

# Development of an ecological impact assessment model for dam construction

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**Abstract** The purpose of this study was to develop a model for assessing the ecological value of a dam reservoir. Various evaluable characteristics (“elements”) that influence the ecology of the target area around the dam were grouped into three classes: (1) physical elements, such as altitude, slope, and aspect; (2) vegetation elements, such as forest physiognomy, vegetation type, age class, diameter at breast height (DBH) class, and density; and (3) habitat elements, such as ecological conditions, vegetation conservation classification, and frequency of wildlife appearances. The evaluation standard was quantified considering the ecological function of each element. The developed assessment model was applied to the Yeongju Dam in the Nakdong River basin in Korea. This study assumed that the ecological condition before the dam construction was 100 %. The results of this study showed that the physical, vegetation, and habitat elements were downgraded to 82.8, 95.5, and 90.7 %, respectively, after the construction of the dam. The overall ecological value was estimated to be 90.0 % and thus decreased by 10.0 % due to dam construction. Additionally, by combining the results for the evaluation elements, an ecologically healthy area was selected. The results of this study should prove

useful for quantifying ecological impact and for establishing an ecological restoration plan for dam reservoirs.

**Keywords** Dam reservoir · Ecological impact · Habitat · Physical factors · Vegetation

## Introduction

In Korea, rainfall is concentrated in the summer, and local variations in rainfall are large. Accordingly, damage from droughts and floods has occurred on an ongoing basis, and efficient water resource management is urgently needed. In addition, there is a need for dam construction in preparation for expected water shortages arising from increased water usage due to industrial and economic development and population growth. In Korea, dams have been constructed to manage water resources since before the 1980s. However, in each case, only the water use and flood control functions of the dam (e.g., securing water resources and reducing flood damage) have been emphasized, and the development of water resources has mainly focused on large-scale, multipurpose dams. Since the 1990s, due to increasing concern about the environment and the need to improve quality of life, the focus has shifted to environmental problems related to water resource development projects. With the introduction of the Environmental Impact Assessment System in 1981 and the legislation of the Environmental Impact Assessment Act in 1993, the environmental impacts of new dam construction projects are now being considered. Since the turn of the century, methods for ecological restoration have been actively applied during the construction of new dams. However, there is still a need for clear planning/design standards for ecological restoration following dam construction as well

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as clear standards for evaluating the ecological impact of dam construction.

The construction of a dam has diverse environmental impacts. The primary effect is that the geophysical structure of the river changes dramatically. The water in the reservoir formed by the presence of the dam is deeper than it was before the dam was built, and dam construction results in the formation of a stagnant stream; both of these changes affect the geophysical habitat of aquatic organisms. In contrast, the reservoir upstream of the dam experiences the problem of continuous sediment deposition, which leads to changes in the river and to longitudinal/transversal changes in the bed structure because the sediment supply to the river downstream is blocked. Additionally, an increase in the number of stagnant streams degrades the water quality of the dam reservoir, and this effect on the water quality affects aquatic plankton and aquatic macroplants, which in turn influences the habitat and species composition of aquatic macroinvertebrates and fish (Petts 1984; Bergkamp et al. 2000). Habitat isolation due to dam construction includes isolation due to habitat separation and the loss of biodiversity due to the loss of biological resources. Barriers to the migration of aquatic organisms (e.g., fish) and wildlife induce changes in geophysical habitats due to flow variations in the dam reservoir and the consequent changes in species, and they block the migration of species. If the migration of wildlife in a forest habitat and the upstream/downstream sections of a river is blocked due to the formation of a dam, rather than simply causing species and population declines or reducing and disturbing the genetic resources of wildlife, the health and safety of the general ecosystem of the dam are threatened (Korea Environment Institute 2003).

To examine the effects of dam construction on ecological environments, an evaluation that considers various factors must be performed. The World Commission on Dams (WCD) (Bergkamp et al. 2000) analyzed the effects of a dam on the surrounding environment and ecosystem based on each river ecosystem and biological taxon, and Chen et al. (2011) suggested a conceptual model that analyzes the environmental impact of a dam project in terms of an ecosystem network. However, in the above-mentioned studies, the evaluation was not applied to an actual dam, and it was noted that a substantial amount of data are needed for a quantitative evaluation. In Korea, there have been few studies that have aimed to evaluate the ecological environment of a dam, and only a small number of studies have investigated river ecosystem evaluation or wetland function evaluation techniques. Among these studies, Lim and Lee (2011) suggested a dam basin river ecosystem evaluation method for conservation and management in terms of ecotopes based on the case of the Yongdam Dam basin, and Kim et al. (2011) evaluated the

function of the Yongdam Dam wetland using the hydrogeomorphic (HGM) approach. These evaluation methods can be used to quantitatively evaluate an ecological environment in its current state, but it is difficult to use them to examine the ecological impact of dam construction.

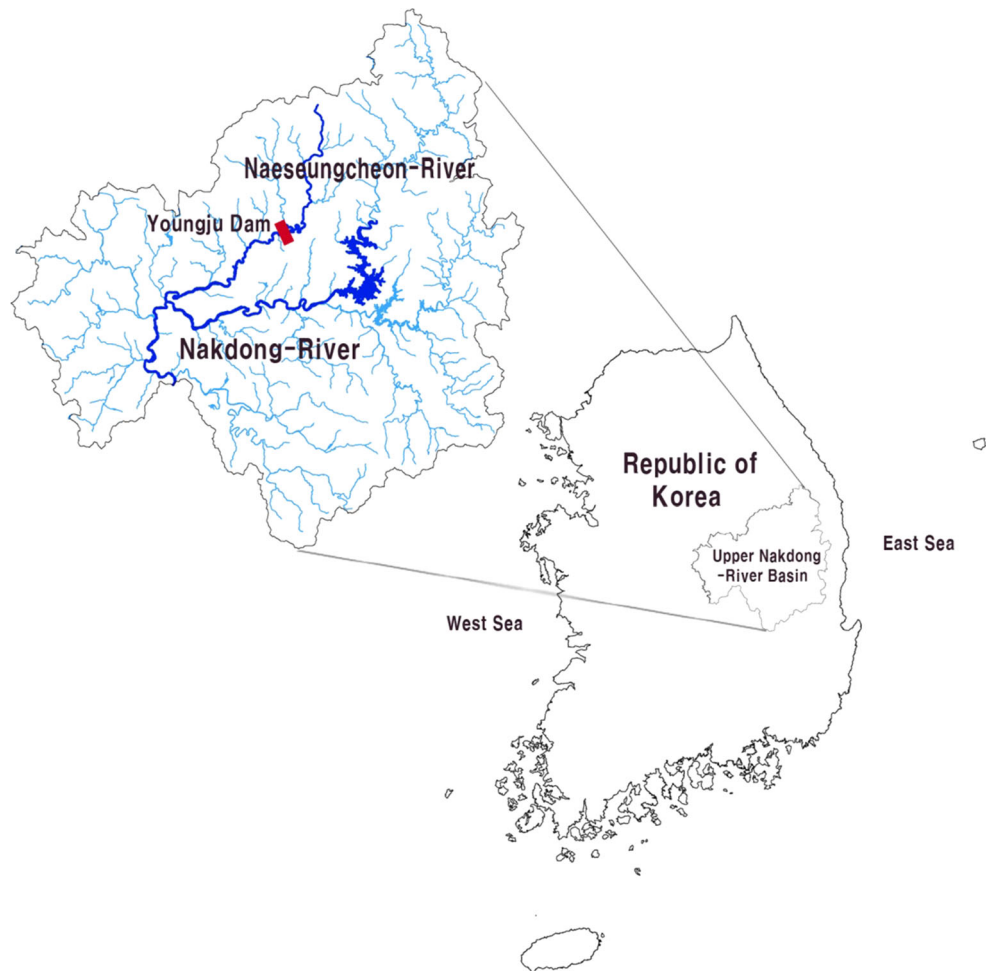
After examining the effects of a dam, it is necessary to plan and apply appropriate ecological restoration techniques accordingly. In Japan, diverse ecological restoration techniques that are suitable for dams have been actively developed and introduced, and the latest restoration techniques and ecosystem impact mitigation measures attract considerable interest (Harada 2002; Harada and Yasuda 2004). In Korea, the Korea Water Resource Corporation (1997) organized environmentally friendly design guidelines and provided examples of successful construction projects. Koo (2004) investigated environmentally friendly elements for reducing environmental damage that could occur during dam construction and suggested environmentally friendly practices. However, for a dam construction project, active and diverse ecological restoration measures, especially restoration plans that are specifically designed for each dam, are needed. Therefore, for efficient dam reservoir ecological restoration in the future, supplementation must be performed based on quantitative predictions of the required restoration measures for each dam and of the components that are likely to experience more damage, rather than on the application of uniform restoration measures for any dam. In this study, an evaluation technique that can be used to quantitatively evaluate the ecological value of a dam, thus facilitating the efficient ecological restoration of its surroundings, is proposed. A method that quantifies the ecological impact of dam construction using various evaluable elements, such as geophysical, vegetation, and habitat elements, is therefore suggested. This method is applied to the Yeongju Dam, and the results are analyzed.

## Materials and methods

### Research area

The Nakdong River basin in Korea experiences relatively large amounts of flood damage compared to other basins. A substantial amount of damage was incurred during Typhoons Russa and Maemi in 2002 and 2003, respectively, as well as Typhoon Sarah, which occurred in 1959 and passed through the Gyeongsang-do and Gangwon-do regions. In particular, the monetary value of the flood damage to the Nakdong River basin caused by Typhoon Russa amounted to approximately 2.4405 trillion won. The major flood prevention measures of the Nakdong River basin are based on increasing bank heights and

**Fig. 1** Location of the study site



constructing dams, and the government has planned the construction of new dams, including the Yeongju Dam, to prepare for future flood damage. The Yeongju Dam is currently under construction. The specifications of the dam are as follows: the height is 50 m, the total storage capacity is 181 million tons, and the flood control capacity is 75 million tons. Figure 1 shows the location of the Yeongju Dam.

Table 1 summarizes changes in the presence of endangered species (mammals, birds, and fish) before and during the construction of the dam. Note that the birds *Accipiter nisus*, *Otus sunia*, *Charadrius placidus*, and *Aquila heliaca* were not monitored after dam construction. In addition, Fig. 2 shows the changes in the observed numbers of bird, mammal, herptile, fish, and vegetation species. All of these showed significant changes due to dam construction aside from the number of herptile species. Note that, in Korea, the legally defined range of the riparian area of a river or a lake is generally set as 0.5–1 km from the boundary of the river or lake (Ministry of Environment (MOE) 2002). Therefore, in this study, the region that is up to 1 km from the boundary of the dam reservoir was regarded as the

range affected by the dam, and this region was selected as the target area for analysis.

### Evaluation element selection

To evaluate the ecological impact of a dam, the major characteristics (“elements”) of ecological environments that are affected by dam construction must be identified and then considered in the evaluation. Thus, in this study, the diverse elements that affect wildlife habitats were identified by examining the GIS data and ecological data and then categorized into three groups corresponding to three major factors that affect the ecological environment of the dam: geophysical elements, vegetation elements, and habitat elements; these are summarized in Table 2. Altitude, slope, slope aspect, and land use were selected as geophysical elements; forest physiognomy, vegetation type, vegetation age class, vegetation diameter at breast height (DBH) class, and vegetation density were selected as vegetation elements; and ecological conditions, vegetation conservation classification, and wildlife appearance (i.e., number of appearances of both endangered and

**Table 1** Changes in the presence of endangered species due to dam construction (a dot indicates that the species was observed to be present)

Species	Before		After	
	2002	2003	2009	2011
<b>Mammals</b>				
<i>Prionailurus bengalensis</i>	●	●	●	●
<i>Lutra lutra</i>	●	●	●	●
<i>Pteromys volans</i>			●	
<b>Birds</b>				
<i>Buteo buteo</i>	●	●		●
<i>Ciconia nigra</i>		●	●	●
<i>Accipiter soloensis</i>	●			●
<i>Accipiter nisus</i>		●		
<i>Falco subbuteo</i>	●	●		●
<i>Otus sunia</i>		●	●	
<i>Falco columbarius</i>	●			
<i>Aix galericulata</i>	●	●	●	●
<i>Circus cyaneus</i>		●		●
<i>Buteo hemilasius</i>				●
<i>Buteo lagopus</i>				●
<i>Falco tinnunculus</i>	●	●	●	●
<i>Charadrius placidus</i>	●	●	●	
<i>Aquila heliaca</i>	●			
<b>Fishes</b>				
<i>Lampetra reissneri</i>		●	●	●
<i>Gobiobotia nakdongensis</i>	●	●	●	●

Note: the data were collected by monitoring

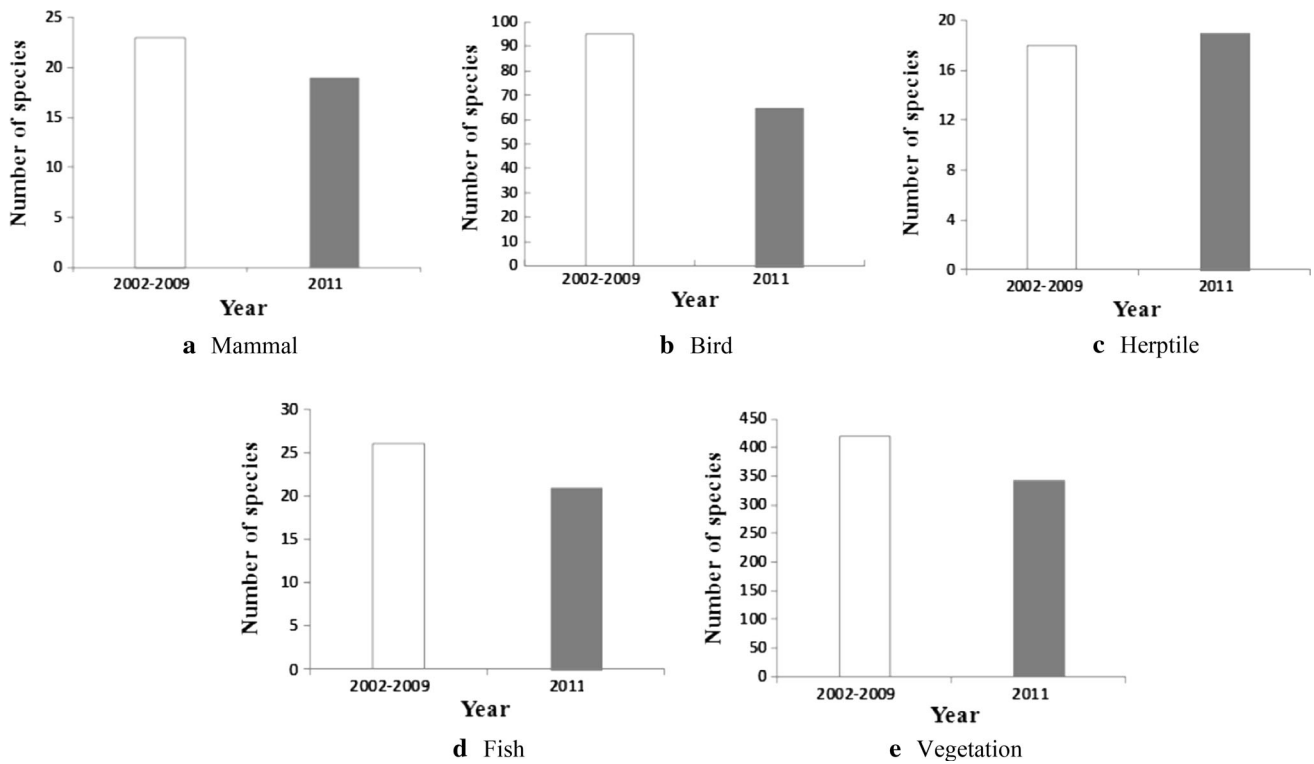
general wildlife) were selected as habitat elements (see Table 2). Not all species can be evaluated with the same criteria because each species has their own characteristics. However, the evaluation process used in this study is proposed for use in an overview evaluation, such as that performed when considering dam construction sites and ecological effects during the dam planning stage. Therefore, the evaluation performed in this study is useful for judging overall ecological impact, but it cannot determine the ecological impacts on particular species of wildlife.

Spatial information data were collected for the analysis of each physical, vegetation, or habitat element. Topographic data on the altitude, slope, and aspect were extracted by generating a digital elevation model (DEM) using the 1:25,000 digital map published by the National Geographic Information Institute. The Ministry of Environment's 2007 intermediate-level land cover classification data were used to determine land cover. Ecological condition data from the Ministry of Environment and the fourth forest physiognomy map of the Korea Forest Service were used to extract information on vegetation. The second- and third-survey data from the Ministry of

Environment and National Institute of Environmental Research (MOE and NIER 2006, 2012) were used for the wildlife survey data. The ecological monitoring data were based on the Environmental Impact Assessment of the Hantan River Dam and the wildlife survey data of the Post Environmental Impact Assessment. Data were extracted from each dataset, and an analysis was performed based on the extracted data using ArcGIS 10.0 (ESRI, Redlands, CA, USA). The target area was divided into 10 × 10 m grids, and geographic information system (GIS) vector data were converted to a raster format. Monitored ecological scores were assigned to each cell of the converted map.

The National Ecosystem Survey of the Ministry of Environment has been performed every ten years to establish systematic national-scale natural conservation measures based on the Natural Conservation Law into Natural Environment Conservation Act. The third of these surveys is the most recent. The Second National Ecosystem Survey was performed between 1997 and 2005. Territories were divided up based on the water system and forest, and the survey was conducted based on a representative mountain within the territory. The third survey was performed between 2006 and 2012. A map-sheet-based survey was performed, where a single map sheet of a 1:25,000 scale topographic map was selected as the survey unit and was divided into a grid of nine cells (2'30'' along the latitude and longitude); every grid cell was surveyed (Ministry of Environment and National Institute of Environmental Research 2006). The National Ecosystem Survey in Korea contains data uncertainty because this study presumes that the wildlife present in habitats can be monitored using their traces and excrement. However, this study applied the National Ecosystem Survey data because the amount of wild species survey data available is very limited in Korea. The fauna and flora surveys in the Environmental Impact Assessment and the Post Environmental Impact Assessment are the basic data used to minimize the damage to ecosystems due to dam construction and to establish an appropriate mitigation plan. The Environmental Impact Assessment of the Hantan River Dam was performed between 2000 and 2001, which was before construction began. In the case of the Post Environmental Impact Assessment, seasonal surveys were continuously performed every year between 2002 and 2011. Submerged areas and the surrounding regions were surveyed, and the changes in the animals, plants, and terrestrial/aquatic ecosystems before and during the construction of the dam were investigated.

For the vegetation and habitat evaluations performed in this study, a natural condition or a generally favorable condition to wildlife was arbitrarily defined as 1.0. An unnatural condition or an adverse condition to wildlife was defined as 0.0. Intermediate scores were assigned with



**Fig. 2** Changes in the number of species due to dam construction

**Table 2** Assessment elements for the ecological environment of a dam

Factor	Category	Assessment elements	Method of analysis
Physical elements	Terrain analysis	Altitude	GIS analysis
		Slope	
		Aspect	
Vegetation elements	Land use	Land cover map	Monitoring
	Forest vegetation	Forest physiognomy	
Vegetation type			
Age class			
Diameter at breast height (DBH) class			
Habitat elements	Wildlife	Wildlife appearance	GIS analysis
	Conservation area	Ecological condition	Vegetation conservation classification
		Vegetation conservation classification	

equal distributions. Additionally, the ecological score of the entire dam region was calculated by multiplying the evaluation score for each cell by the area. There is no specific rule for assigning scores to items, and current researchers have unequally assigned scores to the various items depending on the purpose and content of the research (Kim et al. 2000; Sagong et al. 2011; Lee and Song 2008).

The survey contains uncertainty due to the difference between the actual and the observed mammal presence caused by the long survey gap and the accessibility of the survey area. However, this study did not consider this

uncertainty in observed mammal presence because the period of the survey was long (1997–2013) and all of the environmental changes are greater than the uncertainty in the surveys. Finally, places at which wildlife appeared were monitored, and the geophysical elements (altitude, slope, and slope aspect) of the corresponding places were extracted and collected using the data from the National Ecosystem Survey of the Ministry of Environment (MOE and NIER 2006, 2012). This study identified ecologically valuable regions of the target area by considering the frequency of wildlife appearances in each habitat for

simplification. The order of wildlife migration was adapted from the habitat monitoring analysis based on land cover in the Han River performed by Gangwon-do (2011) and Kang et al. (2011). The scores were unequally assigned to account for differences in the degree of influence on wildlife migration. We judged that the influence decreased in the following order: urbanized area and residential area > greenhouse cultivation > rice paddy and field farmland > pasture and orchard > natural grassland and shrub forest > natural forest.

## Results

### Geophysical element evaluation

There are well-known standards for geophysical conditions that are suitable for wildlife habitats. However, in this study, new standards for the geophysical elements were developed because it was thought that the existing standards did not reflect the topographic characteristics of the

target dam region. In particular, the geophysical characteristics necessary for a wildlife habitat and the biological characteristics (e.g., food resources) vary depending on the region, so it is reasonable to perform analyses using wildlife appearance location data for each target point. Places where wildlife appearances were observed may, however, differ from the actual places where the wildlife was present, because mammal point measurements use feces.

Table 3 summarizes the evaluation standards for each element. For the geophysical standards, ranges of altitude, slope, and aspect that exhibited frequent wildlife appearances were defined as “outstanding” regions: 1 point was assigned to such regions and 0.5 points were assigned to the other regions. Additionally, when scoring the ranges of altitude, slope, and aspect, the Instream Flow and Aquatic Systems Group (1986) was referenced. Studies relevant to the geophysical evaluation of wildlife habitats have established different scoring systems. Therefore, in this study, based on the altitude and slope ranges that showed the greatest presence of wildlife, 1.0 points were assigned

**Table 3** Quantification of the ecological value of a dam

Physical elements									
Terrain analysis						Land use			
Altitude (m)		Slope (°)		Aspect (°)		Land cover map			
150–200	1.0	Under 15	1.0	Flatland	1.0	Natural forest	1.0		
Remainder	0.5	Remainder	0.5	22.5–157.5	1.0	Natural grassland, shrub forest	0.8		
				Remainder	0.5	Pasture, orchard	0.6		
						Rice paddy, field farmland	0.4		
						Protected cultivation	0.2		
						Urbanized and residential areas	0.0		
Vegetation: forest vegetation									
Vegetation type		Forest physiognomy		Age class		DBH class		Density	
Mixed forest	1.0	Natural forest	1.0	Class 5	1.0	Large pole	1.0	High density	1.0
Deciduous forest	0.7	Artificial forest	0.5	Class 4	0.8	Medium pole	0.8	Medium density	0.7
Coniferous forests	0.3	Non-forest	0.0	Class 3	0.6	Small pole	0.5	Low density	0.3
Non-forest	0.0			Class 2	0.4	Sapling	0.3	Non-forest	0.0
				Class 1	0.2	Non-forest	0.0		
				Non-forest	0.0				
Habitat									
Wildlife appearance		Conservation area							
		Ecological condition			Vegetation conservation classification				
Appearance	0.5	Grade 1	1.0	Grade 3	1.0				
Non-appearance	0.0	Grade 2	0.7	Grade 4	0.7				
		Grade 3	0.3	Grade 5	0.3				
		No data	0.0	No data	0.0				

to the range in which at least 50 % of all appearances occurred, and 0.5 points were assigned to the remaining range, because the wildlife appearance frequency was relatively small in this range.

A total of 247 wildlife appearances were noted within the target area of Yeongju Dam. Figure 3 shows the altitude, slope, and slope aspect distributions for the wildlife at the Yeongju Dam. In this study, an ecological value of 1 was assigned to a particular altitude or slope range and to a particular type of land cover based on the method from the Instream Flow and Aquatic Systems Group (1986). As shown in Fig. 3a, when the altitude was divided into 10-m intervals, an altitude range of 160–170 m exhibited the highest proportion of wildlife appearances (15.4 %). Out of a total of 247 species, 132 species (53.3 %) were distributed in the 150–200 m section. Thus, 1.0 points were

assigned to the 150–200 m section, as it is a region in which there is a high possibility of wildlife appearing, and 0.5 points were assigned to the remaining regions. For the slope, 0° showed the highest proportion of wildlife appearances (18.6 %). Among a total of 247 species, 144 species (58.3 %) were distributed in the 0–15° section. Thus, 1.0 points were assigned to the 0–15° section, and 0.5 points were assigned to the remaining regions (Fig. 3). In terms of the slope aspect distribution of the target area, the number of wildlife appearances was relatively high on the flatland and in the southeast. Thus, 1.0 points were assigned to the flatland and to the slope oriented in the northeast-southeast direction, and 0.5 points were assigned to the remaining regions because the number of wildlife appearances was relatively small.

For the geophysical element of land use cover, scores were assigned as summarized in Table 3 depending on the appropriateness of the cover as a wildlife habitat: 1.0 points were assigned to natural forest, 0.8 points to natural grassland and shrub forest, 0.6 points to pasture and orchard, 0.4 points to the rice paddy and field farmland, 0.2 points to other and greenhouse cultivation, and 0.0 points to urbanized and residential areas. Table 4 summarizes the results of the evaluation of the geophysical elements. When evaluating the possibility of wildlife appearances in the Yeongju Dam target area according to altitude, the percentage of the total score before dam construction for the region with a high possibility of wildlife appearances decreased from 54.7 % before dam construction to 43.4 % after, and the percentage of the total score for the region with a low possibility of wildlife appearances decreased from 45.3 % before to 38.1 % after. Thus, after dam construction, the total score was only 81.6 % of the total score before dam construction. Similarly, when evaluating the possibility of wildlife appearances in the Yeongju Dam target area according to the slope, the percentage of the total score before dam construction for the region with a high possibility of wildlife appearances decreased from 60.6 % before dam construction to 39.9 % after, and the percentage of the total score for the region with a low possibility of wildlife appearances decreased from 39.4 % before to 37.5 % after. Thus, after dam construction, the total score was only 77.3 % of the total score before dam construction. Further, when evaluating the possibility of wildlife appearances in the Yeongju Dam target area according to the slope aspect, the percentage of the total score before dam construction for the region with a high possibility of wildlife appearances decreased from 57.7 % before dam construction to 50.6 % after, and the percentage of the total score for the region with a low possibility of wildlife appearances decreased from 42.3 % before to 33.3 % after. Thus, after dam construction, the total score was only 83.9 % of the total score before dam construction.

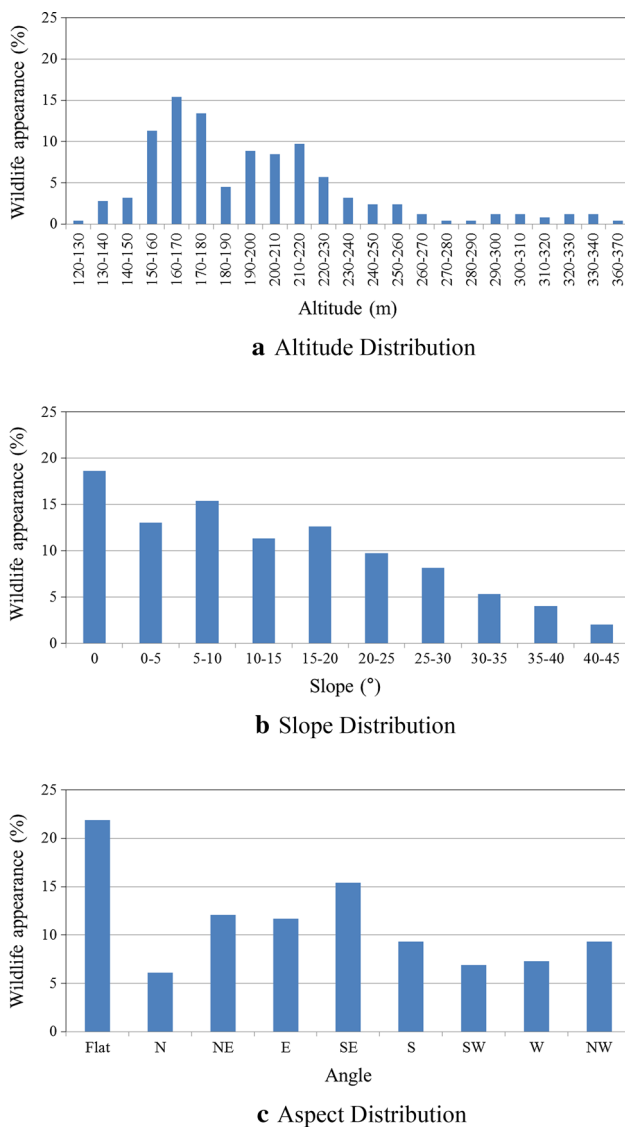


Fig. 3 Distribution of wildlife appearances at Yeongju Dam

**Table 4** Results of evaluating physical element parameters

	Grading standard	Area (100 m <sup>2</sup> )		Score		Percentage	
		Before	After	Before	After	Before	After
<b>Altitude</b>							
Low possibility of wildlife appearances	0.5	370,970	312,063	185,485	156,032	45.3	38.1
High possibility of wildlife appearances	1.0	223,763	177,763	223,763	177,763	54.7	43.4
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>409,248</b>	<b>333,795</b>	<b>100.0</b>	<b>81.6</b>
<b>Slope</b>							
Low possibility of wildlife appearances	0.5	336,155	319,643	168,078	159,822	39.4	37.5
High possibility of wildlife appearances	1.0	258,578	170,183	258,578	170,183	60.6	39.9
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>426,656</b>	<b>330,005</b>	<b>100.0</b>	<b>77.3</b>
<b>Aspect</b>							
Low possibility of wildlife appearances	0.5	353,615	278,539	176,808	139,270	42.3	33.3
High possibility of wildlife appearances	1.0	241,118	211,287	241,118	211,287	57.7	50.6
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>417,926</b>	<b>350,557</b>	<b>100.0</b>	<b>83.9</b>
<b>Land cover</b>							
Urban area	0.0	15,728	9,605	0	0	0.0	0.0
Protected cultivation	0.2	1,267	1,063	253	213	0.1	0.0
Farmland	0.4	207,118	133,112	82,847	53,245	18.4	11.8
Pasture, orchard	0.6	5,844	4,437	3,506	2,662	0.8	0.6
Grassland	0.8	9,100	4,003	7,280	3,202	1.6	0.7
Forest	1.0	355,676	337,606	355,676	337,606	79.1	75.1
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>449,563</b>	<b>396,928</b>	<b>100.0</b>	<b>88.3</b>

Bold numbers indicate total percent in each category

Finally, when evaluating the possibility of wildlife appearances in the Yeongju Dam target area according to the land cover, after dam construction, the total score was found to be only 88.3 % of the total score before dam construction.

### Vegetation evaluation

For vegetation type, a mixed forest community with a species composition that is close to that of natural vegetation and is appropriate for a wildlife habitat was defined as the best class, followed by broad-leaved forest and coniferous forest. Thus, 1.0 points were assigned to mixed forest, 0.7 points to broad-leaved forest, 0.3 points to coniferous forest, and 0.0 points to a non-forested area (Table 3). For the classification of forest physiognomy, 1.0 points were assigned to natural forest, 0.5 points to artificial forest, and 0.0 points to a non-forested area. For age class, scores were assigned to the age classes based on the effects of stand age on wildlife habitats: 1.0 points were assigned to age class 5, 0.8 points to age class 4, 0.5 points to age class 3, 0.3 points to age class 2, 0.2 points to age class 1, and 0.0 points to a non-forested area. For DBH class, scores were assigned based on how wildlife habitats are influenced by the diameter at breast height of the stand:

1.0 points were assigned to a large pole size, 0.8 points to a medium pole size, 0.5 points to a small pole size, 0.3 points to young trees, and 0.0 points to a non-forested area. For density, scores were assigned based on how wildlife habitats are influenced by the vegetation density: 1.0 points were assigned to a high density, 0.7 points to a medium density, 0.3 points to a low density, and 0.0 points to a non-forested area.

Table 5 summarizes the results of evaluating the vegetation elements of the target area. For the forest physiognomy evaluation, the percentage of the total score before dam construction decreased from 92.1 % before dam construction to 87.9 % after in the natural forest, but did not show a significant change in the artificial forest (from 7.9 % before to 7.6 % after). After dam construction, the total score was only 95.6 % of the total score before construction. For vegetation type, the percentage of the total score before dam construction changed from 69.4 % before dam construction to 66.2 % after for the mixed forest. After dam construction, the total score was only 95.5 % of the total score before construction. For the vegetation age class evaluation, vegetation corresponding to age classes 2 and 3 accounted for >90 % of the vegetation in the Yeongju Dam target area. As for the effects of the construction of the dam, the percentage of the total score



**Table 5** Results of evaluating vegetation parameters

	Grading standard	Area (100 m <sup>2</sup> )		Score		Percentage	
		Before	After	Before	After	Before	After
Forest physiognomy							
Non-forest	0.0	244,401	154,812	0	0	0.0	0.0
Artificial forest	0.5	51,477	49,641	25,739	24,821	7.9	7.6
Natural forest	1.0	298,855	285,373	298,855	285,373	92.1	87.9
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>324,594</b>	<b>310,194</b>	<b>100.0</b>	<b>95.6</b>
Vegetation type							
Non-forest	0.0	244,401	154,812	0	0	0.0	0.0
Coniferous forests	0.3	198,879	190,793	59,664	57,238	28.5	27.4
Deciduous forest	0.7	6,345	5,672	4,442	3,970	2.1	1.9
Mixed forest	1.0	145,108	138,549	145,108	138,549	69.4	66.2
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>209,213</b>	<b>199,757</b>	<b>100.0</b>	<b>95.5</b>
Age class							
Non-forest	0.0	244,401	154,812	0	0	0.0	0.0
Class 1	0.2	17,481	16,925	3,496	3,385	2.0	1.9
Class 2	0.4	147,831	140,797	59,132	56,319	33.9	32.3
Class 3	0.6	181,796	174,731	109,078	104,839	62.6	60.1
Class 4	0.8	2,960	2,548	2,368	2,038	1.4	1.2
Class 5	1.0	264	13	264	13	0.2	0.0
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>174,338</b>	<b>166,594</b>	<b>100.0</b>	<b>95.6</b>
DBH class							
Non-forest	0.0	244,401	154,812	0	0	0.0	0.0
Sapling	0.3	17,481	16,925	5,244	5,078	3.0	2.9
Small pole	0.5	329,627	315,528	164,814	157,764	95.5	91.4
Medium pole	0.8	3,224	2,561	2,579	2,049	1.5	1.2
Large pole	1.0	0	0	0	0	0.0	0.0
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>172,637</b>	<b>164,890</b>	<b>100.0</b>	<b>95.5</b>
Density							
Non-forest	0.0	262,130	171,985	0	0	0.0	0.0
Low density	0.3	3,581	3,404	1,074	1,021	0.4	0.4
Medium density	0.7	163,359	157,190	114,351	110,033	40.7	39.1
High density	1.0	165,663	157,247	165,663	157,247	58.9	55.9
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>281,089</b>	<b>268,301</b>	<b>100.0</b>	<b>95.5</b>

Bold numbers indicate total percent in each category

before dam construction changed from 33.9 % before dam construction to 32.3 % after for age class 2 and from 62.6 % to 60.1 % for age class 3. After dam construction, the total score was only 95.6 % of the total score before construction. For the vegetation DBH class evaluation, the percentage of the total score before dam construction decreased from 95.9 % before dam construction to 91.4 % after for the small pole size in the target area. After dam construction, the total score was only 95.5 % of the total score before construction. For the vegetation density evaluation, the percentage of the total score before dam construction decreased from 58.9 % before dam construction to 55.9 % after for the high-density vegetation, and decreased slightly from 40.7 % to 39.1 % for the medium-

density vegetation. After dam construction, the total score was only 95.5 % of the total score before construction.

### Habitat evaluation

For wildlife appearance, scores were assigned to a target area within a 500-m radius from the location where wildlife appeared based on the second- and third-survey data from the National Ecosystem Survey (MOE and NIER 2006; 2012). A score of 1.0 points was assigned to legally protected species (endangered wildlife and natural monuments) and 0.5 points were assigned to general species. The following scores were assigned to the classes according to the Ecosystem and Nature Map: 1.0 points to class 1, 0.7

**Table 6** Results of evaluating habitat parameters

	Grading standard	Area (100 m <sup>2</sup> )		Score		Percentage	
		Before	After	Before	After	Before	After
<b>Wildlife appearance</b>							
Non-appearance	0.0	247,274	303,505	0	0	0.0	0.0
Wildlife appearance	0.5	134,398	142,853	67,199	71,427	24.0	25.5
Endangered wildlife appearance	1.0	213,061	148,375	213,061	148,375	76.0	52.9
<b>Total</b>		<b>594,733</b>	<b>594,733</b>	<b>280,260</b>	<b>219,802</b>	<b>100.0</b>	<b>78.4</b>
<b>Ecological classification</b>							
No data	0.0	265,202	176,108	0	0	0.0	0.0
Grade 3	0.3	64,058	60,492	19,217	18,148	9.3	8.8
Grade 2	0.7	263,295	252,732	184,307	176,912	89.6	86.0
Grade 1	1.0	2,178	494	2,178	494	1.1	0.2
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>205,702</b>	<b>195,554</b>	<b>100.0</b>	<b>95.1</b>
<b>Conservation classification</b>							
No data	0.0	583,808	479,064	0	0	0.0	0.0
Grade 5	0.3	0	0	0	0	0	0
Grade 4	0.7	0	0	0	0	0	0
Grade 3	1.0	10,925	10,762	10,925	10,762	100.0	98.5
<b>Total</b>		<b>594,733</b>	<b>489,826</b>	<b>10,925</b>	<b>10,762</b>	<b>100.0</b>	<b>98.5</b>

Bold numbers indicate total percent in each category

points to class 2, 0.3 points to class 3, and 0.0 points for no data. For the vegetation conservation classification, 1.0 points were assigned to class 3, which is the highest class in the target area; 0.7 points to class 4; 0.3 points to class 5; and 0 points for no data (Table 3). Tables 3 and 6 do not show classes 1 and 2 for the vegetation conservation classification because paddy, farm, or orchard areas (defined as class 1) and artificial forestation areas (class 2) do not exist around Yeongju Dam.

Table 6 summarizes the results of the evaluation of the habitat elements in the target area. The examined wildlife appearance data indicated that 25 legally protected species and 222 general species appeared in the target area. For the wildlife appearance evaluation, the percentage of the total score before dam construction decreased from 76.0 % before dam construction to 52.9 % after for the protected species. After dam construction, the total score was only 78.45 % of the total score before construction. Therefore, we assumed that the effects of the construction of the dam on wildlife appearance would be relatively large. For the regions graded according to the classification system of the Ecosystem and Nature Map, the percentage of the total score before dam construction decreased from 89.6 % before dam construction to 86.0 % after in the grade 2 regions and from 9.3 % to 8.8 % in the grade 3 regions. After dam construction, the total score was only 95.1 % of the total score before construction. For the evaluation of the vegetation conservation classification, after dam

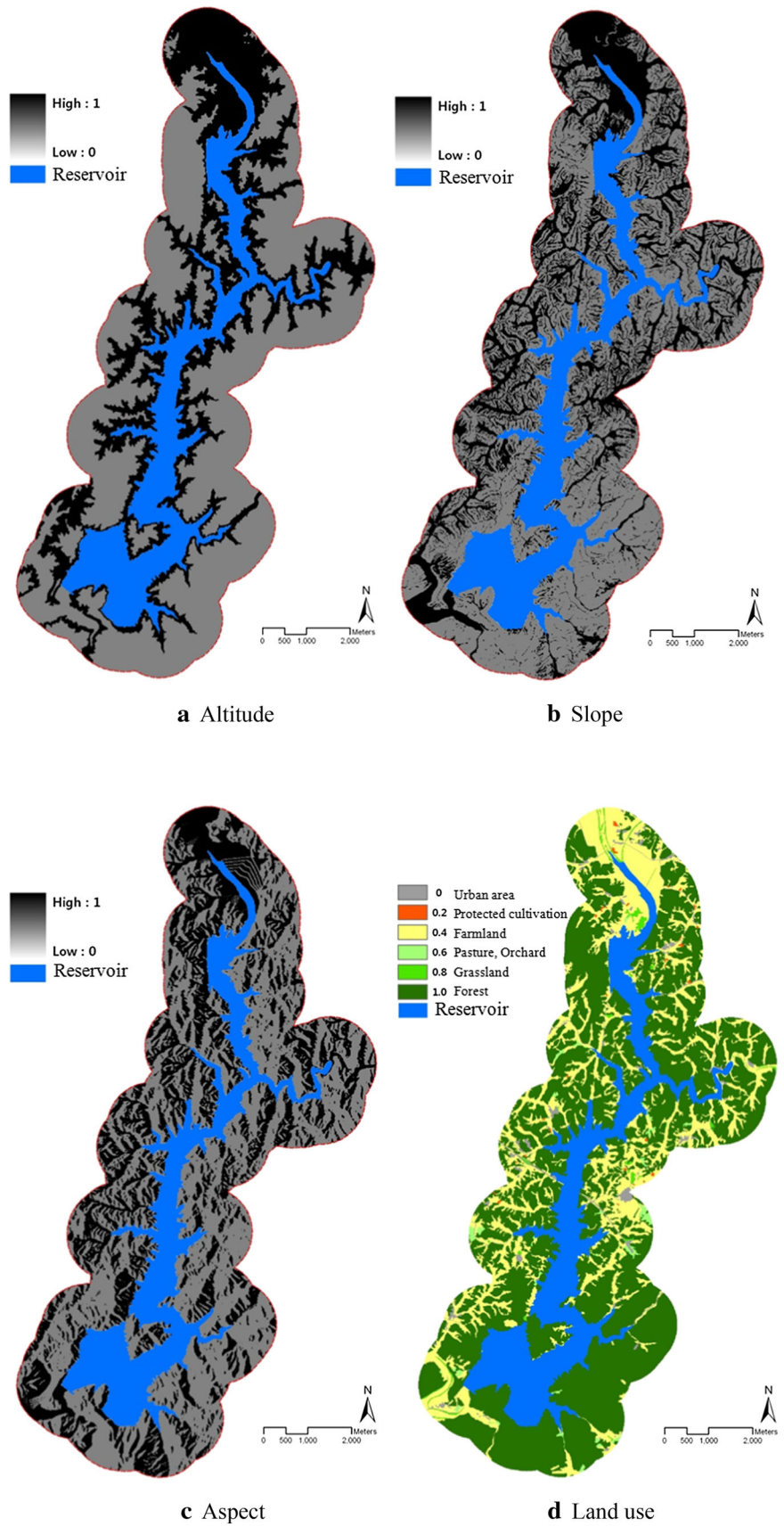
construction, the total score was only 98.5 % of the total score before construction.

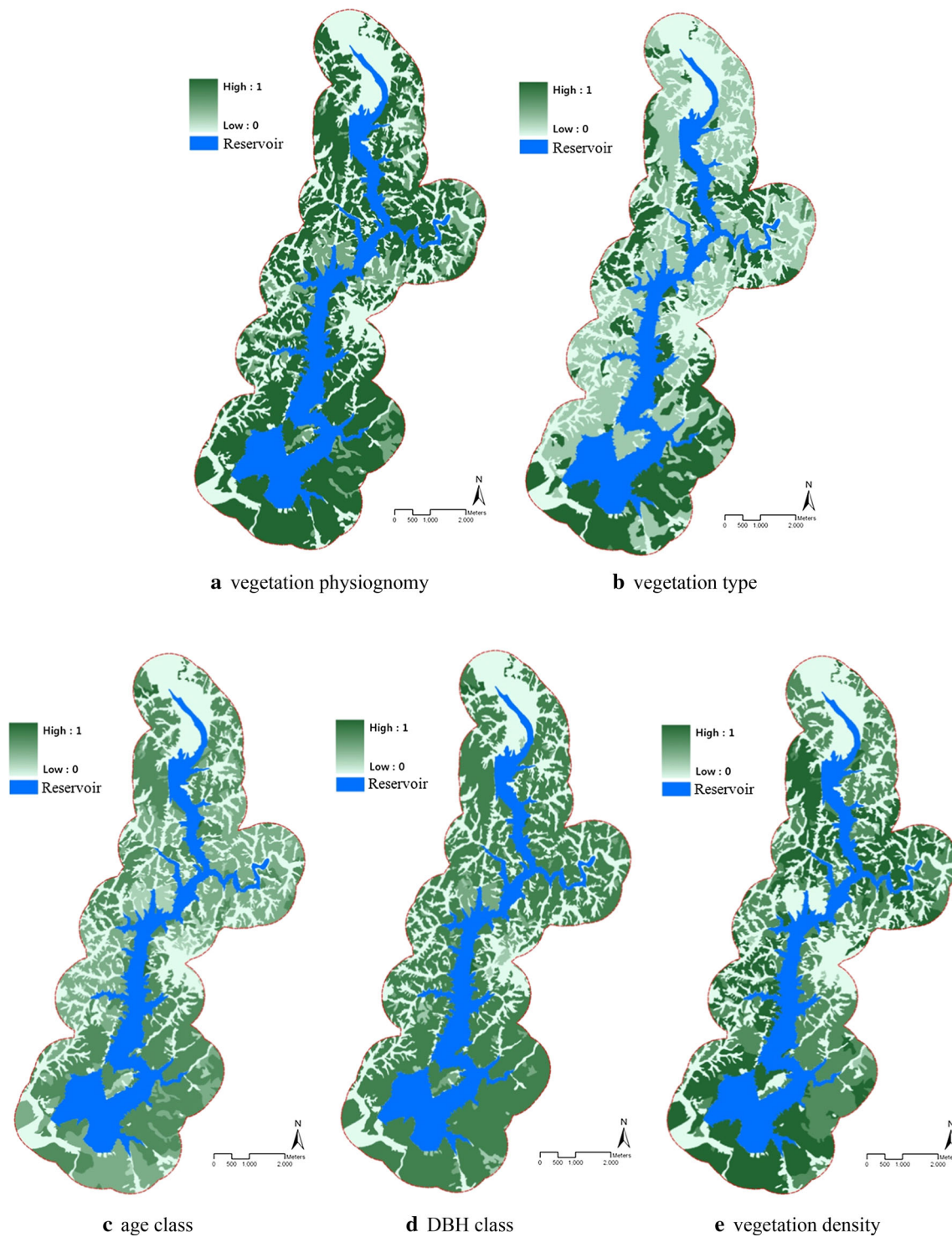
### Overall evaluation

Figures 4, 5, and 6 show the spatial distribution of the grading standards (and thus scores) for each element after the construction of the dam. As shown in Fig. 4, the scores for the geophysical elements of altitude and slope were high in the vicinity of the boundary of the reservoir and upstream of the reservoir. In contrast, the score as a function of the land use was high downstream of the reservoir. The score based on vegetation item, as shown in Fig. 5, was higher in the vicinity of the downstream area than the upstream area. Therefore, this area was expected to have a high overall ecological score. As shown in Fig. 6, the ecological condition score was high in the region where the vegetation item score was high and in regions that had been designated vegetation conservation areas.

The calculation of the overall ecological score of the target area indicated that the total ecological score for the geophysical elements after dam construction was only 82.8 % of the corresponding score before construction, the total ecological score for the vegetation elements after dam construction was only 95.5 % of the corresponding score before construction, and the total ecological score for the habitat elements after dam construction was only 90.7 % of the corresponding score before construction. The sum of

**Fig. 4** Spatial distributions of physical element parameters



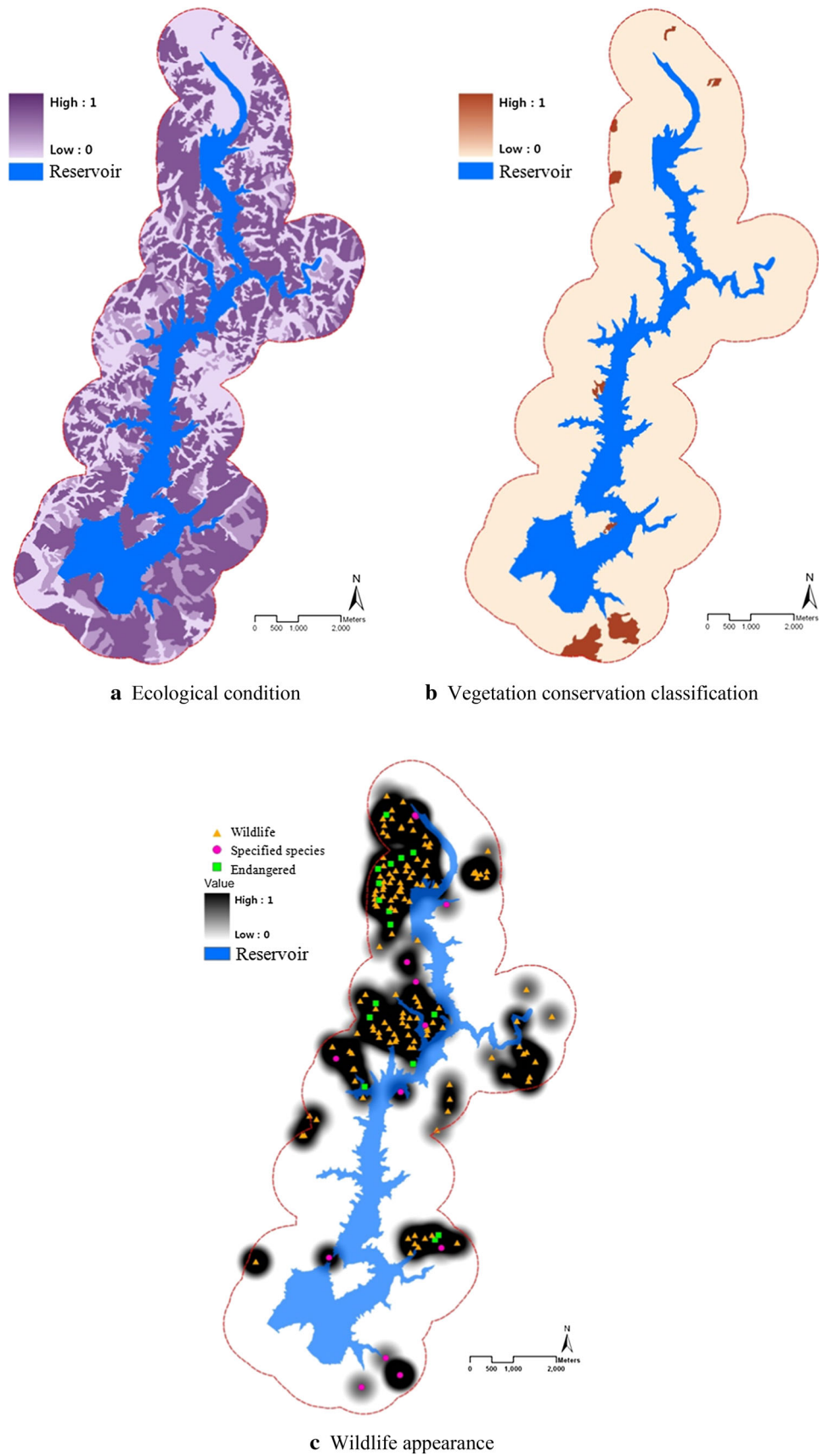


**Fig. 5** Spatial distributions of vegetation parameters: **a** vegetation physiognomy; **b** vegetation type; **c** age class; **d** DBH class; **e** vegetation density

the ecological scores for the Yeongju Dam obtained by quantifying the geophysical, vegetation, and habitat element data indicated that after dam construction, the total score was only 90.0 % of the corresponding score before construction—a change in ecological score of  $-10.0\%$

(Table 7). The above evaluation results show that the geophysical elements and habitat elements were significantly affected by the construction of the dam. In particular, geophysical elements such as slope, slope aspect, and altitude cannot be improved in the future, so construction

**Fig. 6** Spatial distributions of habitat parameters



**Table 7** Ecological score for the Yeongju Dam

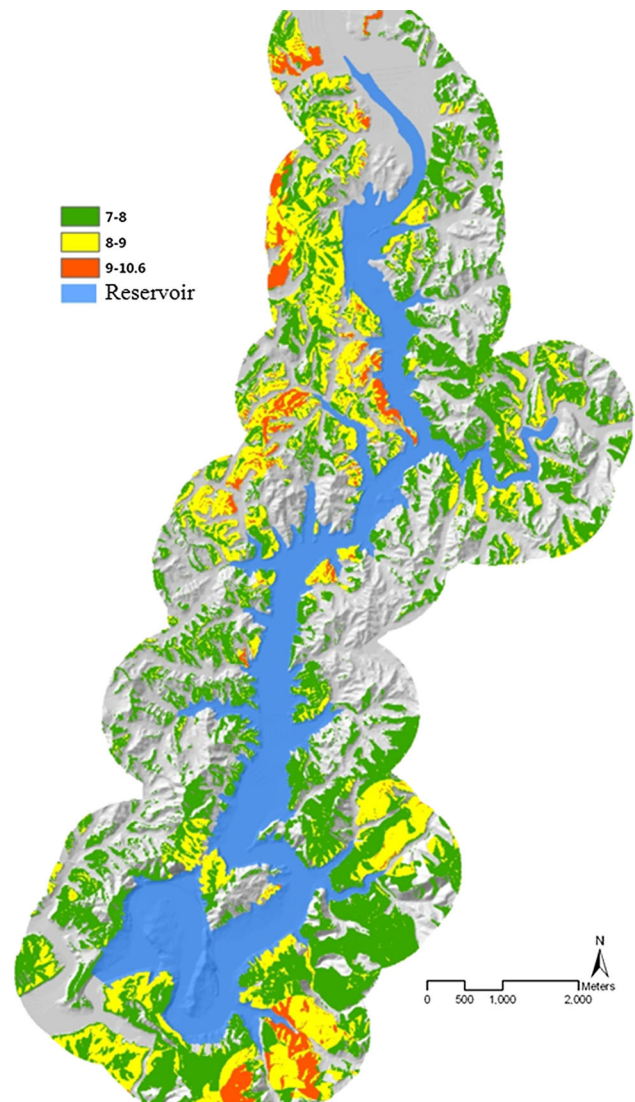
Evaluation element	Before	After	Average	
			Before	After
<b>Physical elements</b>				
Altitude	100	81.6	100	82.8
Slope	100	77.3		
Aspect	100	83.9		
Land cover	100	88.3		
<b>Vegetation</b>				
Vegetation physiognomy	100	95.6	100	95.5
Vegetation type	100	95.5		
Age class	100	95.6		
DBH class	100	95.5		
Density	100	95.5		
<b>Habitat</b>				
Ecological condition	100	95.1	100	90.7
Conservation classification	100	98.5		
Wildlife appearance	100	78.4		
<b>Total average</b>	<b>100</b>	<b>90.0</b>	<b>-10.0 %</b>	

Bold numbers indicate average scores

of the dam inevitably causes the score to decrease. Therefore, for the dam reservoir, it is necessary to restore the habitats of relatively vulnerable species by restoring damaged regions and performing continuous monitoring after the project. In addition, as the technique used in this study can be applied to a number of dams, an evaluation of the ecological impact of each of those dams is possible based on its ecological score.

## Discussion

This study developed methods for quantifying the ecological effects of the construction of a proposed dam. This study examined the Yeonju Dam and estimated the ecological impact based on geophysical, vegetation-related, and habitat-related parameters (“elements”). To examine the spatial distribution of regions of outstanding ecological function in the target area around the dam, the ecological function of each region was determined by calculating the score for each ecological item evaluated and then presenting the results of the evaluation in a diagram. The map overlay method of Ian McHarg (Mcharg 1969) was used to collectively analyze and evaluate the various evaluation elements. In the map overlay method, each thematic map of the evaluation elements is drawn based on a suitable site analysis, and the zones selected are identified by overlaying each thematic map. This research method serves as the current theoretical basis for GISs (Jang 2008). The spatial distribution of regions with high values was obtained by



**Fig. 7** High-scoring ecological areas around Yeongju Dam, based on evaluations of the 12 items listed in Table 7

overlaying the results for the various elements used to evaluate the ecological environment of the dam. The results of evaluating the 12 elements in Table 7 were summed for each cell, as shown in Fig. 7. A perfect score for an item was 1.0 points, so, the maximum score in an evaluation was 12 points. Weighting was not performed for any item because this evaluation technique overlaid the results of evaluating the geophysical elements, vegetation/forest, and habitat and because it was assumed that each item was of identical importance.

Based on the results of the overlaying process, regions with scores of >8 points were selected as outstanding ecological areas, and a map with different colors plotted according to the score was created (see Fig. 7). Regions with 7–8 points accounted for the largest proportion of the area considered (24.9 %), while regions with low

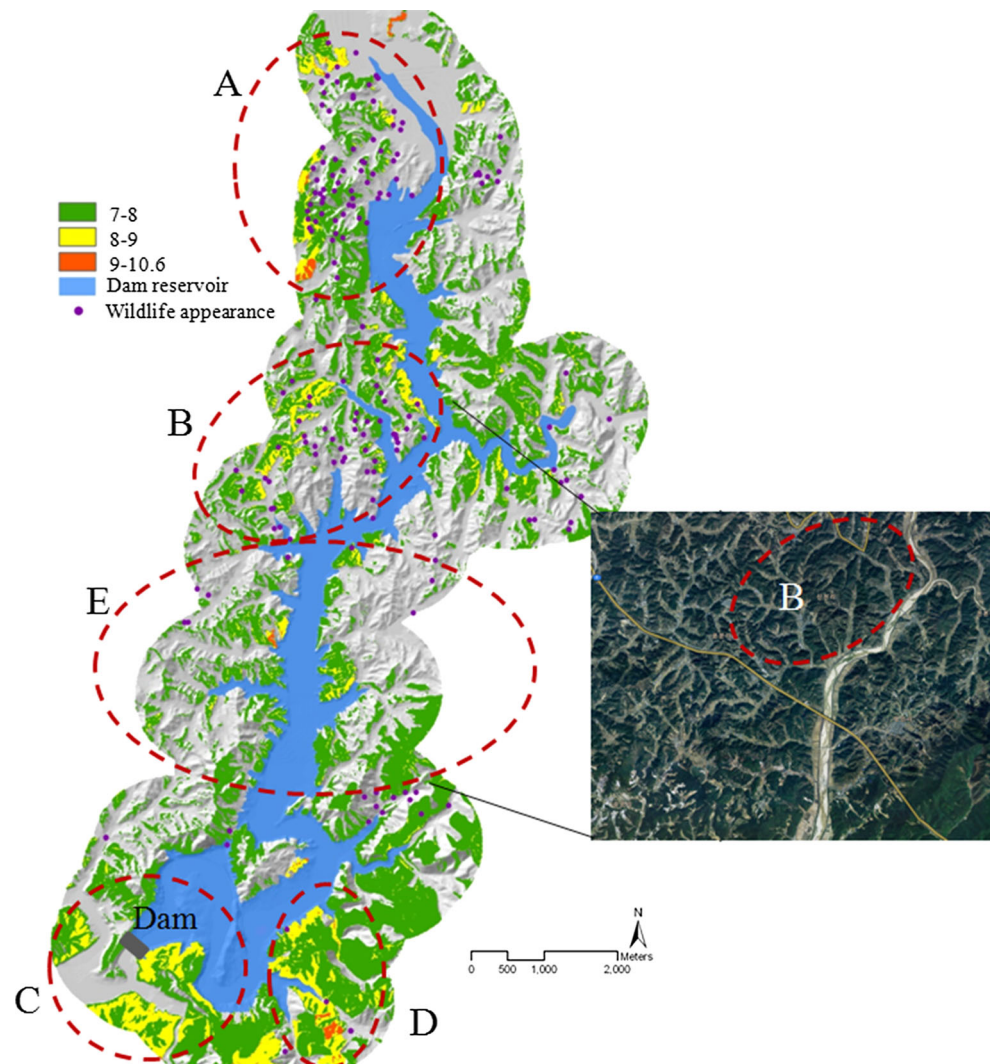
**Table 8** Evaluation results for the target area of Yeongju Dam, obtained by summing the scores for the 12 elements listed in Table 7

Evaluation score	Area (100 m <sup>2</sup> )	Percentage (%)
1.5–2	3,090	0.5
2–3	53,604	9.0
3–4	73,737	12.4
4–5	28,214	4.7
5–6	25,487	4.3
6–7	71,735	12.1
7–8	148,163	24.9
8–9	72,064	12.1
9–10.6	13,732	2.3
Dam reservoir	104,907	17.6
Total	594,733	100.0

evaluation scores of 3–4 points accounted for 12.4 % of the area considered. Among the outstanding ecological areas, regions with scores of >8–9 points accounted for 12.1 % of

the total area considered, as shown in Table 8. The regions identified as outstanding ecological areas are key ecological areas that should be designated conservation areas when making future development plans.

Figure 8 shows a comparison between the regions with high ecological scores based on the summation of 11 elements (all except for wildlife appearance) in Table 7 and the locations at which wildlife appeared. This comparison was used to check the results of this study. Data from the National Ecosystem Survey of the Ministry of Environment (Ministry of Environment and National Institute of Environmental Research 2006, 2012) were used to get information on the locations at which wildlife had appeared (as shown in Table 7). As shown in Fig. 8, regions with high ecological scores were broadly divided into three regions. Among these, wildlife appearance points were concentrated in outstanding ecological area A and outstanding ecological area B. In area E, no wildlife appearances were observed on either the left or right banks, and the results

**Fig. 8** Comparison of the regions with high ecological scores based on 11 elements (all except for wildlife appearance) in Table 7 with the locations at which wildlife appeared

from the model indicated that the ecological score was relatively low in this region. An aerial photograph of this region (refer to Google Earth) shows that most of the land is used for distributed small-scale fields and villages, and that the forest zones are disconnected. In contrast, it is thought that in area C, which is a dam construction site, there were no wildlife appearances due to the construction project. In area D, the ecological score was relatively high but the amount of wildlife appearance data was small. Area D had relatively high values for the vegetation score and the ecological condition score, but this is thought to be due to the limitations of the wildlife survey. In other words, there may be issues with accessibility or limited access in this area; to ensure the reliability of the results of this study, comparisons with additional field survey data are needed in the future. However, when compared with all of the survey data available for this area so far, our method gave reasonable results.

Based on the results of this study, it is thought that the method developed here for evaluating the ecological value of a dam could be used to guide ecological restoration plans in the future. Using the technique proposed in this study, regions requiring restoration can be identified, allowing habitat restoration plans for each taxon to be established. Until recently, habitat restoration plans relating to river projects in Korea were based primarily on the judgments of experts. In the future, it is expected that such plans will be established using a more scientific and systematic method. Additionally, for a dam that is due to be built or already under construction, the conditions after dam construction can be predicted and ecological scores can be estimated. For example, if a dam had to be constructed in the Naeseong Stream basin in the same manner as the Yeongju Dam, several candidate target areas could be selected, and after evaluating the ecological impact on each region, the one that would suffer the smallest ecological impact could be selected as the planned construction site. In addition, the degree of ecological restoration possible can be judged at the dam construction planning stage, and plans for this restoration can then be established. Such a procedure has long been needed for dam projects in Korea but could not be implemented due to the lack of a method for quantitatively evaluating the ecological impact of a dam. In Korea, there have been frequent disagreements about dam construction, as is the case in other countries. Therefore, government officials, environmentalists, local residents, and experts on dam construction need to come together to transparently highlight the advantages (e.g., flood control and water use) and disadvantages (e.g., ecological impact) of the construction of a dam, and to establish goals and plans for the degree of ecological impact. This study describes one of the quantitative

approaches that can be used to evaluate the ecological impact of dam construction.

In this study, the ecological impact of dam construction was analyzed, focusing on terrestrial animals and plants. However, diverse variables of the water body such as hydrological effects, water quality effects, and bed structure should also be included in the evaluation, although we could not obtain such data for the target dam of this study because the dam reservoir was still being constructed. Although data from another dam were used, results obtained using those data were limited because the characteristics of water bodies vary among regions. Therefore, it would be useful to analyze the effects of the construction of a dam on ecological values using a continuous monitoring system centered on the dam; this should include an additional analysis of the impact of dam construction on aquatic organisms. The evaluation technique employed in this study was applied to estimate the ecological value of Yeongju Dam using physical, vegetation, and habitat parameters.

To summarize, in this study we have proposed an evaluation method for assessing the ecological impacts of dam construction. The utilization of this method could facilitate the implementation of technical approaches that reduce the ecological impacts of dam construction.

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