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Insect diversity in various distances to forest edge in small nature reserve: A case study of Bantarbolang Nature Reserve, Central Java, Indonesia

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Abstract. *Darsono, Riwidiharso E, Santoso S, Sudiana E, Yani E, Nasution EK, Aprilliana H, Chasanah T. 2020. Insect diversity in various distances to forest edge in small nature reserve: A case study of Bantarbolang Nature Reserve, Central Java, Indonesia. Biodiversitas 21: 4821-4828.* A nature reserve is a conservation area with the objective of conserving the biodiversity of the flora and fauna within its boundaries. However, many nature reserves are fragmented into small extent and isolated from natural habitat, causing the so-called edge effect. This research aimed to investigate insect diversity across various distances to forest edge in small and isolated protected areas. Research was conducted in the Bantarbolang Nature Reserve, Pemalang District, Central Java, Indonesia. A survey was conducted to determine the diversity of insects, especially those from the Diptera (flies), Lepidoptera (butterfly), and Hymenoptera (bees and wasp) orders. The environmental parameters recorded were temperature, humidity, and flowering plant diversity and abundance. Line transects were laid at a length of 100 m, parallel to the forest edge at three different distance ranges from the edge: 0-50 m, 50-100 m, and 100-150 m. Species diversity was measured using the Shannon-Wiener index, evenness index, and Sorensen similarity index. Over the 4-month study period, 1713 individual insects from 63 species and from the following three orders were found: Lepidoptera (Rhopalocera; 33 species, 5 families, 932 individuals); Hymenoptera (20 species, 423 individuals) and Diptera (10 species, 7 families, 376 individuals). The highest diversity was found at the edge of the forest and the lowest at the distance of 100-150 m from the forest edge. While the study area can support a diversity of insects, especially pollinating insects, but it is unable to support the conservation of light-sensitive butterflies. The results of this study suggest that small nature reserve can support a diversity of pollinating insects, especially from the Diptera, Lepidoptera, and Hymenoptera. However, it has limited conservation potential because of the significant impact of forest edges on species composition, especially on specialist butterfly species with habitat in forest interior.

Keywords: Diptera, forest edge, Hymenoptera, Lepidoptera, line transect, polyculture agriculture

INTRODUCTION

Based on the Act of the Republic of Indonesia No. 5 of 1990 concerning the conservation of biological natural resources and their ecosystems, a nature reserve is a protected ecosystem in its natural state containing unique plants and animals. The IUCN classification system states nature reserves as strictly protected areas to support the preservation of its species' populations and allow ecological processes to occur with as few obstacles as possible. The function of a nature reserve is to preserve biodiversity and life-supporting systems; therefore, conservation is the primary management objective.

However, while many nature reserves throughout the world have been set aside for the protection of particular species (Vina and Liu 2017), they are currently threatened by pressures from surrounding communities (Francoso et al. 2015). This condition also happens in Indonesia in which many protected nature reserves in the country have experienced many challenges, mainly due to limited resources for management and extensive utilization of resources by surrounding communities, leading to changes in land use and vegetation condition. Eventually, these changes in land use and type of land cover bordering the nature reserve lead to the fragmentation and isolation of existing forest plots. These forests are characterized by their small area, isolation from other forests, and high edge/core area ratio (Xu et al. 2017).

Forest edges are defined as the transition zone between open habitats and forests. There can be significant variability in their three-dimensional structure, such as width, shape, and tree stem density (Esseen et al. 2016). The quantity and quality of available habitats in the edges depend in part on forest structure (Dodonov et al. 2013). Edge size is an important factor in evaluating the environmental impacts within a forest fragment. Data from the relevant literature indicate that edges can range from 50 to 500 m, and that edge effects typically extend 150 m into a fragment (Roberts et al. 2017).

The impact of forest edges puts pressure on the role and function of nature reserves. According to Astiani et al. (2018), forest fragmentation due to changes in land use and vegetation cover causes temporary or permanent damage, and produces forest edges that affect the population and structure of vegetation as well as the composition of associated species. Increasing edge effects increases disturbed habitat types compared with stable habitats (De Fries et al. 2007). Forest edges cause physical and environmental changes that are different from those within the forest (Van Halder et al. 2011), as well as edaphic factors that result in changes in the structure and composition of supporting species (Bunyan et al. 2012; Deb et al. 2015; Welti et al. 2017). Negative impacts from edge effects include prevention of migration, decline in effective population sizes, loss of genetic variability, and invasion of exotic species (Sundarapandian and Karoor 2013; Bossart and Antwi 2016). Forest edges can be seen by altered plant species richness and community composition (Eldegard et al. 2015). Since the tree layer and its species composition have been shown to influence herb layer composition, changes in tree species composition or richness may weaken or strengthen edge effects in forest ecosystems (Erdos et al. 2019).

The changes in vegetation composition and richness in forest edge affect other biotic elements, including insects. Insects play an essential ecological role in forest ecosystems by ensuring the delivery of various ecosystem services, such as plant pollination (Adelusi et al. 2018). According to Perry et al. (2016) and Buchori et al. (2018), insects are ideal indicators of biodiversity since they are closely related to the environment and vegetation cover and are sensitive to habitat disturbances. The variety of flowering plants at forest edges is related to the diversity of pollinating insects, especially from the Hymenoptera (Apoidea) (Widhiono et al. 2017), and plays a vital role as a food resource for wild pollinating bees (Widhiono et al. 2017). According to Filgueiras et al. (2016), Pe′er et al. (2011), Widhiono (2015), Orlandin et al. (2019), and Koneri et al. (2020), the diversity and abundance of butterfly populations are related to the diversity and abundance of flowering plants. In addition, forest edges also influence the diversity of wild bees (Rands and Whitney 2011; Roberts et al. 2017).

Research has been conducted on the diversity of butterflies and other pollinator insects in relation to habitat quality. Subahar et al. (2010) examined the diversity of butterflies in Boscha Bandung. Widhiono (2015) evaluated the diversity of butterflies on Mount Slamet, Central Java. Harmonis and Saud (2017) conducted analyses in Central Kalimantan and Koneri et al. (2019) in the Talauds Islands of North Sulawesi. In general, the results showed that butterfly diversity is higher in habitats with moderate disturbance than in stable habitats. The relationship between the diversity of pollinating wild bees and habitat quality was also evaluated by Widhiono et al. (2017) on Mount Slamet, Central Java. Rands and Whitney (2011), Bayle et al. (2013), Widhiono et al. (2017), and Roberts et al. (2017) assessed the impact of forest edges on the diversity of pollinating wild bees and showed that forest edges significantly affect their diversity.

Various studies on insect diversity in conservation areas have been carried out such as Kyerematen et al. (2014) at Kogyae Strict Nature Reserve in Ghana (386 km^2), Adelusi et al. (2018) in Makurdi, Benue State, Nigeria (34.5 km^2), Chung et al. (2019) in Sg. The Rawog Conservation Area in Segaliud Lokan Forest Reserve, Sabah, Malaysia (57474 ha). The results of the study showed that insect diversity is higher in the conservation areas compared to the non-conservation areas. Other studies specializing in butterfly diversity, such as those conducted by Basavarajappa et al. (2018) in Karnataka, India (643.99 km^2), Orimaye et al. (2016) in Ise Forest Reserve, Ise Ekiti, Ekiti State, Nigeria, and Harisha et al. (2019) at Shettihalli Wildlife Sanctuary, Shivamogga District, Karnataka, India (777 km^2), show that butterfly diversity is very high in conservation areas compared to non-conservation areas. While those studies were conducted on large nature reserves (more than a thousand hectare), limited analyses were focused on small reserves (less than a hundred hectare). As such, it is essential to do similar analysis but in the context of small nature reserve.

The Bantarbolang Nature Reserve is one of several nature reserves in Central Java, Indonesia, located in Kebon Gede village, Bantarbolang Sub-district, Pemalang District. It has an area of 24.7 ha, and its primary purpose is for the conservation of teak tree (*Tectona grandis*). When the reserve was initially established, it was in the middle of teak forest, but it is now directly adjacent to residential areas, rice fields, roads, and agricultural fields. As such, this nature reserve provides an excellent case study to investigate the impacts of habitat fragmentation and isolation on insect diversity in small and isolated protected areas. The results of this study can fill the gap on the knowledge of the factors that influence the diversity in fragmented habitats and the effects on native populations so that it can help to establish the appropriate strategies and control mechanisms for the management of these areas.

MATERIALS AND METHODS

Study area and period

Research was conducted at Bantarbolang Nature Reserve (7º11′53″.8 S and 109º39′56″.33 E) in Pemalang District, Central Java, Indonesia from April to August 2019. The reserve has an area of 25.6 ha with a length of 707.73 m and a width of 361.9 m. Bantarbolang nature reserve has borders with the newly logged (2017) teak forest in the north and east, in the west bordering residential zones and rice fields, and the southern part bordering on dryland agricultural areas (Figure 1).

Sampling method

Sampling was conducted on the north, south, east, and west sides of the forest. On each side of the forest, three plots were set at distance ranges of 0-50 m, 50-100 m, and 100-150 m (Figure 1). For each field, ten transect lines were made with length of 100 m and width of 5 m starting from the edge of the forest into the forest interior. In total, there were 30 transect lines. The diversity and abundance of flowering plants were recorded in a 5 × 5 m quadrat, with total of ten quadrats in each plot and laid randomly from edge forest into the forest interior.

Figure 1. Study site at Bantarbolang Nature Reserve in Pemalang, Central Java, Indonesia

Environmental parameters, such as air temperature, humidity, light intensity, and flowering plant diversity, were measured at each distance from the forest edge (0 m, 50 m, 100 m, and 150 m). Air temperature, humidity, and light intensity were measured three times per day, namely in the morning (8.00 am), noon (12.00 pm), and afternoon (3.00 pm).

Collection of Lepidoptera (butterfly)

Field survey of butterflies was conducted using the modified Pollard Walk method using kite netting at the three distinct distance ranges from the forest edge. Butterflies were captured on sunny days at a constant speed on each transect from 8 a.m. to 12 a.m. local time for 4 consecutive days. This process was repeated at 2-weeks intervals, maintaining the same spatial scale in each sampling site. For butterfly identification, the book by Schulze (2009) was used. Collected specimens are now housed at the Entomology Laboratory at Jenderal Soedirman University, Purwokerto, Banyumas, Central Java, Indonesia.

Collection of Hymenoptera (bees and wasp)

Hymenoptera (wild bees and wasps) were recorded in the morning between 6:00 a.m. and 12:00 p.m. in a standardized manner along the transects. Sampling was conducted twice a month (with a total sampling of six times per transect) by using sweep-netting in the herbaceous layers. Where possible, all observed bees were captured. For identification, the book by Mead (2013) was used. Collected specimens are now housed at the Entomology Laboratory, Jenderal Soedirman University, Purwokerto, Banyumas, Central Java, Indonesia.

Collection Diptera (flies)

Flies were sampled in the morning between 6:00 a.m. and 12:00 p.m. in a standardized manner along the transects. Sampling was conducted twice a month (with a total sampling of six times per transect) by sweeping-netting in the herbaceous layers. Where possible, all observed flies were captured. For identification, the book by Sarwar (2020) was used. Collected specimens are now housed at the Entomology Laboratory, Jenderal Soedirman University, Purwokerto, Indonesia.

Collection of wild plants

Following each insect survey, wild plant species and densities in each subplot were recorded. Samples of the wild plants were stored for identification in the Plant Taxonomy Laboratory, Faculty of Biology, Jenderal Soedirman University, Purwokerto, Banyumas, Central Java, Indonesia. Wild plant species were identified with the help of a plant taxonomy expert.

Data analysis

The Shannon-Wiener diversity index was used to estimate the diversity of butterfly, bees, and wasp, and flies in each habitat. This index was calculated using the equation:

$$H' = \sum_{i=1}^{s} pi \ln pi$$

Where; *pi* is the proportion of individuals found in the *i*th species, and 'ln' denotes the natural logarithm. Evenness (E) was calculated using the equation:

$$E = \frac{H'}{\ln S}$$

Species dominance across habitats was estimated using Simpson's dominance index to determine the proportion of more common species in a community or area using the following formula:

$$D = \sum (pi)^2 = \sum (\frac{ni}{N})^2$$

Comparisons of insect species composition among the various distance range from the forest edge were estimated using single linkage cluster analysis based on Bray-Curtis similarity. Biodiversity Pro version 2 (McAleece et al. 1997) was used for data analysis. Statistical analysis (ANOVA) was done to compare the difference between distances from forest edge using SPSS 23.0 software.

RESULTS AND DISCUSSION

The results revealed 1713 individual insects from 63 species within three orders: Lepidoptera (Rhopalocera; 33 species, 5 families, 932 individuals), Hymenoptera (20 species, 423 individuals), and Diptera (10 species, 7 families, 376 individuals). The greatest number of species and individuals were found at a distance of 0-50 m from the edge of the forest (55 species, 597 individuals), followed by 50-100 m (53 species, 409 individuals) and 100-150 m (36 species, 595 individuals) (Table 1).

The results indicated that the difference in insect diversity at various distances from the forest edge is caused by differences in the number and species of flowering plants. Measurements of environmental parameters showed that there were significant differences in the number of flowering plants according to the distance from the edge of the forest, especially between 0-50 m or 50-100 m and 100-150 m ($F_{12,72}$ p <0.0178). Some or all of the insect species found were related to flowering plants. This is consistent with the conclusion of Filgueiras et al. (2016) that plant diversity is related to insect diversity, especially at a local scale, and reinforced by the findings of Kemp and Ellis (2017) and Welti et al. (2017) that the diversity of herbivore insect spread is limited by the diversity of flowering plants. According to Widhiono et al. (2017), the number of flowering plants greatly influences the diversity of pollinating insects because it is the main source of food for wild bees. Subahar (2010), Widhiono (2015), and Koneri et al. (2019) found a higher diversity of butterfly species in open land because of the greater diversity of flowering plants. However, in terms of conservation values, especially for insects with a high conservation value - namely rare insect species (or open-endemics) - open areas are not very supportive of butterfly diversity (Widhiono, 2015).

Based on the diversity index, the highest diversity was observed at 0-50 m from the forest edge and the lowest was at 100-150 m (Table 2). However, the highest dominance index was observed at 100-150 m from the edge of the forest, indicating that more dominant insect species were found in interior forest habitats.

Cluster analysis based on the Bray-Curtis single linkage similarity value showed the percent similarity between species composition across three distance from forest edge. Distance of 0-50 m showed linkage of 49.59% with 50-100 m, and represents the lowest similarity with 100-150 m. Distance of 50-100 m was linked at 53.30% similarity to the distance 100-150 m (Figure 2) . This result indicates that distance from forest edges resulting different diversity of insects.

Species diversity within an order changes with the distance from the forest edge, and this was reflected in the order Lepidoptera (Rhopalocera) (butterflies) (Figure 3). At the distance of 0-50 m from the forest edge, species composition was dominated by flower visitors, namely within the families of Pieridae and Nymphalidae, whereas at the distance of 100-150 m, species composition was dominated by species within the families of Satyridae and Amathusidae. This is likely because both families tend to prefer habitats that are protected from sunlight (Vu et al. 2015). Species in the Satyridae and Amathusidae, including the Morphinae and Satyrinae, exclusively feed on monocotyledonous plants, which are restricted to lower forest layers in Southeast Asian rainforests (Harsh et al. 2015). Vu et al. (2015) found that fruit-feeding Satyrinae and Morphinae, with relatively uniform phenotypes that feed on a comparatively small set of larval food plants, are restricted mostly to lower vegetation layers, and many are sensitive to changes in humidity. We also found that four species of satyrid were restricted to forest habitats, including *Ragadia makuta*, *Ypthima nigricans*, *Mycalesis moori*, *Melanitis leda*, and one species from Amathusidae *(Faunis canens canens)*. The former group primarily feeds on a small set of larval food plants, such as *R. makuta*, which depend only on Selaginella, occur only in closed forests, and are highly sensitive to humidity (Vu et al. 2015). The latter group depends exclusively on grasses as food plants, which tend to be abundant in all habitats, especially open areas.

Table 1. Species composition and abundance of insects at various ranges of distance from the forest edge

Order	Family	Species	0 - 50 m	50 - 100 m	100 - 150 m
Hymenoptera	Vespidae	*Delta campaniforme*	1	9	12
		Ropalidia romandi	12	8	13
		Ropalidia fasciata	7	9	14
		Ropalidia stigma	9	7	14
		Polistes aurifer	6	8	10
		Polistes dorsalis	3	3	4
		Vespa tropica	2	4	6
	Scoliidae	*Vespula* sp.	3	4	5
		Campsomeris plumipes	15	5	2
	Apidae	*Apis cerana*	10	23	31
		Tetragonula laeviceps	13	23	44
		Xylocopa confusa	10	0	10
		Xylocopa latipes	6	0	6
		Amegilla zonata	3	9	0
		Ceratina negrolateralis	6	10	9
		Ceratina cognata	2	2	0
	Halictidae	*Nomia strigata*	4	8	2
		Nomia melanderi	0	4	5
		Nomia thorarica	3	5	0
		Augochlora pura	7	6	2
Diptera	Syrpidae	*Episyrphus balteatus*	14	10	30
		Syrphus rostata	9	4	13
	Sarcophagidae	*Sarcophaga carnaria*	35	8	43
	Calliphoridae	*Lucilia* sp.	14	8	22
	Dolichopodidae	*Psilopus bituberculatus*	8	0	8
	Lonchaeidae	*Lonchaea* sp.	4	4	8
	Empididae	*Empis livida*	1	0	1
	Muscidae	*Musca* sp.	17	18	0
Lepidoptera	Papilionidae	*Graphomya maculata*	3	0	3
		Phaonia rufiventris	0	24	24
		Papilio polytes javanus	8	4	3
		Losaria coon	8	4	6
		Atrophaneura priapus	4	3	8
		Graphium sarpedon	20	7	28
		Graphium agamemnon	12	5	0
	Pieridae	*Gandaca harina*	49	2	0
		Eurema andersoni	29	2	0
		Eurema blanda	18	0	0
		Eurema hecabe	15	0	0
		Catopsiliia pyrante	17	0	0
		Catopsillia pomona	17	0	0
		Leptosia nina	21	8	0
		Delias pasithoe	10	1	0
		Prioneris autothisbe	8	0	0
	Satyridae	*Ypthima nigricans*	0	17	45
		Mycalesis moori	0	10	36
		Ragadia makuta	0	20	52
	Amathusidae	*Melanitis leda*	0	16	49
		Faunis canens canens	0	7	23
		Elymnias hypermnestra	0	4	4
	Nymphalidae	*Junonia hedonia*	10	9	0
		Junonia atlites	14	5	0
		Junonia almana	11	7	0
		Junonia ipthima	9	3	0
		Hypolimnas bolina	13	6	0
		Hipolymnas misippus	10	2	0
		Euploea climena	7	8	0
		Euploea tulliolus	8	5	0
		Euploea mulciber	9	5	0
		Neptis hylas	9	9	0
		Neptis nisaea	10	4	0
		Tanaecia trigerta	12	7	0
		Euthalia monina	12	6	0

Table 2. Diversity parameters of insects at three different distances from the forest edge

Parameter	0 - 50 m	50 - 100 m	100 - 150 m
Number of species	55	53	36
Number of individuals	597	409	595
Dominance_D	0.02877	0.02838	0.05088
Shannon_H	3.767	3.756	3.197
Evenness_E	0.7867	0.8072	0.6792

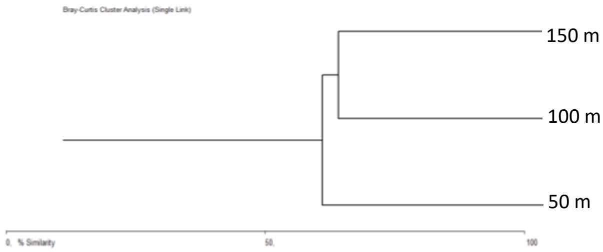

Figure 2. Similarities among the distance range from the forest edge

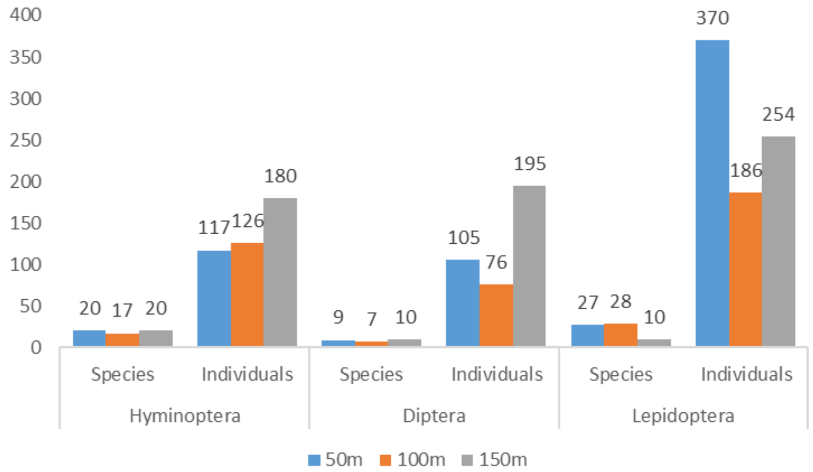

Figure 3. Species richness and abundance of three insect orders at various distances from the forest edge

The distribution pattern of species richness across the three distance ranges from the forest edge within the Diptera order differed with that of the Lepidoptera. The composition of species in the Diptera did not show any significant difference ($F=_{12,72\ p=\ 0,972}$) across distances. This is probably due to the feeding behavior and type of food source needed, such as the *Sarcophaga carnaria* (Sarcophaga) which is a carcass feeder (Dao et al. 2017) and *Episyrphus balteatus* (Syrpidae) which is aphidopagous, or aphid eating; thus, its abundance depends on the presence of aphids in plants (Odermatt et al. 2017).

The species richness of the Hymenoptera order differed significantly ($F_{=12,72\ p\ =\ 0,0495}$) across the distance ranges from the edge of the forest. The number of individuals was higher at the distance of 100-150 m from the edge of the forest, indicating that members of the Hymenoptera order tend to prefer forest habitats. Except for pollinator species, this result corroborates the findings of Schuepp et al. (2012) that wasp species richness is directly related to tree frequency. Bee pollinating species are more commonly found in habitats that have a greater diversity of flowering plants (Schuepp et al. 2012; Andrieu et al. 2018), but the habitat surrounding this nature reserve is agricultural. The results of this study are in line with the findings of Rubene et al. (2014), Ferreira et al. (2015) and Withaningsih et al. (2018), who found that the diversity of wild bee pollinators in isolated habitats is influenced not only by the condition of the forest where they are found, but also by the surrounding habitat.

The results of this study suggest that small nature reserves, in general, can support a diversity of pollinating insects, especially from the Diptera, Lepidoptera, and Hymenoptera. However, small reserves have limited conservation potential because of the significant impact of forest edges on species composition, especially that of butterfly species in forest habitats. We conclude that the Bantarbolang Nature Reserve can support a diversity of insects, especially pollinating insects, but is unable to support the conservation of light-sensitive butterflies.

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