XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Integration of InVEST-Habitat quality with landscape pattern indexes: A case study of Mondulkiri province in Cambodia

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Abstract

Many attempts have been carried out to halt the biodiversity loss and deforestation, both from the management and policy side. The development of RS, GIS, satellite tracking and ecological model, quantification and visualization of the regional biodiversity evaluation at spatial scale and time scale was widely used. Landscape biodiversity was the premise foundation for identifying key biodiversity protection areas at geographical scale. Empirical studies had been conducted for biodiversity evaluation and spatial pattern based on InVEST model. Cambodia is of global conservation importance which still contain nearly intact species assemblages. The purpose of this study is to look at the spatial and temporal changes in land use and to derive patches with high habitat quality by tracking changes in habitat quality according to the characteristics of landscape metrics and changes in Mondulkiri province in Cambodia. (1) Observation of land use change patterns (2) Examine major landscape change factors, and examine the extent to which landscape patches contribute to securing habitat quality. Hoping the results could be used to support spatial planning and protection of biodiversity, especially for the fragile mountainous area. Mondulkiri has undergone a relatively strong process of land-use change. the most notable characteristic was a transformation from forest land into cropland or plantation during the 30 years. Landscape proportion reduced from 0.59 to 0.52, indicating that as the proportion of forest area patches decreased. Number of patches increased from 394 to 725 which means landscape patches become more fragmented and similarly patch density slightly increased. The northern and eastern parts of the Mondulkiri are dense crop areas with a high proportion while the southern regions have a large number of plantation land. The results could be used to support spatial planning and protection of biodiversity, especially for the fragile mountainous area.

Keywords: Adaptive and integrated management, Biodiversity conservation, Deforestation and forest degradation, Sustainable forest management, Landscape management

Introduction, scope and main objectives

Forest ecosystems are capital assets that yield many vital services for humans. In terms of biodiversity, there are genetic, species, and ecosystem diversity, and each diversity has some beneficial effects on humans, their importance, however, is often determined by comparing their value with that which could be obtained from converting forests for other land uses (i.e. agriculture). Despite large potential ecosystem values, the increasing conversion of native ecosystems into agricultural land to meet ever increasing food demands worldwide is a major cause of habitat destruction and losses of valuable ecosystems. For that reason, there are international movements to protect biodiversity by establishing protected areas. Many attempts have been carried out so far to halt the biodiversity loss and habitat fragmentation, both from the management and policy side. The effectiveness of biodiversity conservation within the PA network was found to be higher than outside (e.g., Gray et al., 2016) and needs to be further improved (e.g., Andam et al., 2008).

Landscape biodiversity was a description of the number and dominance of different patch types contained within a spatially heterogeneous area (Batáryet al., 2012; Liddicoat et al., 2018), and was the premise foundation for identifying key biodiversity (priority) protection areas at geographical scale. The change and fragmentation of habitats affected habitat quality (Guiomar et al., 2015). Thus, landscape change was related to ecological diversity (Walz and Syrbe, 2013; Schindler et al., 2013; García-Llamas et al., 2018), and currently there was increasing consideration of landscape as the most suitable scale for biodiversity assessment and management actions (Rossi and van Halder, 2010; García-Llamas et al., 2018). The other one was landscape fragmentation, connectivity and land use pattern change (de Chazal and Rounsevell, 2009), which could be reflected by landscape pattern indexes (Haines-Young, 2009; Lausch et al., 2016). Landscape pattern indexes were a set of quantitative indicators that reflected the structural composition and spatial distribution of the landscape (Plexida et al., 2014), and some of them were applied for biodiversity assessment or a proxy of species richness (Rossi and van Halder, 2010; Ng et al., 2013; Santini et al., 2017), such as landscape connectivity, Sørensen similarity index, Shannon index and other metrics of landscape structure (e.g. shape, fragmentation, separation index, etc.).

In addition, landscape pattern indexes were easier to get by the newly developed remote sensing (RS) and Geographic Information Systems (GIS). Recently, with the development of RS, GIS, satellite tracking and ecological model, quantification and visualization of the regional biodiversity evaluation at spatial scale and time scale was widely used (Scholes et al., 2012; Lausch et al., 2016; Remme et al., 2016). Moreover, advanced remote-sensing techniques are demonstrated to support the monitoring of biodiversity (e.g., Nagendra et al., 2013). Lausch et al. (2016) provided a comprehensive review of the role of earth observation to detect, describe, predict and assess biodiversity. Li et al. (2012) took counties as the evaluation unit to assess the biodiversity and its spatial distribution in Chengdu-Chongqing Economic Zone of China. increasing the understanding of spatial and temporal processes and patterns at multiple scales was considered a key area of future research in mountain biodiversity (Payne et al., 2017) and landscape ecology (Wang et al., 2017), although currently the spatial and temporal pattern of biodiversity research based on the grid unit at the regional scale was relatively rare in China (Nelson et al., 2009; Murguía et al., 2016).

Cambodia is of global conservation importance because it contains the largest remaining examples of habitats that were previously spread across much of Indochina and Thailand, and which still contain nearly intact species assemblages, albeit at heavily reduced densities. Although several policies and regulations have been implemented in Cambodia to strengthen the protection of species and habitats, such as the establishment of Protected area (National park, Wildlife sanctuary, Multi-purpose use management area, Biosphere reserve, Natural heritage site. Marine park, and Ramsar site, their success at enhancing biodiversity conservation has been poorly assessed. The purpose of this study is to look at the spatial and temporal changes in land use and to derive patches with high habitat quality by tracking changes in habitat quality according to the characteristics of landscape metrics and changes. To this end, (1) Observation of land use change patterns (2) Examine major landscape change factors, and examine the extent to which landscape patches contribute to securing habitat quality. Hoping the results could be used to support spatial planning and protection of biodiversity, especially for the fragile mountainous area.

Methodology/approach

Study area

MondulKiri is located in Eastern Cambodia (277km from Phnom Penh). It is the richest forest resources area in Cambodia (Figure 1), but this province has critically changed of the forest cover. This problem had severely impact to the habitat of endangered wildlife including elephant, vulture, tiger, banteng, crocodile, etc. The areas, which have the highest value of habitat quality, are within in the territory of Phnom Prich wildlife sanctuary, Mondul Kiri protected area and some part of Seima protected area. Mondulkiri has a dry season from November to April and a wet season from May to October, with mean annual rainfall of c. 2,000–2,500 mm and . 3,200 mm in more mountainous parts of the Province (Javier, 1997). Surveyed habitat types were semi-evergreen mixed deciduous and dry dipterocarp forests. Bamboo was present in all habitat types, with a cover ranging from sparse to continuous.

Data source

This study utilized SERVIR-Mekong's land cover time-series maps, which were generated using the Regional Land Cover Monitoring System (RLCMS). The data was extracted for the period from 1988–2018, using the Landsat and MODIS legacy collections and machine learning methods in the Google Earth Engine (GEE) open platform. The landscape of Moudulkiri is composed of 9 LULC type, following surface water, forest, plantation, built up, cropland, barren, wetland, grassland, and shrubland.

Landscape index

Some landscape metrics were chosen at the class and landscape levels: percentage of landscape (PLAND), number of patches (NP), patch density (PD), mean patch area (MPA) largest patch index. (LPI), fractal dimension index (FRAC), mean shape index (SHAPE_MN), Overall core area (OCA), patch cohesion index (COHESION). In this study, calculation of the selected landscape pattern index was carried out in FRAGSTATS 4.2, and the land-use landscape pattern selected in the calculation had a 250 m x 250 m grid. A brief introduction was shown in Table 1 and their detailed meaning can be found in the help manual of Fragstats

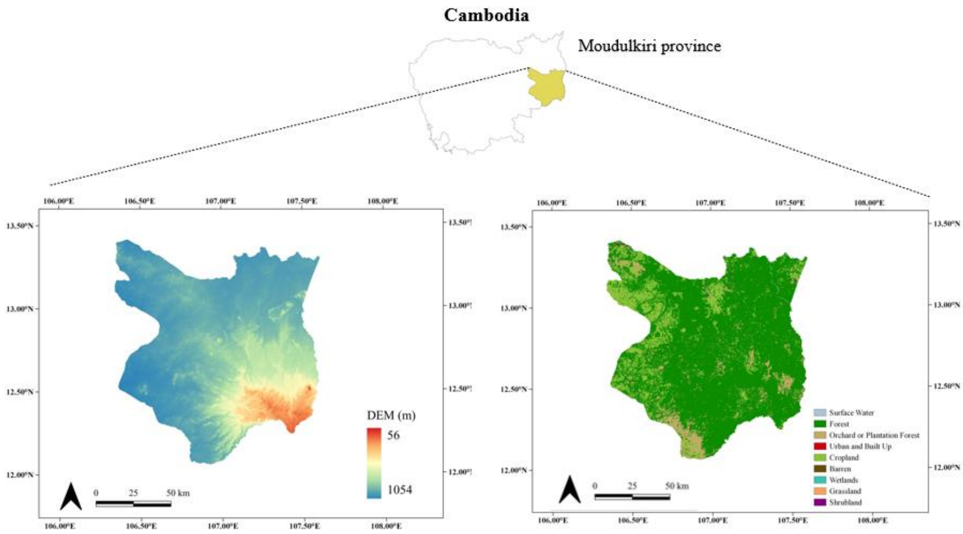

Fig. 1: DEM (a) and land use types (b) of the Mondulkiri in 2018

Landscape index

Landscape metrics can highly condense landscape pattern information, such as landscape structure, landscape diversity, spatial heterogeneity, and fragmentation, which can reflect the basic characteristics of landscape pattern dynamics and spatial configuration changes (Su et al., 2012a; Tanner and Fuhlendorf, 2018). Some landscape metrics were chosen at the class and landscape levels: percentage of landscape (PLAND), number of patches (NP), patch density (PD), mean patch area (MPA) largest patch index. (LPI), fractal dimension index (FRAC), mean shape index (SHAPE_MN), Overall core area (OCA), patch cohesion index (COHESION). In this study, calculation of the selected landscape pattern index was carried out in FRAGSTATS 4.2, and the land-use landscape pattern selected in the calculation had a 250 m x 250 m grid. A brief introduction was shown in Table 1 and their detailed meaning can be found in the help manual of Fragstats.

Table 1: Landscape index used in the study

Acronym	Metric name	Description
PLAND	Percentage of landscape	Percentage of area occupied by certain land cover class
NP	number of patches	number of patches
PD	Patch density	patches per area
MPA	Mean patch area	Mean of size of the patches
LPI	Largest patch index	Percentage of total area occupied by the largest patch
FRAC	Fractal dimension index	patch shape complexity measure that approaches 1 for simple shapes and 2 for complex shapes
SHAPE_MN	mean shape index	sum of each patch perimeter divided by the square root of patch area
OCA	Overall core area	the sum of the core areas of each patch
COHESION	patch cohesion index	the physical connectedness of the corresponding patch type

Habitat quality assessment via InVEST model

We used the InVEST Habitat Quality (HQ) model to map and assess the habitat quality in the study area. This approach is particularly useful for making an initial assessment of conservation needs (Terrado et al., 2016). As reported by Terrado et al. (2016), The model is based on the hypothesis that areas with higher habitat quality support higher richness of native species, and that decreases in habitat extent and quality lead to a decline in species persistence. HQ is directly related to the suitability of each LULC class to provide habitat for biodiversity (Hj). The Hj ranges between 0 and 1, where 1 indicates LULC classes with the highest suitability for species (Leh et al., 2013. It is worth noting that very similar HQ values can be found in pixels belonging to different LULC classes, thus potentially having quite different Hj and threats' impacts.

Table 2: Threats parameter used as input for the InVEST model

MAX_distance	Weight	Threat	Decay
1.6	0.69	crop	exponential
0.6	0.42	plantation	exponential
1.7	0.79	built up	exponential
1.5	0.86	pave	linear
0.9	0.61	unpave	linear

Table 3: Input values for the sensitivity to threats

NAME	Habitat	crop	plantation	built up	pave	unpave
Surface Water	0.83	0.76	0.53	0.72	0.7	0.6
Forest	0.82	0.63	0.44	0.76	0.84	0.68
Plantation Forest	0.6	0.51	0.35	0.61	0.61	0.52
Built Up	0.05	0	0	0	0	0
Cropland	0.26	0	0.12	0.51	0.61	0.47

Barren	0.1	0.31	0.21	0.56	0.56	0.46
Wetlands	0.96	0.8	0.59	0.79	0.84	0.69
Grassland	0.86	0.75	0.52	0.72	0.8	0.63
Shrubland	0.81	0.72	0.51	0.69	0.78	0.63

Hotspot and Coldspot analysis

The hotspot is intended as an area characterized by high density clusters of a specific indicator (HQ or HD, in our case), and surrounded by low density clusters of the same indicator, referable as a coldspot (Hartigan, 1975). More specifically, we applied a methodology based on the combination of spatial analyses and statistical procedures using the Local Indicators of Spatial Association. This approach allowed us to spatially identify statistically significant hotspots, coldspots, and spatial outliers using the Anselin Local Moran's I statistic implemented in the "Cluster and Outlier Analysis" tool in the ESRI ArcGIS® software package.

Results

Land-use change from 1988 to 2018

The land-use types in Mondulkiri mainly include forestland, cropland, and plantation, these land-use types constitute the landscape matrix, and the proportions of surface water, built up, barren, wetland, grassland, and shrubland are much smaller. The spatial distribution of each land-use types has its own characteristics. Forest land is the widely distributed and Agriculture is mainly distributed in the northeast mountainous area while the most plantation is concentrated in center and south area.

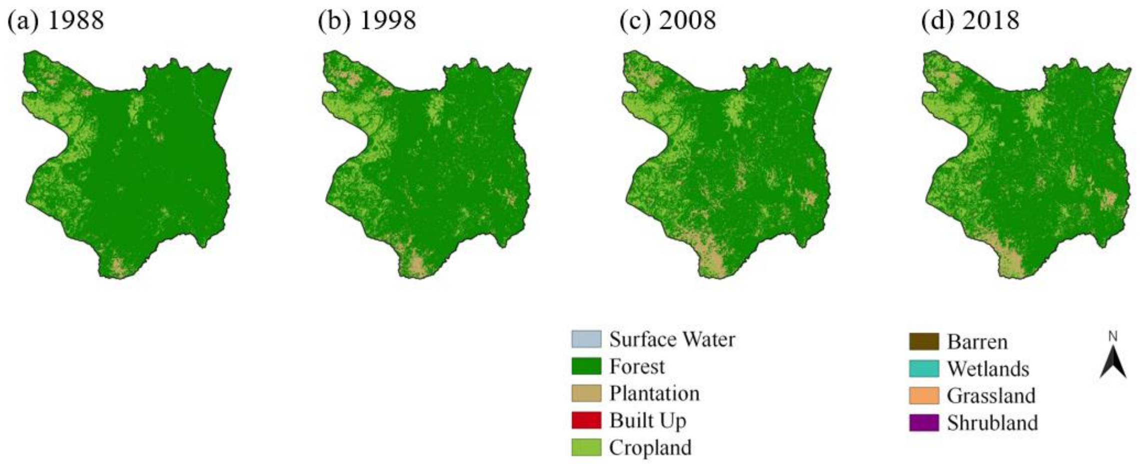

Fig. 2: Spatial distribution of the land-use in Mondulkiri from 1988 to 2018; (a) 1988, (b) 1998, (c) 2008, (d) 2018.

The area of each land-use type in 1988, 1998, 2008, and 2018 are shown in Figure 2. Mondulkiri has undergone a relatively strong process of land-use change. Specifically, the area of forestland decreased significantly, with a decrease of 141,962.6 ha (13%) from 1988 to 2018. The barren and surface water reduced slightly, cropland, plantation, shrubland, grassland increase by varying degrees. Obviously, the rapid expansion of cropland, plantation and dramatical reduction of forest land were the main characteristics of land-use change in the Mondulkiri during the past 30 years.

To further clarify the interaction between each land-use type in the process of expanding agriculture land, a land-use transition graph was constructed. The land use of the transition matrix was conducted every 10 years from 1988 to 2018. During the 30 years, land conversion occurred between almost each two land-use types. Among which, the most notable characteristic was a transformation from forest land into cropland or plantation. There were 78,314.28 ha and 73,440.88 ha respectively in the three periods. From the whole research period, there was a total of 13.06 ha of forest land transformed into built-up, which is 35% of built-up area in 2018. It indicated that urban spatial expansion mainly depended on encroaching forest land during the process of rapid urbanization. The main reason for forest and crop land to water transition is that local farmers have spontaneously excavated them into ponds for aquaculture, in order to obtain a higher income.

Landscape index change from 1988 to 2018

From 1985 to 2015, Landscape proportion reduced from 0.59 to 0.52, indicating that as the proportion of forest area patches decreased. Number of patches increased from 394 to 725 which means landscape patches become more fragmented and similarly patch density slightly increased. Mean patch area and large patch index decreased from 3044.69 to 1459.76 ha and 87.55 to 75.45 respectively, which revealed that patch size was reduced. Fractal dimension index did not change much and remained simple shape as the value was closed to 1. Core area is defined as the area of old forest, free of edge effects, where the edge effect is a function of the state of the surrounding habitat. Overall core area decreased from 989,381.39 to 710,749.26, which can be harmful to the group of animals having large home range.

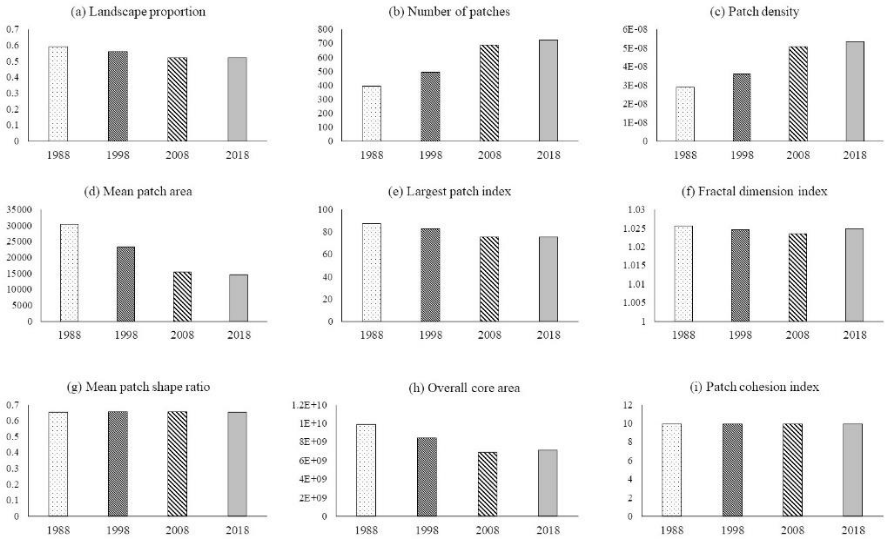

Fig. 3: Landscape fragmentation analysis result. Class-level metrics for the built-up class for 30 years in Mondulkiri.

Habitat quailty

The HQ results of the TLB in 1985–2015 is shown in Figure 5. From the perspective of time variation, in general, the HQ showed a significant downward trend, and the average HQ were 0.760 in 1988, 0.744 in 1998, 0.722 in 2008, and 0.719 in 2018. The area ratio of HQ at different grades is shown in Table 5. During the study period, most of the study area was at the relatively high level and high level of HQ. The area of high level of HQ in the study area decreased significantly, from 87.91 % in 1988 to 77.78 % in 2018 while the relatively high level of HQ slightly changed. Relatively low increased from 9.89 % in 1988 to 15.41 % in 2018. The average of HD increased from Moderate in 1988 (0.012) to the relatively high level in 2005 (0.019).

The minimum HQ value was 0, which appeared in the non-habitat LULC type, i.e., built up, and the maximum HQ value was 0.93, which appeared mainly in mountainous areas and water areas. Forests in the mountainous area are important habitats, the threatening factors and human activities are widely distributed. The spatial distribution pattern of HQ was lower in the north-center and the east than in the west, which was similar to the plantation and crop land distribution. The northern and eastern parts of the Mondulkiri are dense crop areas with a high proportion while the southern regions have a large number of plantation land.

Table 4: Ratio of each Habitat Quality and Habitat Degradation level of the Mondulkiri in 1988, 1998, 2008, and 2018 (%). SD = Standard deviation

Habitat Quality	Range	1988	1998	2008	2018
High	0.8 – 1	87.91%	83.51%	77.52%	77.78%
Relatively High	0.6 – 0.8	0.42%	0.48%	0.42%	0.46%
Moderate	0.4 – 0.6	1.78%	4.29%	7.97%	6.35%
Relatively low	0.2 – 0.4	9.89%	11.71%	14.09%	15.41%
Low	0 – 0.2	0.01%	0.00%	0.01%	0.00%
Mean (SD)		0.760(0.168)	0.744(0.182)	0.722(0.197)	0.719(0.203)
Habitat Degradation	**Range**	**1988**	**1998**	**2008**	**2018**
High	0.2 – 0.4	0.04%	0.04%	0.02%	0.02%
Relatively High	0.15 - 0.2	0.10%	0.11%	0.12%	0.13%
Moderate	0.1 – 0.15	0.88%	0.97%	0.90%	0.93%
Relatively low	0.05 - 0.1	6.40%	7.39%	9.23%	10.05%
Low	0 – 0.05	92.59%	91.49%	89.73%	88.88%
ean (SD)		0.012(0.023)	0.014(0.024)	0.019(0.023)	0.019(0.023)

Discussion

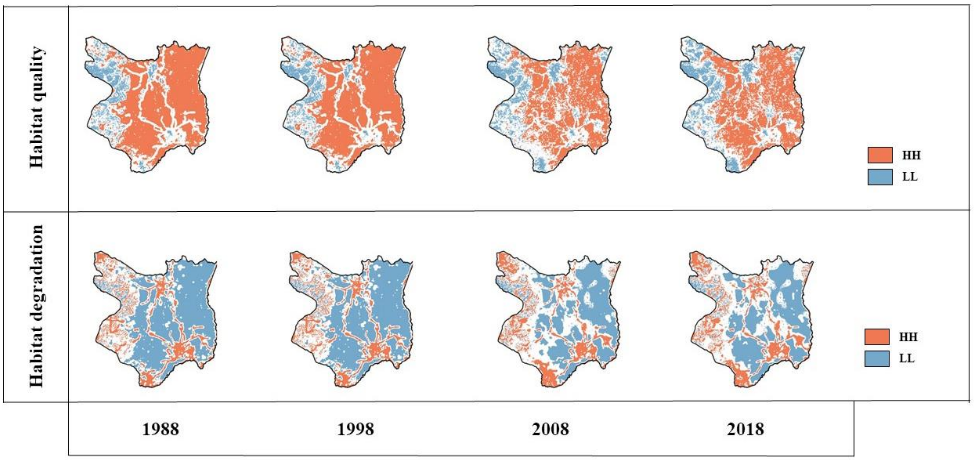

Fig. 4: Hotspots distribution of HQ and HD of the TLB in (a) 1988, (b) 1998, (c) 2008, and (d) 2018. HH for a statistically significant cluster of high values and LL for a statistically significant cluster of low values.

The spatial hotspots distribution of HQ in the TLB is shown in Figure 5. The spatial distribution of HQ in the Mondulkiri showed a pattern of "hot in the east and cold in the west. The hotspots area was mainly located in the center and east, clustered around mountains. Mountains and freshwater are important habitat types where human disturbance is relatively small, thus the HQ was generally higher. The cold spots areas were mainly distributed in the west and south of Mondulkiri. These areas were flat terrain, plantation, and cropland. From 1985 to 2015, the hotspots area showed a decreasing trend, and was more obvious in the east mountainous area, while the cold spots area showed an increasing trend, and the southern and west-northern areas were more visible.

Conclusions/ wider implications of findings

The purpose of this study is to look at the spatial and temporal changes in land use and to derive patches with high habitat quality by tracking changes in habitat quality according to the characteristics of landscape metrics and changes in Mondulkiri province in Cambodia. (1) Observation of land use change patterns (2) Examine major landscape change factors, and examine the extent to which landscape patches contribute to securing habitat quality. Hoping the results could be used to support spatial planning and protection of biodiversity, especially for the fragile mountainous area. Mondulkiri has undergone a relatively strong process of land-use change. the most notable characteristic was a transformation from forest land into cropland or plantation during the 30 years. Landscape proportion reduced from 0.59 to 0.52, indicating that as the proportion of forest area patches decreased. Number of patches increased from 394 to 725 which means landscape patches become more fragmented and similarly patch density slightly increased. The northern and eastern parts of the Mondulkiri are dense crop areas with a high proportion while the southern regions have a large number of plantation land. The results could be used to support spatial planning and protection of biodiversity, especially for the fragile mountainous area.

Acknowledgements

This work was supported by Korea Environment Industry & Technology Institute(KEITI) through Urban Ecological Health Promotion Technology Development Project, funded by Korea Ministry of Environment(MOE)(2020002770002).