by microclimatic and habitat factors**

The variables considered are:

a) Habitat variables:

Canopy cover

Proportion of native trees

b) Microclimatic variables:

Temperature

Humidity

Intensity of sunlight

## **CHAPTER 2**

### **Materials and Methods**

#### **Study Design**

Study sites were selected based on reconnaissance survey carried out in the month of December, 2012 and January, 2013. A total of 16 sites were selected which includes 7 in fragments (sacred groves), 7 in matrix (5 in coffee plantation, 2 in paddy field) and 2 in large contiguous forest (Reserve Forest). They lie within an area of 50 sq. km in the western part of Virajpet taluka of Kodagu district. Sites with existing trails were selected to facilitate visual detection of target taxa (butterflies). Fragments were selected to represent a size gradient ranging from 3.04 ha to 10.13 ha and such that they are similar in topography, altitude and surrounding matrix. I walked along the boundary of each fragments with a GPS to obtain their area. Sampling in the inter-habitat matrix was restricted to two dominant land use type in the area i.e. coffee plantation and paddy field.

#### **Butterfly Sampling**

Conventionally Pollard's walk method (Pollard et al 1993) is used for abundance estimation of butterflies where observers record butterflies observed within a 5 meter band on both sides of a transect, while walking at a slow and steady pace. The technique can be used for finding absolute abundance assuming that detection probability within the fixed width is 1. But this may not be true in reality. As far as butterflies are concerned, detection probability may vary between different sites and between different species even within the 5m box (Isaac et al. 2011). Also, some amount of data is lost as observations outside the 5 meter box are not taken into consideration. Another method is conventional distance sampling which can provide better estimates but are limited by several theoretical and practical considerations while applying to a highly mobile group of organisms like butterflies (Isaac et al. 2011). Provided the lack of a sound technique for incorporating detection probability I used time constrained survey (Blair et al. 1997, Ricketts 2001, Royer et al. 1998, Niell et al. 2007) which although not a robust technique can provide large sample size within a limited period of time. Existing trails were walked with a steady pace and visual searches were conducted within a fixed interval of time (30 minutes). All butterfly species observed were

recorded. Each site was sampled 3 times between January 10 and April 8, 2013. Sampling was done between 9:00 to 14:00 hours of the day which roughly corresponds to peak activity period of butterflies in the region. A total of 26 time-constrained surveys were carried out in the fragments, 15 in continuous patch and 21 in matrix. Individuals observed were identified to species level whenever possible based on Evans (1927), Wynter-Blyth (1957) and Kunte (2000). Individuals were captured using a hand net for closer examination whenever necessary and released.

### **Measuring Habitat Variables**

- i. Microclimatic variables:** Light intensity was measured using a digital lux meter at start, after 15 min and end of each time constrained survey in matrix sites. Ambient temperature and relative humidity was also measured at the start, after 15 min and end of each time constrained survey with a digital max/min thermo-hygrometer.
- ii. Proportion of native trees & canopy cover:** To estimate the proportion of native trees in coffee plantation 3, 20\*20 m square plots were established in each site. The number of native trees and exotic trees within each plot were recorded. Canopy cover was estimated using spherical densitometer at 5 random points within each plot.

### **Data Analysis**

In order to test matrix tolerance hypothesis, an index related to fragmentation vulnerability was generated for each species using abundance data obtained from time-constrained surveys. The Fragmentation Vulnerability Index, FVI (Gascon et al. 1999, Dixo et al. 2010) was defined as the ratio between average abundance of the species in the fragments and average abundance in the continuous patch.

For a particular species,  $FVI = \text{Average abundance in fragments} / \text{Average abundance in continuous forest}$

A lower value of the index indicates high sensitivity of species to fragmentation and higher value indicates low sensitivity. The FVI values were then transformed to ranks. Average

abundance of the species in the matrix was also transformed into ranks. Spearman's rank correlation was then used to test the association between rank FVI and rank matrix abundance of each species. All species encountered in the continuous patch were included in the analysis irrespective of their abundance in fragments or matrix. According to matrix tolerance hypothesis a positive correlation is expected between matrix abundance and FVI. Independent Student's t test was conducted to test the difference in fragmentation vulnerability of species recorded in the matrix and species not detected in the matrix.

In order to understand the effect of fragment size on matrix tolerance model, the fragments were classified into two size classes, small (3 - 6.6 ha) and large (8.5 – 10.1 ha). FVI was then calculated for the two classes separately and analyses were repeated. Arc GIS software was used to calculate area of the fragments from tracks obtained by walking around them with GPS. To test whether the influence of fragment size on the relation is significant, ANCOVA was done. Average abundance of species in the matrix was the predictor variable, FVI was the response variable and fragment size was taken as covariate. Analyses were carried out using SPSS 16 software.

In order to test different habitat and microclimatic factors that explain estimated species richness of butterflies, Generalized Linear Models (GLMs) were constructed. As the response variable was continuous, Gaussian family of error distribution was used in the models. Selection of suitable model was done on the basis of AICc value instead of AIC value as the sample size was low ( $n=7$ ). Models with delta AICc value of two or less were selected from the set of candidate models (Burnham et al. 2002). As more than two hypothesized predictors were found to be strongly correlated, variance inflation factor (Hair et al. 2006) was estimated for models which included these parameters. Parameters were selected following the analysis. Weight of each parameter was also calculated to demonstrate their relative importance following Burnham et al (2002). This analysis was carried out using the free statistical software R (version 3.0.1, R core team 2013).

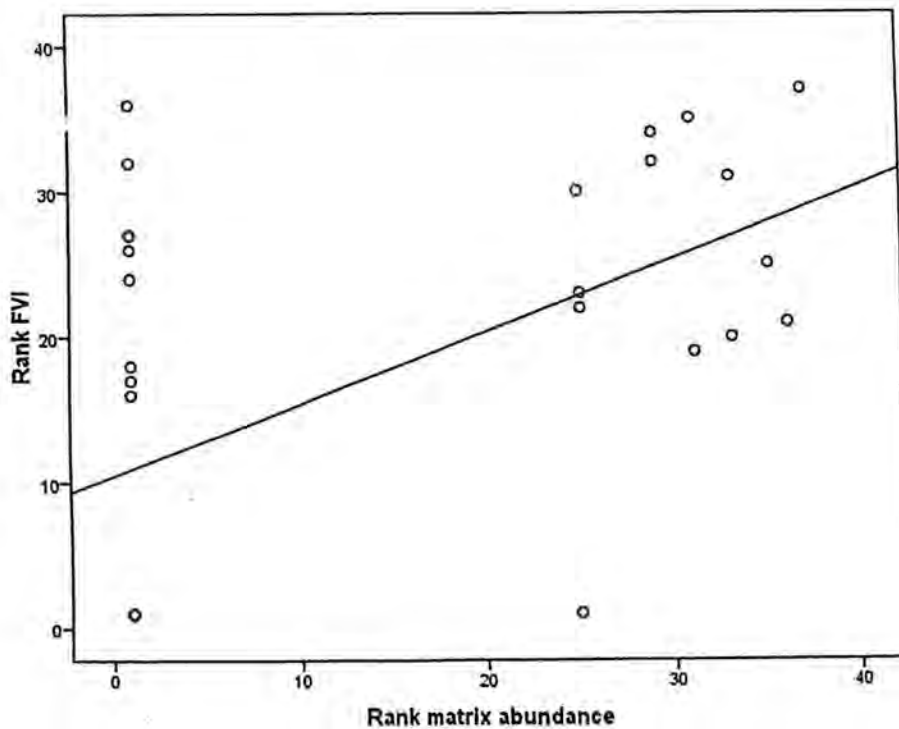
## CHAPTER 3

### Results and Discussion

#### Results

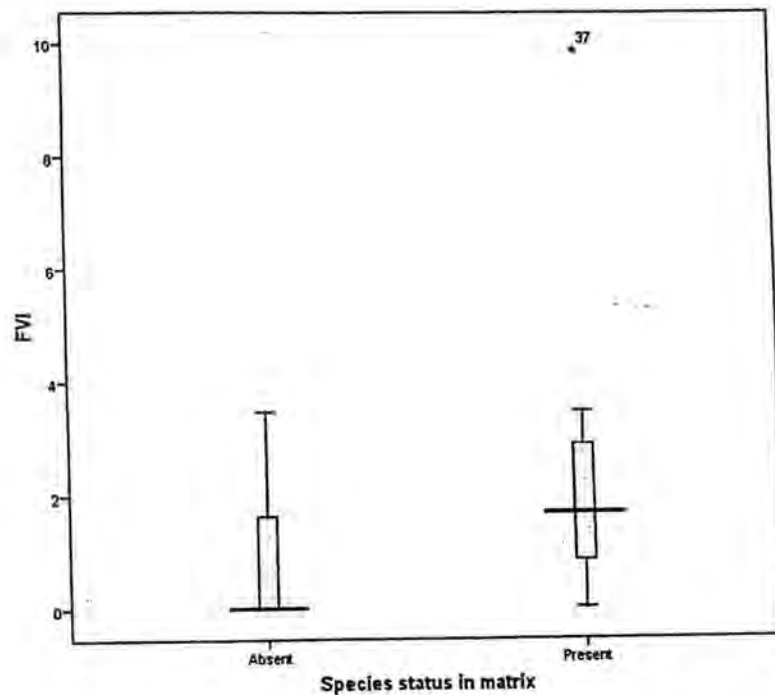
A total of 82 species belonging to 60 genera were detected during sampling. Species belonging to all 6 families present in the Indian subcontinent were recorded. The family Nymphalidae was represented by most number of species (39%) and Riodinidae by least number of species (1.2%). Species richness estimated for continuous forest using Chao 1 estimator was 68.9 (S.E=3.81), for fragments was 78.6 (S.E=1.49) and for inter-habitat matrix was 51.1 (S.E= 1.39). Estimated species richness in coffee plantation was 53.22 (S.E= 2.32) and in paddy field was 8.25 (S.E= 0.21). 11% of the total number of species detected was exclusively found in continuous forest, 17.07% exclusively in fragments and 9.75 in matrix.

The relation between rank matrix abundance and rank FVI was positive and significant ( $r_s=0.514$ ,  $p = 0.001$ ,  $N = 37$ ; fig.2) for all fragments.



**Fig.2** Relationship between rank matrix abundance and rank Fragmentation Vulnerability Index (FVI) for all fragments. Fitted regression line is for illustrative purpose only.

There was a significant difference between Fragmentation Vulnerability Index of species present in the matrix and species not detected in the matrix ( $t = -2.292$ ,  $p = 0.038$ ,  $N_1 = 24$ ,  $N_2 = 13$ ; fig 3).



**Fig.3** Box plot showing distribution of FVI values for species present in the matrix and species not detected in the matrix.

The relation between rank matrix abundance and rank FVI was also positive and significant for small fragments ( $r_s = .487$ ,  $p = 0.001$ ,  $N = 37$ ) and large fragments ( $r_s = .502$ ,  $p = 0.001$ ,  $N = 37$ ). But fragment size didn't have a statistically significant effect on relation between matrix abundance and fragmentation vulnerability index ( $F = 0.758$ ,  $p = 0.387$ ,  $df = 1$ ).

Canopy cover explained the variation in estimated species richness better than other competing models (Table 2). Canopy cover (weight = 0.8,  $\beta = 0.8$ ,  $p = 0.008$ ) significantly influenced estimated species richness of butterflies in inter-habitat matrix (Table 2).

**Table 2** Five candidate models were constructed to predict estimated species richness out of which canopy cover was found to be the most likely predictor.

Model	AICc	Delta	Weight	Parameters
1	56.85832	0	0.79706	Canopy cover
2	60.36625	3.507935	0.13796	.
3	62.18239	5.324072	0.05564	proportion of native trees
4	65.75138	8.893062	0.009341	Humidity
5	111.198	54.33964	1.26E-12	Canopy cover+proportion of native trees+Humidity

## Discussion

The estimated species richness was higher for fragments compared to that of continuous forest. This could be due to the difference in number of spatial replicates between two strata. While 26 time constrained surveys were carried out in 7 fragment sites, continuous forests were represented by 15 time constrained surveys in 2 sites. Another possibility is that the increased species richness is due to higher habitat heterogeneity in fragments. Structurally complex habitats may provide more niches and diverse ways of exploiting the environmental resources and thus increase species diversity, as explained by 'habitat heterogeneity hypothesis' (Simpson 1949, Lack 1969, Tews et al. 2004). There are evidences from studies on arthropods which support 'habitat heterogeneity hypothesis' (Haslett 1997, Brose 2003).

The present study shows that there is a significant association between abundance of a species in the inter-habitat matrix and its vulnerability to fragmentation. Matrix tolerance hypothesis forms a simple framework to understand sensitivity of species to habitat fragmentation by simultaneous study of native forest patches and surrounding human modified matrix (Dixo et al. 2010). The abundance of a species in the matrix is an indicator of its ability to use the matrix for dispersal, resource exploitation or reproduction. The

species which are found in the matrix include those which prefers habitat similar to the matrix or those which are nominally primary evergreen forest species or those which are habitat generalists. Apart from species like *Junonia lemonias* and *Junonia iphita* which prefer open habitat, majority of the species used for analysis in the present study were primary forest species (Kunte 2008) but were present in the matrix in varying abundances. The response to habitat fragmentation of most of the species can be explained by their differential ability to tolerate matrix. Habitat specialist species like *Rohana parisatis*, *Kallima horsfieldii* and *Idea malabarica* present in the continuous forest were never recorded in matrix as well as in the fragments, as expected from the model. These are species highly vulnerable to habitat fragmentation. They probably avoid modified habitats altogether. Species like *Jamides celeno* and *Iambrix salsala* were less vulnerable to fragmentation as indicated by their high FVI values but were never detected in the matrix. So, all species that avoids matrix are not necessarily vulnerable to fragmentation. Though exact reason for this deviation from the expected model is not clear, individual species requirements could possibly help in explaining these patterns. Even if patch size is small population of a species may persist in a fragment irrespective of its ability to tolerate the matrix if the fragment is rich in adult and larval food resources (Dixo et al. 2010). Thus species characteristics and life-history traits can also be crucial in determining sensitivity of species to fragmentation. Most of the butterfly larvae feed on plant parts while adults feed on nectar, plant sap, rotten fruit etc and the preferred food resources vary from species to species. This makes it difficult to tease out the effect of species life history traits on matrix tolerance model. Most of the species which were abundant in the matrix were less vulnerable to fragmentation as expected from the model.

The relation between matrix tolerance and fragmentation vulnerability holds true for small as well as large fragments. But fragment size didn't have a significant influence on the relation. Compared to larger patches, persistence of species in smaller patches depends to a greater extent on their ability to tolerate matrix. Hence, according to matrix tolerance model a stronger positive correlation between fragmentation vulnerability index and matrix abundance is expected for smaller patches compared to larger patches (Dixo et al 2010). But in the present study the relationship was stronger for larger patches even though the difference was not significant. This could be due to smaller range of fragment sizes in the

present study (3.04 to 10.13 ha) preventing the manifestation of any significant effect. Another possibility is that the effect of patch size was masked by confounding factors like patch isolation and patch quality which were not quantified.

Among various habitat and microclimatic variables measured, canopy cover was found to have a significant influence on estimated species richness in matrix sites. Proportion of native trees and humidity didn't have any significant effect on estimated species richness. Being ectothermic butterflies prefer areas with intermediate shade level where they can bask in the sun during low temperature and rest in shaded areas during high temperature conditions. If the canopy is too dense, the microclimatic conditions below canopy layer may not suit most of the butterfly species because of the lack of "basking spots". But coffee plantations generally have a moderate level of canopy cover as the shade trees are never grown too close to each other. Compared to paddy field, canopy cover is higher in coffee plantations and this could be the reason for increase in species richness with increasing canopy cover in matrix sites. Earlier studies have also highlighted the importance of tree covered nature of coffee plantations (Bhagwat et al. 2005). Compared to other land use types like paddy cultivation, coffee plantation may reduce species loss in forest fragments by acting as a buffer around them. The structure and composition of the adjoining matrix vegetation can also have a strong influence on edge effects (Laurance et al. 2007). Owing to its similarity to native forests in habitat structure, coffee plantation may reduce edge effects associated with fragmentation. In the present study, species richness was also higher for sites in coffee plantation compared to paddy field.

This study is one of the first to look at effect of fragmentation on butterflies at a landscape level in Western Ghats. It provides valuable insight into how fragmentation vulnerability of a species is influenced by its ability to tolerate inter-habitat matrix. The only invertebrate taxon on which matrix tolerance model was tested before are ants (Gascon et al. 1999) But there was no significant association between matrix abundance and fragmentation vulnerability in ants. So, present study is the first conclusive evidence for existence of a close association between matrix abundance and fragmentation vulnerability in an invertebrate taxon. The most plausible explanation for the relationship is that the populations of matrix tolerating populations in fragments are bolstered by demographic

contributions of immigrants from native forests or the matrix itself (Brown et al. 1977). If such species become locally extinct in a patch they are easily re-established by colonists due to their ability to use matrix as alternate habitat or for dispersal (Gascon et al. 1999). Also matrix tolerant species are tolerant to edge effects (Malcolm 1991).

The conservation value of matrix tolerance model is convincing for it provides a framework to study sensitivity of species to habitat fragmentation by studying their abundance in human modified habitats. It also helps to understand how different human modified habitats influence biodiversity in forest remnants. It would prove more useful if the model is broadened to incorporate life history traits important in determining species response to habitat loss and fragmentation.

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## APPENDIX 1

### Checklist of Butterfly Species encountered during the study period in Virajpet, Kodagu District

Sl. No.	Scientific name	Common Name
1	<i>Appias albina swinhoei</i>	Sahyadri Common Albatross
2	<i>Caleta decidia decidia</i>	Indian Angled Pierrot
3	<i>Athyma inara inara</i>	Himalayan Color Sergeant
4	<i>Rohana parisatis atacinus</i>	Sahyadri Black Prince
5	<i>Papilio polymnestor polymnestor</i>	Indian Blue Mormon
6	<i>Kallima horsfieldii</i>	Sahyadri Blue Oakleaf
7	<i>Badamia exclamationis</i>	Brown Awl
8	<i>Ampittia dioscorides dioscorides</i>	Indian Bush Hopper
9	<i>Mycalesis perseus tabitha</i>	Dakhan Common Bushbrown
10	<i>Ariadne sp.</i>	Castor sp.
11	<i>Iambrix salsala luteipalpis</i>	Southern Chestnut Bob
12	<i>Junonia iphita iphita</i>	Oriental Chocolate Pansy
13	<i>Parthenos sylvia virens</i>	Sahyadri Clipper
14	<i>Libythea myrrha carma</i>	Peninsular Indian Club Beak
15	<i>Graphium sarpedon teredon</i>	Dakhan Common Bluebottle
16	<i>Jamides celeno celeno</i>	Oriental Common Cerulean
17	<i>Acytolepis puspa feldri</i>	Malabar Common Hedge Blue
18	<i>Cheritra freja butleri</i>	Sahyadri Common Imperial
19	<i>Delias eucharis</i>	Indian Jezebel
20	<i>Pantoporia hordonia hordonia</i>	Oriental Common Lascor
21	<i>Prosotas nora ardates</i>	Indian Common Lineblue
22	<i>Papilio polites romulus</i>	Indian Common Mormon
23	<i>Castalius rosimon rosimon</i>	Oriental Common Pierrot
24	<i>Pachliopta aristolochiae aristolochiae</i>	Indian Common Rose
25	<i>Neptis hylas varmona</i>	Indian Common Sailor
26	<i>Sarangesa dasahara dasahara</i>	Indian Common Small Flat
27	<i>Pachliopta hector</i>	Crimson Rose
28	<i>Hypolimnas misippus</i>	Danaid Eggfly
29	<i>Jamides bochus bochus</i>	Indian Dark Cerulean
30	<i>Catopsilia pomona pomona</i>	Oriental Lemon Emigrant
31	<i>Euploea core core</i>	Indian Common Crow
32	<i>Eurema hecabe hecabe</i>	Oriental Common Grass Yellow
33	<i>Pseudocoladenia dan dan</i>	Sahyadri Fulvous Pied Flat
34	<i>Mycalesis junonia</i>	Malabar Glad-eye Bushbrown
35	<i>Parantica aglea aglea</i>	Coromandel Glassy Tiger
36	<i>Hypolimnas bolina jacintha</i>	Oriental Great Eggfly

37	<i>Hebomoia glaucippe australis</i>	Sahyadri Great Orange-tip
38	<i>Tanaecia lepidea miyana</i>	Peninsular Grey Count
39	<i>Junonia atlites atlites</i>	Oriental Grey Pansy
40	<i>Rapala varuna lazulina</i>	Lazuli Flash
41	<i>Junonia lemonias lemonias</i>	Chinese Lemon Pansy
42	<i>Cepora nadina remba</i>	Sahyadri Lesser Gull
43	<i>Papilio demoleus demoleus</i>	Northern Lime Butterfly
44	<i>Papilio buddha</i>	Malabar Banded Peacock
45	<i>Idea malabarica</i>	Malabar Tree-Nymph
46	<i>Melanitis leda leda</i>	Oriental Common Evening Brown
47	<i>Melanitis phedima varaha</i>	Sahyadri Dark Evening Brown
48	<i>Nacaduba sp.</i>	Six-Lineblue
49	<i>Oriens goloides</i>	Smaller Dartlet
50	<i>Prioneris sita</i>	Painted Sawtooth
51	<i>Pseudozizeeria maha ossa</i>	Dakhan Pale Grass Blue
52	<i>Papilio sp.</i>	Peacock
53	<i>Junonia almanac almanac</i>	Oriental Peacock Pansy
54	<i>Abisara bifasciata suffusa</i>	Suffused Double-banded Plum Judy
55	<i>Leptosia nina nina</i>	Oriental Psyche
56	<i>Aeromachus pygmaeus</i>	Pygmy Scrub Hopper
57	<i>Neopithecops zalmora dharmia</i>	Sri Lankan Common Quaker
58	<i>Papilio helenus daksha</i>	Sahyadri Red Helen
59	<i>Notocrypta curvifascia curvifascia</i>	Chinese Restricted Demon
60	<i>Cupha erymanthis maja</i>	Sahyadri Rustic
61	<i>Orsotriaena medus mandata</i>	Sahyadri Medus Brown
62	<i>Cirrochroa thais thais</i>	Sahyadri Yeoman
63	<i>Athyma sp.</i>	Sergeant
64	<i>Eurema brigitta rubella</i>	Red-line Small Grass Yellow
65	<i>Troides minos</i>	Sahyadri Birdwing
66	<i>Discophora lepida lepida</i>	Sahyadri Duffer
67	<i>Spialia galba</i>	Indian Grizzled Skipper
68	<i>Eurema laeta laeta</i>	Indian Spotless Grass Yellow
69	<i>Tagiades gana silvia</i>	Dakhan Suffused Snow Flat
70	<i>Graphium agamemnon menides</i>	Dakhan Tailed Jay
71	<i>Telicota bambusae bambusae</i>	Oriental Dark Palm-Dart
72	<i>Eurema blanda silhetana</i>	Sylhet Three-spot Grass Yellow
73	<i>Zizula hylax hylax</i>	Indian Tiny Grass Blue
74	<i>Tirumala limniace exoticus</i>	Oriental Blue Tiger
75	<i>Tirumala septentrionis dravidarum</i>	Dakhan Dark Blue Tiger
76	<i>Udara akasa mavisa</i>	Sahyadri White Hedge Blue
77	<i>Tagiades litigiosa litigiosa</i>	Sylhet Water Snow Flat

78	<i>Mycalesis anaxias anaxias</i>	Sahyadri White-bar Bushbrown
79	<i>Yasoda tripunctata tripunctata</i>	Sylhet Branded Yamfly
80	<i>Ixias pyrene sesia</i>	Dakhan Yellow Orange-tip
81	<i>Ypthima baldus madrasa</i>	Sahyadri Common Five-ring
82	<i>Ypthima huebneri</i>	Common Four-ring
83	<i>Phalanta phalantha phalantha</i>	Oriental Common Leopard
84	<i>Papilio clytia clytia</i>	Oriental Common Mime
85	<i>Elymnias hypermnestra undularis</i>	Wavy Common Palmfly
86	<i>Cepora nerissa phryne</i>	Dakhan Common Gull
87	<i>Charaxes athamas athamas</i>	Oriental Common Nawab
88	<i>Jamides alecto eurysaces</i>	Himalayan Metallic Cerulean
89	<i>Spindasis sp.</i>	Silverline
90	<i>Coladenia indrani indra</i>	Dakhan Tricolored Pied Flat
91	<i>Appias libythea</i>	Western Striped Albatross
92	<i>Graphium antiphates naira</i>	Sahyadri Five-bar Swordtail
93	<i>Graphium doson eleius</i>	Dakhan Common Jay
94	<i>Eurema andersonii ormistoni</i>	Sri Lankan One-spot Grass Yellow
95	<i>Acraea violae</i>	Tawny Coster
96	<i>Junonia hierta hierta</i>	Oriental Yellow Pansy
97	<i>Euploea sylvester coreta</i>	Double-branded Black Crow
98	<i>Lethe rohria neelgheriensis</i>	Dakhan Common Treebrown
99	<i>Psolos fuligo subfasciatus</i>	Indian Dusky Partwing
100	<i>Lampides boeticus</i>	Pea Blue
101	<i>Euchrysops cnejus cnejus</i>	Oriental Gram Blue
102	<i>Arnetta vindhiana</i>	Vindyan Bob
103	<i>Curetis thetis</i>	Indian Sunbeam
104	<i>Prosotas dubiosa indica</i>	Indian Tailless Lineblue
105	<i>Neptis jumbah nalanda</i>	Nalanda Chestnut-streaked Sailor
106	<i>Taractrocera ceramas nicevillei</i>	Complete Tawny-spotted Grass Dart
107	<i>Zipaetis saitis</i>	Banded Catseye
108	<i>Celaenorrhinus leucocera</i>	Common Spotted Flat
109	<i>Cyrestis thyodamas indica</i>	Indian Map Butterfly
110	<i>Tajuria cippus cippus</i>	Indian Peacock Royal
111	<i>Hasora taminatus taminatus</i>	Lankan White-banded Awl
112	<i>Danaus chrysippus chrysippus</i>	Oriental Plain Tiger
113	<i>Danaus genutia genutia</i>	Oriental Striped Tiger
114	<i>Talicauda nyseus nyseus</i>	Indian Red Pierrot
115	<i>Baracus hampsoni</i>	Malabar Hedge Hopper

## APPENDIX 2

**List of butterflies used for the analysis and their Fragmentation Vulnerability Index (FVI) values**

Sl. No.	Species	FVI
1	<i>Notocrypta curvifascia curvifascia</i>	0.00
2	<i>Caleta decidia decidia</i>	0.00
3	<i>Prosotas nora ardates</i>	0.00
4	<i>Jamides bochus bochus</i>	0.00
5	<i>Athyma inara inara</i>	0.00
6	<i>Rohana parisatis atacinus</i>	0.00
7	<i>Kallima horsfieldii</i>	0.00
8	<i>Tanaecia lepidea miyana</i>	0.00
9	<i>Idea malabarica</i>	0.00
10	<i>Melanitis phedima varaha</i>	0.00
11	<i>Athyma sp.</i>	0.00
12	<i>Discophora lepida lepida</i>	0.00
13	<i>Mycalesis anaxias anaxias</i>	0.00
14	<i>Prioneris sita</i>	0.00
15	<i>Abisara bifasciata suffusa</i>	0.00
16	<i>Parthenos sylvia virens</i>	0.19
17	<i>Graphium sarpedon tereon</i>	0.23
18	<i>Yasoda tripunctata tripunctata</i>	0.29
19	<i>Papilio helenus daksha</i>	0.38
20	<i>Junonia lemonias lemonias</i>	0.58
21	<i>Junonia iphita iphita</i>	0.84
22	<i>Neopithecops zalmora dharmia</i>	1.15
23	<i>Cupha erymanthis maja</i>	1.52
24	<i>Leptosia nina nina</i>	1.53
25	<i>Jamides celeno celeno</i>	1.68
26	<i>Ariadne sp.</i>	1.73
27	<i>Ampittia dioscorides dioscorides</i>	1.73
28	<i>Papilio polytes romulus</i>	1.73
29	<i>Hebomoia glaucippe australis</i>	1.73
30	<i>Papilio polymnestor polymnestor</i>	1.99
31	<i>Neptis hylas varmona</i>	2.69
32	<i>Tagiades gana silvia</i>	2.88
33	<i>Hypolimnas bolina jacintha</i>	2.88
34	<i>Mycalesis junonia</i>	3.13
35	<i>Iambrix salsala luteipalpis</i>	3.46
36	<i>Ixias pyrene sesia</i>	3.46
37	<i>Zizula hylax hylax</i>	9.87

### APPENDIX 3

#### Images of study sites



**Fig 4** Image taken from sacred grove (fragment) in Bettoli



**Fig 5** Sanctum sanctorum in the sacred grove of Kolathodu Bygodu



**Fig 6** Image taken from Reserve Forest in Perumbady



**Fig 7** Image taken from coffee plantation in Kuklur



**Fig 8** Image taken from paddy field in Bittangala

## APPENDIX 4

### Images for identification of butterfly species



**Fig 9** Upper side of male *Mycalesis perseus* with brand and tuft of hair (length, position & color of brands on upper hindwing and under forewing are important taxonomic characters for species level identification of individuals belonging to *Mycalesis* genus)



**Fig 10** Underside of male *Mycalesis perseus* (brand is visible at the lower margin of forewing)

## APPENDIX 5

**Table 3 Butterfly species observed in a mass congregation and number of individuals marked**

**Site: Moist deciduous forest, Thithimathi, Virajpet**

**Duration: 08-01-13 - 25-02-13**

<b>Species</b>	<b>Male</b>	<b>% of males</b>	<b>Female</b>	<b>% of females</b>	<b>Total</b>
<i>Danaus genutia</i>	249	65.87	129	34.12	378
<i>Euploea sylvester coreta</i>	28	44.44	35	55.55	63
<i>Tirumala septentrionis</i>	15	57.69231	11	42.30769	26
<i>Euploea core core</i>	4		1		5
<i>Tirumala limniace</i>	0		1		1