Micro-landform Structure and Tree Distribution in Subalpine Riparian Area of V-shaped Valley, Minami Alps, Central Japan

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Received November 12, 2014; Accepted August 24, 2015

Abstract Riparian areas are unique habitats that contribute to biodiversity, so they have been focused on in many regions; however, subalpine riparian forests have hardly been examined in Japan. We investigated the micro-landform structure and spatial pattern of tree distributions in a V-shaped valley at 2,000–2,200 m a.s.l. in the Minami Alps, central Japan, using a 0.42 ha core-plot and 16 belt-transects set in a headwater area of Norogawa River. As riparian topographical components, channel, floodplain, scarp of terrace and terrace were detected, which were arranged roughly from lower to higher elevations from streams, as well as mountain slope as a micro-landform unit outside the riparian area. Single-layered floodplain, conspicuous terrace segments and the probable lack of a lower sideslope were identified as features that differ from those found in previous studies on other climatic/large-scale geomorphological conditions. The distribution of deciduous species was biased to lower elevations, with the representatives Salix cardiophylla var. urbaniana on floodplains and Alnus matsumurae on scarps of terraces. These micro-landform units were recognized as a riparian zone in terms of vegetation. Meanwhile, climatic climax evergreen conifers, mainly Abies veitchii, Tsuga diversifolia and A. mariesii, dominated not only mountain slopes but also terraces, indicating that terraces are upland areas in terms of their vegetation. A much smaller area, low species diversity and an assumed direct succession from pioneer to climax phase, because of poor long-lived riparian species capable of forming a mid- or late successional phase, were properties differing from those found in previous studies on other climatic/geomorphological conditions.

Key words riparian forest, topography, conifer, Salix cardiophylla var. urbaniana, Alnus matsumurae

Introduction Ecosystems in riparian areas have been focused on because of their unique contributions to biodiversity in forested regions (Gregory et al. 1991; Naiman and Décamps 1997; Sakio and Tamura 2008). Riparian areas include a variety of habitats associated with both fluvial processes and dissecting processes of valleys: For fluvial processes, erosion and sedimentation of shifting rocks and sandy gravel disturb the ground during floods at various frequencies and intensities. As dissecting processes, shallow and rapid slope failures occur on lower sideslopes of valleys, a major topographical component of riparian areas, which are disturbances that are remarkably frequent compared with those at upper slopes (Hupp and Osterkamp 1985, 1996; Nilsson et al. 1989; Baker 1990; Poff et al. 1997; Sakio 1997; Sakio et al. 2002; Suzuki et al. 2002; Osterkamp and Hupp 2010; Ito et al. 2012). These land-surface disturbances generate highly dynamic environments in riparian areas (Naiman and Décamps 1997; Sakio et al. 2002; Suzuki et al. 2002; Sakio and Tamura 2008; Osterkamp and Hupp 2010). Here, as such disturbances function as land-forming processes, structurally complex micro-landforms often develop in riparian areas. Examination of the micro-landform structure can provide a framework for understanding the spatial pattern of heterogeneous local habitat conditions in riparian areas (Osterkamp and Hupp 2010).

In lower montane and hilly regions, micro-landform units at a scale of 10^3–10^7 m^2 (Gregory et al. 1991; Tamura 1996) have been used as a basis for vegetation classification as well as units for analyzing local environmental conditions (Tamura 2008). In other words, when understanding patterns and processes of riparian vegetation, defining the composition and rules of arrangement of micro-landform units has been given priority. Tamura established a topographical classification for valley heads using a method based on the work of Savigear (1965) and Curtis et al. (1965) (Tamura 1969), extended it to downstream areas (Tamura and Takeuchi 1980), and after
It was updated by other researchers, he presented a systemized general landform classification (Tamura 1996): For riparian areas, micro-landform units such as lower sideslope, footslope, small terrace surface, bottomland and channelway were defined, which are roughly arranged from upper to lower elevations. Above the lower side-slope, the upper sideslope was recognized as being situated outside riparian areas. However, this generalization was established in temperate hilly regions. Components and arrangements of micro-landform units have not been examined in subalpine zones, where there might be a pattern that differs from Tamura’s scheme due to the different climatic and geo-historical conditions (Suzuki et al. 2012).

Investigations of vegetation based on micro-landform units have revealed that the distributions of woody species tend to be restricted to certain units (Hara et al. 1996; Nagamatsu and Miura 1997). For example, so-called riparian species like Fraxinus platypoda and Pterocarya rhoifolia were found to be locally distributed on foot-slopes and bottomlands (Kikuchi 1968; Sakio 1997; Sakio et al. 2002). These units are generally strongly influenced by debris flows and floods, so these species were interpreted to be specialists at adapting to such types of disturbance (Sakio 1995, 1997; Sakio et al. 2002; Kawanishi et al. 2004, 2006; Ito et al. 2006; etc.). Similarly, Euptelea polyandra was found to be mainly distributed on lower sideslopes (Sakai and Ohsawa 1993, 1994), which is generally the unit most frequently subjected to slope failures, with high disturbance tolerability via re-sprouting (Sakai et al. 1995). On the other hand, it has been repeatedly reported that late successional, or climax species in Clement’s sense, dominate outside riparian units (Hara 2006). For example, the habitat preferences of Fagus crenata and Abies firma were found to be biased to upper sideslopes on hills (Kikuchi and Miura 1991) and ridges on mountains (Kitagawa et al. 2014), both of which are characterized by relatively stable ground.

However, these vegetation studies were mainly conducted in cool-temperate montane zones or focused on cool-temperate species. In subalpine and subarctic or northern temperate zones where conifers dominate, detailed studies on riparian forests have been limited to large flooded areas (e.g., Shin et al. 1999; Nagoaka and Okuda 2000; Wada and Kikuchi 2004), which are rather rare geomorphological landscapes in subalpine zones on the main island of Honshu, Japan. Because of the geological conditions in Japan, the subalpine zones of Honshu are usually located in areas of steep relief, where stream topography is basically regulated by excavating processes that prevail over debris accumulation, which latter is recognized as the collateral process (Tsukamoto 1998).

This causes a typical landscape of well-dissected V-shaped valleys in the subalpine areas of Honshu (Yonekura et al. 2001), including Minami Alps (Matsuoka et al. 2013). Little is known about riparian forests in such typical subalpine valleys, such as species composition and forest structure, or about the composition and arrangement of micro-landform units.

In this study, we thus examined micro-landform structure and distribution patterns of woody species in the valley of Norogawa River, Minami Alps, central Japan, as a case of a riparian forest in a subalpine V-shaped valley.

**Methods**

**Study area**

Field surveys were carried out at 35°40′N and 138°12′E at 2,000–2,200 m a.s.l. along Norogawa River (Figure 1) in 2010. Norogawa River is the uppermost stream of the Hayakawa River and runs from Mt. Kitadake of the Akaishi Mountains. Norogawa River branches into two streams at the head, Hidarimata Stream and Migimata Stream, and the study sites were located along these streams and near their confluence. The water catchment areas of Hidarimata Stream and Migimata Stream are 360 ha and 466 ha, respectively. Stream gradient is approximately 1/10, meaning that it is extremely steep.

According to 1-km-mesh climatic data for the past thirty years (National Information Division, Climate Mesh 2010 data ver. 2.1, MLIT of Japan 2012a; grid square code: 5338-41-06; 2,120 m a.s.l. on average), the annual mean air temperature is 2.6°C, and 13.4°C from June to September and −8.4°C from December to February. The annual mean precipitation is 1,884 mm. Maximum snow depth is observed during December to March and, according to annual records, it is 43 cm on average.

The Norogawa catchment area is underlain by Mesozoic sedimentary rocks of the "Shimanto group", which consists of Mesozoic sedimentary rocks including hard sandstone, shale, chart, acidic tuff, slate, greenstone and mélange in this area. These rocks intermingle, and the type of bedrock changes along streams, affecting the local gradient and width of streams (Kondo and Sakai 2013). The section of streams examined in this study is dominated by mélange, which can cause a relatively steep stream because of its susceptibility to corrosion (Kondo and Sakai 2013). The Akaishi Mountains were formed by rapid uplifting of seafloor sediments that began ca. two million years ago. The current speed of this uplift is about 4 mm/year (Dambara 1971), which is one of the fastest
globally. This area is near the Median Tectonic Line and the Itoigawa-Shizuoka Tectonic Line, where many faults and shatter zones have been identified. Because of the geological conditions and abundant rainfall, deep valleys have developed. Deep-seated large landslides adding shallow and rapid slope failures frequently occur as one of the most active mass-movement areas in Japan (MLIT Japan 2012b; Matsuoka et al. 2013). Basements of valleys are sometimes covered with thick deposits originating from the deep-seated landslides (Matsuoka et al. 2013); however, exposed bedrock is continuously observed in this study site, namely, bedrock in 60–90% of the total length of the stream segments studied, indicating a “bedrock channel”, a major type of topographical feature for mountain streams (Tsukamoto 1998).

Natural vegetation is conserved well as this area is included in the Minami Alps National Park and Minami Alps Biosphere Reserve of UNESCO. The subalpine zone ranges from 1,500–1,600 m up to 2,500–2,600 m and is dominated by subalpine conifers, *Abies veitichii*, *Abies mariesii* and *Tsuga diversifolia* (Gansert 2004). Phytosociological studies identified *Toisusu urbaniana* (old name of *Salix cardiophylla* var. *urbaniana*)-*Populus suaveolens* community and *Larix kaempferi* communities as the types of vegetation in valley bottoms in this area (Miyawaki 1985).

**Core plot**

To examine spatial patterns of micro-landforms and wood communities in this riparian region and connected areas, we set a plot of 60 m × 70 m beside Hidarimata Stream (core plot; Figure 1). A small valley cuts into the main valley at this point, which is a common and important geomorphological feature of mountain riparian areas (Tsukamoto 1998). Therefore, we simultaneously treated two general types of micro-landform set along this denuded V-shaped valley, namely, set with and without the contribution of a tributary. The riverbed was exposed mélange with little debris.

Using a laser range finder with an electromagnetic compass (Impulse 200 and Mapstar, Laser Technology Inc.), we first measured every corner of 10 m grids as 56 reference points and then added survey points: horizontal and vertical distances and the azimuth of a survey point from a reference point were recorded. The survey points were placed in order to detect slope changes in as much detail as possible, keeping the distance from a survey point to its nearest neighbor as less than 1 m. Offset surveying was conducted for points that could not be collocated directly from any reference point. Survey points were also placed outside the core plot within 5 m from the edge. A total of 1,996 points were measured.

On the basis of landform survey data, a Digital Elevation Model (DEM) was generated with 1 m as the spatial resolution. A contour map was drawn from the DEM using the Kriging method (Oliver and Webster 1990) (Figure 2-a). Terrain variables, that is, relative elevation and slope inclination (Figure 2-b), were extracted for each 1 m grid from the DEM. ArcGIS (ver. 10, ESRI Inc.) was used for these procedures. We made a geomorphological explanation map (Figure 2-c): small cliffs, shallow channels and convex/concave breaks of slopes were recorded on the contour map in the field, and micro-landform units were detected.
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Although Tamura’s general description for micro-landform units (Tamura 1996) was referenced, because it could not be adopted instantly as denoted in the Introduction, we gave priority to our field observations. The range and average of slope inclination were calculated from the DEM and the land-surface conditions were recorded for each micro-landform unit. Species name, location and diameter at 130 cm in height (DBH) were recorded for all stems with DBH larger than 5 cm. Total basal areas and stem density were calculated for each species and micro-landform unit. Dominant species were determined using dominance analysis (Ohsawa 1984).

Belt transects
To confirm the generality of the forest structure described in the core plot, we set belt transects along the streams (Figure 1), where vegetation had developed fully from the edge of the stream to the upper slopes. Each transect was orthogonal to a stream that was 10 m in width, and the length ranged from 30 m to 105 m depending on the site. The transects were segmented into sub-plots at intervals of five meters in horizontal distance. At the center of each sub-plot, the elevation from the stream and the slope inclination were measured. All plant stems with DBH larger than 5 cm were recorded.

The distribution pattern of each species was analyzed for eight abundant species using a generalized linear mixed model (GLMM); the dependent variable was binary data of the presence (1) or absence (0) of the species concerned, using binomial distribution and logit link function. Independent variables were elevation from the stream, slope inclination and elevation above sea level (altitude) of each sub-plot. Belt transect number was used as a random effect. The best models were selected from models for all combinations of independent variables based on the Akaike Information Criterion (AIC). R ver. 3.1.0 (R Core Team 2014) was used for the analyses.

Results

Core plot
Five kinds of micro-landform unit were identified: “mountain slope”, “terrace”, “scarp of terrace”, “floodplain” and “channel”, which were arranged roughly from higher
### Table 1. Micro-landform parameters and tree species composition for the core plot

| Species                  | Lifeform | ALL       | Floodplain | Scarp of terrace | Terrace | Mountain slope |
|--------------------------|----------|-----------|------------|------------------|---------|----------------|
|                          |          | BA (m²/ha) | RBA (%)    | Density (stems/ha) | BA (m²/ha) | RBA (%)    | Density (stems/ha) | BA (m²/ha) | RBA (%)    | Density (stems/ha) |
| *Abies veitchii*         | C        | 8.1       | 28.07%*    | 467.1            | 0.5      | 11.08%*    | 106.2            | 1.9        | 39.80%*    | 453.7            |
| *Salix cardiophylla var. urbaniana* | B       | 6.2       | 21.52%*    | 376.7            | 0.3      | 7.61%*     | 132.8            | 0.0        | 0.87%      | 18.1             |
| *Tsuga diversifolia*    | C        | 5.7       | 19.73%*    | 158.2            | 0.4      | 9.11%*     | 106.2            | 1.4        | 29.27%*    | 254.1            |
| *Abies mariesii*        | C        | 4.0       | 13.98%*    | 82.9             | 0.7      | 15.78%*    | 79.7             | 0.7        | 14.17%*    | 145.2            |
| *Alnus maritimus*       | B        | 2.5       | 8.81%*     | 467.1            | 0.3      | 4.51%      | 1620.2           | 0.2        | 4.01%      | 381.1            |
| *Larix kaempferi*       | C        | 0.7       | 2.31%      | 7.5              | 0.2      | 5.58%      | 39.8             | 0.3        | 6.40%      | 54.4             |
| *Picea jezoensis var. hondoensis* | C    | 0.7       | 2.99%      | 20.1             | 0.2      | 5.85%      | 39.8             | 0.3        | 6.40%      | 54.4             |
| *Acer ukurundense*      | B        | 0.3       | 1.21%      | 35.2             | 0.0      | 0.18%      | 18.1             | 0.3        | 2.46%      | 113.7            |
| *Betula ermanii*        | B        | 0.2       | 0.83%      | 7.5              | 0.2      | 5.09%      | 54.4             | 0.2        | 1.31%      | 43.7             |
| *Sorbus commixta*       | B        | 0.2       | 0.66%      | 15.1             | 0.0      | 0.21%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| *Betula corylifolia*    | B        | 0.2       | 0.26%      | 5.0              | 0.0      | 0.00%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| *Cercidiphyllum magnificum* | B       | 0.2      | 0.26%      | 7.5              | 0.0      | 0.00%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| *Picea jezoensis var. hondoensis* | C       | 0.0       | 0.00%      | 2.5              | 0.0      | 0.00%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| *Populus maximowiczii*  | B        | 0.0       | 0.00%      | 2.5              | 0.0      | 0.00%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| *Alnus viridis*         | B        | 0.0       | 0.00%      | 2.5              | 0.0      | 0.00%      | 18.1             | 0.2        | 1.31%      | 43.7             |
| **total**               |          | 28.8      | 100%       | 1418.9           | 6.0      | 100%       | 1074.9           | 4.2        | 100%       | 2164.7           |

| Number of Species       | 15       | 3         | 10         | 9                | 10       |
| Area (ha)               | 0.398**  | 0.154     | 0.075      | 0.055            | 0.114    |
| Relative elevation from main stream, Average (range) (m) | 9.2 (0–24.3) | 3.3 (0–11.6) | 7.2 (2.2–18.3) | 9.2 (2.6–20.4) | 11.8 (2.5–24.3) |
| Slope inclination, Average (range) (degree) | 27.5 (0.5–63.8) | 15.5 (0.5–36.3) | 39.5 (13.9–60.9) | 20.5 (1.1–46.4) | 41.4 (17.7–63.8) |

The lifeforms are C: conifer, B: broad-leaved, Ev: evergreen, De: deciduous. *: dominant species (Ohsawa 1984). **: Area does not include channel (0.022ha).
to lower elevations from the stream. These units differed in terms of slope inclination and ground-surface conditions (Figure 2 and Table 1).

Mountain slopes were steep slopes located at the highest parts connecting directly to main ridges above the plot. At these sites, humus and moss covered rocky gravel and bedrock (Appendix 1), indicating relatively stable ground despite the steepness. Under the mountain slopes, terraces were identified. They had relatively flat ground delimited from mountain slopes by concave breaks. Although this shape naturally means it had been under the influence of flooding in the past, it could be considered that the ground surface had been stable for a long time; land-surface condition was similar to mountain slopes and there were humus and moss, although more sandy gravel appeared instead of rocky gravel, adding more soil, and rich understory vegetation was observed. The past flooding that had created these terraces could be considered as events occurring along the main stream for the left bank and originating from the tributary for the right bank. On the right bank, there was also a terrace-like topography between steep slopes (scarps of terraces) at the east end of the plot; however, it was completely covered by a new flood (alluvial), could not be identified with slope change and thus was regarded as a part of the floodplain (alluvial fan).

As lower borders of the terraces, scarps of terraces were recognized with convex breaks of slopes separating them from the terraces. Unfixed rocky gravel was present, indicating instability of the ground. A similar steep slope was also identified in the floodplain area as a fringe, which we also classified as scarp of terrace. Floodplains were relatively flat and covered with deposited materials, mainly exposed rocky gravel. They were separated from scarps of terraces by concave breaks of the slopes. Many shallow channels and small cliffs were observed, indicating active temporal drainage and frequent ground-surface disturbances. Floodplains included an alluvial fan on the right bank, which was considered to have originated from the tributary, beside the bottomland, which was assumed to have been subjected to direct fluvial processes of the main stream. The approximate border is shown in Figures 2 and 3; however, we did not separate them here because their differences in topographic features and substrata were unclear. Channel was the minimum level of the water surface during our field investigations.

For the left bank, the approximate elevation of each unit was 0 to 1 m for floodplain, up to 5 m for scarp of terrace, up to 6 m for terrace and more for mountain slope. For the right bank, floodplain (alluvial fan) reached over 10 m and the other upper units also tended to be located higher than those on the left bank, although they sometimes showed similar elevations. Terraces, which were accompanied by the tributary, were located at 9–13 m from the main stream on the right bank.

Fifteen species were recorded and they showed biased distributions topographically (Figure 3 and Table 1). On floodplains, there were only three species, which were all deciduous trees and were dominated by *Salix cardiophylla var. urbaniana*. On scarps of terraces, the highest tree density was observed across all units owing to abundant *Alnus matsumurae*, while total basal areas in
unit areas were minimal. Evergreen conifers, deciduous broad-leaved trees and a deciduous conifer, *Larix kaempferi*, co-dominated there. Terraces were dominated by evergreen conifers, *Abies veitchii*, *Tsuga diversifolia* and *A. mariesii*, which shared 83.2% of total basal areas. Mountain slopes had a similar composition to terraces, but these three evergreen conifers shared more of the RBA and tree density. Total BA per unit area was the greatest among the units.

**Belt transects**
Sixteen species were recorded (Table 2) on the belt transects. *A. veitchii* and *S. cardiophylla var. urbaniana* were the most abundant, accounting for more than half of the individuals observed. Other major species were *T. diversifolia*, *A. matsumurae*, *L. kaempferi*, *Betula ermanii*, *Cercidiphyllum magnificum* and *A. mariesii*. The distributions of these eight species could all be explained significantly by the elevation from the stream (Table 3 and Figure 4). Evergreen conifers were biased to higher sites; they were nearly absent at streamside, rapidly increased with elevation, and reached 50% at 4.9 m for *A. veitchii* and 4.4 m for all evergreens pooled. Meanwhile, deciduous species were more abundant at lower sites: they often appeared even on valley bottoms, rapidly decreased with elevation, and diminished to 50% at 3.9 m in the case of *S. cardiophylla var. urbaniana* and 7.3 m for all deciduous species pooled. For the other variables (Table 3), *S. cardiophylla var. urbaniana* and *C. magnificum* tended to be distributed more at lower and higher altitudes, respectively. Slope inclination was not a significant factor for the distribution of any species.

**Discussion**

**Micro-landform structure**
We identified mountain slope as a non-riparian micro-landform unit, and terrace, scarp of terrace, floodplain and channel as riparian micro-landform units, which were arranged from higher to lower elevations, partly with lack of terrace and scarp of terrace units. This composition and arrangement of units were generally found in this study site, although each area and inclination varied (Appendix 2). As characteristics of the subalpine riparian micro-landform in this study area of a V-shaped valley, we identified: (1) probable lack of lower sideslopes; (2) conspicuous terrace segments (terrace and scarp of terrace) and (3) single-layer floodplains (i.e., higher floodplain was not recognized), as follows.

1. Lack of lower sideslopes: In Tamura’s general framework (Tamura 1996), there are lower sideslopes that are separated from upper sideslopes by convex breaks of slopes, called erosion fronts. Erosion fronts have been a focal component to understand the landform structure in accordance with topographical processes, especially in hilly regions subjected to active mass movements (Kikuchi and Miura 1991; Sakai and Ohsawa 1993, 1994; Nagamatsu and Miura 1997). Lower sideslopes have been attributed to unstable and/or denuded ground, often with rapid and shallow landslides. Also in mountainous areas, lower sideslopes with erosion fronts have sometimes been recognized. For example, Takaoka (2001) reported habitat separation of temperate deciduous trees and subalpine conifer trees at erosion fronts, inhabiting erodible lower and stable upper slopes, respectively, in Kita Alps climatic transition area. Thus, erosion fronts can exist not only on temperate hilly regions, at which Tamura’s framework was derived, but also in other climatic and mountainous regions. However, such a slope-breaking line between ridges and riparian units was not observed along the stream segments studied here (data not shown). It might be embedded under terrace segments; however, we could not confirm this in the field. Small and shallow hollows suggest slope failures on the mountain slopes (Figure 2); however, these are probably very old scars.

**Table 2.** Tree species composition in belt transects

| Species                          | Lifeform | DBH (cm) mean (min–Max) | n  |
|---------------------------------|----------|-------------------------|----|
| *Abies veitchii*                | C Ev     | 24.8 (4.2–59.6)         | 259|
| *Saliix cardiophylla var. urbaniana* | B De    | 11.8 (4.1–58.6)         | 226|
| *Tsuga diversifolia*            | C Ev     | 28.5 (5.0–89.1)         | 69 |
| *A. matsumurae*                 | B De     | 8.9 (4.1–27.6)          | 61 |
| *Larix kaempferi*               | C De     | 9.3 (4.2–98.3)          | 42 |
| *Betula ermanii*                | B De     | 11.4 (4.0–30.6)         | 42 |
| *Cercidiphyllum magnificum*     | C Ev     | 11.0 (4.2–27.2)         | 42 |
| *A. mariesii*                   | C Ev     | 27.6 (7.5–51.5)         | 41 |
| *Sorbus commixta*               | B De     | 14.7 (5.5–25.3)         | 22 |
| *Acer ukurundense*              | B De     | 11.1 (4.4–30.8)         | 21 |
| *Alnus vindis*                  | B De     | 6.5 (4.2–17.4)          | 18 |
| *Populus suaveolens*            | B De     | 29.6 (5.5–91.3)         | 14 |
| *Cerasus nipponica*             | B De     | 14.5 (4.8–25.7)         | 10 |
| *Betula corylifolia*            | B De     | 11.2 (6.3–16.1)         | 6  |
| *Salix udivensis*               | B De     | 5.2                     | 1  |
| *Acer microthamnium*            | B De     | 5.1                     | 1  |

The lifeforms are C: conifer, B: broad-leaved, Ev: evergreen, De: deciduous.
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Table 3. Results of variable selection of the best model by AIC for presence/absence of eight major species, all evergreen conifers and all pioneer species in the belt transects by GLMM

| Species                          | Intercept | E    | RE   | SI   |
|---------------------------------|-----------|------|------|------|
| Abies mariesii                  | -2.4209***| —    | 0.7668**| — |
| Abies veitchii                  | 1.0880**  | —    | 2.6140***| — |
| Tsuga diversifolia              | -0.7398***| —    | 0.5522**| — |
| Larix kaempfer                  | -3.8240***| —    | -2.6010**| — |
| Salix cardiophylla var. urbaniana| -2.2283***| -1.0364*| -3.6693***| 0.7771 |
| Betula ermanii                  | -1.8481***| —    | -0.9141**| — |
| Alnus matsumurae                | -1.6223***| —    | -1.2779***| 0.4708 |
| Cercidiphyllum magnificum       | -5.1150***| 1.4600*| -5.0740***| — |
| Evergreen conifers              | 2.2750**  | —    | 4.4080**| — |
| Deciduous                       | 0.0745    | —    | -2.0955***| — |

E: Elevation above sea level, RE: Relative elevation from stream, SI: Slope inclination. Verification result of the effectiveness of the explanatory variables with Wald test (***: Pr(|z|)>0.001, **: Pr(|z|)<0.01, *: Pr(|z|)<0.05).

Figure 4. Relationship of the appearance ratio and relative elevation from the stream for eight major species, all evergreen conifers and all deciduous species in the belt transects.

Single regressions are shown because the relative elevation from the stream was the most significant parameter for these distributions (Table 3). Fitting curves are logistic models of generalized linear model (GLM) to binary raw data that is shown by dots plotted at zero for absent and one for present against the relative elevation of sub-plots in all belt transects. All curves are significant, namely, p <0.05 for z values using Wald test.

because edges were unclear and the land was covered by a developed matrix of humus and moss (Appendix 1), also within such hollows. This suggests that slope failures are infrequent, at least at present. Thus, if adopting Tamura’s framework, the mountain slope can be regarded as upper sideslopes rather than lower sideslopes because of relatively stable land-surface conditions.

(2) Distinguished terrace segments: The same as in the general definition (Machida et al. 1981; Hupp and Osterkamp 1985, 1996), terraces in this study can be interpreted as ground surfaces established by large and infrequent debris flows and/or old floodplains at which
the ground is what is left behind after streams dissect valley bottoms. While terraces are features commonly described in riparian studies (Suzuki et al. 2002; Nakamura et al. 2007; Suzuki et al. 2012), they are minor units in Tamura’s schema (Tamura 1996). This is probably related to the large-scale topographical conditions. For temperate regions, Suzuki et al. (2012) surveyed riparian forests from mid- to upper streams of the Kinugawa watershed, and showed that relative areas of terraces among micro-landform units increased at the uppermost parts of streams located in dissected valleys. In addition, Kaneko and Kawano (2002) recorded that terraces had a similar size to floodplains in a mountainous narrow valley in Ashiu, Kyoto. These findings suggest that clear terrace components of our study are common for V-shaped valleys in mountainous regions, irrespective of the climatic zone; besides, terrace segments were more conspicuous, which was caused by scarps of terraces being detectable as clear units. Rocky debris assumed to have been supplied by infrequent deep-seated landslides as noted to be relevant to Minami Alps geology (Matsuoka et al. 2013) may reinforce this morphological attribute. Tsukamoto (1998) also remarked on the contribution of debris flow to the emergence of terrace segments in mountain valleys.

(3) Single-layer floodplains: The floodplains identified in this study were combined segments that originated from the main stream and tributary, and thus their elevation was over 10 m; however, they were basically uniform in terms of land-surface conditions, exhibiting the deposition of rocky gravel that was assumed to have been exposed to seasonal floods of the main stream or tributary. Floodplains have often been classified into two types: lower and upper ones, in riparian studies, based on the step morphology and differences in deposited materials coinciding with the frequency of exposure to flooding, for example, 50% probability per year for lower floodplains but 5% for upper floodplains, as estimated in the Reki-fune Watershed, southern Hokkaido (Shin and Nakamura 2005; Nakamura et al. 2007). Nevertheless, many of these studies were conducted in alluvial fan zones that typically emerge in regions intermediate between mountain valleys and plain river zones. Fluvial processes of both aggradation and degradation function significantly there, leading to wide bottomland and complex micro-landforms including multiple layers of floodplain. Meanwhile, in mountain valleys, especially narrow V-shaped uppermost valleys as in this study area, degradation basically exceeds aggradation (Tsukamoto 1998), and upper floodplains would probably easily disappear if they formed. Single-layered floodplains have been distinguished (Suzuki et al. 2012) or used as micro-landform units (Tamura 1996) for upstream riparian forests in temperate climate zones. We confirmed that they can also be applied to this study segment of a subalpine V-shaped valley.

The micro-landform attributes observed here can be summarized as follows: the riparian area is smaller (from 1) and simpler (1 and 3) while having an extra unit (2) compared with fully developed riparian topography in the temperate zone.

Species composition and distribution

We found that relative height from the valley bottom was a key factor to explain the overall pattern of tree distributions, and that this elevation dependence arose from the fact that each species tended to be restricted to certain micro-landform units. The elevational arrangement of woody species being linked to micro-landform structure has been reported in various regions (Sakai and Ohsawa 1993; Kubo et al. 2001; Suzuki et al. 2002; Ito et al. 2007; Nakamura et al. 2007; Suzuki et al. 2012). We confirm that this also basically holds for our study site of a subalpine V-shaped valley. We can also assert, as indicated repeatedly in other regions, that riparian areas contribute to the biodiversity of mountain forests by providing unique habitats. The significance of this function is emphasized, given the general tendency that species richness and diversity are lower at higher elevations (Ohsawa 1984; Stevens 1992), as reflected in the short species list obtained in this study.

Despite the basic consistency, there are some differences between this riparian area and riparian areas in temperate climate zones or alluvial rivers in subalpine/subarctic areas: the riparian area of our study site is characterized by low species richness and diversity are lower at higher elevations (Ohsawa 1984; Stevens 1992), as reflected in the short species list obtained in this study.

Floodplains were occupied by almost pure stands of *Salix cardiophylla* var. *urbaniana*. Although the extent to which this species has adapted to unstable ground and the mechanisms used have not been examined, it is known to establish itself as a pioneer just after riparian disturbances in upper temperate (Ishikawa 1983; Sakai et al. 1999; Shin et al. 1999; Sashimura and Ide 2007) and subarctic regions (Ishikawa 1987; Niiyama 1987; Nakamura et al. 2007). Salicaceae is a clade that mainly consists of early successional species, with adaptive radiation to various land-surface conditions along rivers (Niiyama 1987; Sashimura and Ide 2007). The texture of land-surface materials is the key factor for niche separation, and across the riparian Salicaceae, *S. cardiophylla*...
var. urbaniana is a species known to prefer mostly rocky ground without clay (Niiyama 1987). This niche is explained by its development of vertical roots alongside a lack of tolerance to submersion in groundwater (Honma et al. 2002). Accordingly, along long rivers, Salix communities dominated by S. cardiophylla var. urbaniana have been recorded typically in mountain valley zones, especially at the uppermost streams, but not in alluvial plain rivers (Ishikawa 1987; Sakai et al. 1999; Shin et al. 1999; Sashimura and Ide 2007; Nakamura et al. 2007). Despite the trend for upper regions to be colder, and in fact S. cardiophylla var. urbaniana shows the cold-end distribution among multiple examined species, Niiyama (1987) revealed that distribution was controlled more edaphically than climatically. Thus, only this species may inhabit this subalpine V-shaped valley owing to its traits and the topographical properties mentioned above. Low species diversity has often been recorded for communities dominated by S. cardiophylla var. urbaniana in studies on other areas (Suzuki et al. 2012).

Ailanthus matsumurae is another typical species reported as a pioneer on rocky surfaces near valley bottoms (Suzuki et al. 1956; Kikuchi 1975; Yoshikawa and Fukushima 1997). In these previous studies, A. matsumurae was often found to co-dominate with S. cardiophylla var. urbaniana, but they were markedly separated in terms of micro-landform units in this study: A. matsumurae could be labeled as the species of scarps of terraces. Scarps of terraces were considered to be subjected to ground-surface disturbances as slope-dissecting processes, rather than fluvial processes that dominate where S. cardiophylla var. urbaniana is located. These species might share the same sites where the ground conditions are intermediate, but their habitat differentiation is clear in this study, probably because of sharper features of the topographic structure. Of the other species showing a biased distribution to lower elevations in belt transects, Larix kaempferi and Cercidiphyllum magnificum were also distributed on scarps of terraces. Although evergreen conifers, A. veitchii, T. diversifolia and A. mariesii, which were species showing biased distributions to more elevated sites in transects, were detected as co-dominants, the deciduous species shared larger basal areas than these evergreen conifers. Accordingly, scarps of terraces as well as floodplains can be regarded as riparian zones in terms of vegetation, and scarps of terraces are considered to be more advanced in terms of their successional stage than floodplains.

Terraces are a riparian segment topographically, but are occupied by upland communities that are basically the same as those on mountain slopes, which were dominated by A. veitchii, T. diversifolia and A. mariesii, the major canopy species of climatic climax forests in this region. This phenomenon, that is, a smaller riparian zone in relation to vegetation, is relevant to the properties of succession as follows:

Micro-topographical differences in composition and structure of wood communities around valleys have generally been explained by differences in successional status after disturbances (Suzuki et al. 2002; Sakio 2005; Shin and Nakamura 2005; Nakamura et al. 2007). In this context, S. cardiophylla var. urbaniana and A. matsumurae are typical species reported to be the earliest immigrants in upper temperate and subalpine/subarctic valleys (Niiyama 1987; Yoshikawa and Fukushima 1997). Because the phase that a community can reach depends on the duration between disturbances, much earlier communities tend to be located much nearer to a stream center, often resulting in Salix communities being arranged at the vegetation front. This interpretation is also relevant for our study sites; however, there is a difference regarding the subsequent phase. Many studies have pointed out that middle successional communities are then established, after which climax communities emerge. On the other hand, this study area has a dearth or absence of a middle successional phase, namely, succession instead proceeds directly from pioneer to climax communities.

This shortcut in succession can be explained by: (1) topographical simplicity; (2) a poor species pool in the regional flora and (3) the characteristics of subalpine climax species:

(1) For subarctic and subalpine large flooded valleys, the middle successional phase is often described as communities that develop on higher floodplains, typically dominated by Ulmus davidiana var. japonica, Fraxinus mandshurica and Quercus mongolica (Kon and Okitsu 1995, 1999; Wada and Kikuchi 2004). In our species list, Larix kaempferi and Populus maximowiczii could occupy this niche (Shin et al. 1999; Shin and Nakamura 2005; Nakamura et al. 2007); however, the lack of a central habitat, higher floodplains, may prevent the development of these communities.

(2) In temperate mountain valleys, riparian species such as Pterocarya rhoifolia, Cercidiphyllum japonicum, Fraxinus platypoda and Aesculus turbinata occupy large areas as pioneers, or middle or edaphic late successional. Once established, these species can persist via their long life spans, namely, 100–150 years for P. rhoifolia (Ann and Oshima 1996; Sato 1988; Kaneko 2009), over 200 years for C. japonicum (Kubo et al. 2005), over 250 years for F. platypoda (Sakio 1997) and over 400 years for A.
Micro-landform Structure and Tree Distribution in Subalpine Riparian Area of V-shaped Valley, Minami Alps, Central Japan

turbinata (Hoshizaki 2009). There is no such ecological guild in this subalpine V-shaped valley. The life span of S. cardiophylla var. urbaniana is about 45 years (Ban and Ide 2004). Although we could not find such life span data for A. matsumurae, Alnus is generally short-lived, that is, a few decades (Kastuta et al. 1998). This suggests that, if the ground surface is stable for only 50 years, the next successional community can emerge. As a result, the succession time from bare ground to climax forests in the subalpine zone that we studied may be shortened.

(3) Three major subalpine climax conifers seem to accept disturbed and thin-soil ground, which is also common outside riparian areas in the Minami Alps. In fact, abundant seedlings and saplings can be observed even on floodplains under S. cardiophylla var. urbaniana (Figure 5). This contrasts with representative climax species in the temperate zone of Japan (e.g. Fagus sp., Abies sp. and Castanopsis sp.), which inhabit relatively stable and moderate slopes with deep soil across major species in regional flora.

The attributes of the vegetation in this study area of a V-shaped subalpine valley can be summarized as follows: Riparian communities were established on floodplains and scarps of terraces, but not on terraces. Terraces were occupied by upland communities. There were two types of riparian community, namely, pure stands of a species of Salix on floodplains and mixed stands with abundant Alnus on scarps of terraces. Upland evergreen conifers, Abies and Tsuga, co-dominated on the scarps of terraces in terms of RBA. The two representative species of riparian communities were short-lived pioneer trees, and these communities would succeed directly to climax stands with the upland conifers in a short time if the land surface is stabilized. This may be because of the lack of the ecological guild of riparian trees having a persistent niche, which has been identified in temperate mountains and subarctic/subalpine alluvial valleys in Japan, and also possibly because the upland conifers have more or less adapted to unstable ground on these geologically active mountains.

Acknowledgements

We are deeply grateful to Dr. Ryo Kitagawa and Dr. Nobuhiko Wakamatsu whose field surveys, comments and suggestions were of inestimable value for our study. We also thank Dr. Akira Mori and Dr. Keiichi Ohno whose comments contributed enormously to our work, and Ms. Michiko Hoshi for her assistance during fieldwork in the Minami Alps. This study was supported by a JSPS Grant-in-Aid for Scientific Research (C) 19570017. Special thanks also go to the anonymous editor and reviewers for their useful comments on our manuscript.

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Appendix 1. Photos showing a panoramic view of the study area (a) and micro-landform units detected in the core plot (b–f)
(a) Photo showing a panoramic view of the study area. The left and right sides of the V-shaped valley contain Hidarimata Stream from Mt. Kitadake (3193 m a.s.l.) and Migimata Stream from Mt. Ainodake (3190 m a.s.l.) in the Minami Alps. (b) Mountain slope in the core plot. (c) Terrace in the core plot. (d) Scarp of terrace in the core plot. (e) Floodplain (alluvial fan) in the core plot. (f) Floodplain and channel in the core plot.
Appendix 2. Cross sections of belt transects measured with 5 m intervals in horizontal distance