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Applying Topographic Classification, Based on the Hydrological Process, to Design Habitat Linkages for Climate Change

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Applying Topographic Classification, Based on the Hydrological Process, to Design Habitat Linkages for Climate Change

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Abstract: The use of biodiversity surrogates has been discussed in the context of designing habitat linkages to support the migration of species affected by climate change. Topography has been proposed as a useful surrogate in the coarse-filter approach, as the hydrological process caused by topography such as erosion and accumulation is the basis of ecological processes. However, some studies that have designed topographic linkages as habitat linkages, so far have focused much on the shape of the topography (morphometric topographic classification) with little emphasis on the hydrological processes (generic topographic classification) to find such topographic linkages. We aimed to understand whether generic classification was valid for designing these linkages. First, we evaluated whether topographic classification is more appropriate for describing actual (coniferous and deciduous) and potential (mammals and amphibians) habitat distributions. Second, we analyzed the difference in the linkages between the morphometric and generic topographic classifications. The results showed that the generic classification represented the actual distribution of the trees, but neither the morphometric nor the generic classification could represent the potential animal distributions adequately. Our study demonstrated that the topographic classes, according to the generic classification, were arranged successively according to the flow of water, nutrients, and sediment; therefore, it would be advantageous to secure linkages with a width of 1 km or more. In addition, the edge effect would be smaller than with the morphometric classification. Accordingly, we suggest that topographic characteristics, based on the hydrological process, are required to design topographic linkages for climate change.

Keywords: connectivity; topographic classes; species distribution; morphometric topographic classification; generic topographic classification

1. Introduction

Many species have been forced to migrate to new habitats or be confronted with extinction because of numerous threats from human-induced environmental changes all over the world [1–3]. Unfortunately, such situations are expected to continue with the rapid growth in the global population [4]. In particular, perpetual fragmentation by urban development is a significant challenge to species that live in habitats with restricted conditions or species that have low dispersal capability.

Moreover, after fragmentation, the remaining habitat patches are affected adversely by changes in the biophysical environment, such as fluxes in energy and water, species, and nutrients [5,6].

To reduce the negative effects of fragmentation, linking habitats in which multi- or focal species can migrate has been identified as the most effective strategy to conserve them [7,8]. In addition, suitable habitat linkages can help conservation planners address conservation problems, such as shifts in species' range induced by climate change [9,10]. To identify the linkages, the most common method employed has been the least-cost path method (LCM) of focal species [11]. Mainly for carnivores and large herbivores with the greatest dispersal abilities, as well as area-sensitive species, low-resistance linkages, which facilitate species movement, have been identified with LCM by drawing a resistance map [12–16]. Although this method could be effective in tracking the movement of the focal species being studied, it might not guarantee the long-term preservation of biodiversity, as it does not include linkages for the other inhabitant species [17,18].

As an alternative target that accounts for a larger diversity of species simultaneously, abiotic variables such as topography and temperature have been proposed as a method for determining habitat linkages [11,19,20]. Among them, topography is less volatile than species distributions, and is considered a significant variable, with substantial potential, in the coarse-filter approach as the basis for plans that aim to conserve biodiversity in the face of climate change [21]. Various researchers have insisted on topographic linkages as habitat linkages [11,19,22,23]. Studies have focused mainly on the shape of the topography (morphometric topographic classification) [11,19]), rather than on the hydrological process, such as the erosion and accumulation associated with the topography, which is related to the habitat environment (generic topographic classification) [24]. Brost and Beier [11] applied topographic variables, such as elevation, slope angle, solar insolation, and topographic position to determine the topographic linkages. However, in determining the topographic linkages based on topography, it may be more important to consider the topographic variables associated with erosion and accumulation [25,26]. Erosion and accumulation are not only attributable to the important process of terrain and soil formation [27], but they also enable seed, water, nutrients, and sediment to move, thereby affecting the vegetation distribution pattern [28–31]. Several studies have identified a close relationship between vegetation and erosion and accumulation [32–34]. Meanwhile, even though vegetation is more vulnerable to climate change because of its insignificant migration [35], it has been excluded often in habitat linkage studies for climate change owing to various uncertainties in estimating the movement ability of vegetation in response to climate change [36,37]. Therefore, to design habitat linkages including flora as well as fauna, we must consider topographic variables related to erosion and accumulation.

Accordingly, in this study, our goal was to compare the topographic linkages applied in generic and morphometric topographic classification to identify the topographic classification with greater potential to support the migration of diverse species in response to climate change. To consider diverse taxonomic groups that have different habitat environment preferences, our focus was on coniferous forest, deciduous forest, mammals, and amphibians. To achieve our goal, we addressed two research questions, as follows: (1) Which topographic classification, focusing on the shape of topography (morphometric) or reflecting the hydrological process by topography (generic), is superior for describing the actual (coniferous and deciduous trees) and potential (mammals and amphibians) habitat distributions? (2) What are the differences in the topographic linkages between the morphometric and generic topographic classifications?

2. Materials and Methods

2.1. Description of Study Areas

We selected three study sites with different areas and topographic patterns in South Korea (Figure 1); all three sites had mountainous areas large enough to contain wildlife habitats. We set the mountains as termini to design the topographic linkages. The mountains were heavily fragmented by human alterations, such as streets, residential areas, and croplands.

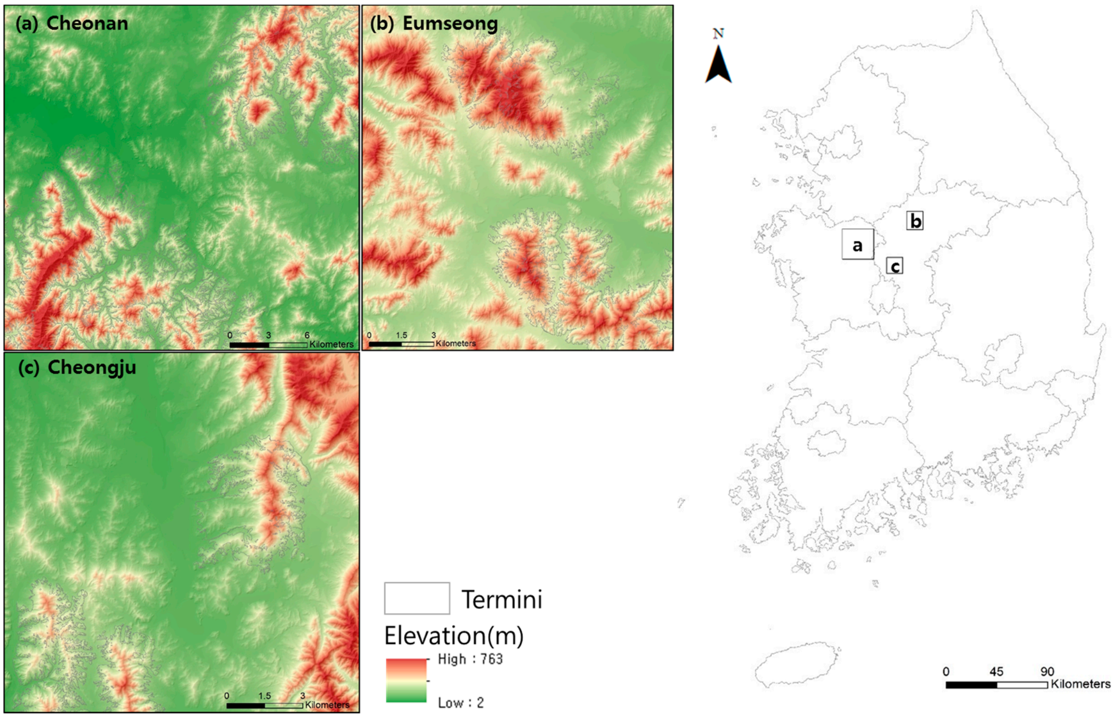

Figure 1. Three study sites in South Korea. (**a**) Cheonan (816 km^2); (**b**) Eumseong (236 km^2); and (**c**) Cheongju (202 km^2).

2.2. Data Collection

In this study, we used digital elevation maps (DEM) of 10 × 10 m cell size from the National Geographic Information Institute of South Korea (2012) in order to create topographic maps, such as elevation, slope, and curvature, which were used to draw the two kinds of topographic classification maps. The reported accuracy for the DEM data is 2 m RMSE vertical. The actual coniferous and deciduous communities distribution maps were obtained from the forest-type map (scale 1:5000) of the Korea Forest Service (2013). We used all mapped coniferous and deciduous tree communities in the three study sites, but mixed tree communities in the forest-type map were excluded because of ambiguous habitat preferences. Coniferous and deciduous trees have different habitat preferences, such as soil acidity and humidity, nutrient contents, and shade tolerance [38]. We considered coniferous trees and deciduous trees, comprised of six communities and nine communities, respectively (Table S1). The information on mammals and amphibians to draw the potential habitat distribution maps was retrieved from the National Ecosystem Survey data of the Ministry of Environment (ME), South Korea, which contains the species occurrence points collected via standardized sampling protocol from 2′30″ latitude-longitude grid sites nationwide in 1997–2012 (2nd: 1997–2005, 3rd: 2006–2012) (Figure S1). We selected six species of mammals and thirteen species of amphibians. Even though occurrence point data were insufficient, these species were targeted because they can represent diverse habitat characteristics in the study sites (Table S1).

2.3. Topographical Classification: Morphometric and Generic

Topographical approaches were divided into two perspective groups, connected to topographical classifications (Figure 2). Morphometric classification refers to the shape of the topography, and generic classification is related to the erosion-accumulation process.

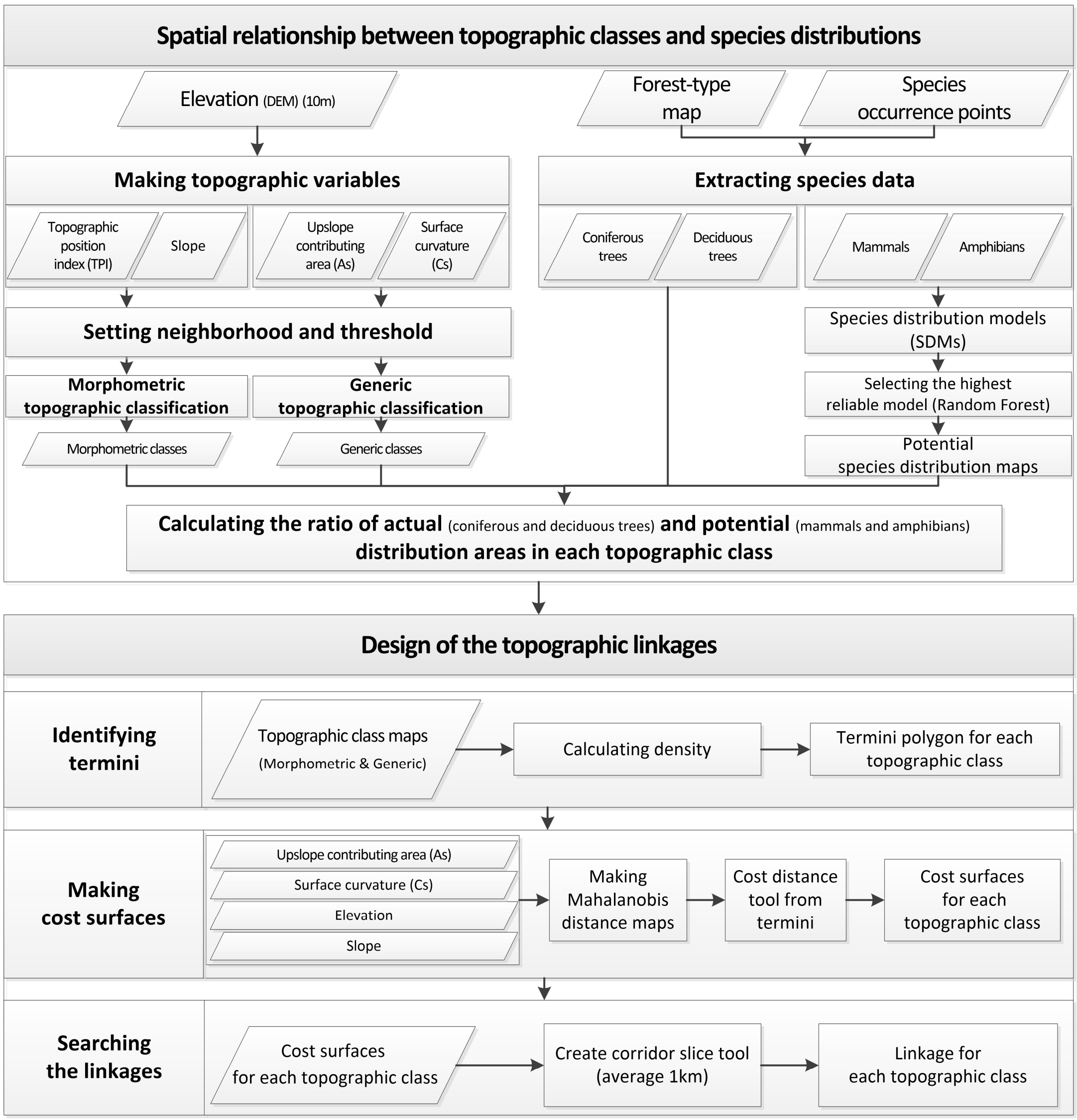

Figure 2. Flowchart of the present study.

First, in the morphometric classification, we used the Topographic Position Index (TPI) as the typical method. The TPI was then graded by differences in the elevation and slope between a criterion grid cell and adjacent cells [39], as in Equation (1):

$$\text{TPI} = \text{int}((\text{Elevation} - \text{focalmean}\,(\text{Elevation, Annulus, Irad, Orad})) + 0.5) \qquad (1)$$

where Irad is the inner radius of the annulus in cells, and Orad is the outer radius of the annulus in cells.

We applied 50 m for Irad equally, and 550 m, 500 m, and 350 m for Cheonan, Eumseong, and Cheongju, respectively, for Orad. These neighborhood values were calculated using the relief energy of topographic profiles based on Jang et al. [40] (Table S2). TPI is a useful index in these areas, which are dominated by mountainous topography, because it can identify the variance of topographic features [41]. A positive value for TPI indicates that the cell was higher than the adjacent cells (i.e., at the top of a mountain), or else the cell was lower than the adjacent cells (i.e., in a valley) [41]. The merit of morphometric classification is that it is less complicated than other methods, requiring only a topographical map or DEM. As the morphometric classification is focused on the shape of the topography itself, it could be unsuitable for determining the ecological processes caused by topography [24]. We used the topographic classification tools provided by the '6-category slope position parameters' tool in the Land Facet Corridor extension of ArcGIS 9.3 (Environmental Systems Research Institute Inc.(ESRI), Redlands, CL, USA) (Table 1). Threshold values and topographic class name were based on the previous analysis [41] that has been applied in many other regions having different topographic features [42–45].

Table 1. Morphometric topographic classes calculated and ordered by Topographic Position Index (TPI) and slope [46].

Topographic Classes	Criteria	
	TPI	**Slope**
Ridges	$\mathrm{TPI} \geq 1$	
Upperslopes	$0.5 \leq \mathrm{TPI} \leq 1$	
Middleslopes	$-0.5 \leq \mathrm{TPI} \leq 0.5$	$\mathrm{Slope} \geq 5°$
Flatslopes	$-0.5 \leq \mathrm{TPI} \leq 0.5$	$\mathrm{Slope} \leq 5°$
Lowerslopes	$-1 \leq \mathrm{TPI} \leq -0.5$	
Valleys	$\mathrm{TPI} \leq -1$	

Subsequently, generic classification, as a geomorphological classification system, could be defined by quantifying the flow of water, energy, and materials [47]. The relationship between the upslope contributing area (As) and the surface curvature (Cs) was used primarily to classify the topography [27]. These variables are defined in Equations (2) and (3):

$$\mathrm{As} = (1/b)\sum_{i=1}^{n} p_i A_i, \tag{2}$$

$$\mathrm{Cs} = \left(\sum_{i=1}^{n} (z_i - z_{n)}/d_{in}\right)/n = g(x,y), \tag{3}$$

where A_i is the area of the grid cell, n is the number of cells draining into the grid cell i, p_i is the weight depending on the runoff generation mechanisms, b is the contour width approximated by the cell resolution, z_i is the elevation of the ith current cell, z_n is the elevation of a surrounding model point, d is the horizontal distance between the two model points, and n is the total number of surrounding points used in the evaluation [47].

The topographic classes by generic classification were defined using the scatter plot between the As and Cs. The classification of topography by generic classification required several parameters to be set, such as $\mathrm{A_{si}}$, $\mathrm{A_{st}}$, $\mathrm{A_p}$, and $\mathrm{C_{si}}$ (Table 2). $\mathrm{A_{si}}$ and $\mathrm{A_{st}}$ were used to separate Summit and Toeslope from Shoulder and Footslope, respectively. $\mathrm{A_p}$ is the value of the upslope contributing area initiating the Channel. Regarding $\mathrm{C_{si}}$, the points near the x-axis must contain both positive and negative values as a quarter of the standard deviation of Cs (Figure 3) [27]. These parameters were applied differently in each study site based on the topographic conditions (Table S3). Topographic drawings of the study sites were included in the analysis. Summit is a flat surface at the top of the slope; Shoulder is a seepage slope and convex creep slope; Backslope I and II are free-face and transportational mid- and low slopes; Footslope is a colluvial footslope; Toeslope is an alluvial toeslope; and Channel is a channel wall and channel bed. Scatter plots were constructed using ENVI (ESRI) and, subsequently, each topographic class region in the study sites was calculated by using the 'Raster calculator' tool in the Spatial Analyst of ArcGIS 9.3 (ESRI). The equations were derived by overlaying As and Cs maps and applying the criteria of As and Cs in Table 2.

Table 2. Generic topographic classes divided by the upslope contributing area (As) and the surface curvature (Cs). The criteria for As and Cs were set by the level of sediment transport and the amount of sediment [27,47].

Topographic Class	Description	Categories in Figure 3	Criteria	
			As	Cs
Summit	The region is divided by two rivers in the one drainage system	a	Min. $\leq A_{st}$	0~Max.
Shoulder	This region has a positive surface curvature value, and, therefore, an erosional process is predominant	b	$A_{si} \leq A_p$	$+C_{si} \leq$ Max.
Backslope I	These regions achieve equilibrium of inflows and outflows	c	$A_{si} \leq A_{st}$	$-C_{si} \leq +C_{si}$
Footslope	This region has a negative value for the surface curvature, which indicates inflow rather than erosion	d	Min. $\leq A_{st}$	Min. $\leq -C_{si}$
Backslope II	These regions achieve equilibrium between inflows and outflows	e	$A_{st} \leq A_p$	$-C_{si} \leq +C_{si}$
Toeslope	This area is saturated with groundwater and accumulates alluvial deposition from the up valley	f	$A_{st} \leq A_p$	Min. $\leq -C_{si}$
Channel	Rivers flow	g	$A_p \leq$ Max.	Min.~Max.

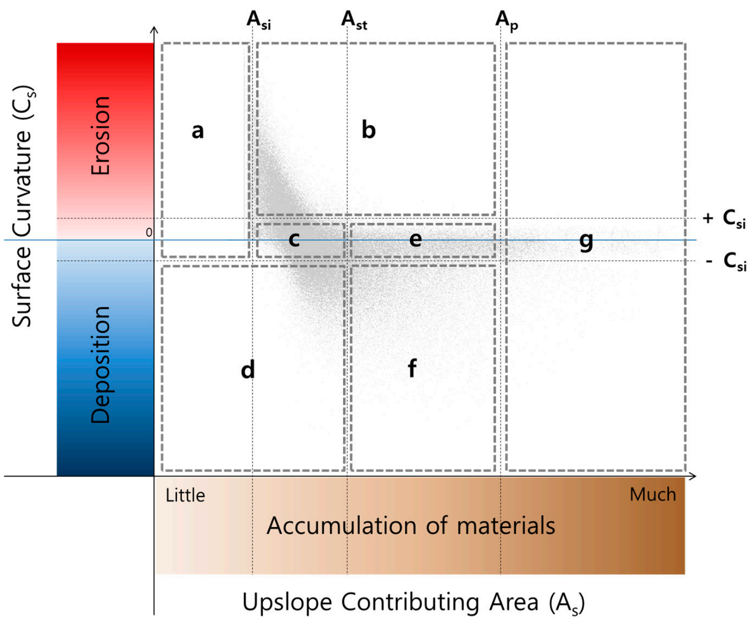

Figure 3. Types of topography defined from the categories in the scatter plot, i.e., (**a**) Summit; (**b**) Shoulder; (**c**) Backslope I; (**d**) Footslope; (**e**) Backslope II; (**f**) Toeslope; and (**g**) Channel (refer to Park 2004).

2.4. Spatial Relationship between Topographic Classes and Species Distributions

We evaluated correspondence between the topographic classifications and species distributions. [48] (Figure 2). Topography primarily affects the habitat conditions or species distribution by the processes of erosion, transmission, and sedimentation [25], as well as the morphological features [11]. To identify which topographic classification method was superior at representing the distribution of the two types of flora and two types of fauna, we calculated and compared the ratio of the (potential) habitat areas in each topographic class area from the morphometric and generic topographic classifications.

The ratios of coniferous and deciduous trees in each topographic class were calculated after a comparison between the areas of coniferous or deciduous trees in each topographic class and the total areas of each topographic class in the forest (Equation (4)). We overlaid the forest-type map with the topographic-class map from the two topographic classifications. The entire forest, coniferous and deciduous trees, were extracted and the areas of each type were calculated in each topographic class from the overlying map.

$$\text{Ratio}\ (\%) = \frac{Areas\ of\ coniferous\ or\ deciduous\ trees\ in\ each\ topographic\ class\ (\text{m}^2)}{Total\ areas\ of\ each\ topographic\ class\ in\ forests\ (\text{m}^2)} \tag{4}$$

The ratios of the potential habitats of the mammals and amphibians in each topographic class were considered in the non-urban area. Subsequently, we produced potential habitats in the mammal and amphibian maps using ten species-distribution models (SDMs) in the biomod2 package in R (R package 3.2.5) [49]. For the modeling, presence data of mammals and amphibians were insufficient. Therefore, we developed two models (the mammal and amphibian models) by synthesizing presence data of each taxon.

The ten SDMs consisted of maximum entropy algorithm (MAXENT), classification tree analysis (CTA), rectilinear envelope similar to BIOCLIM (SRE), flexible discriminant analysis (FDA), multivariate adaptive regression splines (MARS), random forest (RF), generalized linear models (GLM), generalized boosted regression model (GBM), generalized additive models (GAM), and artificial neural network (ANN) (Table S4). We ran each SDM five times to consider the uncertainty from the model running. We selected the best SDM considering the average of AUC (area under the curve) values that showed the highest reliability. The RF model had the highest AUC among SDMs; thus, we used the results of the RF model (Table S5). Specifically, we utilized the result of the RF model run with the highest AUC value (Table S5).

Based on the RF model results, we considered the potential habitat areas as the areas over the threshold of the 'receiver operating characteristic' (ROC) curve [16]. Although various researchers insist that SDMs could overestimate the probability presence, SDMs appear to be a superior choice for mapping the distribution of species, as they require less research effort [50]. As predictor variables, aspect, elevation, slope, distance from stream, and distance from road were used at the 10 m grid cells, and the occurrence points of mammals and amphibians from the *National Ecosystem Survey* were used as dependent variables. We used these occurrence points with 80% for model calibrations and 20% for testing the models. The ratio of the potential habitats of mammal and amphibians in each topographic class was calculated in the same manner, as with the coniferous and deciduous tree analysis (Equation (5)). The analysis was conducted by using ArcGIS 9.3 (ESRI) and we utilized the 'Zonal Statistics as Table'. The graphs of the ratio were visualized by ggplot2 package in R (R package 3.2.5) [51].

$$\text{Ratio}\ (\%) = \frac{Areas\ of\ each\ topographic\ class\ in\ potential\ habitat\ of\ species\ (\text{m}^2)}{Total\ areas\ of\ each\ topographic\ classes\ in\ Non-urban\ area\ (\text{m}^2)} \tag{5}$$

Ultimately, the mean coefficient of variation (CV) in each ratio of the focal species groups in the topographic classes was calculated to evaluate whether the ratios were constant regardless of the site. The CV was used for identifying the measure of spread that describes the amount of variability relative to the mean [52].

2.5. Design of Topographic Linkages

Subsequently, the topographic linkages of each topographic class in the morphometric and generic classification methods were designed (Figure 2). First, to design the linkages, the termini required to be connected were identified for each topographic map, after we had constructed the topographic-class map of the two topographic classifications. However, all the classified topographic types were scattered throughout all the maps; therefore, the polygons that connected the termini were created by applying the focal statistics concept, where their area was large enough to encompass 50% of the termini. The focal statistics concept set the values for the surrounding cells of the focal topography type [11]. The grid cell values were fixed at 1 or 0 by containing or excluding them, and, subsequently, the density was defined. Density refers to the values calculated by summing the neighborhood grid cell values and converting them to a ratio [53]. The termini were subsequently calculated by using the 'identify termini polygons' tool in the Land Facet Corridor extension of ArcGIS 9.3 [46].

Secondly, the cost surface was constructed by applying the Mahalanobis distance, which is the relative distance from a parameter point in a multi-dimensional space [54], calculated by Equation (6):

$$D^2 = (x - m)^T \times C^{-1} \times (x - m) \quad (6)$$

where D^2 is the Mahalanobis distance, x is the data vector, m is the vector of the mean values of independent variables, C^{-1} is the inverse covariance matrix of the independent variables, and T represents a transposed vector. The Mahalanobis distance is used often in manufacturing and medical research. The application of the Mahalanobis distance to independent variables is important because an ideal status is believed to be a parameter, where the parameter is a factor that affects critical responses. Topographic variables, such as elevation, slope, upslope contributing area, and surface curvature that are applied in topographic classifications were used to calculate the Mahalanobis distance map. The analysis was implemented in the Mahalanobis distance extension of ArcGIS 9.3 [11]. The Cost Distance in ArcGIS 9.3 was subsequently used to produce cumulative cost surfaces by summing the two cost-distance maps (one for each terminus).

Finally, the linkages for topography connections were constructed using the LCM. The generation of a linkage area by applying topographic characteristics was achieved by the LCM by using the 'create corridor slices' tool in the Corridor Designer ArcGIS toolbox [39]. The width of the linkage area was set to be greater than the average 1-km width because most linkage areas for focal species (small and large animals) were narrower than this width [17], and the linkage area required a width of over 1 km to sustain the function for many years [55,56].

After designing the linkage areas, the perimeter/area ratio index (P/A) of the linkages was calculated and compared in the study sites. The P/A relates a patch area to a boundary length and reflects the patch shape. This index was used to assess the habitat structure and patch shape in the landscape ecology [57]. The patch with a higher P/A could be affected more by the edge effect and securing the core area could be difficult [58].

3. Results

3.1. Topographic Class Maps

More continuity was observed in the generic topographic class map than in the morphometric topographic class map. In the generic classification, Shoulder, Footslope, and Toeslope each showed a continuous pattern. Channel was classified as representing a river or stream, and not a valley at high elevation. On the other hand, in the morphometric topographic classification, only Middleslope occupied most of the landscape, with the other topographic classes showing inadequate continuous patterns (Figure 4).

The topographic classes were distributed more evenly in the generic topographic classification than in the morphometric topographic classification. In the generic topographic class map, the topographic classes were divided by the erosion-accumulation process. For example, Summit and Shoulder, representing high erosion and little accumulation of materials, appeared near the mountain ridge, and Footslope and Toeslope, representing deposition and significant accumulation of materials, were found near valleys. Backslope I was located between a 'high-level' ridge and a valley, and Backslope II was located between a 'low-level' ridge and a valley, as they characterized 'transmission of materials and water'. However, the morphometric topographic classification produced a topographic class map dominated by Middleslope. As morphometric classification focused on the shape of the topography, the slope and TPI calculated from a comparison of elevations between the focal cell and the adjacent cells were used as the variables of the morphometric topographic classification [11].

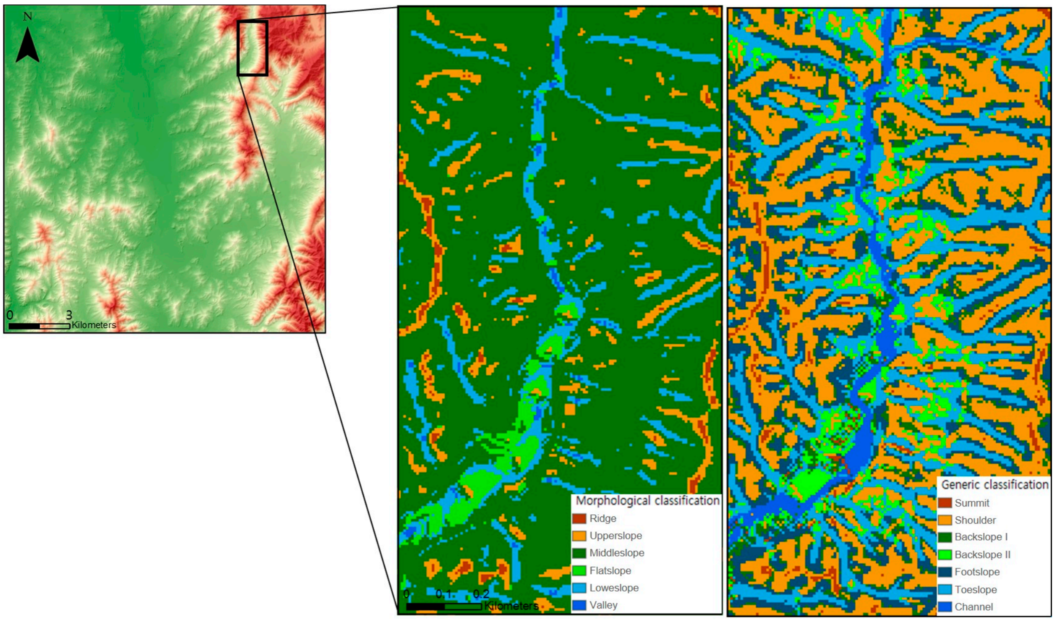

Figure 4. Topographic class maps by generic and morphometric topographic classifications (Cheongju).

3.2. Spatial Relationship with Coniferous and Deciduous Forests

The morphometric topographic classification showed that it was slightly difficult to demonstrate the habitat preferences of coniferous and deciduous trees. The ratios from Ridge to Middleslope increased in the coniferous trees and decreased in the deciduous trees. It is believed that the morphometric topographic classification could show a similar trend with the habitat environments of these types of vegetation. However, the topographic classes having close to zero or negative TPI and a low slope did not match these trends. Regarding coniferous trees, as Flatslope to Valley represented a low slope and concave surface, the trends of the ratios differed from those of coniferous ecological characteristics (Figure 5). In Cheonan and Cheongju, the ratio in Flatslope was higher than in Middleslope. Middleslope had more advantages for conifers to inhabit than Flatslope, as Middleslope had a higher slope that is unfavorable to accumulating nutrients and water. In Eumseong, the ratio in Lowerslope was higher than in Flatslope. Lowerslope had negative TPI values, meaning the focal cell had a relatively lower elevation than the adjacent cells. The deposition of sediment was more likely to occur because of the concave surface of Lowerslope. Consequently, this trend did not match the habitat preferences of the conifers. As regards the deciduous trees, Flatslope included fewer deciduous forests than Middleslope in Cheonan and Cheongju, although the deciduous trees prefer significant sedimentation and low slopes. In Eumseong, the ratio in Valley representing the river and stream was higher than in Lowerslope.

In contrast, the ratios of coniferous and deciduous trees in the generic topographic classification showed a similar trend to the habitat preferences of these trees. The ratios of coniferous and deciduous trees in each topographic class gradually decreased in the instance of the former and increased in the instance of the latter from Summit to Channel (Figure 5). In particular, the result of the deciduous trees indicated that the vegetation preferred habitat features such as abundant nutrients and water [38]. The ratio of the coniferous forest in Backslope II was higher than in that in Footslope only in Cheongju (approximately 1.2 percent). Even though Backslope II represented transportation of materials and water, this was probably because it had larger amounts of materials and water than Footslope, which showed accumulation with a negative Cs value.

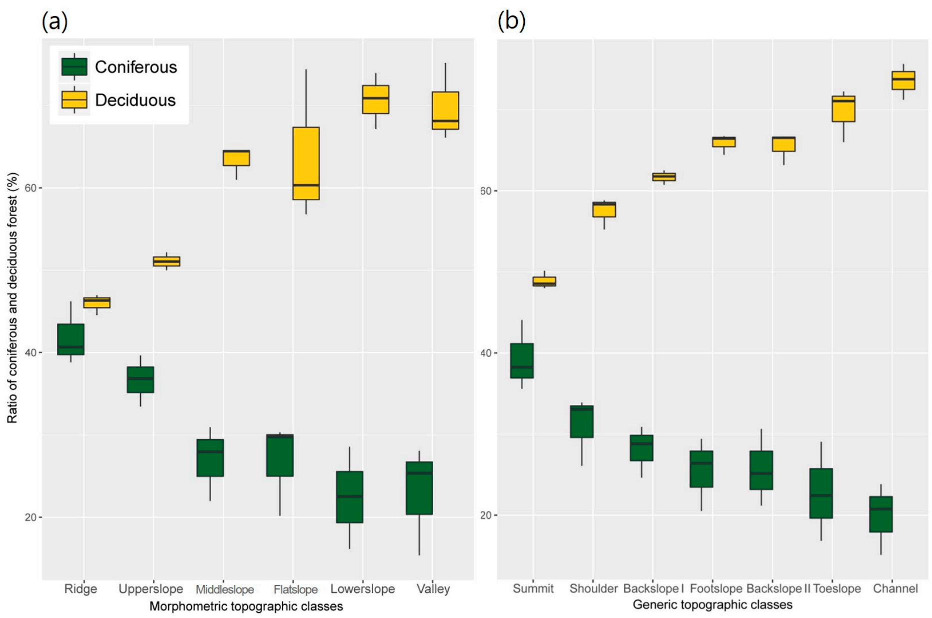

Figure 5. Ratio of coniferous and deciduous forests in morphometric (**a**) and generic (**b**) topographic classes. The ratios of coniferous and deciduous forests in the generic topographic classification showed a similar trend with the habitat preference of these types of vegetation. However, in the morphometric topographic classification, from Flatslope to Valley, representing low slope and concave surface, the ratios had different trends than the coniferous ecological characteristics.

Moreover, in the generic topographic classification, the ratios of coniferous and deciduous trees in each topographic class of the three sample sites were more similar. Comparing the CV to identify whether the ratios were constant regardless of the site, the generic topographic classification showed a smaller value compared with the morphometric topographic classification. The CV in the morphometric topographic classification was 18.78 (coniferous) and 5.71 (deciduous), but the CV in the generic topographic classification was 17.37 (coniferous) and 2.83 (deciduous).

3.3. Spatial Relationship with the Potential Habitat of Mammals and Amphibians

The ratio of the potential habitats of mammals and amphibians in the morphometric topographic classification was quite similar to their habitat preference and movement ability. For mammals, except for Flatslope, all the morphometric classes contained more than 40 percent of the potential habitat, as the mammals had extremely different habitat attributes. These ranged from goral (*Naemorhedus caudatus*) inhabiting the high elevations and steep slopes, mainly comprising rock, to water deer (*Hydropotes inermis*), and living grass land near rivers or streams. For amphibians, Ridge, Upperslope, and Middleslope had quite low ratios of potential habitat, but Flatslope, Lowerslope, and Valley showed relatively higher ratios (Figure 6). However, in the generic topographic classification, the distribution of the amphibians was not related to the erosion-accumulation process. In Cheonan and Eumseong, Summit, Backslope I, Footslope, and Channel had higher ratios. Regardless of erosion-transportation-accumulation, the ratios in each generic topographic class were different. In Cheongju, Backslope II and Channel showed higher ratios.

Moreover, in the morphometric topographic classification, the ratio of the potential habitats of mammals and amphibians in each topographic class of the three sample sites was more similar. The morphometric topographic classification had a smaller CV value compared with the generic topographic classification. The CV in the generic topographic classification was 23.11 (mammal) and

43.88 (amphibian), but the CV in the morphometric topographic classification was 21.33 (mammal) and 28.64 (amphibian).

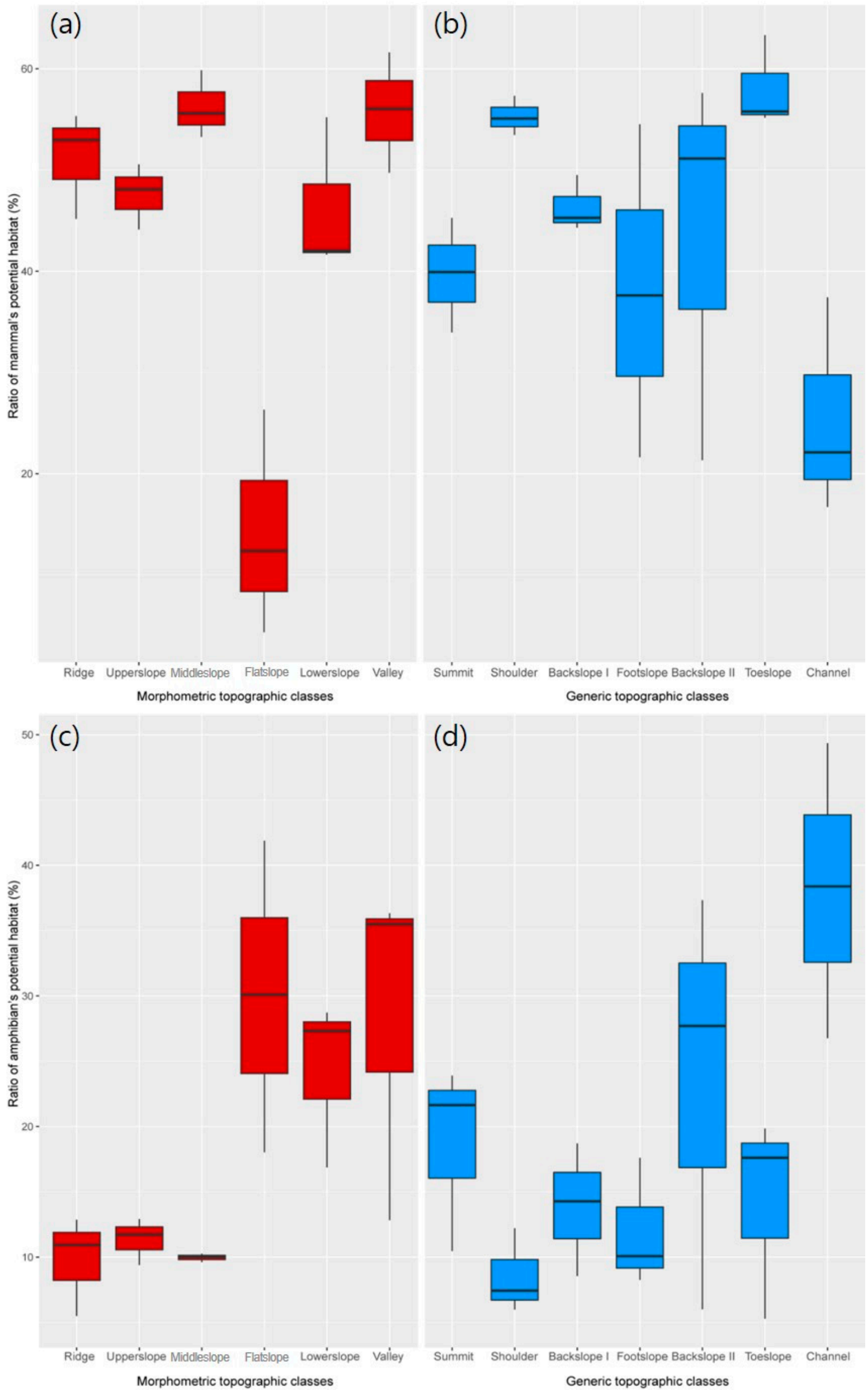

Figure 6. Ratio of the potential habitats of amphibians and mammals in the morphometric (**a**,**c**) and generic (**b**,**d**) topographic classes. The ratio of the potential habitat of mammals and amphibians in the morphometric topographic classification was quite similar to their habitat preference and movement ability. However, in the generic topographic classification, the distribution of the amphibians and mammals was not related to the erosion-accumulation process.

3.4. Topographic Linkages

The generic topographic classification was more efficient in determining the adequate width and extent of the topographic linkages. We set the linkages at greater than the average 1 km width (Figure 7). However, the topographic linkages from the morphometric topographic classification were mostly narrower than 1 km in width. This was ascribed to the differences in the Mahalanobis distance value between the focal cell and the adjacent cells being higher than they were in the generic topographic classification. The width of the linkages in the generic classification exceeded 1 km. The total areas of the linkages were 27.1 km^2, 7.2 km^2, and 6.6 km^2 in the morphometric classification, and 58.5 km^2, 16.6 km^2, and 10.4 km^2 in the generic classification for Cheonan, Cheongju, and Eumseong, respectively.

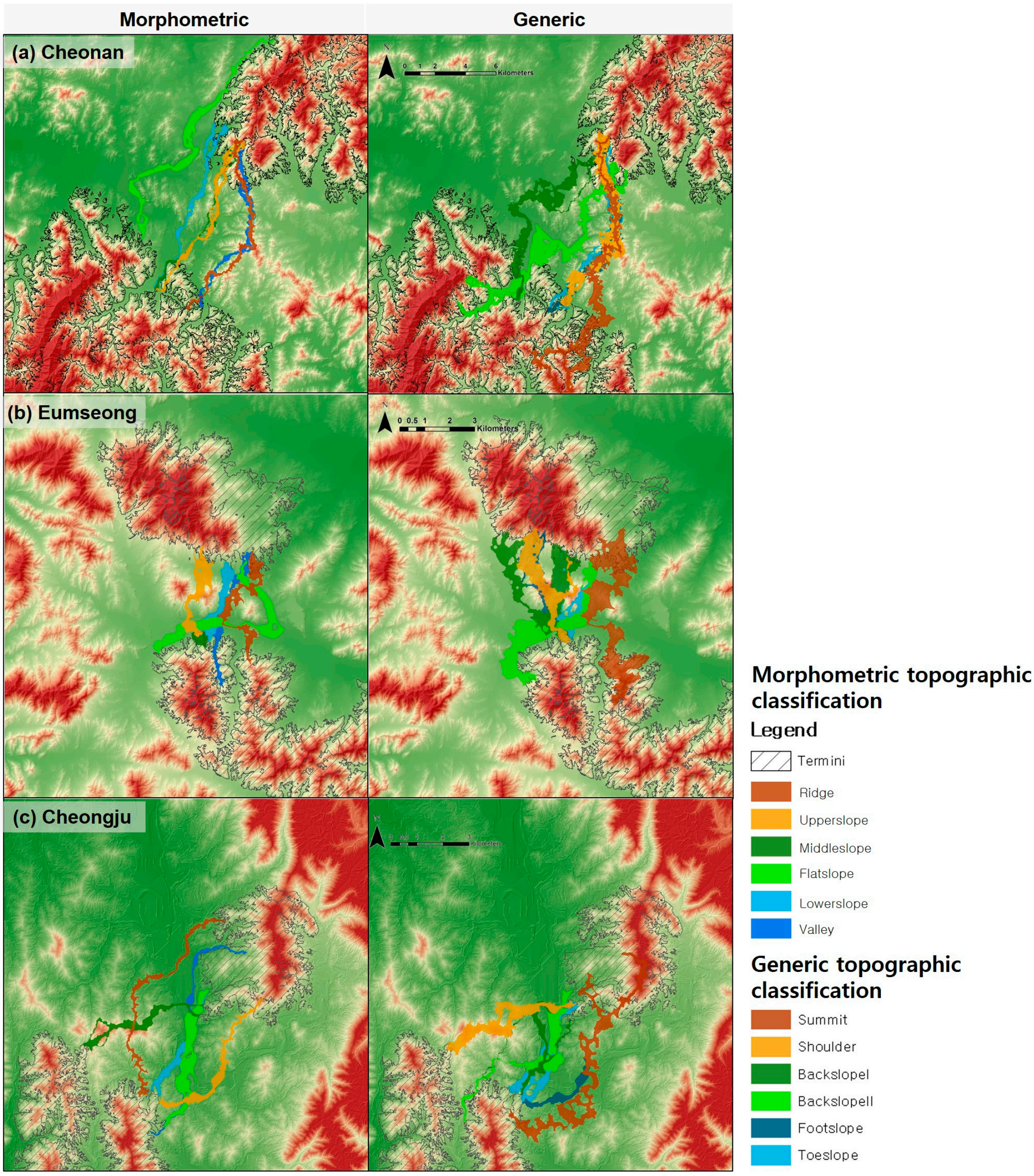

Figure 7. Topographic linkages based on morphometric and generic topographic classification. Compared with the morphometric classification, the generic classification could secure sufficient width and extent of linkages of over 1 km in width. The spatial differences among the topographic linkages were also smaller in the generic classification than in the morphometric classification.

In addition, the spatial differences among the topographic linkages were greater in the morphometric classification than in the generic classification. In detail, in the generic topographic classification, the topographic linkages for Summit, Shoulder, and Footslope were close to each other. The linkage for Backslope II connected the low slope and lowland. In the morphometric topographic classification, the linkage for Ridge appeared along the mountain ridge and the other linkages were only partially overlain (Figure 7).

The P/A ratios of the linkages between the morphometric and generic topographic classifications were clearly different, namely, (1) the P/A ratio in the generic classification was lower and the total areas were larger; and (2) the P/A ratio in the morphometric classification was higher and the total areas were smaller. In all the study sites, the perimeters of the linkages compared with the area were longer in the morphometric classification than in the generic classification (Figure 8). In other words, the topographic linkages from the morphometric classification could be more vulnerable to the edge effect, and the topographic linkages from the generic classification would be more likely to secure the core area in the linkages.

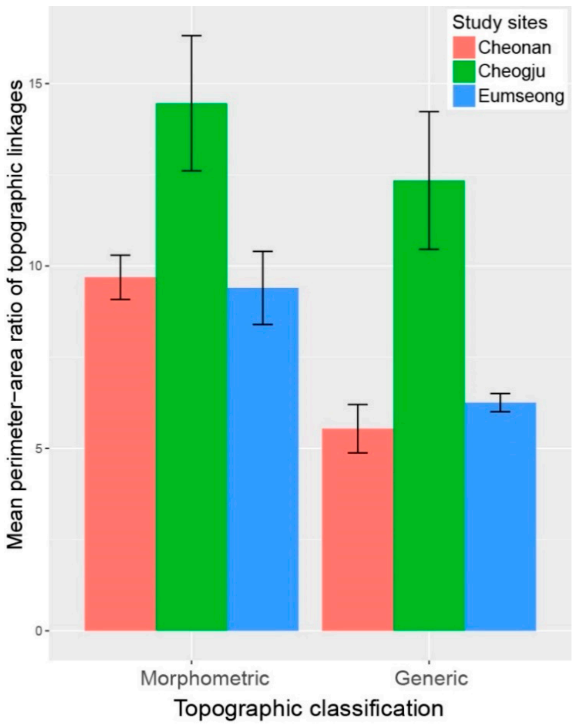

Figure 8. Mean perimeter-area ratio (P/A ratio) of morphometric and generic topographic linkages. The P/A ratio was higher in the morphometric classification than in the generic classification. A high P/A ratio indicates that the topographic linkage could be vulnerable to the edge effect.

4. Discussion

4.1. Topographic Classes as a Surrogate of Species

Focusing on the shape of topography (morphometric) or reflecting the hydrological process by topography (generic), we identified the topographic classification which was superior at describing the actual (coniferous and deciduous trees) and potential (mammals and amphibians) habitat distributions. Previous studies have shown that diverse environmental factors, such as temperature, precipitation, soil, elevation, and slope, influence the ecological process and contribute to the formation of biodiversity patterns [21,59–61]. In particular, topography could be a significant variable in predicting the migration of species which is attributable to long-term effects, such as climate change [11,23].

However, we argue that care needs to be taken regarding the topographic classification approach to be used when topographic characteristics are considered as a surrogate of species.

First, generic topographic classification better describes the habitat preference of coniferous and deciduous trees. The life cycle of coniferous trees has evolved for survival against strong xeric conditions and wind, whereas deciduous trees are distributed on concave slopes or near streams [62,63]. We found that in the morphometric classification, the habitat preference of the trees was shown generally, but Flatslope and Lowerslope showed different trends with the habitat preference. On the other hand, in the generic classification, according to the habitat preference of the trees, the distribution area ratio of coniferous and deciduous trees gradually decreased and increased, respectively, from Summit to Channel (Figure 5). These results show that the distribution of these trees was more affected by the erosion and accumulation processes than the shape of the topography. The generic classification is based on the flow of energy and materials on the surface [47]. Therefore, since it can consider the relationship between topography and soil, it has been recognized for decades that identifying ecological features, such as the distribution of trees and plants, is advantageous [64].

Second, even though the topographic characteristics could not represent animal distributions adequately (below 50 percent), the morphometric topographic classification was superior compared with the generic topographic classification (Figure 6). Several linkage studies on mammals and amphibians included topographic variables such as elevation, slope, and aspect as input variables [19,22,65,66]. These studies revealed that topographic characteristics potentially affect the movement of such animals. In the current finding, the potential habitats of mammals were smaller in Flatslope, as agricultural areas accounted mainly for this class, and mammals are more likely to avoid interferences and danger from humans [13,17]. This is the reason for Flatslope having low distribution ratios in all the three study sites. Amphibians had a high percentage of potential habitats in Flatslope, Lowerslope, and Valley. These results could be related to the habitat feature of amphibians. Amphibians are aquatic in the juvenile stages, with the adult amphibians remaining close to streams and valleys [67].

4.2. Designing Topographic Linkages to Accommodate Climate Change

Topographic linkages supporting the migration of species against climate change are frequently mentioned in studies on the coarse filter approach [21,68–70]. Several studies have recommended the coarse filter approach to conserve diverse communities against long-term effects such as climate change. They have also shown that topographic linkages could be used to support the migration of organisms in response to climate change, as similar topographic and geological characteristics facilitate the connection of species among regions [71,72]. For instance, Brost and Beier [19] found that topographic linkages drawn by the LCM can include the path of focal species. However, these studies mainly considered topographic variables related to the topographic form, such as elevation, slope angle, and insolation, to design linkages, and did not reflect the flow of energy and materials [11,23].

The width of linkages should be wide enough to ensure the conservation of diverse habitat environments. The current findings show that the generic classification has two ecological advantages in designing topographic linkages to support the migration of organisms responding to climate change. First, it will help secure a sufficient width as it is easier with the generic classification than the morphometric classification. Second, since the response of the species to climate change is uncertain [21,73,74]. Maintaining the habitat linkages as wide as possible could enhance the likelihood of species migration. As the generic classification method defines the topographic classes along with the flow of materials, it is difficult to find a topographic class with completely different characteristics around a specific topographic class. Consequently, when designing the topographic linkages using LCM, wider areas could be selected using the generic classification (Figure 7). We also suggest that all the topographic linkages, from Summit to Channel, need to be conserved to include all the hydrological processes, as the generic topographic classification represents the most important hydrological processes affecting the ecosystem. It could be helpful to know the minimum width of linkages in the coarse filter approach.

The P/A ratio of the generic classification was smaller than that of the morphometric classification, so the possibility of being affected by the edge effect is significantly reduced (Figure 8). Theoretically, all patches have the edge effect, because they are in contact with different landscapes [56]. For this reason, the topographic linkages with less edge effect are more important for conservation. In this study, we also found that the length of linkages was shorter in the generic classification. This means that the species could migrate and sequentially colonize efficiently while receiving less influence from human disturbance [75]. Therefore, it is important to design the topographic linkages with less artificial effects.

5. Conclusions

Our finding offer insights into the method of designing topographic linkages and the strengths and weaknesses of the topographic classifications. The generic topographic classification shows potential for designing the topographic linkages in response to climate change. In particular, it has advantages from the viewpoint of considering the distributions of vegetation and finding sufficient width and extent of topographic linkages. In other words, topographic variables incorporating hydrological processes, as well as the conventional topographic variables, such as elevation and slope, need to be considered when topographic linkages are designed as a proactive tool against climate change and fragmentation. However, further research is required on combining and weighing these topographic variables or classifications to construct the topographic linkages for climate change, as both plants and animals must be considered. Nevertheless, the topographic classification approach could be more appropriate in regions lacking data on species' distributions [76]. Therefore, we advocate the use of topographic variables as significant variables and surrogates in planning for mitigating the effects of climate change.

Supplementary Materials: The following are available online at www.mdpi.com/1999-4907/8/12/466/s1, Table S1: Flora and fauna used in this analysis; Table S2: Parameter values that classify the topography in the morphometric topographic classification. SNs in the study sites are the same and LNs are different, but they are comparable with the parameter values in Jang et al. (2009) for the Republic of Korea; Table S3: Parameter values that classify the topography in the generic topographic classification. Although different parameter values were used according to the site, these are comparable with the parameter values in the three previous studies in the Republic of Korea and the United States (Park et al. 2001; Park 2004; Jeong 2011); Table S4: Key features of the 10 Species Distribution Models; Table S5: AUC values indicating the accuracy of the 10 Species Distribution Models; Figure S1: Species distribution data of trees and animals in the study site (Cheonan).

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