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Measuring forest fragmentation in the protected area system of a rapidly developing Southeast Asian tropical region

Mohammad Imam Hasan Reza

Abstract

Forest fragmentation has become a global concern for conservation of important habitats as well as biodiversity. Protected areas that have been a cornerstone for safeguarding biological diversity are also facing enormous stress due to the increasing anthropogenic activities. This study estimates the degree of spatial fragmentation in the protected area system and landscape fragmentation in the State of Selangor, peninsular Malaysia using modern geo-spatial technology. Landsat TM 30 m satellite images of 1988 and 1996 and Landsat ETM+ 30 m satellite image of 2005 were used as base maps in this study. Results show forest fragmentation index (FI) in the entire extent of the state of Selangor was changed at a moderate rate from the year 1988 (34.33) to 1996 (36.33); however, it increased dramatically in 2005 and reached 41.58. Among nine of the protected areas in the study area, Fraser's Hill wildlife protected area shows a relatively unchanged FI, which was lower than 1. Bukit Kutu wildlife protected area was relatively less fragmented in 1988 and 1996 (FI lower than 1.5), but became highly fragmented in 2005 (20.04). However, the other five protected areas have been fragmented at a great degree in all three experimented years and increased with the changes of time. These findings indicate how protected areas have been fragmenting inside their legislative boundaries. Thus, it is important to take necessary initiatives in order to improve the representativeness of ecosystems in the protected area system and to safeguard biodiversity in this mega diverse ecoregion.

Keywords: forest fragmentation index, protected area system, biodiversity, conservation planning, geo-spatial technology, remote sensing, GIS

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Introduction

Landscape spatial pattern in the protected area system has become a central topic in conservation planning. Spatial patterning of landscape elements is functionally linked to ecological processes occurring in a landscape [1–3]. Knowledge of the aspects of the landscape structures that determine the distribution and persistence of plant and animal populations is needed for conservation planning [4–7]. Habitat fragmentation is one of the important conservation issues discussed in the last few decades [8]. This is because habitat fragmentation has caused isolation of habitat, which accelerates the adverse effects on ecosystem patterns and processes [9–11]. Concurrently, it also leads to the different kinds of damages to the ecosystems or ecoregion and results in decreasing ecological integrity of those systems through landscape disintegration, species loss, and deterioration of habitat quality [12–15].

The basic definition of fragmentation refers to the structural changes of the landscapes (the breaking up of habitat patches), which affects the functional attributes and ecological integrity [16–18]. This has caused the disappearance of forested areas as well as biodiversity in many regions of the world, particularly in the tropical regions [19, 20]. Since 1970, a great deal of attention has been given to tropical forest fragmentation where around 50% of the forests disappeared and mostly due to agricultural expansion [21, 22]. Although, the latest report suggests that the rates of forest loss have been reduced, but the forest loss rates in Southeast Asian countries are still more than 1% per year [23]. Therefore, studies on forest fragmentation is important for conservation planning to protect the ecological integrity of these remnant forest patches from an ongoing degree of destruction [24].

Agriculture expansion is one of the proximate causes for destruction of forests in Malaysia, both in the lowland area and in the highlands [25, 26]. Along with changes in human land use, this agricultural expansion severely fragments the forest in the state of Selangor, particularly wetland forest of peat-swamp and mangrove. This process opens up the forest for further destructions, as well as creating easier access for illegal hunters and poachers [27]. Fragmentation associated with forest conversion also impedes the movement of animals between habitat patches, resulting in reduced home ranges and population viability [28, 29]. As a result, many wildlife species like rhino, orangutan, tiger, and the elephant have become threatened and nearly extinct in this region [30]. It is also reported that, fragmentation created their population small and isolated which makes them vulnerable to disturbance and a subsequent loss of genetic diversity have been occurred as aftermath of these processes [31].

Previous studies on spatial processes revealed that anthropogenic activities are the major underlying factors for the destruction of natural landscapes in the tropics [32–34], and similarly for Malaysian forests as well [25, 26]. However, effect of such dominant spatial process on the species persistence and ecological integrity of protected areas in the State of Selangor have not yet been done. Moreover, an index of ecological integrity to measure the terrestrial and aquatic ecosystems in this region is a need for regional sustainable management planning

[18]. To develop such an index, forest fragmentation indices are an important criterion. Furthermore, use of remote sensing and GIS technologies, though widely used worldwide, are not significantly reported for this kind of study in this region.

Therefore, this study intends to analyze the spatial and temporal extent of forest fragmentation using modern geospatial technology, which is later applied through landscape metrics for developing a forest fragmentation index in the State of Selangor. It investigated forest fragmentation patterns of protected areas in the study region. Therefore, this paper studied and examined three fragmentation indices in order to measure the forest fragmentation. The objective of the study is to identify potential areas of the protected areas of the State of Selangor, which require a great deal of concentration for improving their representativeness of ecosystems for sustainable natural areas management.

Materials and Methods

Study area

The State of Selangor (latitude 2° 35'–3° 60' N and longitude 100° 45'–102° 00' E) is a highly developed and populated State in Malaysia (Figure 1), with an area of approximately 800,000 ha. Selangor's climate typically consists of warm, sunny days and cool nights all year with occasional rain. Temperatures range from 23 to 30°C, the humidity usually exceeds 80%, and mean annual rainfall is around 2,670 mm. Selangor has a rich array of ecosystems, both terrestrial and aquatic, and is also rich in geological, mountainous, coastal, wetlands, and vegetation diversity. The country's capital, Kuala Lumpur, and the federal administrative capital, Putrajaya, are federal territories that are situated within this state. Thus, we considered the two federal territories to be part of the study area. We also included all seven wildlife protected areas in the State of Selangor and two wildlife protected areas in Kuala Lumpur (See Table S1 for supporting information). Selangor's geographical position in the central west coast of Peninsular Malaysia has contributed to the State's rapid development as Malaysia's transportation and industrial hub. Selangor has a population of approximately 5.46 million [35]. In addition to industry, commercial agriculture is a thriving sector of Selangor's economy, and a major part of the land use classification are included in this sector. Moreover, the State is also home to the largest port in the country.

Data set

Three land use maps of the year 1988, 1996, and 2005 were used in this study. These maps were developed from Landsat TM 30 m resolution satellite images (of 1996 and 1988) and Landsat ETM+ 30 m images (of 2005) through supervised classification method using Erdas Imagine 9.2. After getting land use raster maps, they were converted to vector maps using ArcGIS 9.3. Among the seven land use/land cover classes—namely built up area, cleared land, commercial agriculture, forest, mangrove, paddy and other agriculture, water body (derived from a land use map developed in other study, manuscript in preparation), *forest* and *mangrove* were considered as forested and other land use classes as human-use categories. Analyses were carried out for the total extent of the study area and also all the protected areas individually. As a result, it can be defined how the forested areas become fragmented over the past few years and at the same time what changes have occurred inside the protected areas. Forest fragmentation of three different times representing three consecutive decades have been studied.

Data analysis

Land use vector maps of the State of Selangor of 1988, 1996, and 2005 were used for this analysis. The year 1988 was the reference year to evaluate the changes. The vector data maps of the above mentioned years were used for the forest fragmentation analysis. V-LATE (Vector-based Landscape Analysis Tools Extension, http://www.geo.sbg.ac.at/larg/vlate.htm) [36] and Patch Analyst 4 [37] were used for the analysis. Both the software applications are ArcGIS extension tools.

Calculation of Forest Fragmentation Index (FI)

There are many landscape structural metrics that have been used for quantifying forest fragmentation in many different aspects over the past few decades [1, 38–41]. However, a single index combining multiple metrics representing the key components of fragmentation is necessary to compare different areas of interest [42]. Such an index is also useful to compare a particular area over a longer time span for sustainable management and conservation planning. Choice of appropriate components of fragmentation and their metric is closely related with the scale and objectives of the study [43]. This study is particularly designed for the regional scale and the objective is to measure the fragmentation index in the forested areas.

Many commonly used fragmentation metrics such as number of patch, patch size, shape metrics, and nearest neighbor metrics were not considered in this study since they are suitable for site scale. Moreover, the pixel size of these data sets (30 m) is not suitable for selecting the metrics for this study. In many cases,

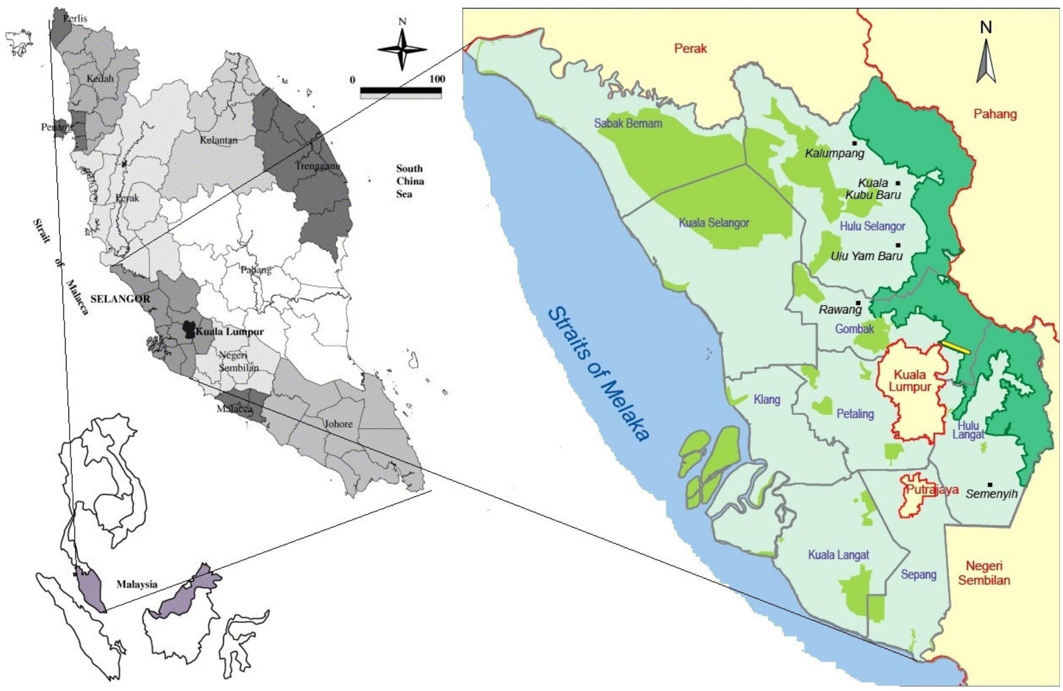

Figure 1: Geographical location of the State of Selangor, peninsular Malaysia

these metrics show incorrect or redundant results in the regional scale [43, 44]. Many studies show that landscape patterns can be characterized by relatively few components; however, they may differ and behave inconsistent to specific landscapes [45, 46]. Moreover, to efficiently combined different metrics in a single index, all metrics must have a similarity in their behavior and relationship with the degree of fragmentation. That means they must be positively correlated with the fragmentation process.

Therefore, the components that have been chosen for this study are based on the combination of three landscape metrics developed by Abdullah and Nakagoshi [25]. The components that have chosen are as follows:

i) proportion of non-forest cover (pnf),
ii) percentage edge (edg); and
iii) patch size coefficient of variation (pscov).

The proportion of non-forest cover (pnf) represents the land uses other than forests in the region and is an important indicator of the degree of anthropogenic activities in the region. It represents the relative amount of each analysis unit that was classified as non-forest land use. Every pixel of the land use/land cover map was reclassified as either forest or non-forest. It was calculated as the total area of non-forest pixels divided by the total area of each analysis unit and multiplied by 100.

The edge (edg) represents the length of the relative amount of the forest area bordered on at least one side by the human land use in a given landscape. Each forested pixel on the land use maps was classified as (human land use) edge or interior. That means the peripheral region of the forested patch that bordered with human land use is considered as an edge; otherwise, is considered as forest interior. The percentage of edge was calculated as the total length of forested patch bordered by the human land use in each analysis unit divided by the total edge and multiplied by 100.

The patch size coefficient of variation (pscov) represents the patch size variability of natural forest. It can be calculated from the patch size standard deviation (pssd) divided by the mean patch size (mps) and multiplied by 100. Thus, this metric is able to represent patch number and size simultaneously [41]. Here, pscov is calculated as the pscov of forested area of each analysis unit divided by the total pscov of the entire analysis unit multiplied by 100.

After calculating all three metrics for each of the analysis units, the values of each metric were then calculated for the combined forest fragmentation index (FI). In this combined index, all the three metrics were given an equal weight.

$$\text{Forest Fragmentation Index (FI)} = (pnf + edg + pscov/3) \quad (1)$$

Results and Discussion

Deforestation and fragmentation of natural ecosystems are major concerns for the loss of biodiversity and environmental change globally, particularly in the tropics [47, 48]. Within the tropical region, Southeast Asian tropics have been experiencing deforestation at a rate more than double than those of others [49]. Under such circumstance, degree of destruction in the remnant forests of Southeast Asian tropics are needed to be measured for biodiversity conservation and sustainable management of natural resources [50]. In this study, we applied methods of Butler et al. [44] and Abdullah and Nakagoshi [25] to measure forest fragmentation. However, they used a more coarse resolution map and coarse grids to estimate forest fragmentation. In this study, 30 m resolution satellite images were used to develop land cover base maps which were vectorised from the raster land use maps. Moreover, the grids are similar to the 30m quadrate frame which provided much accuracy than the previous works. Therefore, this study based on the original data and presents a new forest fragmentation index, integrating three landscape structure components, which could be used for monitoring fragmentation along space and time. However, it is important to consider that landscape metrics are highly scale dependent, therefore, the choice of appropriate observational scales and the quantitative interpritations should have rationale of choice [1, 41]. It will therefore essential to be careful enough in selecting observational scales in order to experiment this index in the diverse area. Presently, suitable and multiple options for remotely sensed data are available and thus it is easy in this modern time to calibrate the scale according to the case.

Results revealed that, forest fragmentation has changed significantly from the initial year (1988) considered in this study. Forest fragmentation (FI) changed at a moderate degree from the year 1988 (34.33) to 1996 (36.33); however, it increased dramatically in 2005 and reached 41.58 (Figure 2). Furthermore, forest fragmentations show great variation in the protected areas (Figure 3). Among nine of the protected areas, Fraser's Hill wildlife protected area showed a relatively unchanged FI, which was lower than 1. Bukit Kutu wildlife protected area was relatively less fragmented in 1988 and 1996 (FI lower than 1.5), but became fragmented in 2005 (20.04). A rapid change of forest land use patterns in the study area indicated the degree of human interference over the study period. It is clear from the analyses that the development activities are the main driver for fragmenting natural forest patches. Increase in FI over the study period indicate the degree of anthropogenic disturbances on the natural landscapes; eventually, forests became reduced. These rapid changes in shifting natural landscapes to anthropogenic settlements also reported in some studies on this study area [26]. In particular, increasing population, expanding urban and housing areas, and townships are the possible drivers of such changes (see also [25]). Results from this analysis have a similarity in the years (1988 and 1966) with the previous study [25]; however, the pace of forest fragmentation identified in 2005 breaks the record and projections derived from the findings of previous decades.

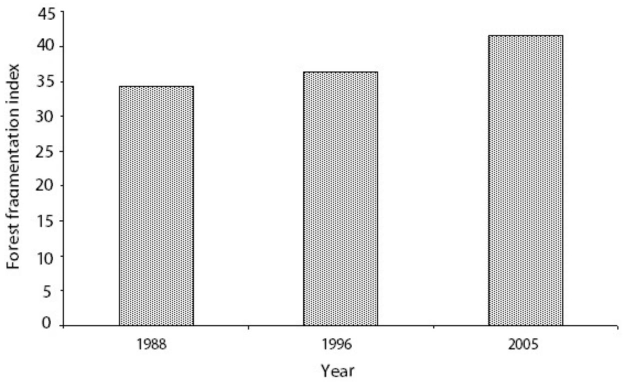

Figure 2: Forest fragmentation index in the year 1988, 1996 and 2005

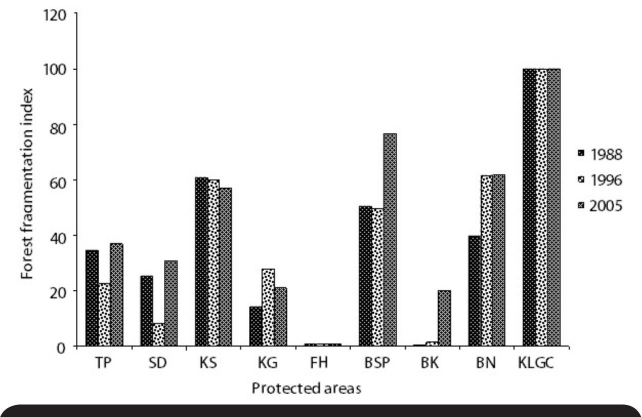

Figure 3: Forest fragmentation indexes of protected areas in the state of Selangor, peninsular Malaysia showing changes in three decades

TP = Templer Park, SD = Sungai Dusun, KS = Kuala Selangor, KG = Klang Gate, FH = Fraser's Hill, BSP = Bukit Sungai Puteh, BK = Bukit Kutu, BN = Bukit Nenas, KLGC = KL Golf Course wildlife protected area

Table 1:
Values of forest fragmentation indices in different years shown in a) 1988; b) 1996; and c) 2005

a) 1988

Protected areas	nfa	edg	pscov	FI
Templer Park	25.62	55.39	22.86	34.62
Sungai Dusun	2.12	26.07	47.94	25.38
Kuala Selangor	88.42	80.58	13.51	60.84
Klang Gate	12.69	30.12	0	14.27
Fraser's Hill	0.09	4.53	0	1.54
Bukit S Puteh	50.76	72.43	28.25	50.48
Bukit Kutu	0.02	1.88	0	0.63
Bukit Nenas	35.29	33.71	50.43	39.81
KL Golf Course	100	100	100	100

b) 1996

Protected areas	nfa	edg	pscov	FI
Templer Park	25.19	29.93	12.43	22.52
Sungai Dusun	1.71	22.86	0	8.19
Kuala Selangor	83.61	71.51	24.92	60.01
Klang Gate	17.58	49.56	16.37	27.84
Fraser's Hill	0.07	2.5	0	0.86
Bukit S Puteh	67.23	81.56	0	49.60
Bukit Kutu	0.2	4.32	0	1.51
Bukit Nenas	52.94	62.34	69.23	61.5
KL Golf Course	100	100	100	100

c) 2005

Protected areas	nfa	edg	pscov	FI
Templer Park	21.45	53.08	36.36	36.96
Sungai Dusun	4.78	40.86	46.87	30.84
Kuala Selangor	79.94	74.48	16.17	56.86
Klang Gate	9.94	38.84	14.21	21
Fraser's Hill	0.13	2.63	0	0.92
Bukit S Puteh	94.26	84.8	50.91	76.66
Bukit Kutu	4.38	33.68	22.06	20.04
Bukit Nenas	52.94	59.34	73.1	61.79
KL Golf Course	100	100	100	100

Table 1 shows the values of different fragmentation indices and the FI values of 1988 (Table 1a), 1996 (Table 1b), and 2005 (Table 1c). Significant variations of forest fragmentation have been observed in different protected areas over the study periods. Generally, forest fragmentation was not severe between 1988 and 1996. Exceptions were for Bukit Nenas and Bukit Kutu protected areas, where significant changes have occurred in those years. In many cases, it seems that the protected areas overcame some damages in 1996 that had happened in 1988. In 2005, the results show that protected areas experienced a great deal of forest fragmentation (with the exception of Sungai Dusun wildlife protected area, which shows recovering features from an earlier trend of fragmentation in 2005). Moreover, Fraser's Hill remains unchanged despite such ongoing degree of forest fragmentation.

Almost all of the protected areas in the study region have been suffering from tremendous anthropogenic pressure. Similar changes in human land use, both inside and outside the protected areas, also reported by DeFries et al. [51] in the Southeast Asian tropics. Many other studies illustrate similar problems faced by protected areas throughout the Southeast Asian tropics [52].

Generally, FI is enough to represent the fragmentation feature and the degree of human intervention inside the protected areas. It revealed from the analysis that many of the protected areas become highly fragmented with the changes of time. A considerable proportion within the wildlife protected area boundaries of the Templer Park, Sungai Dusun, Klang Gate, Bukit Nenas, and KL Golf Course were found to be fragmented (Figure 3). Moreover, FI of Kuala Selangor, Bukit Sungai Puteh, and Bukit Nenas wildlife protected areas scored more than 50 in the year 2005. The figure was lower than that in the previous year for the protected areas Bukit Sungai Puteh and Bukit Nenas. In case of Bukit Sungai Puteh, FI recorded 76.7 in 2005, which was less than 50 in 1996.

The temporal pattern of the forest fragmentation index in the state of Selangor as well as in each protected area indicates that the intensity of human disturbance is critical. Shifting in human land use in recent years has caused more destruction than that of the previous time. Moreover, this change in land use created more pressure on the protected areas and the pressure extended to the high-land areas as well. Forest fragmentation in 2005 in Bukit Kutu (1,000 m.a.s.l.) and Templer Park (400–500 m.a.s.l.) wildlife protected areas are clear evidences in this regard (see Figure 3). Therefore, fragmentation and associated destruction of forested lands in the protected areas have increased significantly.

Surprisingly, IUCN categories for the protected areas did not create any significant safeguards to protect these natural areas from human intervention and associated destruction like fragmentation. Sungai Dusun, Klang Gate, and Bukit Sungai Puteh wildlife protected areas are designated under the IUCN categories Ib, II, and III respectively, but they have experienced a high degree of fragmentation. This may be due to the lack of understanding and awareness of the conservation importance of these categories.

Protected areas situated in high-land areas, for example Fraser's Hill and Bukit Kutu, are experiencing less fragmentation, particularly in the duration between 1988 and 1996. However, this trend has changed due to modern technology and development activities expanded in the high-land areas in the latest time [44]. Therefore, in 2005, it is seen that the forested areas in Bukit Kutu wildlife protected area, which is situated above 1,000 m.a.s.l., has experienced fragmentation within its legislative boundary.

It is also reported that the protected areas situated within the highly developed Kuala Lumpur and Selangor conurbation face more anthropogenic pressures and thus found greater FI, for example, Bukit Nenas, KL Golf Course, and Bukit Sungai Puteh (Table 1c). At the same time, protected areas situated in relatively low-land and flat areas are easily accessible to people and thus experience more fragmentation (also refer to [25, 44]). For example, Sungai Dusun, KL Golf Course, Bukit Nenas, Bukit Sungai Puteh, and Kuala Selangor have been experiencing high degree of fragmentation and anthropogenic pressure.

It can be anticipated that this composite forest fragmentation index might be a suitable tool to describe the destruction and vulnerabilities of the forest ecosystem in the region like this [25, 26, 44], moreover, it can be an effective indicator to determine the level of anthropogenic pressure received by these natural ecosystems at a particular time. Therefore, this index may facilitate biodiversity conservation, landscape management decision making, climate change impacts and sustainable management strategies [53].

Conclusions

In the present time, global biodiversity faces an immense crisis that overtakes previous records. Specifically, habitat destruction in Southeast Asia is the more pervasive for 'wholesale extinction' of biodiversity [54, 55]. Identifying and delineating such 'key biodiversity area' is, therefore, important for prioritizing conservation planning. Outcomes of such study generates valuable data which is important for regions like this particularly in the Southeast Asian tropics. Protected areas are thought to be the key biodiversity area, but many of them have become less capable to perform that role and thus suffering to protect valuable flora and fauna within their legislative boundaries in particular and their surrounding ecosystems in general. This study shows the facts and trends of the protected areas that how they have been experiencing anthropogenic pressures. However, more comprehensive and continuous study on habitat fragmentation and its harmful effects may provide necessary information to examine the efficiency of the existing protected area systems as well as to identify potential areas for systematic conservation planning. Therefore, it can be assumed that this study on forest fragmentation, particularly in the protected area system, may be useful to identify the threatened ecosystems and protected areas for conservation initiatives. Furthermore, such delineation can provide the basis for systematic conservation planning, ideal land use decision, climate change impacts, adaptation and mitigation initiatives to climate change and ecologically feasible sustainable management of natural forests in the regional level.

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Supplemental data

Table S1: Wildlife protected areas in the state of Selangor and federal territory of Kuala Lumpur

Wildlife protected areas Total area (ha) Legislative area	Establishment year and the enactments	IUCN category	Location	Elevation (meter above sea level)	Special feature
Fraser's Hill 2,811 Selangor	1922, Wild Animal & Bird Protection Enact. 1921	VI	3°36′–3°42′N & 101°40′–101°48′E	350–1,200	Lower montane, upper dipterocarp forest, eco-tourism area
Bukit Kutu 1,844 Selangor	1922, Wild Animal & Bird Protection Enact. 1921	VI	3°30′–3°33′N & 101°42′–101°46′E	250–1,053	Lower montane, upper dipterocarp forest
Templers Park 1,299 Selangor	1955, Land Code (Selangor)	V	3°16′–3°20′N & 101°39′–101°41′E	160–500	Hill dipterocarp forest, park
Klang Gate 1,345 Selangor	1935, Wild Animal & Bird Protection Enact. 1921	II	3°12′–3°16′N & 101°43′–101°46′E	130–400	Lake, park, granite habitat, hill forest
Bukit Sungai Puteh 82 (Selangor) 04 (Federal)	1931, Wild Animal & Bird Protection Enact. 1921	IV	3°05′43″–3°06′N & 101°45′–101°45′34″E	300	Hill dipterocarp, bird conservation
Sungai Dusun 5,116 Selangor	1964, Wild Animal & Bird Protection Ordinance.1955	Ib	3°39′–3°41′N & 101°20′–101°29′E	25–253	Lowland dipterocarp, peat-swamp
Kuala Selangor 144 Selangor	1922, Wild Animal & Bird Protection Enact. 1921	VI	3°19′–3°21′N & 101°13′–101°14′E	0–7 at the coast and 50 at the hill	Silver haired monkey, mangrove forest
Bukit Nenas 17 Federal	1934, Wild Animal & Bird Protection Enact. 1921	N/A	3°08′08″–3°08′13″N & 101°38′01″–101°39′09″E	70	Bird sanctuary
KL Golf Course 165 Federal	1923, Wild Animal & Bird Protection Enact. 1921	N/A	3°09′3″–3°09′19″N & 101°42′07″–101°42′21″E	55	Bird sanctuary