Evaluation of Forest Canopy Density and Forest Fragmentation Using Landsat Data in Phu Khieo Wildlife Sanctuary, Thailand

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Abstract
Forest abundance in the region of Phu Khieo Wildlife Sanctuary (PKWS) was evaluated qualitatively and quantitatively using the method of forest canopy density (FCD) in combination with patch analyst tool for ArcGIS 10.2 and landscape fragmentation using Landsat 8 images. The strong relationship between FCD and the biomass have qualitatively assured that the distributions of the forest by density are highly acceptable (R^2 = 0.8772). A quantitative approach was derived from the FCD level for landscape ecology with a patch and fragmentation analyses. The patch data demonstrated shapes and degrees of forest abundance into 4 types as the core, perforate, edge and patch. The fragmentation data demonstrated that the core is the most occupied, approximately 71.33%. The high percentage of the core imply as the high abundance, whereas the low percentage of other three patch classes imply the areas of degradation. Combinations of these two approaches can support policies, laws and guidelines for sustainable management to protect biodiversity and ecosystems in PKWS.

1. Introduction

Dense forest areas are important for sustaining living creatures by providing them habitats and food resources. To maintain the forest areas sustainable policies, laws and guidelines with suitable management are required which will directly contribute to the reduction in current global climate change and protection in biodiversity (Woinarski, 2010, Jetz et al., 2012 and Nagendra et al., 2013). Despite the success of the conservation of forest area in Southeast Asia which resulted in an increase of forested area but overall yield and biomass carbon of forest are continuingly reducing (FAO, 2016). To assess the overall status of forest abundance both qualitative and quantitative analysis with information technology tools are required. Remote sensing and Geographic Information System (GIS) are important practical tools to assess the fragmentation of forests from local to regional and global scales in metric forms as landscape ecology maps (Gustafson, 1998 and Amarnath et al., 2012). These maps can indicate locations of forests and its classes as well as fragmentation of forest landscape (Forman, 1995 and Wickham et al., 2007). The qualitative evaluation of forest abundance is based on forest canopy density (FCD) using satellite images, which can reveal the different classes and abundances of the studied forest sites (Roy et al., 1996). Three elements which are generally incorporated to analyze the FCD from Landsat TM satellites are advanced vegetation index (AVI), bare soil index (BI), and shadow index (SI). Rikimaru et al., (2002) had developed a method to analyze biophysical properties of the FCD layers by satellite images from Landsat TM. In addition, Jamalabad and Abkar (2004) modified the three indices to estimate the FCD; however, it was seen that AVI is less suitable than the soil adjusted vegetation Index (SAVI) which produces higher sensitivity to vegetation spectrum of the tree and bushes occupied in the satellite images. Currently, SAVI is generally accepted and recognized by several researchers as a suitable index for the study of forest density (Huete, 1988, Foody et al., 2003, Schlerf et al., 2005, Singh and Das, 2014 and Mokarram et al., 2015). Based on the above application sequences of the forest canopy, these indices demonstrate the development for assessment on the abundance of forest.

The quantitative evaluation of forest abundance is based on the use of landscape ecology as a tool for assessing and monitoring biodiversity (Rocchini, 2009 and Peres et al., 2010). Singh et al., (2010) applied Landsat and SPOT satellite images data to classify forest types, and also analyzed the patterns of patches of forest. The patches used in this approach composed of nine categories which are patch area, patch density, largest patch, total edge length, mean area, total core area, mean proximity

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index, aggregation index and adjacency index (Amarnath et al., 2012). In patch analysis, landscape metrics refer to indices developed for categorical map patterns into their general use and interpretation. Chawla et al., (2012) and Baral et al., (2014) assessed landscape structure using Patch analysis as an extension tool in ArcGIS. Analyses of forest patches by using focal and zonal principles from the Landsat satellite images was done the year 2009 which investigated and classified the forest data with the model builder application of ArcGIS into 4 changing patches patterns: perforation, subdivision, shrinkage and attrition (Li and Yang, 2015). Furthermore, Vogt et al., (2007) under the Center for Land Use Education and Research (CLEAR) developed and improved Landscape Fragmentation Tool (LFT), an extension advantage and capabilities of ArcGIS, to classify the forest patches into 4 categories as patch, edge, perforated and core.

The total area under forests in Thailand in 2016 shows a slight increase (Royal Forest Department, 2016); however, the increment of forest areas did not support the forest abundance (IUCN, 2015). Phu Khieo wildlife sanctuary (PKWS) located in the northeastern region of Thailand is a conservation area which is of great importance because of its home to a lot of wildlife, including 3 endemic species,19 threatened and 3 endangered species (Department of National Park, Wildlife and Plant Conservation, 2009). These wildlife species demonstrate information supporting the abundance of PKWS forest. Assessment of forest abundance by integrating the Landsat satellite image with FCD analysis can represent the overall forest quality data. Quantitative data of forest abundance can be analyzed by quantifying tree biomass in terms of landscape ecology using patch analysis in order to clarify the spatial heterogeneity or the spatial composition and arrangement of foreground objects in an image as shape and continuity. In addition, LFT is generally applied in order to prioritize problems on each forest category for forest management. However, studies of combinations of the patch analysis and LFT for indicating the degree of forest abundance is lacking. Therefore, the objective of this study was to evaluate the abundance of the PKWS forest area by applying FCD in combination with patch analysis and LFT in order to manage the forest environments such as land, water, soil, plants and animals to sustainability for present and future generations.

2. Study Area

The PKWS is situated in Chaiyaphum province between the 16°15´ to 16°35´ latitude north and 101°20´ to 101°55´ longitude east (Figure 1). It covers an area of approximately 156,000 ha, with elevations between 500 - 1,300 m above sea level (NASA Jet Propulsion Laboratory (JPL), 2005). The PKWS area is under monsoon climate with an average rainfall of 1,400 mm per annum, mostly precipitated between May and October (Meteorological Department of Thailand, 2015). Currently, PKWS is an origin of water resource with a northeast direction of hydro-drainage from numerous creeks to the Chi River.

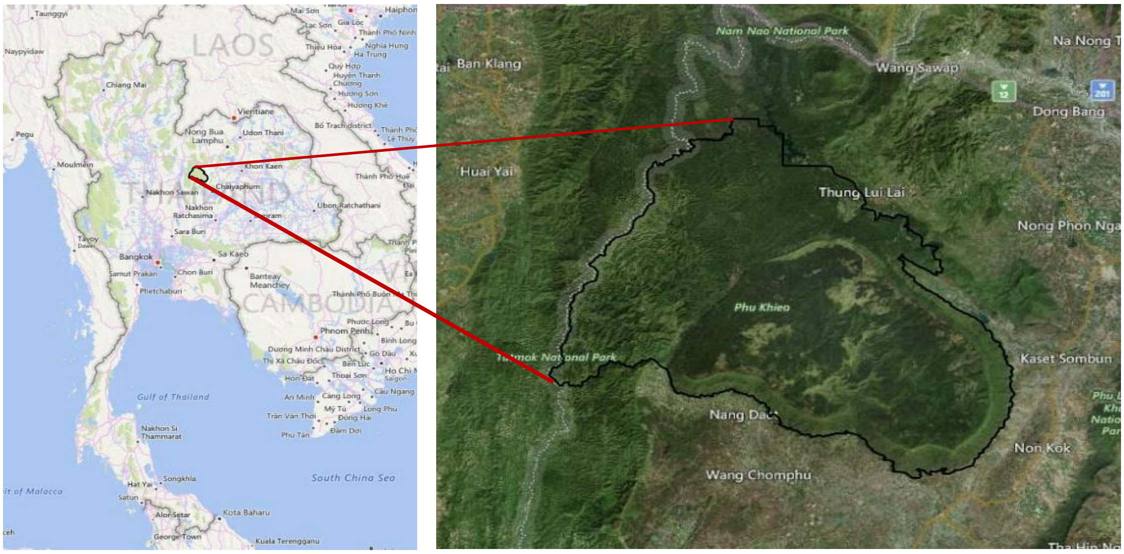

Figure 1: Location and boundary area of the PKWS, Chaiyaphum province, Thailand

Furthermore, hill evergreen, dry evergreen and dipterocarp forests as land cover (LC) occupy mainly in this area. Slope complexity from coarse to fine texture with the varied depth of soil unit is present in the study area (Land Development Department, 2015). Traditional plant crops (cassava, sugarcane and maize), as well as orchard as land use, are found in association with sparse remnant trees around the rim of the Sanctuary.

3. Methodology

Concept of the methodology used in PKWS is shown in Figure 2. The data analyses are divided into 3 parts : I (Data source and Preprocessing; II (Quality of Forest Information and III(Quantity of Forest Information. Preprocessing of Landsat images is done for analyzing various indices which leads to FCD for the qualitative information. The result of the FCD classification was further quantitatively and separately analyzed by Patch Analyst in ArcGIS and landscape fragmentation tool)LFT (version 2.0.

3.1 Data Source and Preprocessing

Landsat 8 OLI data covering two scenes (path 129, rows 48-49) acquired on 1 January 2015 were downloaded from USGS server (http://earthexplorer.usgs.gov). The datasets are level I products of USGS, referenced in the World Geodetic System (WGS 84) datum in GeoTIFF format, and are projected using the Universal Transverse Mercator System (Zone 47 North). The dataset used in this study has 30m spatial resolution with 7 bands: B2(Blue), B3(green), B4(red), B5(NIR), B6(SWIR1), B7(SWIR2) and B10(TIRS). The images presented in digital numbers (DN) which is rescaled to spectral radiance of the top of atmosphere (TOA) as described by USGS (USGS, 2015). The obtained TOA radiances were then normalized to 8 bits using linear transformation.

3.2 Quality of Forest Information

3.2.1 Forest Canopy Density (FCD)

The FCD model is based on the previous study by Rikimura et al., (2002) who proposed that FCD consists of vegetation index (VI), bare soil index (BI), shadow index (SI) and thermal Index (TI). For analysis, authors usually apply SAVI instead of VI as SAVI produces higher sensitivity to vegetation spectrum of the tree and bushes occupied in the satellite images (Foody et al., 2003 and Schlerf et al., 2005). FCD indices with description and equations are showed in Table 1.

3.2.2 Classification Procedure

The conditions of the FCD (Table 2) are classified into 4 levels of canopy densities as high dense forest (HDF), moderate dense forest (MDF), low dense forest (LDF) and non-forest (NF) (Su Mon et al., 2012).

3.2.3 Relationship between FCD and biomass

Forest data of area PKWS for quantifying biomass from 2012-2016 is obtained from 22 survey plots procured from the Protected Areas Regional Office 7 (Nakhon Ratchasima Province), Department of National Park, Wildlife and Plant Conservation. The data were processed and compared with the consistency of FCD values. The logarithmic relationship between the biomass and FCD was plotted and examined and the responses among data are measured as per coefficient of determination (R^2). R squared value was further considered and interpreted the FCD and biomass relationship.

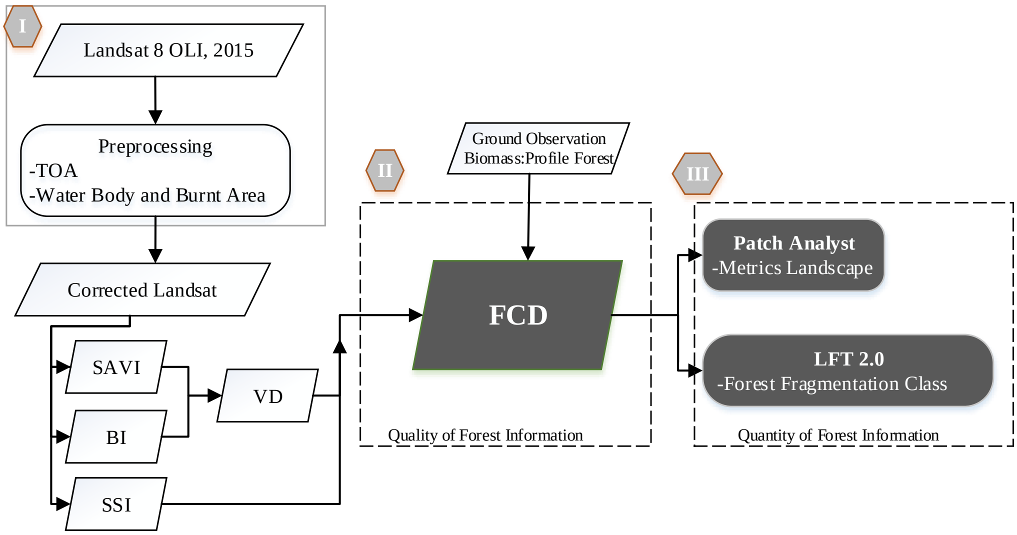

Figure 2: The flow chart of concept of methodology on forest abundance in PKWS

Table 1: FCD indices with description and equations

Indices	Equation
Soil Adjusted Vegetation Index (SAVI): This index indicates the density of the forest and its physiognomic characteristics of trees by analyzing the soil background sensitivity to vegetation. SAVI is calculated as in the equation 1.	$SAVI = (\frac{NIR - RED}{NIR + RED + 0.5})1.5$ Equation 1 Where: NIR = Near-Infrared Band (B_5); RED = Red band (B_4)
Bare Soil Index (BI): This index is used to know the density of the forest floor. BI is calculated as in the equations 2 and 3.	$BIO = \frac{(SWIR + RED) - (NIR + BLUE)}{(SWIR + RED) + (NIR + BLUE)}$ Equation 2 $BI = BIO * 100 + 100$ Equation 3 Where: SWIR = Short-Wave Infrared Band (B_6), NIR = Near-Infrared Band (B_5), RED = Red Band (B_4), BLUE = Blue Band (B_2)
Vegetation Density (VD): This index is used as a principal component analysis of BI and SAVI because these two variables are interrelated negatively high. The scaling value of the index is in the range of 0-100.	
Shadow Index or Scaled Shadow Index (SI or SSI): This index uses tree shadow as density value. It works on the principle that the larger trees make greater shadows in the forest as compared to the smaller trees or fewer trees.SSI is calculated as in the equations 4 and 5.	$SI = [(256 - BLUE)(256 - GREEN)(256 - RED)]^{1/3}$ Equation 4 $SSI = SI * 100 + 100$ Equation 5 Where: BLUE = Blue Band (B_2), GREEN = Green Band (B_3), RED = Red Band (B_4)
Thermal Index (TI): This index uses Landsat 8 band 10 (Thermal Infrared) to separate the burnt area from the shadow area and is not taken into account when calculating the FCD.	
Integration process to achieve FCD model: All indices were integrated and analyzed to set up the most suitable canopy density model. FCD is calculated as in the equation 6.	$FCD = \sqrt{VD * SSI + 1} - 1$ Equation 6

Table 2: Criterion values of forest canopy density in each class

Class	FCD
High Dense Forest (HDF)	74 - Max
Moderate Dense Forest (MDF)	50 - 75
Low Dense Forest (LDF)	25 - 50
Non-Forest (NF)	< 25

3.3 Quantity of Forest Information (Forest Fragmentation)

Quantitative data of ecological landscape is performed by analyzing with the help of the Patch Grid extension in ArcMap program)Rempel et al., 2012(and it can give the metrics for landscape characterization) Table 3(as well as indirect biodiversity of plants and animals in PKWS area. In the case when habitat is abundant, large and continuous, it will influence the integrity of both vegetation and wildlife. Furthermore, Vogt et al.,) 2007(suggested that Landscape Fragmentation Tool)LFT (version 2.0 can help in the analysis of the isolation of the forest and help in classifying the forest into four categories namely patch, edge, perforated and core, by using a buffer of 200 meters.

4. Results and Discussion

4.1 The Quality Forest Information

4.1.1 Forest conditions

Resultant map of FCD displaying different color scales with four levels of density is provided in Figure 3, and statistical results of each density class are shown in Table 4. Overall analysis of forest canopy density indicates that most of the forest in the study area has canopy density close to HDF which is approximately 56.24% followed by the MDF, LDF and NF, respectively.

Most of the HDF areas are distributed in the central and northern region of PKWS, surrounding by the MDF, while the LDF is mostly located close to boundaries in the southern and southeastern region of PKWS. From the FCD data, it can be seen that both HDF and MDF areas occupied is approximately 90.7% while on the other hand the LDF and NF are minority classes were accounted for less than 10% of the area.

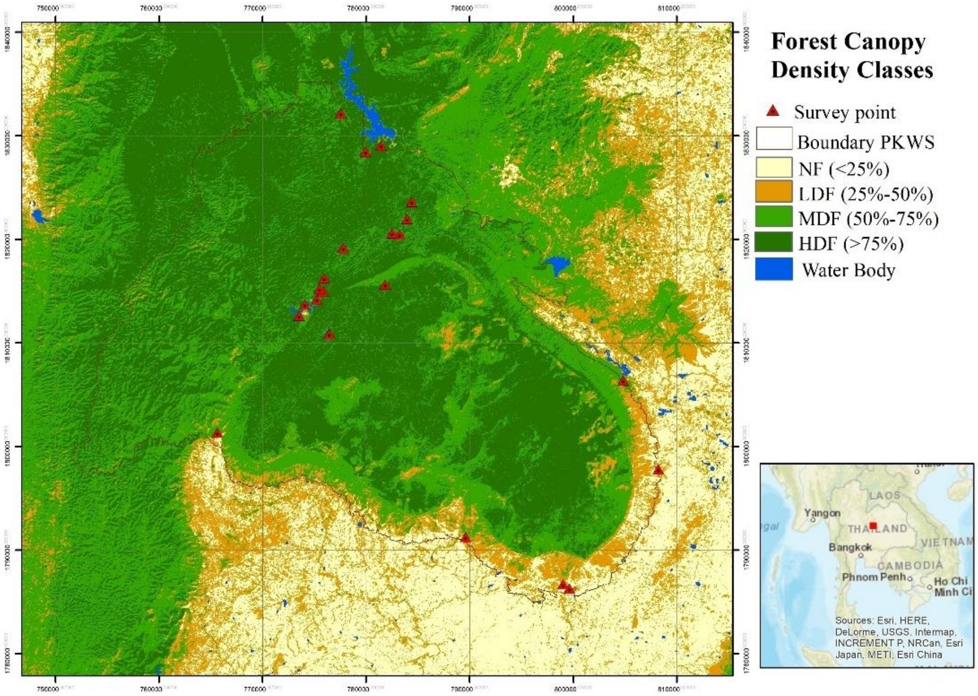

Figure 3: The PKWS color map with 4 Classes of FCD: Non-forest in yellow; Low density forest in orange; Moderate density forest in green; High density forest in dark green; Water body in blue

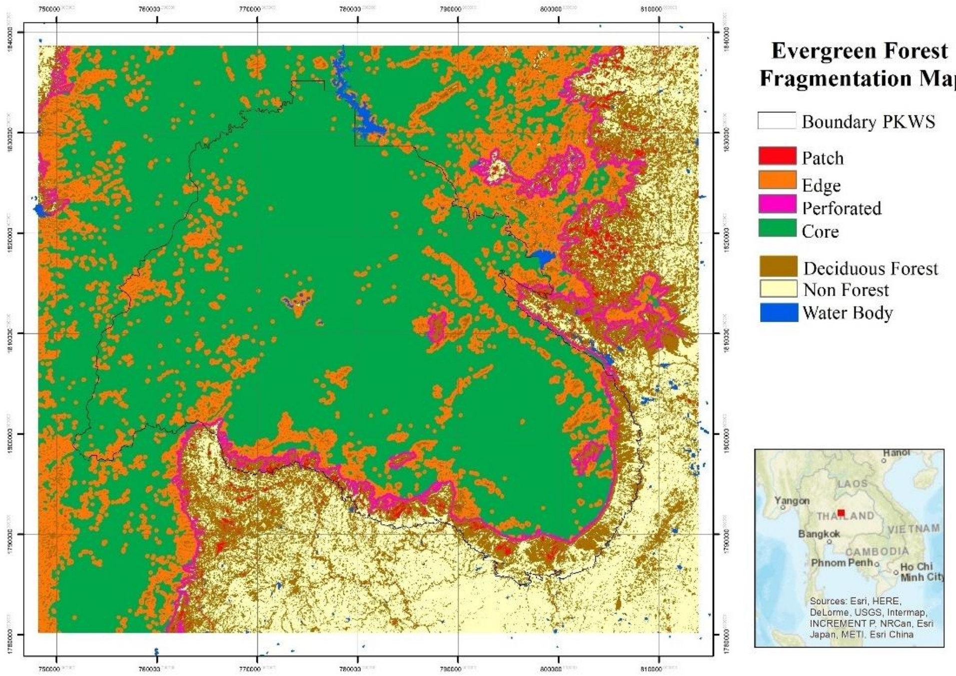

Figure 4: The map of four fragmentation classes of the evergreen forest in PKWS: Patch class in red; Edge class in orange; Perforate class in pink; Core class in green; Deciduous forest in yellow; Non-forest in light yellow; Water body in blue

Table 3: Metrics and units used for the landscape characterization

Metrics	Description	Unit
Class Area(CA)	Area of patch	ha
Number of Patches (NP)	Number of patches of corresponding class	None
Mean Patch Size (MPS)	Average patch size of the corresponding class	ha
Patch Size Standard Deviation (PSSD)	Standard deviation of patch areas	ha
Total Edge(TE)	The total length of Perimeter of patches	(* 1000 m)
Edge Density (ED)	Amount of edge relative to the landscape area	m/ha
Area-Weighted Mean Shape Index (AWMSI)	Shape of patches are circular or irregularity	None
Total Core Area Index (TCAI)	Amount of core area in the landscape	None
Mean Core Area (MCA)	Average core area per patch	ha
Mean Proximity Index (MPI)	The degree of isolation and fragmentation	None
Interspersion Juxtaposition Index (IJI)	Adjacency among patches of corresponding classes	%

Table 4: The areas of FCD classes in PKWS

FCD Classes	Area (ha)	%
High Dense Forest	88,489.08	56.24
Moderate Dense Forest	54,255.69	34.48
Low Dense Forest	10,442.97	6.64
Non-Forest	3,995.10	2.54
Water Body	166.05	0.11

The results of this study can imply that there is the relatively high status of forest integrity in the area. The results of this study on forest conditions were in accordance with West (2009) and Townsend et al., (2012) who demonstrated that Landsat satellite images were capable to track changes in forest areas in conjunction with forest type studies. The principal of the same is that different vegetation type reflects different electromagnetic waves which fall on them (Fuller et al., 1998, Ingram et al., 2005 and Spanhove et al., 2012). This difference is useful in distinguishing and measuring the differences in plant properties in the forms of land cover classification or land use. The applications of vegetation indices and rating classes for biophysical monitoring phenology and the role of compromised timber or vegetation index indicate the status of the evaluation or the canopy of carbon, water or moisture status and not be disturbed (Delalieux et al., 2008, Huete, 2012 and Rahimzadeh-Bajgiran et al., 2012).

4.1.2 Validation of forest conditions with FCD in relation to biomass

The relationship of qualitative forest information was measured by FCD with the amount of biomass obtained from the data survey on the field. Diameter at breast height (DBH) and height of the observed tree were used to calculate the biomass.

The relationship result demonstrated as R^2 was equal to 0.8772. The R^2value is in the acceptable range compared to other research reports (Foody et al., 2003, Schlerf et al., 2005 and Singh et al., 2014). The tested results hence confirmed that FCD can be used to represent the abundance of forests and to differentiate the forest types. The results of forest conditions in the class of HDF and MDF can be referred to the evergreen forests. As the value of FCD is approximately 80% and greater it hence represents the evergreen forest, while the FCD value less than 60% , it represents the mixed deciduous forest.

4.2 Quantity Forest Information

4.2.1 Patch Pattern

Table 5 gives the result of fragmentation analysis with Patch Analyst around the PKWS and hence demonstrates an arithmetic shaped forest with homogeneity and continuity. HDF has more CA than MDF, but it's lower than the NF and LDF. In the PKWS, according to Khon Kaen University and Phu Khieo Wildlife Santuary (1995), the HDF area is dominated by hill evergreen forest and MDF forests, mostly covered by dry evergreen forest. While consideration the shape rather than a continuation of the area, HDF is relatively low in terms of NP, TE and ED.

Table 5: Landscape metric categories of four classes of forest density

Metrics	HDF	MDF	LDF	NF
CA (ha)	42,953.62	39,842.50	61,354.53	72,219.96
NP	4,513	10,603	20,031	5,371
MPS (ha)	9.52	3.76	3.06	13.45
PSSD	280.94	191.83	309.25	887.09
TE (*1000 m)	7,743.450	11,937.240	15,118.530	10,863.900
ED	35.79	55.17	69.87	50.21
AWMSI	27.20	49.27	57.03	72.61
TCAI	77.52	63.69	71.08	81.05
MCA	7.37	2.49	3.23	10.48
MPI	20,531.66	25,837.45	53,982.04	20,0847.25
IJI (%)	1.38	59.52	54.85	0.25

Remark: HDF = High dense forest, MDF = Moderate dense forest, LDF = Low dense forest, NF = Non forest

Table 6: Fragmentation classes areas

Class	Area (ha)	Percent
Patch	16,765.38	1.60
Edge	242,267.94	23.14
Perforate	41,103.00	3.92
Core	746,816.40	71.33

In the case of MPS is quite large, and the levels of disaggregation of both MPI and IJI are less, the MDF with less area and great NP is in an opposite direction to the HDF area. Furthermore, as the MPS is small while the length of the TE is very long, they can imply that the shape of the MDF is not a large parcel of continuity, and the level of separation is very high. In the area of LDF, the area is covered with grasslands and the deciduous forest has less in continuity as demonstrated from the NP, MPS and TE, it could suggest that the LDF occupy along the edges of the HDF as well as the MDF. The bordering area along the west to the east region of PKWS with steep slopes are quite shallow with rocky soils and low fertility (Asanok and Marod, 2016), which is the original factor of nature that classed in the LDF. LDF may be change to NF, if it is caused by human activities, such as deforestation and building roads accessing into the area (Ballantyne et al., 2014). As the MPI is relatively large, whereas the NP and MPS are relatively low, it could imply that the NF area is large (Lopez-Barrera et al., 2014). In addition, the high value of PSSD could show the less uniformity of the patch. According to the high AWMSI and the low IJI, the data can be concluded the NF is large with high compactness and continuity as reported by Baral et al., (2014).

4.2.2 Forest Fragmentation Classes

The four classes of patch types of LFT were analyzed by the core as the MDF and HDF area and hence referred to as the evergreen forest. In this study, the core forest is outside the edge effect over 200 meters in all directions from non-forested areas. According to Figure 4, perforated patch constitutes the interior edge of small non-forested areas within a core forest next to the least disturbed classes (the patch and the edge). Edge patch is in the exterior periphery of core forest tracts, where it meets with non-forested areas. Patch is an area with small fragments of the forest surrounding by non-forested areas.

The results of analytical data are shown in Table 6 and Figure 4. The data demonstrated that the core is most occupied areas is approximately 71.33% followed by the edge, perforate and patch as 23.14%, 3.92% and 1.60%, respectively. The high percentage of the core as the evergreen forest could suggest to the high abundance, whereas the low percentage of other three patch classes could imply to an occurrence of forest degradation as reported by Batar et al., (2017). In the case of the patch class with separation from the core, it requires several key elements of forest management to reconnect the patch to the original core, including an extent of forest resources, biodiversity, forest health and viability as well as enforcement of policies, guidelines and laws for sustainability to protecting biodiversity and forest ecosystems (Sharma et al., 2016). In the case of the edge class, it should be monitored, without further change or deterioration. These are in accordance with the reports by FAO (2003) and Secretariat of the Convention on Biological Diversity (2009). In the central part with the violations of the edge and perforate classes in the PKWS, they urgently need to restore the forest abundance by re-establishing the forest to the original core condition, especially distributions of check dams as well as moisture for increase species diversity, leading to the high primary productivity, i.e. increase of biomass in PKWS ecosystem.

5. Conclusion

Application of remote sensing technology by using Landsat satellite images on the PKWS forest area can demonstrate and provide forestry information in term of quality and quantity relating to the forest abundance. Qualitative approach by evaluation of forest abundance based on the FCD as well as the strong relationship between FCD and the biomass in the field of exploration plots has assured that the dense forest distributions are highly acceptable as FCD values approximately 0.87. Quantitative approach derived from the FCD level for landscape ecology with a patch and fragmentation analyses can provide the better understanding of the size and shapes of the forest area as well as the type of the patch with LFT 2.0. The patch analysis can classify the forest contiguous parcels into 4 types as core, perforate, edge and patch and it can demonstrate the degree of forest degradation or the risk of decay. Analysis of specific FCD values can imply an abundance of forest area due to the proportion of HDF 56.24% and MDF 34.48% in PKWS; however, after using the patch analysis, it can reveal that the fragmented MDF pattern may be change to LDF as well as NF, if it is caused by human activities. The study of forest degradation by integrating both FCD and LFT using data over a period of time will make clear more the rate and trend precise space specifications. In addition, integrated FCD and LFT as demonstrated in the PKWS could further apply to evaluate the forest abundance in other places for helping in making policies, guidelines and laws of enforcement with a strong collaboration between government agencies and safeguarding local livelihoods as sustainable management for protecting biodiversity and ecosystems at the present and in the future.

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