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REVIEW ARTICLE

Four Types of Geodiversity for Nature Conservation with a Focus on the Relationship Between Landform and Vegetation

Sadao Takaoka[1]

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Abstract
This paper examined how geodiversity is related to biodiversity at regional and local scales by reviewing previous studies focusing on landforms and geomorphic processes. The results showed four types of geodiversity that can contribute to vegetation diversity creation: diversity of landform types, diversity of ecological functions of landforms, diversity of landform dynamics, and diversity of linkages among landforms. The last three imply that individual landforms have different roles and dynamics in each area, even if they are of the same landform type. Considering that the four geodiversity types are important for nature conservation and resource management, long-term effects on vegetation changes in geodiversity, especially those related to geomorphic processes, need to be carefully considered.

Keywords Biodiversity · Geodiversity · Landform · National park · Nature conservation

Introduction

Biodiversity and geodiversity need to be considered inseparable in nature conservation and resource management (Gray 2004, 2013), and a broad understanding of the linkages between the two is useful in considering biodiversity conservation under changing climate (Brazier et al. 2012; Beier et al. 2015). However, it has not been fully applied to environmental policies (Gordon et al. 2012; Matthews 2014; Brilha et al. 2018; Schrodt et al. 2019). This is partly because there is not much empirical research on the relationship between the two (Hjort et al. 2012; Alahuhta et al. 2020).

Quantitative studies of the links between geodiversity and biodiversity are gradually accumulating; however, most of the studies are GIS-based and use grid cell data at broad scales (i.e., global, continental, and regional scales) (e.g., Jačková and Romportl 2008; Bailey et al. 2017; Kärnä et al. 2019; Tukiainen et al. 2017; Antonelli et al. 2018; Toivanen et al. 2019). Broad-scale studies analyze the relationship between spatial patterns of biodiversity and geodiversity but do not directly help understand the relationship's processes. Understanding the processes allows for a deeper understanding of how geodiversity contributes to the creation of biodiversity. Such an understanding is beneficial for nature conservation based on conserving nature's stage approach (Beier et al., 2015; Hjort et al. 2015). Considering that the effects of geodiversity on biodiversity are strong at finer scales (Tukiainen et al. 2017; Bailey et al. 2017), more research on patterns and processes at regional and local scales should be conducted, in parallel with broad-scale, quantitative studies.

This paper examined how geodiversity is related to biodiversity at regional and local scales by reviewing previous studies focusing on landforms and geomorphic processes. This review will facilitate future process-based research to improve our understanding of the relationship between biodiversity and geodiversity and contribute to nature conservation. The focus on landform is due to the characteristics of landforms in ecosystems and methodological advantages, as described below.

Geodiversity includes diverse geological, geomorphological, soil, and hydrological features (Gray 2013), along with climatic features (Benito-Calvo et al. 2009; Parks and Mulligan 2010). Among these, geomorphological features (landforms and geomorphic processes) are useful in considering the relationship between biodiversity and geodiversity. This is because landforms influence ecosystem processes in various ways (Swanson et al. 1988). For example, landforms are

✉ Sadao Takaoka
takaoka@isc.senshu-u.ac.jp

[1] Department of Geography, Senshu University, Higashimita 2-1-1, Tama-ku, Kawasaki, Kanagawa 214-8580, Japan

related to soil evolution, hydrological processes, and the formation of micro-climatic conditions. Furthermore, the formation and distribution of landforms is often closely related to geology. Therefore, analyzing landforms helps in understanding the influence of other features. It is also important to note that landforms, unlike geology, soils, hydrology, and climate, are easy to recognize for their spatial distribution and morphological changes. Remotely sensed information (satellite images, aerial photographs, and high-resolution LiDAR-derived digital elevation models (DEMs)) can be quantitatively or qualitatively interpreted to determine the morphology and distribution characteristics of landforms (e.g., Guitet et al. 2013; Benito-Calvo et al. 2009; Tukiainen et al. 2019). Based on this, we can make inferences about their evolutionary processes and future changes.

This study reviews previous reports on the role of geodiversity in biodiversity creation, with the case of Chubu Sangaku National Park in central Japan, particularly in the Kamikochi area located in the southern part of the park (Fig. 1). Here, the focus was placed on landforms and geomorphic processes and their relationship with vegetation diversity. The primary objective of national parks is to protect natural biodiversity and its underlying ecological structures, support environmental processes, and promote education and recreation (Dudley 2008). Following this objective, many people visit national parks to admire nature. However, since lodging facilities and walking trails need to be protected from landslides and flooding, artificial alteration in landforms and geomorphic processes has been conducted in national parks in Japan. Such alterations in national parks affect individual species or their collective habitats and fundamentally alter the geoecological processes key to habitat formation, speciation, and evolution (Chakraborty 2021). The Chubu Sangaku National Park has long been reported to be undergoing construction work that can modify landforms and geomorphic processes (Iwata 1999), and the problem is ongoing (Chakraborty 2020).

Four Types of Geodiversity Contributing to Vegetation Diversity Creation

Vegetation Mosaics Created by Various Landforms

Chubu Sangaku National Park (1743 km^2) is a mountainous national park. The major vegetation zones are the montane

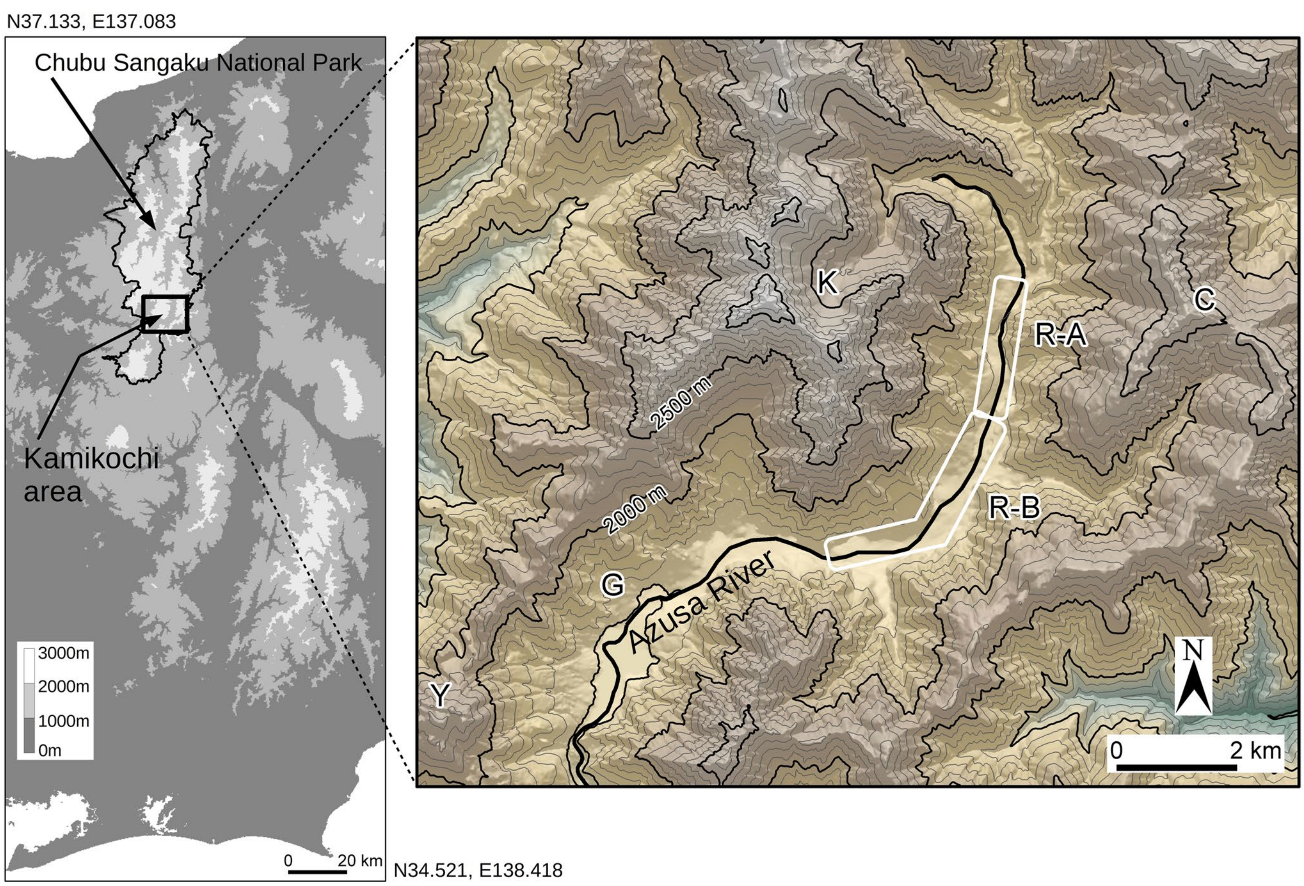

Fig. 1 Study area. C, Mt.Chogatake; G, Genbunzawa watershed; K, Karasawa cirque; Y, Mt. Yakedake; R-A, river reach A; R-B, river reach B

forest zone (around 700–1600 m) dominated by broad-leaved deciduous forests, subalpine forest zone (around 1600–2500 m) dominated by evergreen coniferous forests, and alpine zone (around 2500–3000 m), mainly composed of evergreen dwarfed coniferous scrub and alpine meadows.

The region has various mountain landforms by glacial, periglacial, volcanic, hillslope, and fluvial processes. In the Kamikochi area, the following landforms are observed (Iwata 2016). First, glacial landforms are developed, although no active glaciers are formed in this area. Cirques are formed at elevations of 2300–3100 m (Fig. 2a); moraines are located at the lowest elevation of 1650 m. U-shaped valleys are developed between them. Second, periglacial processes are not active, but there are small areas of wind-beaten rubble slopes along the main ridges (2600–2800 m). Periglacial processes also form the talus cones at the bottom of cirque walls (2350–3000 m). Fossil periglacial landforms include rock glaciers (2600–3000 m) and blockfield (2250–2800 m). Third, large landslides and gravitationally deformed slopes occur at 1500–2600 m (Fig. 2b). Several linear depressions formed by gravitational slope deformation are found in the upper part of the mountain slopes, particularly in areas consisting of sedimentary rocks; multiple ridges are formed on the high ridgeline area (Fig. 2c). Fourth, a volcano, Mount Yakedake, with a summit elevation of 2456 m, is located in the southern part of the Kamikochi area (Fig. 2d). The summit consists of a lava dome, while the hillside consists of smooth slopes made of pyroclastic flow deposits and lava flows. Furthermore, the Azusa River forms a wide, gently sloping floodplain at an elevation of 1500–1650 m, and alluvial cones develop at the confluence with its tributaries.

Within the alpine, subalpine, and uppermost montane vegetation zones found in the Kamikochi area, landforms give characteristics to the spatial structure of vegetation. Taking landslide landforms as an example, the relationship between micro-landforms and vegetation diversity is described below. Landslide scarps and landslide masses are abundant on the hillside slopes in the Kamikochi area. In the upper part of the subalpine zone, forests dominated by *Abies mariesii* and *Abies veitchii* are predominant, but *Larix kaempferi*, a pioneer species, has formed forests on relatively new sliding scarps (tens to hundreds of years old). Furthermore, forests dominated by *Picea jezoensis* var. *hondoensis* are formed in some landslide-mass areas (Takaoka and Kariya 2020). The lower part of the subalpine zone is covered by forests dominated by *Tsuga diversifolia* and *Abies homolepis*, but *L. kaempferi*-dominated forests are formed on landslide scarps; *Pterocarya rhoifolia* and *Cercidiphyllum japonicum* dominate in some landslide-mass areas. On slopes covered with boulders within landslide-mass areas, *Thuja standishii* and *Chamaecyparis pisifera* are dominant. Also, in the Kamikochi area, the area size and frequency of landslides are different between sedimentary rock and granite areas. As a result, large patches of *L. kaempferi* forests are sparsely found in sedimentary rock areas. In contrast, many small patches of *L. kaempferi* forests are found in granite areas, creating contrasting vegetation between the two areas (Takaoka 2006).

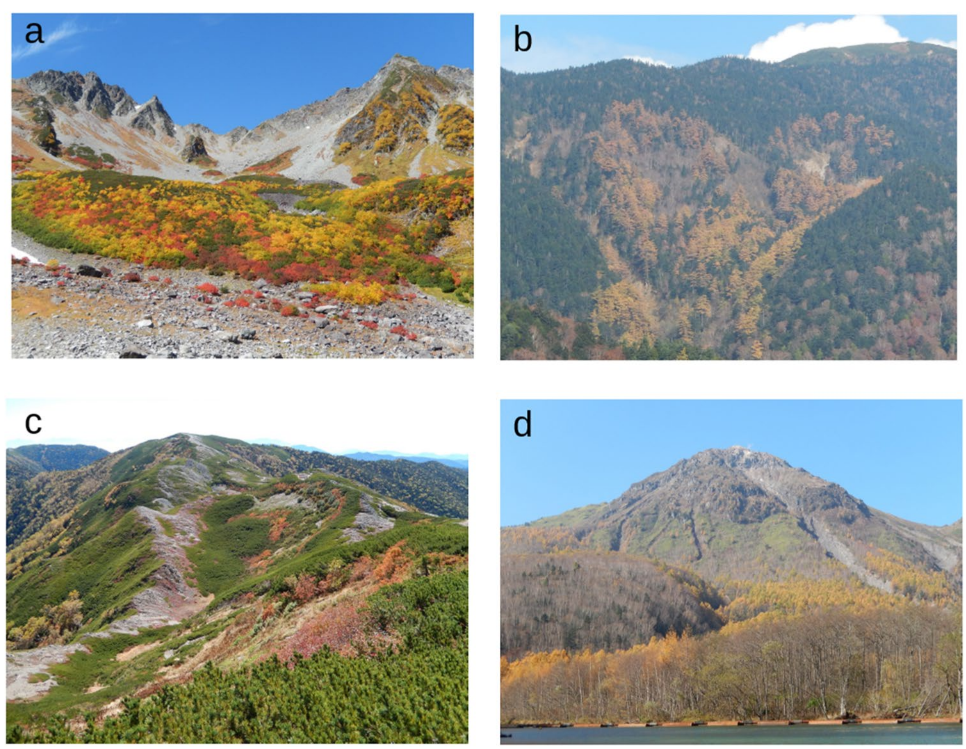

Fig. 2 Vegetation patterns concerning landforms, taken in the Kamikochi area. **a** shrublands with colored leaves on moraines in the Karasawa cirque; **b** larch forests established on landslide scarps in the Gembunzawa watershed; **c** vegetation mosaic formed around multiple ridges near Mount Chogatake; **d** vegetation formed on the hillside slopes of Mount Yakedake

Studies of vegetation in the high elevation areas of the Hida Mountains show that such effects of landslides on vegetation are observed throughout the Chubu Sangaku National Park. The highly diverse vegetation found on the slopes of landslide-mass areas is substantially different from the surrounding periglacial slopes. Complex vegetation patterns found in landslide sites are probably formed by the conditions of microclimate, hydrology, and soil properties related to the micro-landforms formed by landslide activities (Kariya et al. 2009, 2013).

Summarily, landforms and geomorphic processes create vegetation diversity by determining the spatial patterns of resource availability and disturbance regimes. Additionally, the presence of various mountain landforms results in various vegetation mosaics.

Diversity of Ecological Functions of Landforms

The spatial relationship between landforms and vegetation described in the previous section can appear differently between areas. For example, the vegetation formed in a landslide site on the southern slope of Mount Happo in the northern part of Chubu Sangaku National Park shows a mosaic structure of coniferous, broad-leaved forests, *Sasa* grasslands, meadows, mires, ponds, and rubble fields (Takaoka 2019). However, such vegetation mosaic structures are not found in every landslide site in the national park. Takaoka (2019) described the variations in vegetation at different landslide sites within a region that approximately overlapped the extent of Chubu Sangaku National Park and examined the possible causes of the regional diversity of vegetation at these sites. The results indicate that maximum snow depth, summer temperatures, and bedrock lithology are the most important factors that cause vegetation complexity in the landslide sites. In the snowier areas of the region, snow has greater effects on the development of vegetation at the landslide sites. Furthermore, non-forest vegetation, such as shrubs, *Sasa* grasslands, and meadows, are particularly abundant in landslide sites in those areas.

Studies examining the distribution of ponds also show that the relationship between landform and vegetation is not fixed in the region. Landslide landforms are the major sites of pond basins in Chubu Sangaku National Park (Takaoka et al. 2012; Takaoka 2015). Ponds provide a habitat for aquatic plants, and wetland vegetation develops around the pond. Ponds occur in depressions in landslide-mass areas and linear depressions behind large landslide scarps. These ponds frequently occur in the snowiest parts of the region, although geological setting also affects pond formation. Furthermore, depending on the area, ponds may not form in the depression.

The cases mentioned above indicate that even in the same type of landforms, their role in vegetation formation varies between areas and regions. This means there is spatial diversity in the ecological functions of landforms.

Geomorphic Processes and Their Spatial Diversity

The Azusa River, which flows through the Kamikochi area, has a wide floodplain with braided channels, and riparian forests are well developed on the floodplain (Fig. 3). The riparian forests consist of pioneer Salicaceae species. The fluvial geomorphic processes cause forest disturbances essential for establishing and regenerating riparian forests (Shimazu 2013). For example, *Salix arbutifolia*, a riparian forest species, requires disturbance that creates bright sand and gravel bars for their regeneration (Ishikawa 2008).

In the Azusa River, the regeneration pattern of riparian forests depends on river reaches, indicating that the disturbance regime by geomorphic processes is spatially different. Comparing the aerial photographs taken in 1958 and 1999, the distribution of riparian forests changed owing to fluvial disturbances: forests in photographs from 1958 had disappeared by 1999 in some places, and young forest stands had newly established in other places by 1999 (Fig. 4) (Takaoka 2009). The percentage of such young forest stands relative to that of the total riparian forest in 1999 was high in cross-sections in reach A with a flood plain that is often 200 m or less wide. However, in reach B with a 400-m or more floodplain, young stands occupied only 10–20% of riparian forests at most cross-sections. These observations suggest that the disturbance regime in riparian forests varies depending on the reach. In the river reach with a narrow floodplain (reach A), riparian forest stands are frequently replaced with young stands by lateral migrations of river channels. In contrast, riparian forests in the river reach with

Fig. 3 View of the Kamikochi Valley with its broad floodplain. This photo was taken upstream from near the summit of Mt. Yakedake

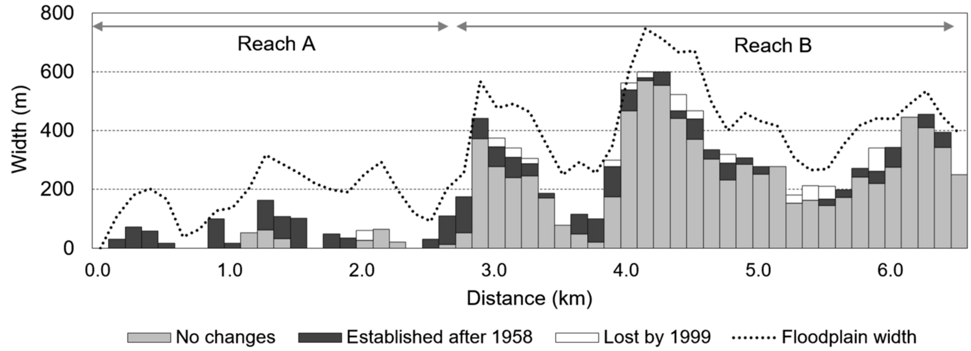

Fig. 4 Riparian lost forests and new riparian forests established between 1958 and 1999. The locations of river reaches A and B are shown in Fig. 1. The width of the riparian forest on the floodplain was measured using GIS along transects that were established at 125-m intervals in a direction perpendicular to the Azusa River channel (Modified from Takaoka 2009)

a wide floodplain (reach B) are mosaics of forests of different stand ages, including mature trees.

Such a spatial difference in the fluvial disturbance regime is also recognized at the national park-wide level. The gently sloping and wide floodplain with braided channels, as seen in the Azusa River, is not found in other national park areas. There are no rivers that have a wide valley floor at a similar altitude to the Kamikochi area. The reason why *S. arbutifolia*, which is distributed in northeast Asia, is isolated and found only along the Azusa River in Honshu Island, central Japan, may be due to the unique disturbance regime of the river in this area (Nagamitsu et al. 2014). In Honshu Island, the cool climatic conditions in which *S. arbutifolia* can grow are mountainous areas usually with V-shaped valleys, not those of lowlands with broad flood plains. The sedimentation of a lake created this unusual wide valley floor in the old Kamikochi area, which was created when the old Azusa River was blocked by the activity of the Yakedake volcano group 12,400 years ago (Harayama 2015).

Summarily, geomorphic processes are essential for establishing certain vegetation types. However, the processes that form one landform type (e.g., fluvial processes) are spatially diverse and consequently contribute to the formation of vegetation diversity in a region.

Linkages Between Landforms and Their Diversity

Geomorphic processes that work in one place can also affect the landforms of adjacent places. For example, landslides are predominant in the Genbuzawa watershed, a tributary of the Azusa River, and sediment yielded from the watershed forms an alluvial cone at the confluence with the Azusa River. Although mature forests dominated by *Abies homolepis* have developed on the alluvial cone, even-aged *Alnus inokumae* forests have been established where the mature forests were disturbed by debris flows (Fig. 5a). *P. jezoensis* var. *hondoensis* forests and mixed forests of *Abies homolepis* and *P. jezoensis* var. *hondoensis* are found on a large debris lobe (LDL) in the alluvial cone, which was formed by the deposition of sediments from a large landslide that occurred about 370–350 years ago in the central part of the Genbunzawa watershed (Takaoka and Kariya 2020). Furthermore, the LDL has altered the local disturbance regime on the alluvial cone, limiting the area where debris could flow (Fig. 5b) and, consequently, the area where young *A. inokumae* forests to the south of the LDL.

The case in the Genbuzawa watershed indicates that the diversity of vegetation on the alluvial cone located in the lower part of the watershed is formed by the sediment supply associated with the geomorphic processes occurring in the upper part of the watershed. It is observed that such geomorphic linkages form vegetation structures on alluvial cones along the Azusa River. Landforms similar to the LDL of the Genbunzawa watershed are also found in several other tributary watersheds.

Vegetation on alluvial cones is not the same on all cones. The area size of the alluvial cone has a relationship with the topography and lithology of each tributary watershed (Takaoka 2006), and the vegetation in each alluvial cone is also different (Fig. 6). Some are dominated by *Fagus crenata*, *L. kaempferi*, and *A. inokumae* forests, while others, such as the Genbunzawa watershed, are dominated by *A. homolepis* and *P. jezoensis* var. *hondoensis*. This suggests that there is diversity in the geomorphic linkages due to differences in frequency of debris flows and grain-size distribution of sediments. Furthermore, the diversity creates differences in vegetation among alluvial cones.

Geodiversity and Nature Conservation with a Focus on Landforms

The Chubu Sangaku National Park examples show that the landform diversity creating vegetation diversity can be characterized into the following four types. The first is the diversity of landform types. The existence of various landforms is related to the formation of complex and diverse vegetation structures. The second is the diversity of ecological functions of landforms. The ecological roles of landforms in creating vegetation diversity differ depending on areas with different environmental conditions (e.g., climate, geology), even if they are the same landform type. The third is

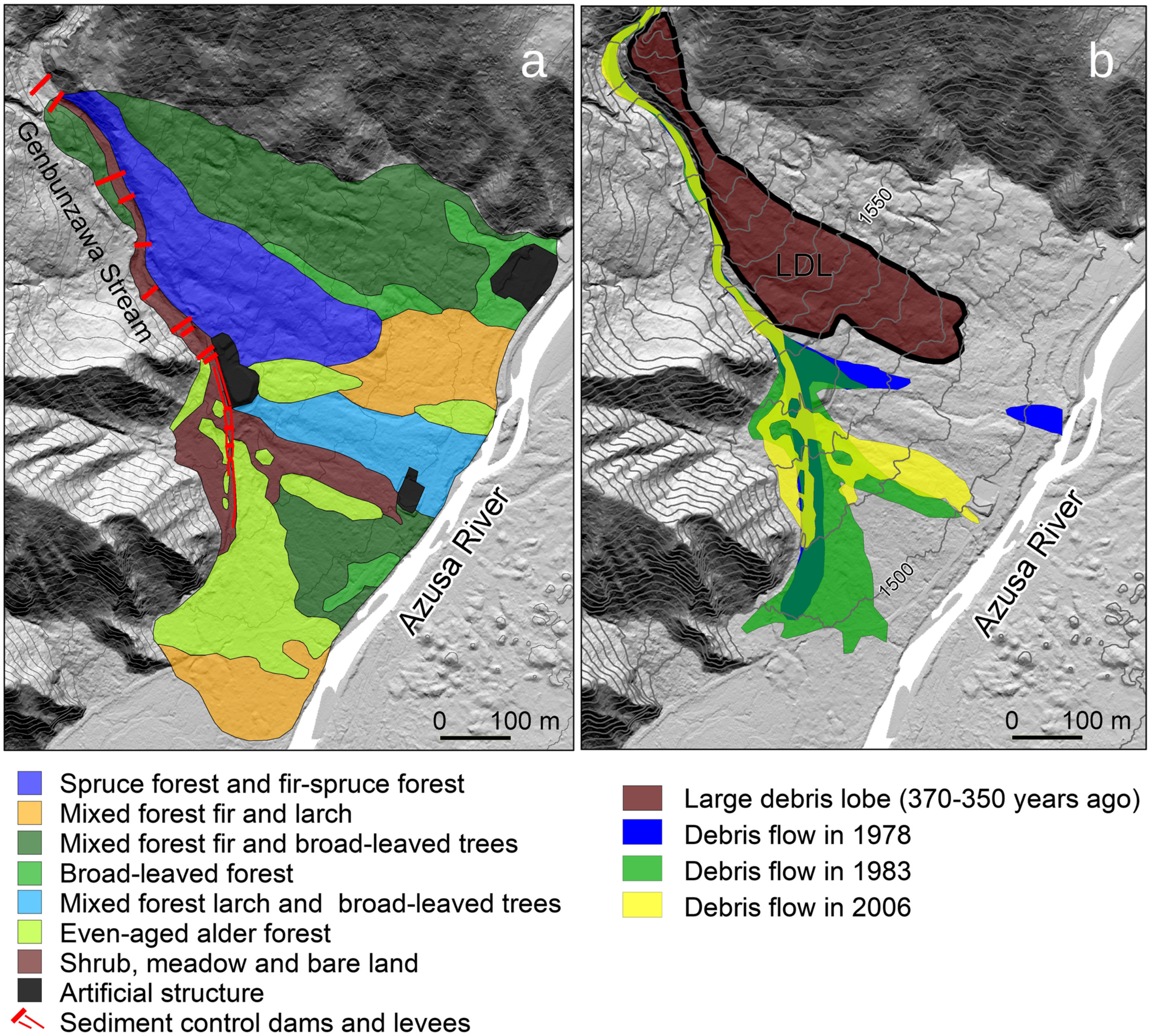

Fig. 5 Vegetation on an alluvial cone formed at the confluence of the Genbunzawa stream and the Azusa River (**a**), and a LDL and the remains of a debris flow whose flow path were restricted by it (**b**) (modified from Takaoka and Kariya 2020). Vegetation was illustrated by the interpretation of aerial photographs taken in 2009, and sediment control dams and artificial levees were illustrated by field observation and the interpretation of shaded relief derived from 1 m resolution DEM generated from LiDAR data taken in 2010. The path of debris flows was mapped by interpreting aerial photographs taken in the past where debris flows destroyed vegetation

the dynamics of landforms and their diversity. Geomorphic processes create opportunities for vegetation regeneration, and these processes are not homogenous within and between areas. Fourth is the linkage between landforms and the diversity of ways they are linked to each other. For example, one landform change can affect the formation of adjacent landforms, which can affect vegetation formation, and such landform linkages vary among watersheds.

For each of the four diversity types, Table 1 shows examples of artificial development activities that can cause loss of geodiversity in Chubu Sangaku National Park. The first two of diversities in this table consider landforms as static, and the conservation of landforms as historical heritage is necessary for conserving vegetation. In contrast, the latter two consider landforms as dynamic, and maintaining geomorphic processes is necessary for vegetation conservation.

There are no large-scale and serious landform alterations related to the first two types of geodiversity in Chubu Sangaku National Park. Natural Parks Law regulates artificial development in national parks, and large-scale developments that alter landforms and vegetation that are important to the composition of the scenery are particularly restricted.

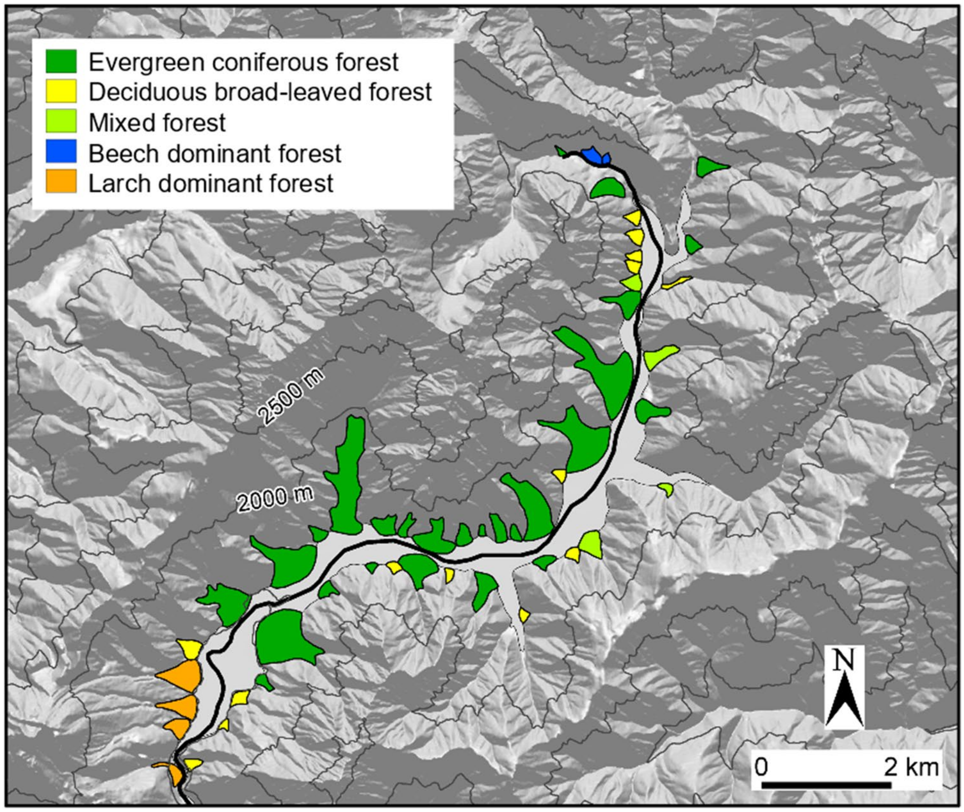

Fig. 6 Distribution of vegetation types in alluvial cones

Table 1 Examples of artificial alteration in landforms and geomorphic processes in the Chubu Sangaku National Park

Geodiversity type	Examples of development activities that degrade geodiversity	Approaches to conserve geodiversity necessary to maintain vegetation diversity
Diversity of landform types Diversity of ecological functions of landforms	Alteration of landforms by construction of accommodation facilities (Kamikochi and other areas) and mountain roads (Tateyama and Norikuradake areas)	Conserving landforms as historical heritage with limiting earth excavation and fill
Diversity of landform dynamics	Alterations of fluvial processes by construction of levees and concrete groundsills in floodplains of the Azusa River	Maintaining geomorphic processes with limiting the installation of structures that prevent erosion and sedimentation
Diversity of linkages among landforms	Alterations of sediment transportation processes by construction of sediment control dams along tributaries of the Azusa River	

Lodging facilities and automobile roads have been constructed in Chubu Sangaku National Park, but artificial alteration of landforms has been limited to a minimum area.

However, artificial modifications of geomorphic processes that involve no major direct landform alteration or vegetation destruction have been conducted. Artificial levees have been constructed on the floodplain since the 1970s to protect lodging facilities, roads, and nature trails. They have changed the fluvial disturbance regime of the Azusa River: the frequency of disturbance has become different between areas protected by levees and unprotected riverside areas. In the reach where artificial levees have been constructed, the riparian forests in the protected area are unlikely to be disturbed by the river in the future, and therefore difficult to regenerate. In that reach, fluvial processes are now working on the floodplain that artificial levees have narrowed, so the disturbance frequency to the riparian forest has increased in the riverside area. As a result, the riparian forests in the riverside area are predicted to be increasingly occupied by young forests, as in reach A where the floodplain was originally narrow (Fig. 4). Artificial levees have been installed mainly in river reaches with wide floodplains. Consequently, the differences in vegetation among river reaches would be reduced in the area.

Linkages between landforms have also been artificially altered. Since the Kamikochi area is located in a

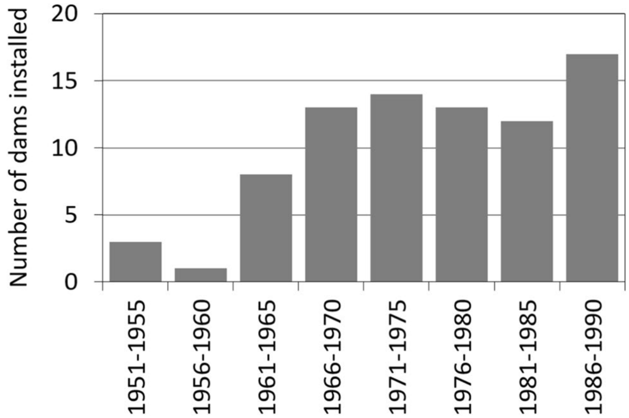

Fig. 7 Installation of new sediment control dams in the Kamikochi area

mountainous region with active geomorphic processes, some accommodations and roads are built on alluvial cones that are not affected by the flooding of the Azusa River, but these alluvial cones are vulnerable to debris flows from tributaries. Hotels and water treatment plants have been constructed on the alluvial cones in the Genbuzawa watershed, and sediment control dams and artificial levees have been installed to protect them (Fig. 5). These erosion control structures alter the landform linkages that were formed by sediment transport processes within the tributary area.

Sediment control dams and levees have been constructed along tributaries of the Azusa River since the 1950s (Fig. 7). The installation of new sediment control dams and levees has decreased drastically over the past two decades, but works to maintain the dams and levees already in place have continued, and the impact of those erosion control facilities continues. As a result, the diversity of vegetation on the alluvial cones formed by the disturbance of debris flows will be degraded in the future. It may even affect the diversity of vegetation that varies from one alluvial cone to another.

Concluding Remarks

This study focused on landforms and showed four types of geodiversity that can contribute to the creation of biodiversity at the regional and local scales: diversity of landform types, diversity of ecological functions of landforms, landform dynamics and their diversity, and linkage among landforms and its diversity. The latter three of the four geodiversity types imply that individual landforms have different roles and dynamics in each region, even if they are of the same type of landform.

In Japanese national parks, the emphasis tends to be on conserving the visual appearance of the land characterized by landforms and vegetation. Therefore, landform alterations that directly change the scenery are strictly restricted. In contrast, alterations in geomorphic processes are relatively less restrictive. Changes in geomorphic processes may alter ecological processes and thereby lead to changes in the vegetation being maintained. However, the consequences of changes in geomorphic processes may not be immediately apparent in landforms or vegetation. While all four types of geodiversity are important when considering nature conservation and resource management, the long-term effects of geodiversity on vegetation, especially those related to geomorphic processes, need to be carefully considered. Removal of erosion control structures and relocation of roads and buildings should also be considered in the future to minimize changes in geomorphic processes.

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Declarations

Competing Interests The author declares no competing interests.

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