Finding Topographical Connectivity for Sustainable Forest Ecosystem

: Considering Ecological Characteristics

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Finding Topographical Connectivity for Sustainable Forest Ecosystem
: Considering Ecological Characteristics

산림생태계의 지속가능성을 위한 지형학적 연결
- 생태적 특성을 중심으로 -

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■ Abstract

Finding Topographical Connectivity for Sustainable Forest Ecosystem

: Considering Ecological Characteristics

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For the past few decades, forest research has focused on conservation of limited natural resources and protection of ecological systems and production for future generations. Forest ecosystems, which comprise a substantial proportion of natural ecosystems, were addressed in terms of sustainability that would maintain the present forest structures and functions. However, anthropogenic activities have caused habitat loss, especially due to climate change associated with industrialization. Consequently, many previously established biodiversity conservation strategies are now being reviewed against the impacts of human activities.

One of the most active strategies for maintaining sustainable ecosystems is the securing of ecological connectivity. Nowadays this strategy is used by abiotic variables such as temperature and

topography as tools. Topographical variables, which are the basic physical factors of biological environment, are particularly favored as these are more stable than climate and other factors. Many researchers have studied the correlation between topography and vegetation properties and distribution using the concept of the vegetation catena, or the continuous differences observed in a vegetation community caused by changes in topography. The definitions of land forms can vary, so the methods of topographical classification are divided broadly into morphometric and generic classifications.

The main objective of this study is to establish topographical connectivity by considering ecological features that sustain forest ecosystems. First, this research analyzes the correlation between topographic variables and ecological characteristics. Second, it defines more suitable topographical classifications that consider ecological characteristics, and establishes a linkage area by applying topographic characteristics against morphometric and generic topographic classifications. A sample case examines whether the Baekdudaegan protected area, which is recognized as a significant ecological axis, contains linkage areas that consider topographic characteristics.

The influence of topographic characteristics on vegetation habitat conditions was determined by using correlation analysis between vegetation distribution and topographic characteristics. Both topographical classifications were related to ecological features like coniferous forests and amphibian distributions. A linkage area

established by applying topographic characteristics was more effectively achieved using generic topographic classification. Comparison of the linkage area found by applying topographic characteristics to the Baekdudaegan protected area revealed that none of the linkage areas except the ridge line were included in the present boundary of the Baekdudaegan protected area. The linkage area for the lowland, in particular, was very different. This emphasizes the importance of having the protected area reflect the topographic characteristics of the lowland area.

Establishment of protected areas should consider topographic characteristics, in addition to species distributions, as important criteria in order to complement low species distribution data or uncertainty.

The study had some limitations, such as failure to consider the present land cover conditions. Additional topographic classification methods also should be applied. Nevertheless, the linkage area found by applying topographic characteristics shows potential for use in maintaining forest ecosystem sustainability in response to fragmentation and climate change.

keywords : Topographic characteristic, Vegetation catena, Connectivity, Morphometric topographic classification, Generic topographic classification

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Table of contents

List of tables

List of figures

1. Introduction

1.1 Background

For the past few decades, forest research has focused on conservation of limited natural resources and on the protection of ecological systems and production for future generations. Forest ecosystems form major ecologic units, so the maintenance of forest structures and functions is important for sustainability (Arborvitae, 1995). However, many diverse development activities conducted by humans have resulted in substantial habitat loss (Czech et al., 2000).

Habitat fragmentation caused by urbanization is particularly serious and the spatial range of urbanization is expanding in both suburban and peri-urban areas (Vimal et al., 2012). Urbanization precludes the movement of species between the fragmented patches, so the numbers of individuals within the patches decline (Kim, 2002). Climate change caused by industrialization also negatively influences wildlife habitat and changes in temperature and precipitation continue despite the efforts of many countries to reduce greenhouse gas emissions (IPCC, 2001). The alterations in temperature and precipitation due to climate change also cause species to migrate from traditional locations for survival (Iverson et al., 2004).

Many biodiversity conservation strategies have been reviewed to counteract the effect of human activities, like development, on habitat loss. Among these diverse strategies, securing ecological connectivity has been the most actively studied (Hodgson et al., 2009; Heller and Zabaleta, 2009), and is now the most common method for maintaining biodiversity in response to climate change (Game et al., 2011).

Several theories and methodologies have been advanced for securing ecological connectivity. For example, the establishment of ecological networks containing cores, buffers, and corridors has been adopted by many countries (Jongman et al., 2004). Path prediction of focal species is often used to find linkage areas for these species (Song, 2011) and can successfully find and connect a suitable habitat for a given species, allowing it to adapt to climate change (Iverson et al., 2011; Kim, 2012). However, this type of path prediction is limited to the focal species and the corridors identified may not be suitable for other species (Beier et al., 2009). This method for climate change adaptation also has a level of uncertainty due to variability of climate change scenarios (Rowland et al., 2011). These limitations can be circumvented, to some extent, by the use of abiotic variables, such as temperature and topography, as tools for connecting habitats. Topographic variables are the basic physical features of a biological environment, and are more stable than climate or other factors (Beier and Brost, 2010). A linkage area in Arizona, USA, found by applying topographic characteristics provided a two-fold higher connectivity (Brost and Beier, 2012b). The catena concept also comes into play, since the soils of a slope system from the summit to lowlands also show continuous differences; therefore, topography affects both soil and vegetation properties (Milne, 1935; Weil, 2003). Diverse topographic variables have been used and topographical classification methods have been developed to reflect the real topography and identify correlations with the flow of water and materials.

The methods of topographic classification are divided broadly into morphometric and generic classifications (Park, 2004). Several different topographic variables are usually used when considering topographical characteristics; however, elevation and slope are the most widely used variables in GIS analysis in South Korea (Jeon et al., 2010). Korea has diverse topographical and ecological features that vary with latitude and longitude. The Baekdudaegan Protected area is the main core ecological axis, but research thus far has only focused on the line of the highest ridge (Korea Forest Conservation Movement, 2005; Jeon et al., 2010).

1.2 Research objectives

The main research objective is to determine topographical connectivity by considering the ecological features that will sustain a forest ecosystem. The following three research questions are addressed:

(1) Do topographic characteristics show effects or correlations with ecological characteristics such as species distributions?
(2) Which topographic classification methods are more suitable to explain the observed ecological features and to establish a linkage area?
(3) Are linkage areas of topographic characteristics that consider the ecological features currently included in the Baekdudaegan protected area?

1.3 Research frameworks

The research questions are addressed using a research framework composed of four major components.

The introduction briefly described the background and objectives of this research and reviewed related studies about ecological connectivity, the vegetation catena concept, and topographic classification methods.

The correlation between topographic characteristics and vegetation type distributions was then analyzed to confirm the availability of topographic characteristics for ecological connectivity.

The third part reviewed and compared the methods for topographic classification with respect to the ecological characteristics using coniferous forest and amphibian emergence data. The linkage areas were then found using topographic characteristics classified in three sample sites and the results were compared with the results from each topographic classification.

Lastly, this method was applied in several National Parks (Seorak Mountain National Park, Odae Mountain National Park, Songni Mountain National Park, and Worak Mountain National Park) and the results were compared to those obtained for the Baekdudaegan protected area. The importance and limitations of this research were discussed in the conclusion section.

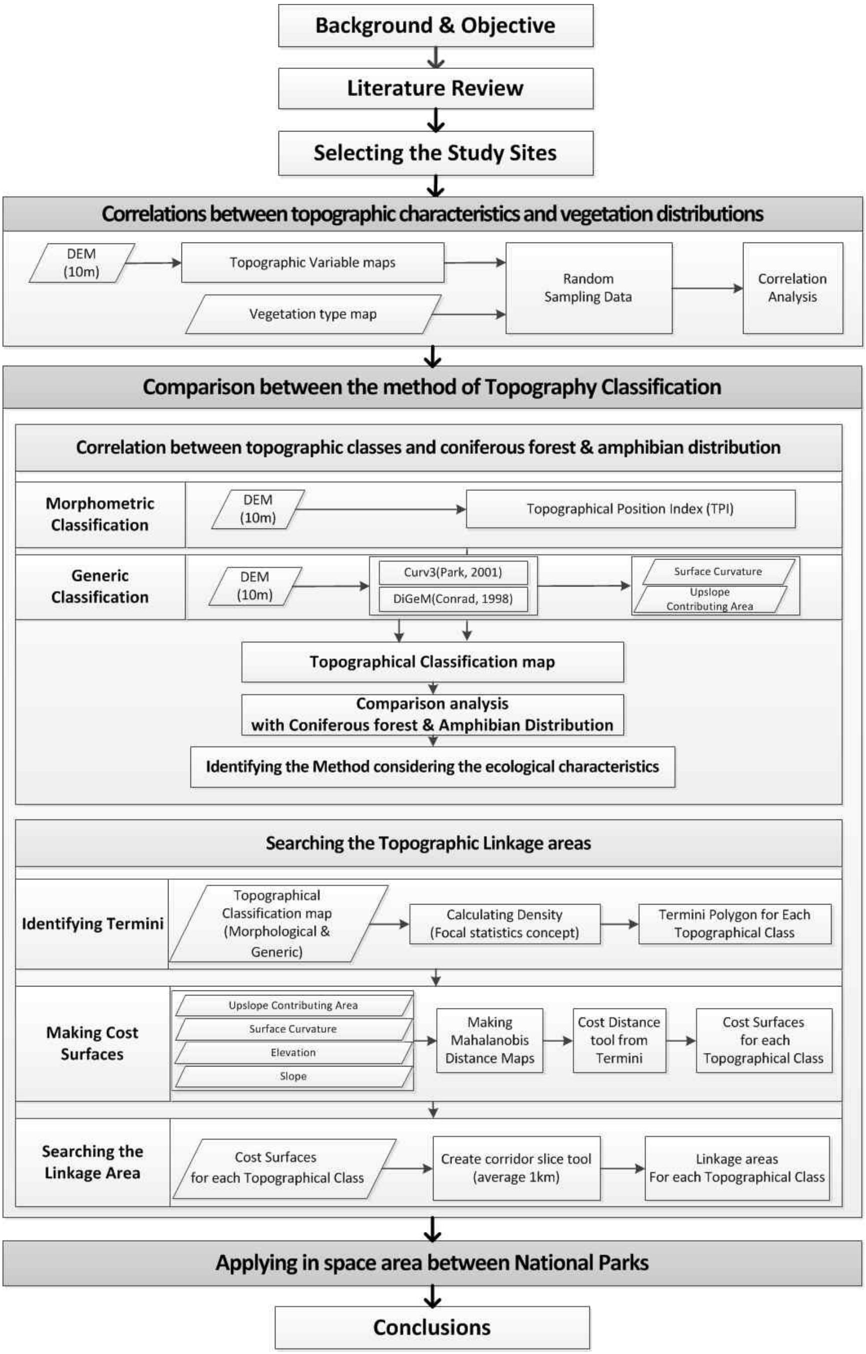


Figure. 1. Flow of Study

1.4 Literature reviews

1.4.1 Sustainable forest ecosystems

Sustainability describes how biological cycles remain variety and productivity in future generations. Examples of sustainable biological systems are long-lived healthy forests and wetlands (Wikipedia, 2013). In terms of sustainability of a forest ecosystem, "the environmental effects and benefits of a forest's structures and functions are secured through biodiversity conservation" (Fuehrer, 2000). However, forests have been recognized as commercial goods for at least 20 years, and historically humans have affected their natural dynamics and species compositions (Bengtsson et al., 2000). Consequently, forest research has aimed to achieve two significant objectives: timber production and biodiversity conservation (Carey and Curtis, 1996). The CBD (Convention on Biological Diversity) introduced the following principles for sustainable ecosystems: "ecosystems must be managed within the limits of their functioning" and "the ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity."

Indicators related to the structure and functions of forest species have also been applied in many studies to improve the sustainability of forest ecosystems (Arborvitae, 1995). The structure-based indicators used for sustainable biological diversity are structural complexity, plant species composition, connectivity, and heterogeneity (Lindenmayer et al., 2000). Lindenmayer et al. (2006) suggested further principles as strategies for biodiversity conservation such as connectivity, heterogeneity of landscape, and structural complexity, etc. Connectivity relates to key processes of biodiversity conservation, such as population persistence after a disturbance, the exchange of individuals and genes within a population, and the occupancy of habitat patches (Leung et al., 1993; Lamberson et al., 1994; Villard and Taylor, 1994).

Table. 1. CBD's twelve principles of the ecosystem approach (CBD, 2013)

1. The objectives of managementt of land, water and living resources are a matter of societal choice. 2. Management should be decentralized to the lowest appropriate level. 3. Ecoststem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems. 4. Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. 5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach. 6. Ecosystems must be managed within the limits of their functioning. 7. The ecosystem approach should be undertaken at the appropriate spatial and temporal scales. 8. Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set fore the long term. 9. Management must recognize that change in inevitable. 10. The ecosystem approach should seek the appropriate balance between, and integration of biologcial diversity. 11. The ecosystem approach should consider all forms fo relevant information, including scientific and indigenous and local knowledge, innovations and practices. 12. The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

1.4.2 Ecological connectivity

The securing of ecological connectivity for biodiversity conservation has become a topic of active study in recent years (Heller and Zavaleta, 2009). Bunn et al. (2000) identified graph theory as a feasible method for establishing ecological landscape connectivity and asserted that this method could be used in biological conservation studies. Lee et al. (2008) described corridors for ecological connectivity of medium and large mammals, and suggested that small green spaces should be incorporated into national ecological networks.

Connectivity is increasingly being recognized as a method that enables the movement of species necessitated by climate change.

Table. 2. The number of articles for biodiversity conservation strategy for climate change ranked by times cited (revised to Heller and Zavaleta, 2009)

Rank	Recommendation	No. articles
1	Increase connectivity	24
2	Integrate climate change into planning exercises	19
3	Mitigate other threats	17
4	Study response of species to climate change physiological, behavioral, demographic	15
	Practice intensive management to secure populations	15
	Translocate species	15
5	Increase number of reserves	13
6	Address scale problems match modeling, management, and experimental spatial scales for improved predictive capacity	12
	Improve inter-agency, regional coordination	12
7	Increase and maintain basic monitoring programs	11
	Practice adaptive management	11
	Protect large areas, increase reserve size	11
8	Create and manage buffer zones around reserves	10

Primarily, these studies provide estimates of the changes in species distributions due to climate change and identify the connections between the predicted habitats with the present habitats through assessments of habitat suitability (Parmesan and Yohe, 2003).

Vos et al. (2008) predicted suitable habitats as part of climate change adaptation and found linkage areas for connectivity using the climate change scenarios for the years 2020 and 2050. Carvalho et al. (2011) also anticipated present and future suitable habitats using climate change scenarios and identified regions where additional protected areas would be required. However, focal species and range shift studies for climate change have limitations for suggesting pragmatic solutions because of the uncertainty of climate change scenarios and the lack of knowledge of responses of different species to climate change in a complex ecosystem (Brown et al., 2001; Beier et al., 2009; Heller and Zavaleta, 2009).

Alternative methods have therefore been proposed recently that use abiotic factors related to habitat conditions, such as temperature, geophysical stage, bedrock, soil, and topographic characteristics etc. (Beier and Brost, 2010; Game et al., 2011; Nunez et al., 2012). The main phenomenon associated with climate change is rising temperature. For this reason, Nunez et al. (2010) assumed that species would move along “temperature gradients” that show less temperature difference than climate change. Temperature contours were drawn and corridors depicted using the temperature gradients that had the lowest temperature differences. The concept of “climatic refugia," similar to the concept of temperature gradients, was also studied and asserted to be valid because these areas are important as habitats for species affected by climate change and may improve the ability of natural ecosystems to adapt to climate change.

Beier and Brost (2010) claimed that the linkage area found by applying topographic characteristics could help to establish ecological connectivity because topographic characteristics like geology and topography are more stable than other environmental factors (Hunter et al. 1988). Brost and Beier (2012a) developed methodology for establishing a linkage area based on topographic characteristics such as elevation, slope, solar insolation, and geology. Three topographic classifications were established by TPI (Topographic Position Index) and Fuzzy c-means methods. The linkage areas for each topographic classification were then designed and merged.

1.4.3 Vegetation catena

The term catena refers to the continuous differences seen in the soils of a slope system from summit to lowland; that is, these are compound rather than individual soils. Compound soils also influence the vegetation properties, so that a vegetation catena is also formed (Milne, 1935; Weil, 2003). The impacts of soil properties on the vegetation community can therefore be seen on slopes (Chen et al., 1997).

A compound soil is divided into eluvial, colluvial, and illuvial zones. The eluvial zone is located in the topmost area, so water and materials are eroded. The colluvial zone occurs on the sloping sides and transports water and materials. The illuvial zone is located in the lowland area and materials are accumulated in this area, so the soil is rich in moisture and organic matter. The mechanisms causing differences between upland and lowland areas are also different from the ecological changes caused by forest fire and flood (Morison et al., 1948).

Davis and Goetz (1990) estimated the distribution of oak forests due to geology, topography, and solar radiation. The geology showed the closest relationship to the vegetation pattern and slope, while solar radiation also had a considerable correlation. Sakai and Ohsawa (1994) reported that the differences seen in two different groups located in a valley and on a ridge were related to the erosion – sedimentation processes occurring in the valley and the ridge.

Vegetation has distinctive distribution patterns that are determined by topographic features like uplands, slope areas, lowlands, and floodplains. For example, typical patterns -—broad banded, spotted, and dashed— were found in western British Somaliland (d'Herbes et al., 2001). Topographic factors have also been recognized in past ecological studies factors that affect the plant and animal distributions (Beier and Brost, 2010), so that topography has been used as an analogue of species diversity in conservation planning (Wessels et al., 1999; Lombard et al., 2003). Some species appear along secondary environmental gradients in a particular landscape, which explains how a vegetation community is related to the landscape property (Austin and Smith, 1989).

Rouget et al. (2003) analyzed the spatial correlation between biodiversity hotspots, spatial factors like soil, riparian corridors, elevation, and ecological processes on a regional scale and suggested that spatial factors could be used as a substitute for biodiversity. Lombard et al. (2003) identified the relationship between biodiversity pattern and topographic classification, and used topographic characteristics for terrain and geological features. Cavalli et al. (2003) analyzed the correlation between geomorphometric units and vegetation cover types and categorized them into 10 classes using geomorphometric variables of elevation, slope, and aspect.

1.4.4 Topographic classification

Landforms have been defined in several ways. This section identified the strengths and weaknesses of each topographic classification, and the most suitable topographical classification to be pursued in this study. Two main classifications, 'Generic topographic classification' and 'Morphometric topographic classification,' were analyzed for dealing with catenas in soil-landscape complexes, and several studies that applied these methods were evaluated.

1.4.4.1 Generic classification

Generic classification is more focused on the flow of water and materials from an ecological perspective (Park, 2004). Pennock et al. (1987) identified soil properties and the relationship between the flow of material and topography by classifying seven topographic classifications based on slope, profile curvature, and plan curvature. The transfer of water and the distributions of slope systems on landforms were confirmed to influence soil properties.

Soil properties affected by topographic characteristics in turn influence vegetation properties (Morison et al., 1948), as shown by generic classification studies conducted many years ago to show the relationship with crop yield. A relationship was identified between soil distribution and topographic characteristics defined by landform segment, and the impact on crop yields was assessed by the substantial losses of soil organic carbon at the landscape scale (Pennock et al., 1994). Macmillan et al. (2000) further developed the previous classification model of Pennock et al (1987; 1994) to solve problems such as recognizing and classifying topographic characteristics in lower land area, fragmentation of topographic characteristic patterns, and the inflexibility of the spatial scale. In total, 15 topographic classes were identified and grouped into 3 or 4 units that explained the relationship with crop yield.

Reuter et al. (2005) also modified the classification of Pennock et al. (1994) and added a planar landform unit to identify 11 topographic classes. Four landforms (Shoulder, Backslope, Footslope, and Level) were aggregated and showed that crop yield could vary by as much as 0.7 $t \cdot ha^{-1}$ between these landforms. The protein content in the grain also increased from the shoulder to the footslope. Therefore, the use of topographic classification could be expanded to improve the management of crop growth.

Park et al. (2001) automated the 'nine-unit soil-landscape model' of Conacher and Dalrymple (1977) and developed the Terrain Characterization Index (TCI) to reflect the geomorphological and biological processes in a slope area. The TCI had a substantial correlation with the thickness of the A horizons (r = -0.63) and the thickness of loess (r= -0.78). This model was also applied in Korea by Park (2004), who assumed that hydrological and pedological processes on the earth's surface are critical factors of ecological consequence. Eight topographical classes were identified by adapting the model of Conacher and Dalrymple (1977).

1.4.4.2 Morphometric classification

Morphological characteristics like elevation, slope, and curvature are significant indexes for morphometric classification, an object-based analysis. This method could provide quantitative information of topography under current conditions (Park, 2004). Dragut and Blaschke (2006) tried to further improve the nine class system of Dikau (1989) to reflect a real landscape using topographic variables such as elevation, slope, profile curvature, and plan curvature. Nine new topographic classes were recognized and three groups were stratified along the elevation. This method is feasible for use in diverse scales and regions because it calculates the relevant differences with a peripheral object (Dragut and Blaschke, 2006). Gercek et al. (2011) used slope, profile curvature, plan curvature, maximum curvature, and minimum curvature, and developed 15 topographic classes by adapting several morphometric and topographic classification methods that involved the local geometry of the surface. Diverse scale units were also implemented at the study sites and showed that morphometric classification was strongly related to the scale.

The TPI has been used in recent years to reflect the topographical context (Weiss, 2000). For example, Jang et al. (2009) applied TPI for mountainous topographic classification and found a scale factor that could interpret the land forms of mountain forests in South Korea. Several other studies also found correlations between TPI and species distributions. The cougar (Puma concolor) was found to discriminate topographic position by use, primarily using canyon bottoms and gentle slopes primarily for traveling or hunting, while avoiding ridge areas compared to other topographic positions (Dickson and Beier, 2007). Park et al. (2007) predicted the distribution of forest wetlands by applying topographic classification calculated by TPI. The slope criteria impacts on the distributions of potential forest wetlands were determined by comparing them with real forest wetlands. Brost and Beier (2012a) developed methodology for establishing the linkage area by considering topographic characteristics like elevation, slope, solar insolation, and geology. Three topographic classifications were divided by TPI and Fuzzy c-means method and a linkage area was then designed for each topographic classification.

2. Methods

2.1 Study sites and data

2.1.1 Study sites

Three sample sites were chosen for identifying the feasibility of establishing connectivity using the topographic characteristics in Chungcheong-do. The sites were fragmented by roads, residential areas, and crop lands, etc. and were sufficiently sized to contain wildlife habitats.

Two sites located between National Parks were selected in the application stage for designing a linkage using topographic characteristics. National Parks are important as nodes for establishing the Ecological Network in South Korea (Sin, 2013). The first site, which has the highest mountains, is in the area between Seorak Mountain National Park and Odae Mountain National Park. The second site, which links two large mountain ranges (Seorak~Taebaek Mts. and Jiri Mt.), is in the area between Songni Mountain National Park and Worak Mountain National Park (Sin, 2013).

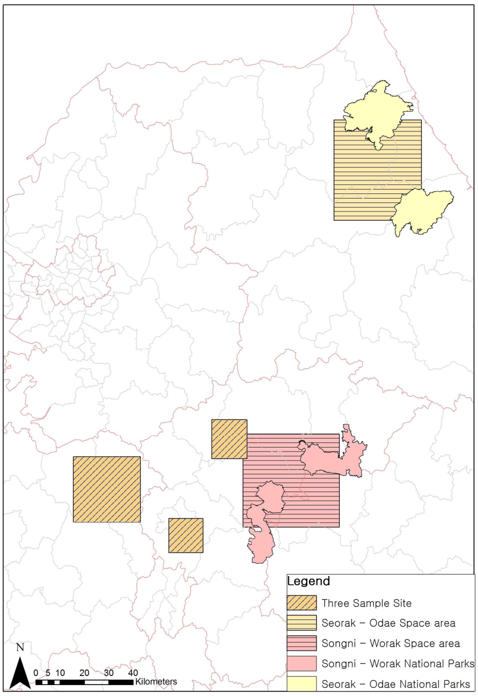


Figure. 2. Study sites are consists of 3 sample sites and 2 space between National parks (Ministry of environment, 2011)

2.1.2 Data

The Digital elevation model (DEM) presents a continuous topographical relief as a 2-dimensional surface and is used extensively in topographic analysis (Jeon et al., 2010). This study used a 10m DEM map (National Geographic Information Institute, South Korea) that best reflects the topographic characteristics of South Korea. Use of a grid cell size larger than 10m could result in loss of geomorphological information by the 'smoothing effect,' while use of a grid cell size smaller than 10m could create errors such as microvariance and interpolation errors (Park and Yu, 2004).

Vegetation type distribution data were obtained using the Forest Cover Type map (Korea Forest Service), which divides the study sites into three forest types: coniferous, deciduous, and mixed. Amphibian appearance data was obtained from the National Ecosystem Survey (2^{nd}'97～'05, 3^{rd}:'06～'08).

2.2 Correlations between topographical characteristics and vegetation type distributions

2.2.1 Topographic and vegetation type variables

The topographic variables used in a correlation analysis are elevation, slope, aspect, upslope contributing area (A_s), surface curvature (C_s), and topographic wetness index (TWI). These variables are applied to find the relationship between topographic characteristics and vegetation typologies (Cavalli et al., 2003). Elevation is a known factor that affects the distribution of vegetation due to its close association with climate and meteorology. Vegetation distribution is related to microclimate under the influence of aspect and slope (Birkland, 1999). The A_s is used for hydrological and soil erosion-accumulation algorithms and refers to the total catchment area above a given point on a landscape (Park et al., 2001). The Multiple-Flow-Direction Method used to calculate the upslope contributing area distributes the materials to adjacent cells, in contrast to the Single-Flow Direction Method, and transmits the materials to the steepest cell (Freeman, 1991). The A_s in Eq. (1) is defined as (Park et al., 2001):

$$A_S = (1/b)\sum_{i=1}^{n} p_i A_i \tag{1}$$

Where A_i : the area of the cell i (m^2)
n : the number of cells draining into the grid cell i
p_i : the weight depending on the runoff generation mechanisms
b : the contour width approximated by the cell resolution (m)

Surface Curvature is about three-dimensional surface curvature index (C_s) is calculated by the following Eq. (2).

$$C_s = (\sum_{j=1}^{n}(z_j - z_n)/d_{jn})/n = g(x,y) \tag{2}$$

Where z_i : the elevation of the grid cell I (m)
z_n : the mean elevation of the surrounding grid cells (m)
d : the horizontal distance between two grid cells (m)
n : the total number of surrounding cells used in the evaluation

The formation of a convex or concave slope depends on the Cs value. A Cs value larger than zero indicates a primarily convex slope, while a negative Cs value generally means a concave slope. A convex surface reflects erosion while a concave surface indicates accumulation. Surface curvature and slope aid in determining the amount and speed of the stream of soil materials, organic matter, water, and minerals (Florinsky et al., 1996).

The TWI is useful for predicting the spatial distribution of vascular plant species richness (Zinko, 2004). The TWI is calculated by Eq. (3)

$$TWI = \ln(A_s / \tan ß) \qquad (3)$$

Where A_s : upslope contributing area (m^2)

ß : slope (degree)

The slope and aspect were calculated by ArcGIS 9.3. The upslope contributing area and TWI were calculated by the System for Automated Geoscientific Analyses (SAGA). Surface curvature was obtained using the program by Park et al. (2001).

The vegetation type variable was restricted to coniferous and deciduous forests. Mixed forest data could not be used because they lacked the distinct environmental property of vegetation type distribution.

2.2.2 Correlations between topographical characteristics and vegetation type distributions

Correlations between topographical characteristics and vegetation type distributions were analyzed for all three sample study sites. Topographical variables were all continuous variables except for aspect (categorical). Vegetation type value was a nominal variable. The Spearman's Rank Correlation Coefficient, which can cover nonparametric variables, was used in the analysis.

Maps of each topographical variable were first made from DEM and the vegetation type variable was made from the Forest Cover

Type map. Vegetation type variable was encoded from 0 and 1 to make a nominal variable for each forest type. Then, 1,000 random points were created in the coniferous and deciduous forests to give a total of 2,000 random points on each study site map. The values for the points on the variable maps were extracted by using the "Extract Values to Points" tool in the Spatial Analyst extension of ArcGIS 9.3. Spearman's Rank Correlation Coefficient was analyzed using SPSS Statistics 21.

2.3 Comparison between the methods of topographic classification for considering ecological characteristics

2.3.1 The selection of topographic classification

The methods of topographic classification are broadly divided to morphometric and generic classifications (Park, 2004). The generic classification field includes the methods of Macmillan et al. (2000) and Reuter et al. (2005) developed from Pennock et al. (1987; 1994) and the method of Park et al. (2001) adapted from Conacher and Dalrymple (1977). The method of Park et al. (2001) is suitable for considering the hydrological and pedological processes on the earth's surface (Park, 2004), so this method was used, as adapted by Park (2004) and Jeong (2011), for application in South Korea.

The morphometric classification field includes the methods of Dragut and Blaschke (2006), Gercek et al. (2011) and Weiss (2001). The TPI developed by Weiss (2001) was mainly used to find the correlation with ecological characteristics and was applied in South

Korea (Dickson and Beier, 2007; Park et al., 2007; Jang et al., 2009), so that method was adopted in this study.

2.3.2 Morphometric classification

Morphometric classification uses the TPI as the typical method and is graded by elevation or slope difference between a criterion grid cell and adjacent cells. A positive value for the TPI means that the cell is higher than the adjacent cells (i.e., at the top of a mountain); otherwise, the cell is lower than the adjacent cells (i.e., in a valley) (Weiss, 2001). The merit of morphometric classification is that it is easier than other methods because it requires only a topographical map or DEM. It is a sensitive method but it depends on grid cell size (scale). This defect is overcome by applying small neighborhood (SN) and large neighborhood (LN) scales (Lee and Kim, 2001). The SN has the advantage to explaining small changes in topography, while the LN is a better classification method for large areas. The morphometric classification is focused on the shape of the topography itself, so it is not suitable for determining the ecological processes caused by topography (Park, 2004).

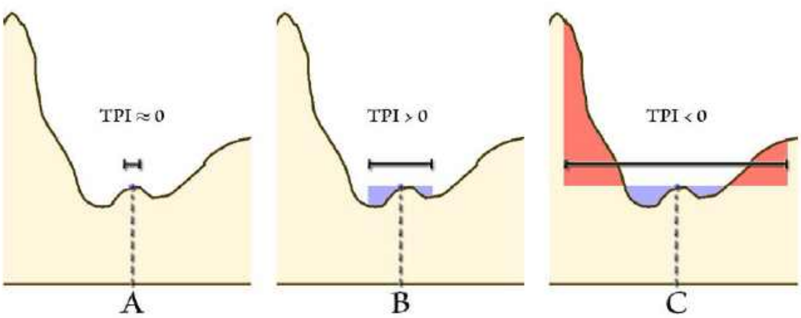


Figure. 3. TPI values depended on scale (Jenness et al., 2012)

2.3.3 Generic classification

Generic classification is characterized by involving the process of terrain formation such as erosion and accumulation. Erosion and accumulation are also in the basis of ecological process. Park et al. (2001) defines generic classification as a geomorphological classification system that is able to quantify the stream of water, energy, and materials. The relationship between the upslope contributing area (A_s) and surface curvature(C_s) is mainly used to classify the topography (Figure 4).

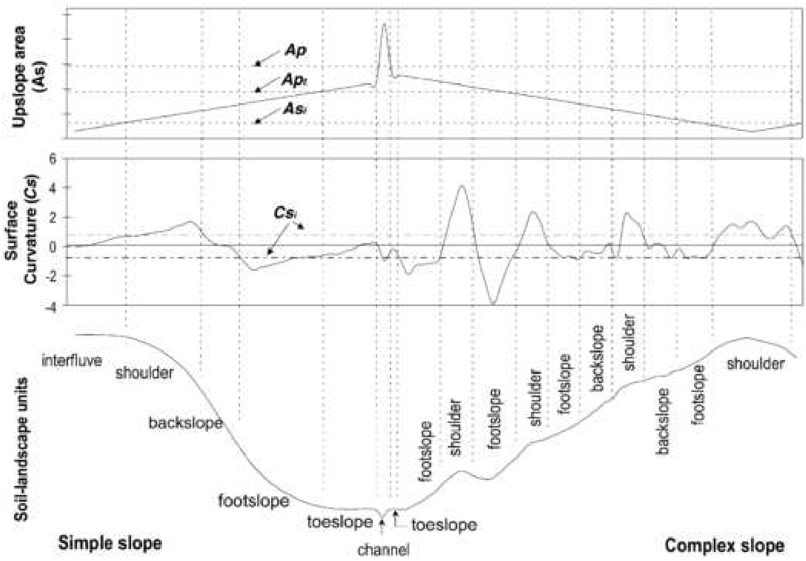


Figure. 4. topographic classification with A_s and C_s in generic classification (Park et al., 2001)

The scatter plot is then made from the data of upslope contributing area and surface curvature is used for classifying the topography (Park et al., 2001). Several types of topography are then defined from the categories in the scatter plot (Figure 5), where ① is Summit (the region divided by two rivers in the one drainage system); ② is the Shoulder (This region has a positive surface curvature value so an erosion process shows predominantly); ③ and ⑤ are Backslope I and Backslope II, respectively (These regions achieve an equilibrium of inflows and outflows); and ④ is the Footslope (This has a negative value for the surface curvature, indicating more of an inflow than erosion); ⑥ is the Toeslope (This area is saturated with ground water and accumulates alluvial deposition from upvalley); and ⑦ is the channel (The river emerge at ⑦) (Park, 2004; Jeong, 2011).

Classification of the topography by generic classification requires some parameters to be set, such as A_{si}, A_{st}, A_p and C_{si} (as in Figure 5). Especially for C_{si}, the points near the x-axis have to be contained between positive and negative values (Park and Giesen, 2004). Drawings of topography shown in the study sites were included in the analysis. Scatter plots were constructed using ENVI Software, and then each topographic region was calculated using the "raster calculator" tool in the Spatial Analyst extension of ArcGIS 9.3.

2.3.4 Comparison analysis with coniferous forest & amphibian distribution

The topographic classifications that can be considered ecological characteristics were identified using the methods of topographic classification to determine whether a relationship existed between the results of topographic classification and species distribution (Davis

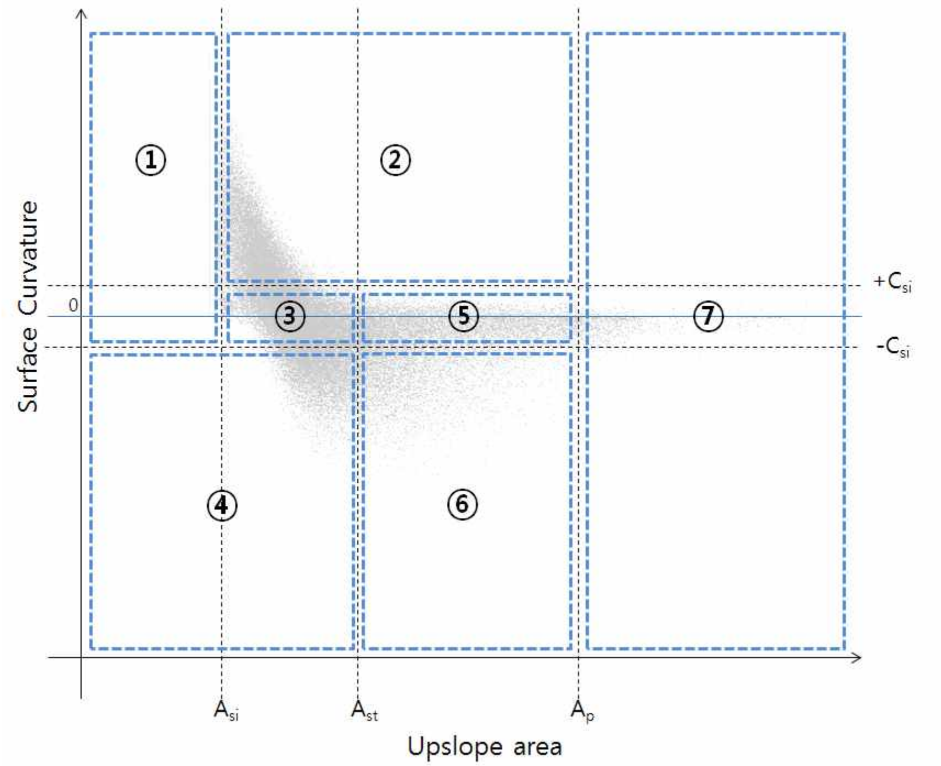


Figure. 5. Correlation between upslope contributing area and surface curvature (referred to Park, 2004; Jeong, 2011)

and Goetz, 1990). Topography affects habitat condition or species distribution such as ecological characteristics mainly by the processes of erosion, transmission, and sedimentation (Morison et al., 1948). These effects were shown between coniferous forests and amphibians in this research.

Coniferous trees are strongly xeric and occur on acidic soils on ridges (Andersson. 2005). Amphibians, in contrast, appears in valleys or adjacent to streams because their life cycles are closely linked with water (Semlitsch and Bodie, 2003). Amphibians are only aquatic in juvenile stages, but adult amphibians remain close to the streams and valleys.

The coniferous forest data were polygons and amphibian appearance data were points, so the area ratio of coniferous forest in each topographic class was made by the “Zonal statistics tool” in ArcGIS 9.3 and analyzed by the “Kruskal-Wallis Test” in SPSS 21.0. The topographic classes that matched with amphibian appearance points were extracted and analyzed by “Analysis of Frequency and Chi-Square Test” in SPSS 21.0.

2.4 Searching the linkage areas by applying topographic characteristics

2.4.1 Identifying the termini

The termini needing to be connected were identified for each map of topography. However, all topography types classified were scattered in all the maps, so the polygons for connecting the termini were made by applying the focal statistics concept and the area was large enough to take possession of 50% of the termini. The focal statistics concept set the values for surrounding other cells of the focal topography type (Brost and Beier, 2012a). Grid cell values were fixed to 1 or 0 by containing or excluding them, and then the density was defined. Density refers to the values calculated by summing the neighborhood grid cell values and converting them to a ratio (Lee et al., 2005) (Figure 6). The termini were then calculated using the “Identify Termini Polygons” tool in the Land Facet Corridor extension of ArcGIS 9.3.

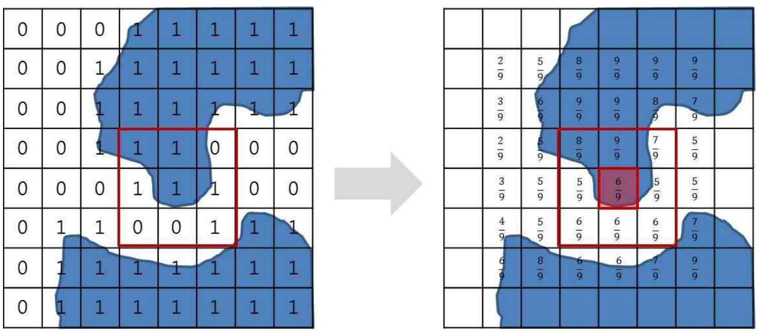


Figure. 6. Density concept (revised by Lee et al., 2005)

2.4.2 Making the cost surface

The linkage area for topography connecting was constructed using the least-cost path analysis, while the cost surface was made by applying the Mahalanobis distance, which is the relative distance from a parameter point in a multi-dimensional space (Hayashi et al., 2001), calculated by Eq. (4):

$$D^2 = (x - m)^T \times C^{-1} \times (x - m) \tag{4}$$

Where D^2 : Mahalanobis distance

x : vector of data

m : vector of mean values of independent variables

C^{-1}: inverse Covariance matrix of independent variables

T : indicates vector should be transposed

The Mahalanobis distance is often used in manufacturing and medical research. Application of the Mahalanobis distance to independent variables is important because an ideal status is thought to be a parameter, where the parameter is a factor that affects critical responses. In the present research, topographic variables closely related to vegetation distributions were used in calculating the Mahalanobis distance map. This analysis was implemented in the Mahalanobis Distance extension of ArcGIS 9.3 (Jenness et al., 2012). The “Cost Distance” to ArcGIS 9.3 was then used to produce cumulative cost surfaces by summing the two cost-distance maps (one for each terminus).

2.4.3 Searching the linkage areas using the least-cost path analysis

Producing a linkage area by applying topographic characteristics was the ultimate objective in this research and was achieved by least-cost path analysis using the Create corridor slices tool in the Corridor Designer ArcGIS toolbox (Majka et al., 2007). The width of the linkage area was set to more than the average 1 km width because most linkage areas for focal species (small and large animals) are less than this width (Beier et al., 2009) and the linkage area should be secured over a 1 km width to sustain its function for many decades (Harris, 1991).

2.5 Applying in the national park

The steps in 2.4 part were applied to the areas between the National Parks (Seorak Mountain and Odae Mountain, Songni Mountain, and Worak Mountain National Parks). The resulting linkage areas for these regions were then compared with the Baekdudaegan Protected Areas.

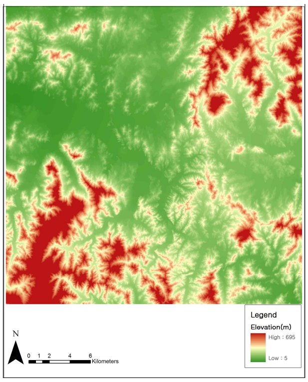
3. Results

3.1 Correlations between topographical characteristics and vegetation type distributions

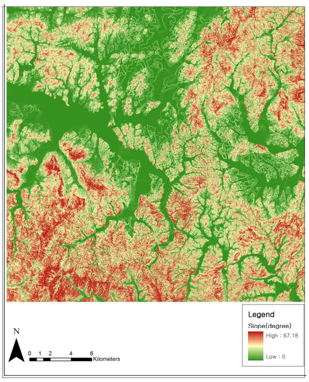
3.1.1 Establishing variables

Six kinds of topographic variables and vegetation type variables were established for each study site (Figure 7). The upslope contributing area variable was replaced by a logarithmic function since the variation in values was very large (Park et al., 2001). The values of the upslope contributing area appeared in the lower elevation and the downstream river area due to the accumulative flow. The TWI is the secondary terrain parameter using the upslope contributing area and slope, and the TWI was showed a similar trend to the upslope contributing area. The surface curvature indicated that closer grid cells gave larger values. A relatively large value of surface curvature means a convex slope, indicating a vigorous erosion process (Florinsky et al., 1996).

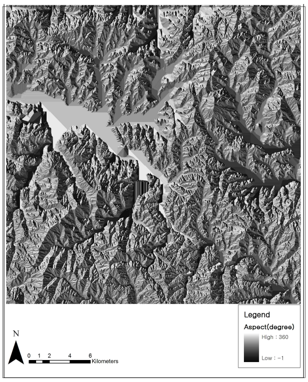
The vegetation type variable was encoded as 0 or 1 to create a nominal variable for each forest type. These file forms were then converted from polygons to rasters to extract the values.



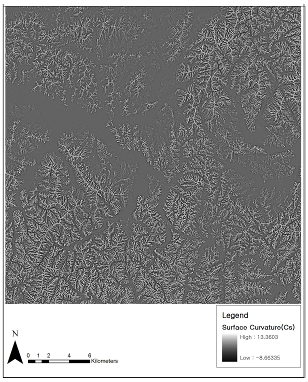
(a) Elevation



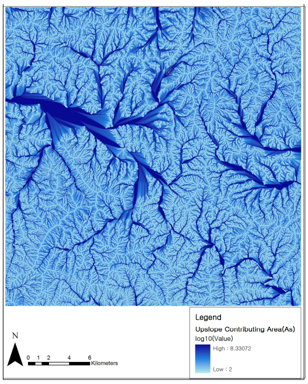
(b) Slope



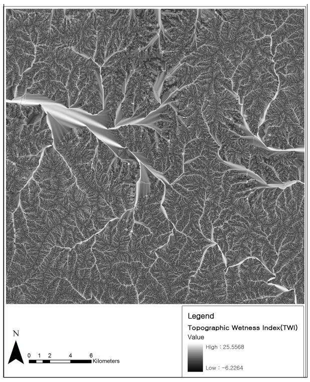
(c) Aspect



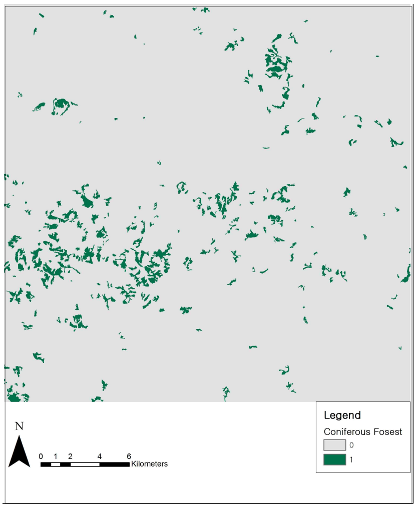
(d) Surface Curvature



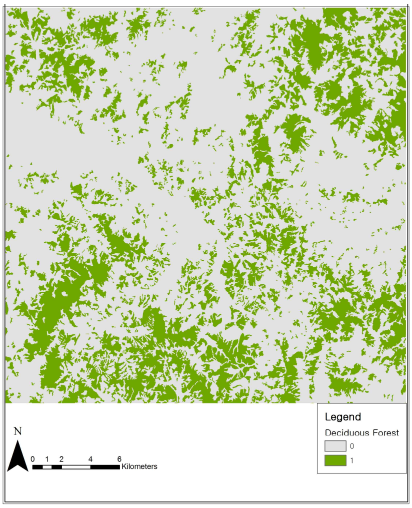
(e) Upslope Contributing Area



(f) Topographic Wetness Index



(g) Coniferous Forest



(h) Deciduous Forest

Figure. 7. Topographic and vegetation type variables used in the site 1

3.1.2 Correlations analysis

The variable maps created earlier were used to analyze the correlations between topographical characteristics and vegetation type distribution in all three study sites (Table 3). The correlations between topographic variables were first tested because the principles of formation of variables were already determined. Almost every variable had significant correlations with each other at the 0.01 and 0.05 level, except for aspect.

The elevation (Elev) had a positive correlation with slope, with correlation coefficients from 0.35 to 0.424. The C_s had a positive correlation with Elev and had a negative correlation with A_s. The correlation coefficient with Elev was from 0.078 to 0.098 and with A_s was from -0.796 to -0.741, indicating that a higher elevation was associated with a larger surface curvature and represented an area where a lot of water accumulated, assuming a concave terrain shape. The TWI is affected by soil erosion and accumulation processes (Zinko, 2004), so the A_s and C_s used for generic topographic classification showed significant correlations with the TWI. The TWI had a positive correlation with A_s and had a negative correlation with C_s. The correlation coefficient with A_s was from 0.345 to 0.405 and with C_s was from -0.363 to -0.278 (Appendix. Table S-1, S-2).

Table. 3. Correlations between topographical characteristics and vegetation type distributions in the site 1

		Aspect	C_s	Elev	A_s	Slope	TWI	Forest
Aspect	Correlation Coefficient	1.000	−.008	.013	−.003	−.024	.019	−.007
	Sig. (2−tailed)		.720	.572	.909	.287	.390	.748
C_s	Correlation Coefficient		1.000	.092**	−.786**	−.020	−.278**	−.057*
	Sig. (2−tailed)			.000	0.000	.370	.000	.011
Elev	Correlation Coefficient			1.000	−.001	.404**	.016	.126**
	Sig. (2−tailed)				.951	.000	.480	.000
A_s	Correlation Coefficient				1.000	−.014	.345**	.083**
	Sig. (2−tailed)					.538	.000	.000
Slope	Correlation Coefficient					1.000	−.025	.087**
	Sig. (2−tailed)						.256	.000
TWI	Correlation Coefficient						1.000	.041
	Sig. (2−tailed)							.064

**. Correlation is significant at the 0.01 level (2−tailed).

*. Correlation is significant at the 0.05 level (2−tailed).

The vegetation type variable had a significant correlation between several topographic variables at the 0.01 and 0.05 levels (Table 4). The Elev and A_s had a significant correlation at the 0.01 level for all three study sites. The C_s and slope had a significant correlation at the 0.01 and 0.05 level for two study sites.

The variables related to erosion and accumulation processes, such as the A_s, C_s, and the slope showed a significant correlation, indicating that the vegetation type and topographic characteristics have a critical relationship. Elev is also related to climate and weather, so it also affects vegetation distribution (Strahler, 1978; Franklin, 1995).

Table. 4. Correlation coefficient between topographic variables and vegetation type distribution

Forest	Aspect	C_s	Elev	A_s	Slope	TWI
Site 1	−.007	−.057*	.126**	.083**	.087**	.041
Site 2	−.019	−.022	.577**	.223**	.416**	.093**
Site 3	−.025	−.091**	−.128**	.146**	−.015	.017

**. Correlation is significant at the 0.01 level (2-tailed).

3.2 Comparison between the methods of topographical classification for considering ecological characteristics

3.2.1 Interpretation of topographic classification

3.2.1.1 Morphometric classification

Morphometric classification, in general, could not reflect topographical characteristic because this method only considered the relative elevation differences with surrounding cells and slope. Ridge and Valley had no connectivity, while Lower slope and Gentle slope were clustered well. River topography, in particular, did not sort out from lowland topography and was contained in the Gentle slope (Figure 8).

The steep slope represented the greatest part of the classification results, ranging from 51.52% to 54.22% in the study sites. The variables showed similar trends in all sites. The gentle slope that included river topography had the least area and a 54.28 - 131.39 m range of elevation. The slope was the steepest for the Steep slope because of the slope parameter (over 5 degrees). The highest values of A_s were in Valley, Lower slope, and Gentle slope, which had a low slope and a low elevation. However, the Steep slope, which had a steeper slope than Upper slope, had a lower A_s value than the Upper slope. The TWI showed a similar tendency to A_s. The surface curvature showed a negative value in the topography outside of the Upper slope and Ridge, and even for the Steep slope (Table 5).

Table. 5. Statistics(means) of morphometric topographic classification

Site 1	percentage of area(%)	Elev	Slope	A_s	C_s
Valleys	0.52	127.48	10.14	4.36	−1.68
Lower slope	11.85	114.44	9.78	3.92	−0.88
Gentle slope	24.93	54.28	0.78	4.16	−0.01
Steep slope	51.73	170.14	19.76	2.92	−0.03
Upper slope	9.30	154.63	13.17	2.38	1.07
Ridge	1.66	173.39	11.27	2.06	1.85

Site 2	percentage of area(%)	Elev	Slope	A_s	C_s
Valleys	0.78	189.33	9.69	4.32	−1.59
Lower slope	13.62	189.21	10.52	3.87	−0.93
Gentle slope	18.62	131.39	1.25	3.70	−0.01
Steep slope	54.22	245.01	20.59	2.90	−0.05
Upper slope	10.57	228.11	14.68	2.38	1.16
Ridge	2.19	243.22	11.88	2.06	1.94

Site 3	percentage of area(%)	Elev	Slope	A_s	C_s
Valleys	0.66	131.04	7.98	4.30	−1.27
Lower slope	12.71	120.93	8.13	3.86	−0.72
Gentle slope	23.68	77.33	1.21	3.61	−0.01
Steep slope	51.52	178.02	18.91	2.90	−0.03
Upper slope	9.60	154.90	11.76	2.43	0.93
Ridge	1.84	177.48	10.49	2.06	1.69

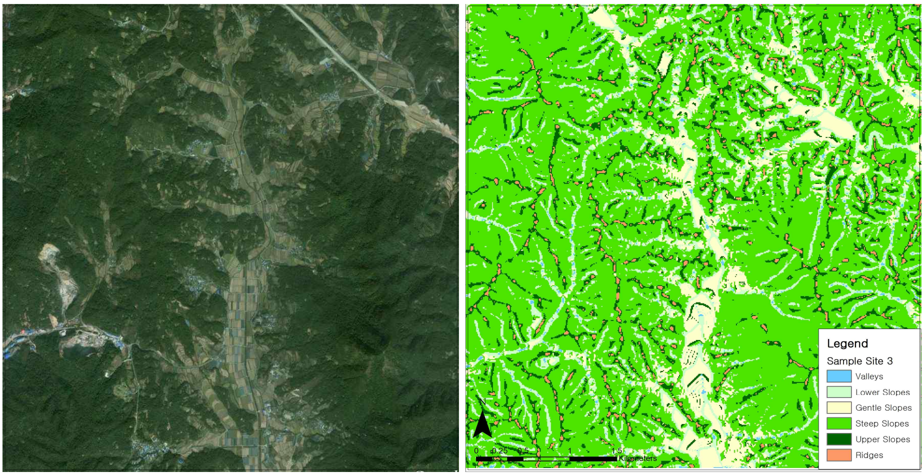


Figure. 8. Morphometric topographic classification results in a part of sample site 3 (source : Google Earth)

3.2.1.2 Generic classification

The criteria have to be fixed to separate the topography characteristics before implementing the generic classification. Tab. 6 shows the criteria for generic topographic classification in the study sites. These criteria can be different values for each region (Park, 2004). However, the criteria used in this research showed a similar tendency with other related study sites located in Korea.

In this research, A_{si} ranged from 2.1 to 2.25. This value is the reference point that separates Influve and Backslope. The point for this value is located at the starting point of the negative relationship between the A_s and C_s. The A_{st} ranged from 3 to 3.2. Footslope and Toeslope were divided by A_{st}. These two topographic characteristics have a negative C_s, meaning that sedimentation and Toeslope have a greater influx of materials than does Footslope. The A_p ranged from

4.5 to 5.2. Toeslope and Channel were divided by A_p. River can appear in Channel, so A_p was controlled to contain river topography.

Table. 6. Criterion values for generic topographic classification in the study sites

	A_{si}	A_{st}	A_p	C_{si}
Site 1 (Cheonan, Asan)	2.25	3	4.5	0.19
Site 2 (Eumseong, Chungju)	2.1	3	5.2	0.22
Site 3 (Cheongju)	2.1	3.2	5	0.18
Park (2004) (Yangpyeong)	1.5	3	4.3	0.17
Jeong (2011) (Namyangju)	2.4	3.6	4.5	0.17
Park et al. (2001) (Wisconsin, USA)	2.5	3.5	4	0.25

The generic classification, on the whole, showed that this method could divide topography in detail. Shoulder appeared clearly at the mountain ridge and Footslope and Backslope appeared principally between Shoulders. Shoulder and Footslope had a good connectivity. River topography was distinguished from the Channel when compared to morphometric classification. However, low elevation areas such as Channel and Backslope II were not accurate when compared to remote sensing satellite image (Jeong, 2011) (Figure 9).

Shoulder was the highest and the steepest areas. It was located in the upper area of the mountains, so this area had the smallest A_s and the largest C_s values, meaning that erosion was the most active. Backslope I and Backslope II have values close to 0, which means that transmission of materials like water, soil, and nutrients, etc. occurred in these areas.

The C_s had a negative value in Toeslope, Footslope, and Channel. The TWI had a positive value in these areas because of the accumulation of soil and organic matter, etc. that occurred in these areas.

Summit represented only a small part of the study sites, accounting for less than 7% of the study areas. This topography was difficult to separate because the present range is restricted to a very small area in Korea (Park, 2004) (Table 7).

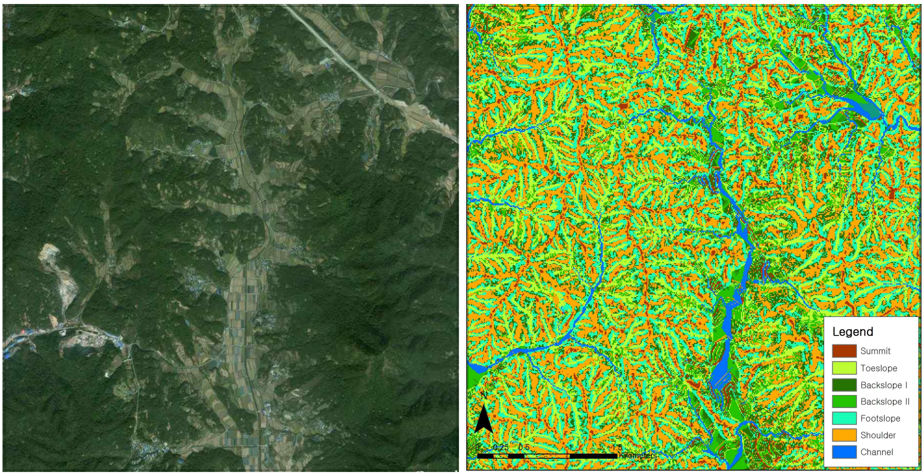


Figure. 9. Generic topographic classification results in a part of sample site 3 (source : Google Earth)

Table. 7. Statistics(means) of generic topographic classification

Site 1	percentage of area(%)	Elev	Slope	As	Cs
Summit	7.17	151.90	10.53	2.12	1.20
Toeslope	18.17	154.47	14.84	3.56	−0.80
Backslope Ⅰ	13.08	123.61	14.17	2.69	0.01
Backslope Ⅱ	16.76	77.00	4.26	3.68	−0.02
Footslope	10.94	160.70	21.68	2.78	−0.62
Shoulder	21.46	182.17	20.59	2.59	0.70
Channel	12.43	67.75	1.85	5.33	−0.18

Site 2	percentage of area(%)	Elev	Slope	As	Cs
Summit	5.79	183.78	6.32	2.02	0.91
Toeslope	20.22	231.72	15.48	3.68	−0.91
Backslope Ⅰ	14.88	198.69	14.35	2.63	0.01
Backslope Ⅱ	18.31	153.17	4.39	3.82	−0.03
Footslope	12.39	235.24	22.35	2.75	−0.68
Shoulder	24.62	261.24	22.03	2.47	0.93
Channel	3.78	142.97	2.34	5.75	−0.22

Site 3	percentage of area(%)	Elev	Slope	As	Cs
Summit	5.60	121.12	5.54	2.02	0.73
Toeslope	14.68	156.00	12.38	3.80	−0.74
Backslope Ⅰ	18.49	128.14	11.51	2.74	0.00
Backslope Ⅱ	16.90	86.80	2.61	3.90	−0.02
Footslope	16.40	166.41	18.68	2.85	−0.58
Shoulder	23.60	190.94	19.39	2.54	0.74
Channel	4.35	92.18	2.30	5.52	−0.22

3.2.2 Comparison analysis with coniferous forest distributions

The area ratio of coniferous forest in each topographic classes was first determined roughly for morphometric and generic classifications. The area ratio of coniferous forest for morphometric classification decreased from Ridge to Steepslope, but a different trend was seen for Gentleslope, Lowerslope, and Valley (Table 8).

Table. 8. Ratio of coniferous forest in each topographic classes in morphometric classification (unit : %). It decreases from Ridge to Steepslope, but the other do not have any trends.

Morphometric Classification	Ridge	Upper slope	Steep slope	Gentle slope	Lower slope	Valleys
Site 1	38.82	33.44	21.98	30.29	16.16	15.37
Site 2	40.67	36.83	30.90	20.19	28.56	28.07
Site 3	46.21	39.65	27.95	29.77	22.53	25.35

The area ratio of coniferous forest for generic classification decreased gradually from Summit to Channel (Table 9). However, at site 3, Footslope had a higher area ratio of coniferous forests than did Backslope II.

Table. 9. Ratio of coniferous forest in each topographic classes in generic classification (unit : %). It decreases from Summit to Channel, except Site 2.

Generic Classification	Summit	Shoulder	Back slope I	Foot slope	Back slope II	Toeslope	Channel
Site 1	35.59	26.08	24.61	20.52	21.18	16.84	15.09
Site 2	38.24	33.89	30.87	29.40	30.63	29.04	23.81
Site 3	44.07	33.06	28.81	26.39	25.16	22.41	20.75

Table. 10. Kruskal-Wallis test results concerning the ratio of coniferous forest

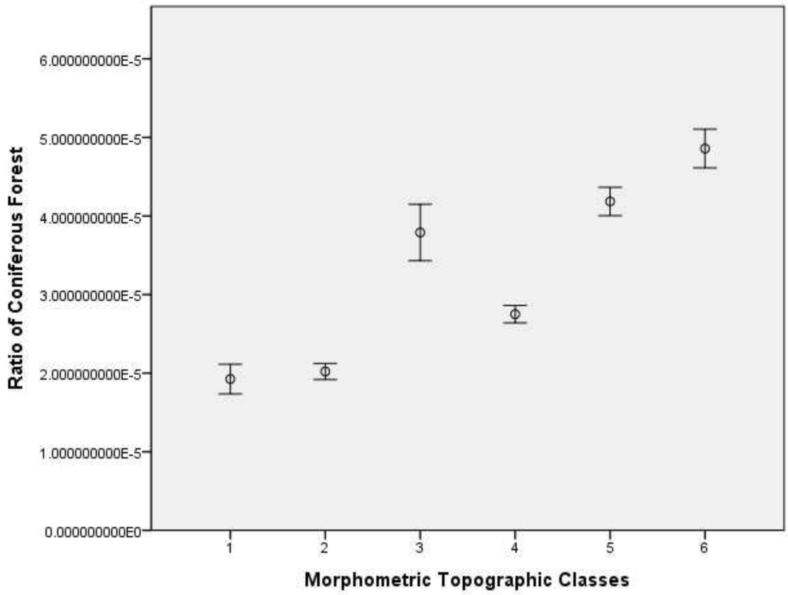
	Morphometric Classification			Generic Classification		
	Chi-Square	df	Asymp. Sig	Chi-Square	df	Asymp. Sig
Site 1	8047.226	5	.000	8407.596	6	.000
Site 2	5191.909	5	.000	6055.741	6	.000
Site 3	4519.880	5	.000	5664.276	6	.000

Erosion topography indicated that coniferous trees that have strong xeric characteristics were represented in two of the topographic classifications well. On the other hand, the transmission and accumulation topography, like Gentleslope, Lower slope, and Valley, did not show this trend in morphometric classification (Figure 10).

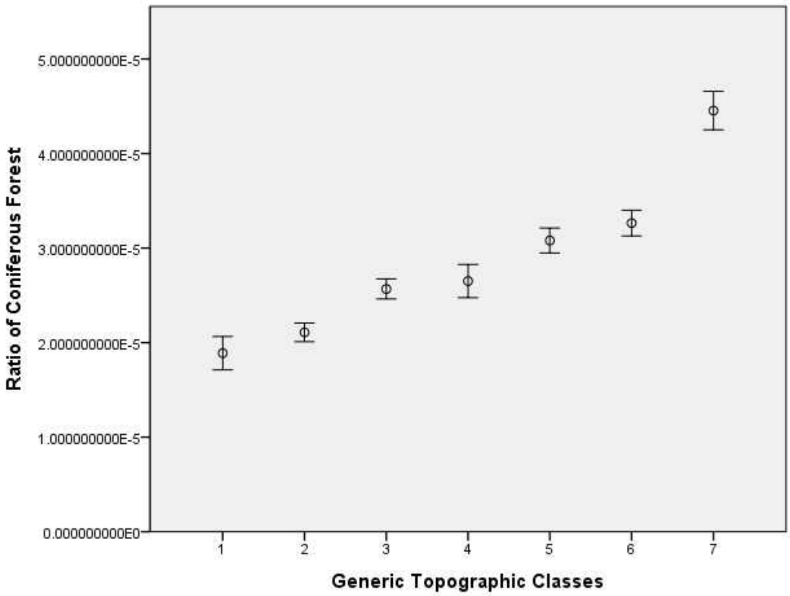
The statistical significance of this result was tested by separating the entire coniferous forest area by each polygon and conducting an analysis using the Kruskal-Wallis test. The results were statistically significant at the 0.01 level and Chi-Square values for generic classification were higher than for morphometric classification. This means that the results of generic classification have more distinct differences than morphometric classification in terms of each topography class in the area ratio of coniferous forest (Table 10).

The mean ratio of coniferous forest in each topographic class also decreased from Summit to Channel in the generic topographic classification and from Ridge to Steepslope in the morphometric topographic classification.

In conclusion, the correlation between coniferous forest showing erosion of materials in topography was also clearly seen in the generic classification.



(① Valleys, ② Lowerslope, ③ Gentleslope, ④ Steepslope, ⑤ Upperslope, ⑥ Ridge)



(① Channel, ② Toeslope, ③ Footslope, ④ Backslope II,
⑤ Backslope I, ⑥ Shoulder, ⑦ Summit)

Figure. 10. The mean graph of the ratio of coniferous forest in two topographic classification in sample site 1

3.2.3 Comparison analysis with amphibian distributions

Topographic classes at amphibian appearance points were analyzed by frequency analysis and tested for statistical significance by a Chi-Square test. The value close to '0' indicated a statistically significant difference between the topographic classes.

The morphometric topographic classification showed Steepslope to have the most amphibian appearance points, at 110 of 221 points, and next was Gentleslope (Table 11). Steepslope appeared at a slope area and adjacent valley area, and Gentleslope was located in the stream and floodplain (Figure 8). However, Steepslope occupied most of the area, at about 50%. The generic topographic classification showed Channel, located in river, to have the most amphibian appearance points, at 53 of 221 points, and next was Toeslope at 47 points (Table 12).

The Chi-Square value was much higher for the morphometric topographic classification than for the generic classification. This means that the morphometric classification showed a stark difference between the topographic classes for generic classification. Therefore, the morphometric topographic classification could be understood to represent the amphibian distribution.

Table. 11. Frequency of amphibian appearance in morphometric classification

Topographic Classes	Observed N	Expected N	Residual
Valleys	4	36.8	-32.8
Lowerslope	54	36.8	17.2
Gentleslope	45	36.8	8.2
Steepslope	110	36.8	73.2
Upperslope	4	36.8	-32.8
Ridge	4	36.8	-32.8
Total	221	-	-

Chi-Squre	242.955
df	5
Asymp. Sig.	.000

Table. 12. Frequency of amphibian appearance in generic classification

Topographic Classes	Observed N	Expected N	Residual
Summit	9	31.6	-22.6
Shoulder	24	31.6	-7.6
Backslope I	26	31.6	-5.6
Backslope II	30	31.6	-1.6
Footslope	32	31.6	0.4
Toeslope	47	31.6	15.4
Channel	53	31.6	21.4
Total	221	-	-

Chi-Square	41.104
df	6
Asymp. Sig.	.000

3.3 Searching the linkage areas by applying topographic characteristics

3.3.1 Identifying the termini

In this part, the linkage area obtained by applying topographic characteristic was established by morphometric and generic topographic classification. Figure 11 shows the results of generic and morphometric topographic classification and the termini for each sample site. To search for the linkage areas by applying topographic characteristics, termini have to be set for every topography characteristic. The termini for topography characteristics were identified by density concept applied focal statistics. The focal statistics concept set the values for cells surrounded by other cells of the focal topography type (Brost and Beier, 2012a). Termini for each topographic characteristic were secured by the polygon shape. The

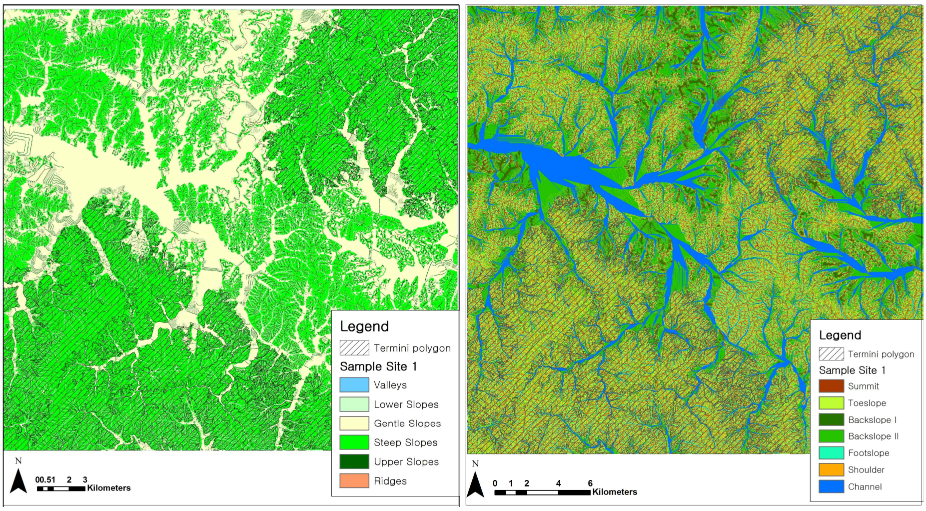
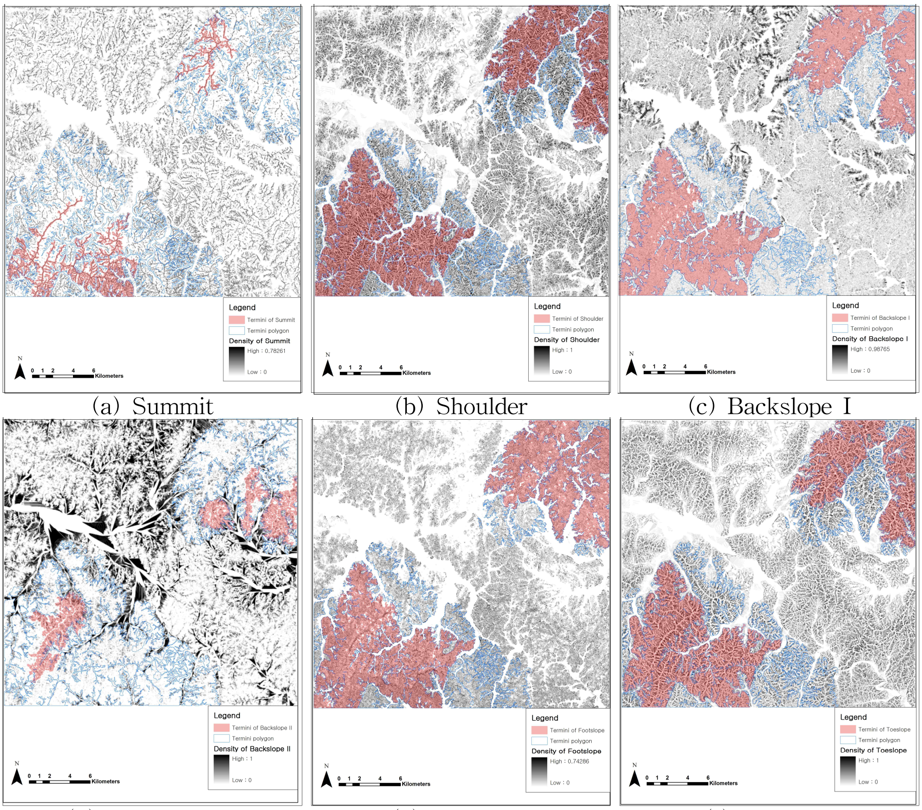


Figure. 11. Topographic characteristics classes and termini in sample sites 1 (left : morphometric, right : generic)

result maps of generic classification are shown in Fig. 12.

The termini of Summit took up small area adjacent to the ridge line and Summit was also shown in small area from the generic classification. The termini of Backslope II were presented around the stream, since this class was shown in the lowland and flood plain. The other termini of topographic classes were similar to the whole termini shown in Fig. 12.



(a) Summit (b) Shoulder (c) Backslope I

(d) Backslope II (e) Footslope (f) Toeslope

Figure. 12. Termini for each generic topographic class (Red) and density results (Grey) in sample site 1

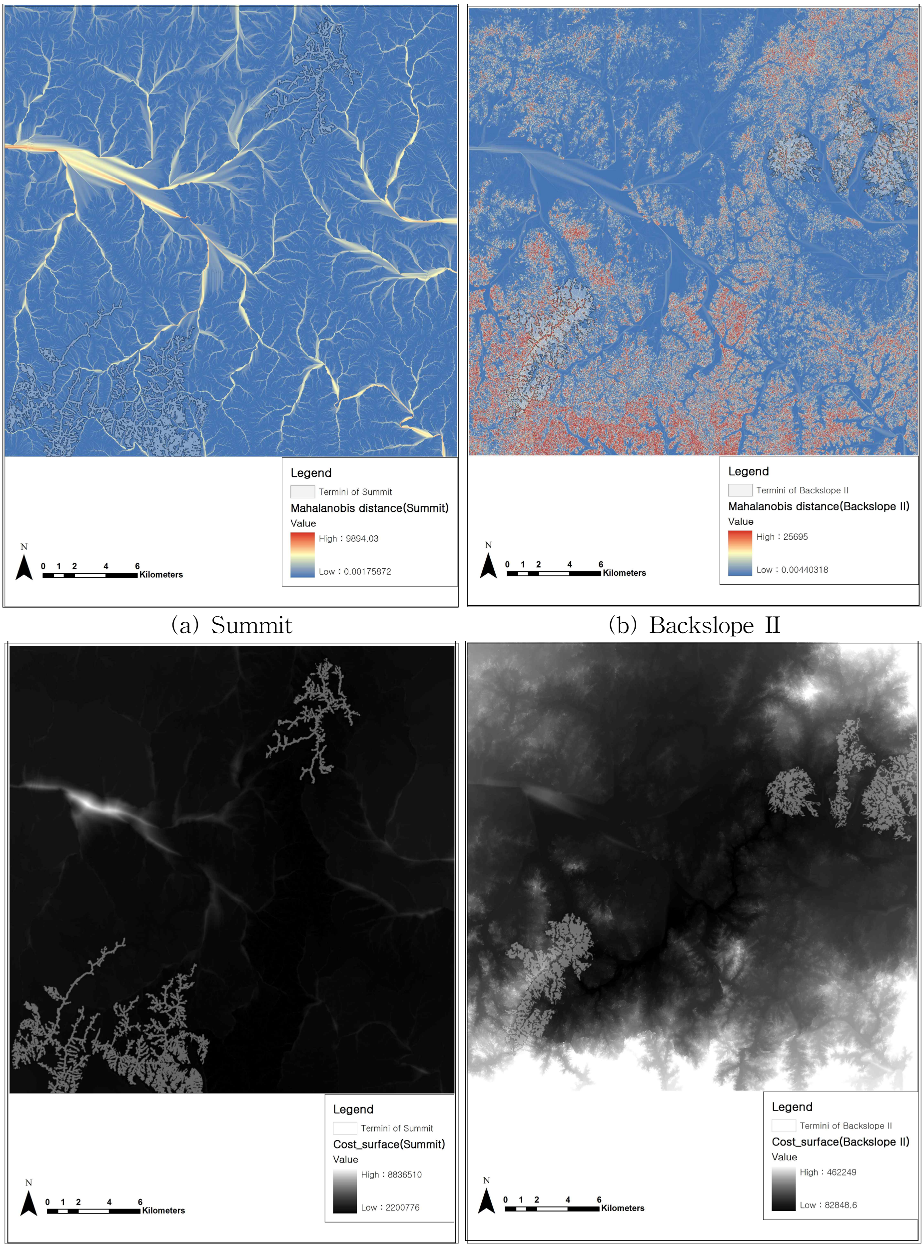
3.3.2 Making the cost surface

This research used the least cost path analysis to search for the linkage areas. The cost surface used in the analysis was calculated by the Mahalanobis distance (Figure 13). The Mahalanobis distance has a relative value from a parameter point in a multi-dimensional space (Hayashi et al., 2001).

In the morphometric topographic classification, in the case of Ridge and Upperslope, the Mahalanobis distance values were large for high elevations and small for the adjacent river because Ridge and Upperslope were found on the mountain ridge. On the other hand, Gentleslope and Lowerslope had high Mahalanobis distance values in mountain areas.

In the generic topographic classification, Shoulder, Footslope and Toeslope appeared in the ridges and valleys of mountainous regions, primarily, and had high elevations and slopes. Therefore, the Mahalanobis distance was larger in the adjacent Channel and Toeslope regions. In contrast, in the case of Toeslope, the Mahalanobis distance was larger in the mountainous region.

The cost distance tool was then used to create the cost surface for each topographic class, accumulated depending on the difference in the Mahalanobis distance from the Termini (Figure 13). The trend of cost surface maps was exactly the same as the cost surface.



(a) Summit (b) Backslope II

(c) Summit (d) Backslope II

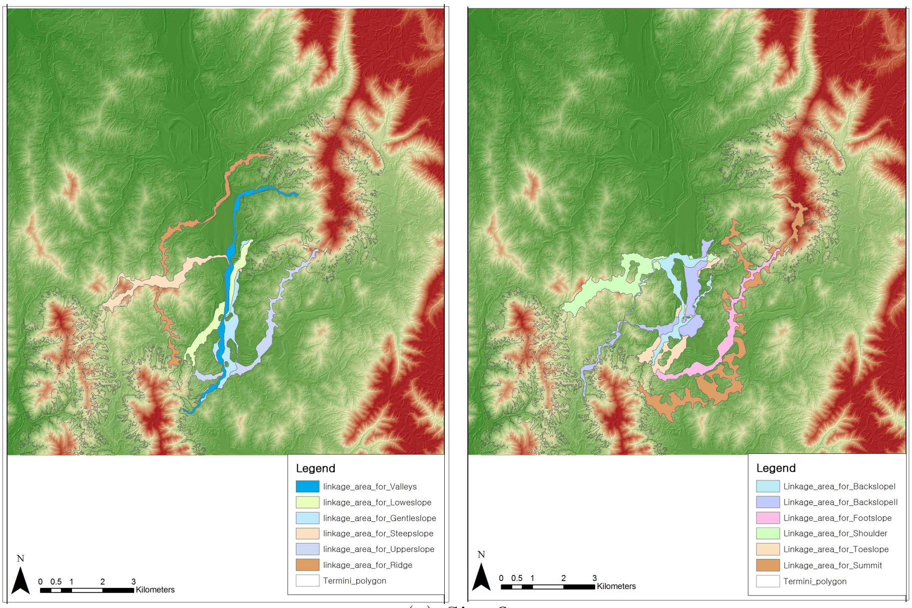
Figure. 13. Mahalanobis distance (a, b) and cost surface (c, d) maps of generic classification in sample site 1

3.3.3 Searching the linkage areas using the least-cost path analysis

The linkage areas of least cost paths for each topographic class were calculated and set to more than the average 1 km width.

In the generic topographic classification, the linkage areas of Summit, Shoulder, and Footslope appeared at similar areas because these areas were also located closely in real terrain. However, according to Backslope II, the linkage areas of these appeared at lowland or river topography (Figure 14).

In the morphometric topographic classification, the linkage area for Ridge appeared in the mountain range area. However, other linkage areas showed similar trends among the three sites. The linkage areas were set to more than the average 1km width, but the linkage areas



(c) Site 3

Figure. 14. Linkage areas by applying topographic characteristics in sample sites (left : morphometric, right : generic) (continued) could not be established to more than a 1km width because the topographic classes in the morphometric classification had less continuity. On the other hand, the generic topographic classification had higher continuity in each topographic class when compared to the morphometric classification.

3.4 Applying in the national parks

3.4.1 The linkage areas by applying topographic characteristics in the national parks

This part of the research tried to identify whether the Baekdudaegan protected area, which is recognized as a significant ecological axis, has linkage areas determined by topographic characteristics. The study sites were the space between Seorak Mt. National Park and Odae Mt. National Park and between Songni Mt. National Park and Worak Mt. National Park. The linkage areas were created by generic topographic classification.

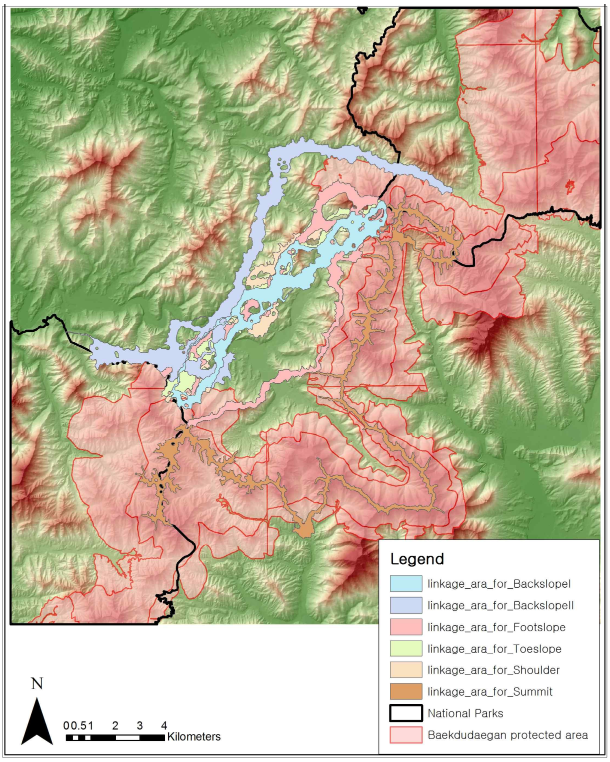


Figure. 15. The linkage area by applying topographic characteristics in the area between Songni Mt. National Park and Worak Mt. National Park.

The linkage area for Summit was similar to the Baekdudaegan protected area. The other linkage areas were not similar to the protected area, but these linkages were established in similar locations to each other. However, the linkage area for Backslope II deviated from the protected area (Figure 15, 16). The reason was that this

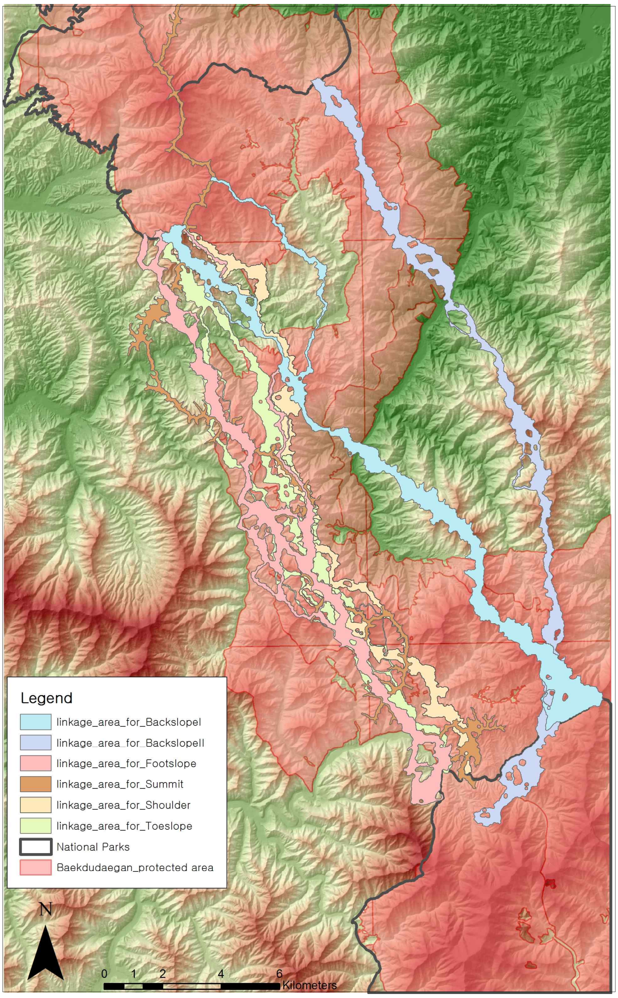


Figure. 16. The linkage area by applying topographic characteristics in the area between Seorak Mt. National Park and Odae Mt. National Park.

topographic characteristic represented a small area in the National Parks, which made a linkage area for lowlands difficult to establish in the space between National Parks.

The Baekdudaegan protected area did not contain diverse topographic characteristics when compared to the results from this research.

3.4.2 Comparison with criteria to establish the Baekdudaegan protected area

Criteria to establish the protected area were regarded as subjective because quantified indexes were not used (Kim, 2012). Therefore, many claims have been made by citizens having land in the protected area. Private land accounts for about 33.5% of the National Parks (Jeong, 2011).

In case of the Baekdudaegan protected area, this area has relatively objective criteria. The boundary of the Baekdudaegan protected area was set by considering physical and ecological criteria (Table 13). The physical criteria considered the high elevation, steep slope, and the area near the "Marugeum" mountain range (Korea Forest Conservation Movement, 2005).

The area over 700m distance from Marugeum was evaluated as having particularly low conservation value. However, the linkage areas from this research were shown to be 3~6 km width. Applying the boundary of the Baekdudaegan protected area to the results from this research would lead to a wider width of the protected area than present.

Table. 13. Criteria for establishing the boundary of Baekdudaegan protected area (Ministry of Environment, 2004)

▪ Physical criteria

rank	elevation	slope	distance from Marugeum
1	over 800m	over 30°	within 300m
2	500 ~ 800m	15° ~ 30°	300m ~ 700m
3	below 500m	below 15°	over 700m

▪ Ecological criteria

rank	Ecological zoning map	vegetation type	age group of vegetation
1	1st grade	nature forest	50 ~ 60 years
2	2nd grade	artificial forest	30 ~ 40 years
3	3rd grade and other	detunded area and etc.	10 ~ 20 years and etc.

4. Discussions

4.1 The relation between topographical and ecological characteristics

The erosion and accumulation process determined from topography are significant factors that determine vegetation distributions (Sakai and Ohsawa, 1994), since topographical characteristics affect edaphic properties and forest structure and dynamics (De Castilho et al., 2006; Menin et al., 2007).

The variables related to vegetation type distributions were determined in this research to be elevation, slope, upslope contributing area, and surface curvature. The correlations between topographical variables and vegetation distributions were studied based on the catena concept of Milne (1935). The variables related to vegetation type distributions were confirmed to be elevation, slope, aspect, and solar insolation (Davis and Goetz, 1990; Cavalli et al., 2003). Cavalli (2003) did not conduct topographic classification, but created topographic units with the combination of elevation, slope, and aspect using DEM (Digital elevation model), and identified correlations with vegetation distributions. The present study indicates that the interpretation of topography can be used to find the relationship between soils and landscape.

The comparison of coniferous forests with topographic classes in this research showed that the distribution area decreased from erosion zones to accumulation zones in generic classification. These results are relevant to previous studies, as Ohsawa (1981) reported that coniferous forests are distributed in the ridge heads while deciduous forests are distributed on concave slopes. The life cycle also has evolved for survival against strong xeric conditions and wind (Kong, 2004). In South Korea, coniferous communities are located at over 1,300 m altitude in the Baekdudaegan area (Korea Forest Conservation Movement, 2005) because elevation has a high correlation with climatic variables such as precipitation and evapotranspiration (Soares and Brito, 2007).

Amphibians were more evident in sedimental topographic classes such as Gentleslope and Lowerslope (stream) and Steepslope (upland adjacent stream) than in erosion classes. The reason for this is because streams or wetlands are critical determinants of the life cycle of amphibians. Amphibian species breed and lay eggs in streams and wetlands, and forage and overwinter in upland areas adjacent to streams (Richter et al., 2001; Semlitsch and Bodie, 2003). The amount of relief also has a negative relationship with amphibian distribution; i.e., amphibian species are more abundant in flat areas than in high slope areas (Soares and Brito, 2007). Many studies suggest that soil variables are the main factors that determine frog distributions (Menin et al., 2007). Therefore, the impact of topographical characteristics on edaphic properties would be large.

4.2 Establishing the linkage area by applying topographic characteristics

Topographical classification had a significant relevance to ecological characteristics, as mentioned earlier in the results section. Consequently, the linkage area found by applying topographic characteristics has the potential for use in maintaining forest ecosystem sustainability in response to fragmentation and climate change. However, morphometric classification was not suitable for controlling the width of the linkage area. This was because topographic classes had little continuity with each other, since this classification determines landform classes categorized by elevation difference with neighboring cells (Weiss, 2000). In contrast, generic classification was suitable for controlling the width of the linkage area because topographic classes are categorized by considering the movement of water and materials from Summit to Channel in the slope area (Park et al., 2001). Therefore, core and buffer area concepts could be considered to set the protected area in a generic classification. The linkage area containing diverse topographic classes could have a relative importance (Brost and Beier, 2012a). Historically, areas of high topographic variety functioned as refugia during past periods of climate change (Hewitt, 2000) and may possibly do so in the future. Even though this research was restricted to a forest ecosystem, a stream or river needs to be recognized as a corridor as well (Brost and Beier 2012a).

The Baekdudaegan protected area did not include diverse topographic characteristics because of the ridge line-oriented criteria (Table 12). Diverse topographic characteristics should be considered as important factors, and the criteria should be established to consider diverse topographic characteristics in the future. The ecological value of lowland areas should be revalued and an ecological survey should be conducted because lowland areas have more organic matter and water compared to erosion zones (Huston, 2005). More importantly, these areas provide different habitat conditions for species.

5. Conclusions

The objective of this research was to establish topographical connectivity that considered ecological features to sustain forest ecosystems. This objective was approached by asking three research questions. First, the correlation between topographic variables and ecological characteristics was analyzed to find a more suitable topographic classification that considers ecological characteristics, and to establish linkage areas by applying topographic characteristics. The study also identified whether Baekdudaegan protected area contains linkage areas that are associated with topographic characteristics.

1) Significant correlation was confirmed between topographic characteristics and vegetation type distribution. The vegetation type variable had strong correlations between several topographic variables at significance levels of 0.01 and 0.05. The variables related to erosion and accumulation processes such as the upslope contributing area, the surface curvature, the slope, and elevation showed a significant relationship with vegetation distributions. This means that topographic characteristics influenced vegetation habitat conditions and the vegetation type distribution.

2) A more suitable topographic classification that considered ecological features was sought by comparing coniferous forest and amphibians because these species are related to the material circulation process (erosion → transmission → accumulation). In the

case of coniferous forest, more distinctive differences were seen for the area ratio of coniferous forest in each topographic class with generic than with morphometric classification, but in the erosion topography in morphometric classification, the characteristics of coniferous tree with strong xeric was presented well. On the other hand, amphibian emergence points were related to morphometric classification, but generic classification showed a trend where the matching number of points increased from Summit to Channel. Therefore, topographical classification was related to ecological features like species distributions, and each topographical classification had the advantage of having more suitable ecological characteristics.

The linkage area was established by applying topographic characteristics and generic topographic classification was more suitable because the classification had higher continuity in each topographic class than did morphometric classification. This means that generic classification could be applied in a more flexible manner whenever topography needs to be connected.

3) This research identified that the Baekdudaegan protected area, which is recognized as a significant ecological axis, did not contain linkage areas found by applying topographic characteristics because the criteria focused on the “Marugeum” mountain range. If the boundary of the Baekdudaegan protected area was applied with the results from this research, the width of the protected area would be wider than the present boundary. The width would be 3 ~ 6km,

based on the results from the three sample sites and the space between the National Parks.

The present Baekdudaegan protected area and National Parks also have a small area occupied by lowlands; consequently, the linkage area for Backslope II was removed from the protected area. Lowland areas should be revalued in terms of ecological value for species.

This research has two significant results: it tried to identify the correlation between topographical characteristics/classifications and ecological characteristics, and it evaluated suitable topographic classifications to make linkage areas that consider the ecological characteristics. The Baekdudaegan protected area needs to consider topographic characteristics as an important factor for habitat condition by comparing the results from this research. However, the research has some limitations, such as not considering the present land cover condition, and more topographic classification methods need to be evaluated.

In conclusion, topographic characteristic factors should be considered for conserving an ecosystem, and criteria should be established for designating protected areas. The results from this study could be used to complement studies showing low species distribution data or uncertainty. The linkage area found by applying topographic characteristics also has potential for use in maintaining forest ecosystem sustainability in response to fragmentation and climate change.

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7. Appendix

Table. S-1. Correlations between topographical characteristics and vegetation type distributions in Site 2

		Aspect	C_s	Elev	A_s	Slope	TWI	Forest
Aspect	Correlation Coefficient	1.000	−.053*	−.035	.029	−.027	.015	−.019
	Sig. (2-tailed)		.017	.114	.188	.232	.489	.386
	N	2000	2000	2000	2000	2000	2000	2000
C_s	Correlation Coefficient	−.053*	1.000	.098**	−.796**	−.029	−.327**	−.022
	Sig. (2-tailed)	.017		.000	0.000	.201	.000	.326
	N	2000	2000	2000	2000	2000	2000	2000
Elev	Correlation Coefficient	−.035	.098**	1.000	.046*	.424**	.010	.577**
	Sig. (2-tailed)	.114	.000		.038	.000	.666	.000
	N	2000	2000	2000	2000	2000	2000	2000
A_s	Correlation Coefficient	.029	−.796**	.046*	1.000	.127**	.405**	.223**
	Sig. (2-tailed)	.188	0.000	.038		.000	.000	.000
	N	2000	2000	2000	2000	2000	2000	2000
Slope	Correlation Coefficient	−.027	−.029	.424**	.127**	1.000	.004	.416**
	Sig. (2-tailed)	.232	.201	.000	.000		.850	.000
	N	2000	2000	2000	2000	2000	2000	2000
TWI	Correlation Coefficient	.015	−.327**	.010	.405**	.004	1.000	.093**
	Sig. (2-tailed)	.489	.000	.666	.000	.850		.000
	N	2000	2000	2000	2000	2000	2000	2000
Forest	Correlation Coefficient	−.019	−.022	.577**	.223**	.416**	.093**	1.000
	Sig. (2-tailed)	.386	.326	.000	.000	.000	.000	
	N	2000	2000	2000	2000	2000	2000	2000

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table. S-2. Correlations between topographical characteristics and vegetation type distributions in Site 3

		Aspect	C_s	Elev	A_s	Slope	TWI	Forest
Aspect	Correlation Coefficient	1.000	.001	-.007	.024	-.009	.004	-.025
	Sig. (2-tailed)		.979	.768	.291	.673	.864	.272
	N	2000	2000	2000	2000	2000	2000	2000
C_s	Correlation Coefficient	.001	1.000	.078**	-.741**	.010	-.363**	-.091**
	Sig. (2-tailed)	.979		.001	0.000	.662	.000	.000
	N	2000	2000	2000	2000	2000	2000	2000
Elev	Correlation Coefficient	-.007	.078**	1.000	-.041	.350**	-.008	-.128**
	Sig. (2-tailed)	.768	.001		.066	.000	.714	.000
	N	2000	2000	2000	2000	2000	2000	2000
A_s	Correlation Coefficient	.024	-.741**	-.041	1.000	-.066**	.383**	.146**
	Sig. (2-tailed)	.291	0.000	.066		.003	.000	.000
	N	2000	2000	2000	2000	2000	2000	2000
slope	Correlation Coefficient	-.009	.010	.350**	-.066**	1.000	-.031	-.015
	Sig. (2-tailed)	.673	.662	.000	.003		.172	.505
	N	2000	2000	2000	2000	2000	2000	2000
TWI	Correlation Coefficient	.004	-.363**	-.008	.383**	-.031	1.000	.017
	Sig. (2-tailed)	.864	.000	.714	.000	.172		.438
	N	2000	2000	2000	2000	2000	2000	2000
Forest	Correlation Coefficient	-.025	-.091**	-.128**	.146**	-.015	.017	1.000
	Sig. (2-tailed)	.272	.000	.000	.000	.505	.438	
	N	2000	2000	2000	2000	2000	2000	2000

**. Correlation is significant at the 0.01 level (2-tailed).

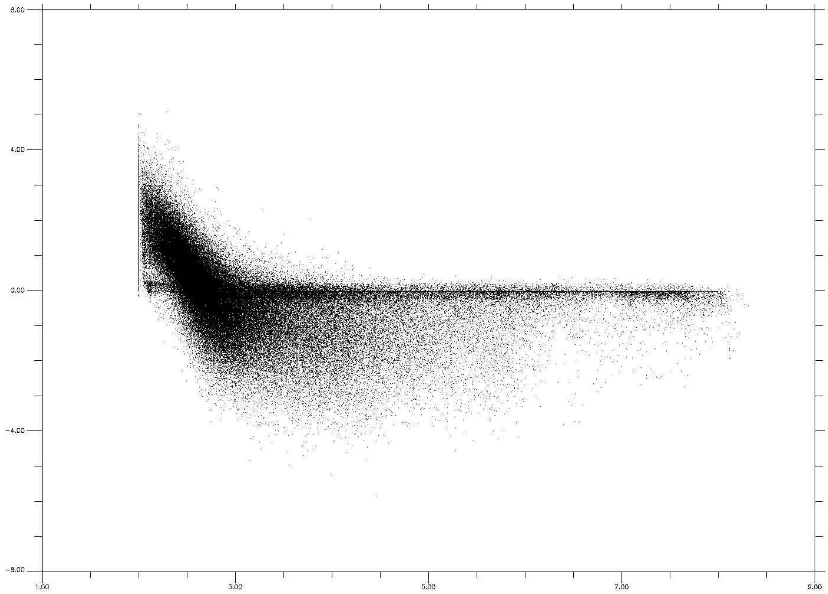

Figure. S-1. Scatter plot combined to upslope area(A_S) and surface curvature(C_s) in the area between Seorak Mt. National Park and Odae Mt. National Park

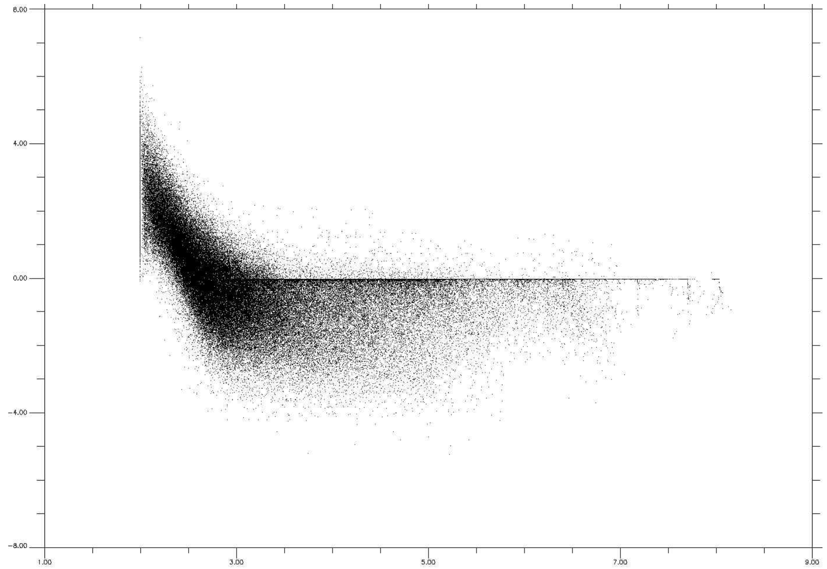

Figure. S-2. Scatter plot combined to upslope area(A_S) and surface curvature(C_s) in the area between Songni Mt. National Park and Worak Mt. National Park

Summary in Korean

이전부터 한정된 자연자원을 효과적으로 이용하면서, 다음 세대에게도 계승할 수 있도록 생물학적 체계의 유지, 생산량의 보전에 관한 지속가능성 연구들이 다수 진행되었다. 그리고 오랜 시간동안 형성된 자연생태계중 가장 큰 비중을 차지하고 있는 산림에서는 기존 산림의 생태적 구조, 기능을 유지하기 위하여 산림생태계 지속가능성이 논의되어 왔다. 하지만 이와 동시에 다양한 인간의 활동에 의해서 생물종 서식처가 감소되어 왔다. 특히 도시화에 의한 서식지 파편화가 심각한 상황이며, 서식지 패치 간 이동을 방해하여 패치 내에 서식하는 개체수의 감소를 야기 시키고 있다.

또한 산업화로 야기되는 기후변화 또한 서식처에 부정적인 영향을 초래하고 있다. 기후변화는 현재부터 어떠한 감축노력을 기울이더라도, 지금까지 방출 된 이산화탄소와 같은 온실가스에 의해 최소 50년 동안 기온과 강수량에 변화를 일으킬 것이다.

이러한 인간의 활동으로 인한 영향들에 대한 생물다양성 보전에 대해 가장 활발하게 연구되고 있는 방법이 생태적 연결성의 확보분야이다. 생태적 연결성의 확보는 생물다양성 관리를 위한 기후변화 적응 전략에 사용되는 가장 일반적인 방법이라고 일컬어지기도 한다. 또한 생물다양성 협약(CBD)에서는 회원 국가들이 각자 나라의 생물다양성을 대표할 수 있는 보호지역 네트워크를 구축하는 것을 요청하고 있다.

생태적 연결성 확보를 위한 방법으로 특정 대상 생물종을 정하고, 그 생물이 현재 살고 있는 서식환경 정보를 통하여 이동할 것으로 예상되는 지역을 탐색하는 방법이 주로 대두되었다. 그리고 최근 비생물적 요소를 통한 연결지역을 구축하는 연구들이 보완방안으로서 제안되고 있다. 비

생물적 요소 중 지형학적 특성은 다른 변수에 비해 안정적이고, 생태적 환경에 영향을 미치는 가장 기초적인 물리적 변수로 인식되고 있다. 과거부터 다수의 연구들이 카테나(catena) 개념에서 파생 된 식생 카테나(vegetation catena)와 같이, 지형학적 특성과 식생의 분포, 속성과의 관계에 대해서 연구들이 진행되고 있다. 또한 지형을 어떻게 구분했을 때, 가장 지형형태를 잘 나타내고, 생태적과정과의 관련성을 잘 보여주는 지에 대하여 다양한 지형구분법들이 개발되었고, 크게 성인적 분류법과 형태적 분류법으로 구분된다.

이에 본 연구에서는 지형학적 변수와 생태적 특성 중 식생분포와의 관계를 알아보고, 생태적 특성을 고려하거나 연결지역을 설정할 때 적합한 지형분류법이 어떤 것인지를 확인하고자 하였다. 침식과정과 관련이 있는 침엽수와 퇴적과정과 관련이 있는 양서류와 지형분류결과와의 상관분석을 실시하였으며, 마할라노비스 거리와 최소비용경로 방법을 이용하여 지형학적 연결지역을 탐색하였다. 마지막으로 현재 우리나라에서 중요한 생태축으로 인식되고 있는 백두대간 보호지역 중 속리산-월악산, 설악산-오대산 국립공원 사이 지역에 본 연구에서 찾은 지형학적 연결지역이 포함되고 있는 지를 확인하였다.

연구결과, 지형학적 변수들 중 고도, 경사, 사면유역지수, 사면곡면률이 식생분포와 밀접한 관련이 있는 것으로 나타나, 지형학적 특성이 식생분포에 영향을 미치는 것으로 나타났다. 또한 지형분류 결과와 침엽수, 양서류 분포와의 관계 분석에서도 각 지형분류법 별로 정도의 차이가 있었으나 관련이 있는 것으로 나타났다. 지형분류를 이용하여 지형학적 연결지역을 탐색한 연구에서는 형태적 분류법이 분류결과 간에 편차가 커서 연결지역 폭을 설정하는데 적합하지 않았으며, 성인적 분류법의 경우에는 정상부터 저지대까지의 물질의 흐름 과정을 고려하여 분류되기 때

문에 분류결과의 값과 분포가 연속되어 나타나 연결지역 폭을 융통성 있게 설정이 가능하였다.

본 연구의 지형학적 연결지역을 백두대간 보호지역과 비교하였을 때, 백두대간 보호지역의 설정기준이 마루금인 산림의 능선중심으로 평가가 되었기 때문에 능선에서 나타나는 지형학적 연결지역은 포함이 되었으나, 그 외 다른 연결지역들은 포함이 안 되는 모습을 보였다. 특히, 저지대는 가장 백두대간 보호지역과 떨어진 지역에 연결지역이 형성되었다. 이를 통해 다양한 지형학적 특성들을 고려한 보호지역의 필요성을 확인할 수 있었으며, 특히 저지대의 경우에는 생태적 가치 및 평가를 실시할 필요가 있다.

본 연구 결과를 통하여 지형학적 요소들이 보호지역 설정 시에도 생물종을 보완할 수 있는 요소로서 활용될 수 있으며, 실제 보전계획 수립 시에 고려될 필요가 있음을 알 수 있었다. 또한, 생물종 서식 관련 자료가 부족하거나 불확실한 곳에서도 보완 방안으로 이용될 수 있을 것이다.

하지만 본 연구에서 다루지 못한 다양한 지형변수, 생태적 특성들도 앞으로 고려할 필요가 있으며, 연결지역 선정 시 현재의 토지피복 상태를 고려하고, 다른 지형분류법도 적용해 볼 필요가 있다. 그럼에도 불구하고, 지형학적 특성을 고려한 연결지역이 앞에서 논의 된 파편화, 기후변화와 같이 산림생태계의 지속가능성에 영향을 미치는 요인들에 대한 대응 방안으로서 잠재적 가능성을 확인하였고, 더 나아가 보호지역 설정 시에 활용될 수 있을 것이다.

❑ ***주요어 : 지형학적 특성, 식생 카테나, 연결성, 형태적 지형분류법, 성인적 지형분류법***

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