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Riparian forest and environment variables relationships, Chichibu mountains, central, Japan

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In most mountainous parts of the temperate zone of Japan along the Pacific Ocean, some climatic climax forests, whose main dominant species is *Fagus crenata*, *F. japonica* or *Quercus mongolica* var. *grosseserrata*, are distributed. In the riparian regions of the zone, however, there appear summer green forests composed of the different species from the climatic climax forests. Climate plays an important role in determining the overall distribution of vegetation, but some environmental factors, i.e., topography, soil type, soil moisture content, etc. have a great influence on vegetation formation. Riparian forests seem to be controlled by various geomorphologic disturbances, such as landslide, soil erosion and accumulation.

The study aims to present the relationships among vegetation, soils and landforms in the process of determining riparian forests dominated by *Fraxinus platypoda* and *Pterocarya rhoifolia* establishment in the mountainous region of central Japan. The study area extends an area of 302 ha with a range of elevation between 925 m and 1,681 m at the Chichibu mountains. The landforms were corditied at sampling grids (25 × 25 m, n = 4,843) using a hierarchical system, and a brief description of the forest soil classification was also given. The mutual relationship analysis indicated that forest soils and landforms play a significant role in determining the geomorphological process of riparian forest, and shaping the ultimate pattern of vegetation.

At the study area, riparian forests were mainly found on the B_E forest soil type and steep slopes (> 30°) at convex slopes along the streams. On the other hand, the direction of slopes did not have a significant impact on the establishment of the riparian forests. A mosaic of patchy distribution of those riparian forests on the slightly wetter B_E forest soil type was one of the characteristic features of the study area. This particular soil which contained large talus gravels was found on the land formed by erosion and deposition of landslide.

Key words : Chichibu mountains, Forest soils, Environmental gradients, Landforms, Riparian forest

1. Introduction

Riparian forests are transitional ecosystems lie between aquatic and upland ecosystems. Their plant associations are an assemblage of native vegetation in equilibrium with the environment on a fluvial surface[1~13]. The importance of floodplain geomorphological processes on the riparian forest formation has recently been stressed[7,11,14~17].

At the study area of the Chichibu mountains, riparian forests are formed along the V-shaped valleys of narrow interface[17~20]. The diversity and growth of riparian forests can be influenced not only by the climate but also by other environmentally variable factors.

The study examined an area of crest at the elevation of between 925 m and 1,681 m. A relatively small area (302 ha) of riparian forest was examined in relationship with the forest types, soils, landforms to see how they interact each other in the process of the riparian forest establishment.

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2. Study area

The Chichibu mountains of central Japan spread through an interior the Kokushi mountain (35°52′ N; 138°40′ E; alt., 2,592 m). As Fig. 1 indicates, the study area (36°05′ N; 138°39′ E; 302 ha) lies in a primary forest located at the elevation from approximately 920 to 1,680 m surrounded by crests (3.2 × 1.2 km). The average annual temperature ranges from approximately 9 to 5℃ on alt. 900-1,700 m (assuming the altitudinal lapse rate of 0.6℃/100 m, 36°05′ N, 138°47′ E, alt. 480 m, 1900-1940), and the average annual precipitation was 1,250 mm and concentrated in August, and scarce in January[19]. The area contains steep slopes and valleys on the Chichibu-Paleozoic[19,20].

The Maebashi Forestry Office (1974) described the *Fagus crenata* Blume community zone at the temperate montane, and also following classification. A relatively dry forest type of *Tsuga sieboldii* Carriere-*Rhododendron dilatatum* Miquel association consisted chiefly of *Rhododendron wadanum* makino, *Enkianthus subsessilis* Miquel, *Rhododendron obtusum* var. *kaempferi* (Planchon) Wilson, but also included *pieris japonica* (Thunb.) D. Don, *Lyonia ovalifolia* var. *elliptica* (Sieb. et Zucc.) Hand.-Mzt., etc.; *Sasamorpha borealis* dominated in the forest floor on mountainsides, and canopy trees consisted of *Fagus japonica* Maxim., *Betula grossa* sieb. et Zucc., *Abies firma* Sieb. et Zucc., *Fraxinus lanuginose* f. *serrata* (Nakai) Murata, *Stewartia Pseudo-camellia* Maxim., *Acea* sp., etc.; on valleys consisted of the *Fraxinus spaethiana* Lingelsh.-*Dryopteris polylepis* Fr. et Sav. association, and overstory included mainly of *F. spaethiana*, *Pterocarya rhoifolia* Sieb. et Zucc., *Aesculus turbinate* Blume, *Cercidiphyllum japonicum* Sieb. et Zucc., *Cornus controversa* Hemsley, *Acer*

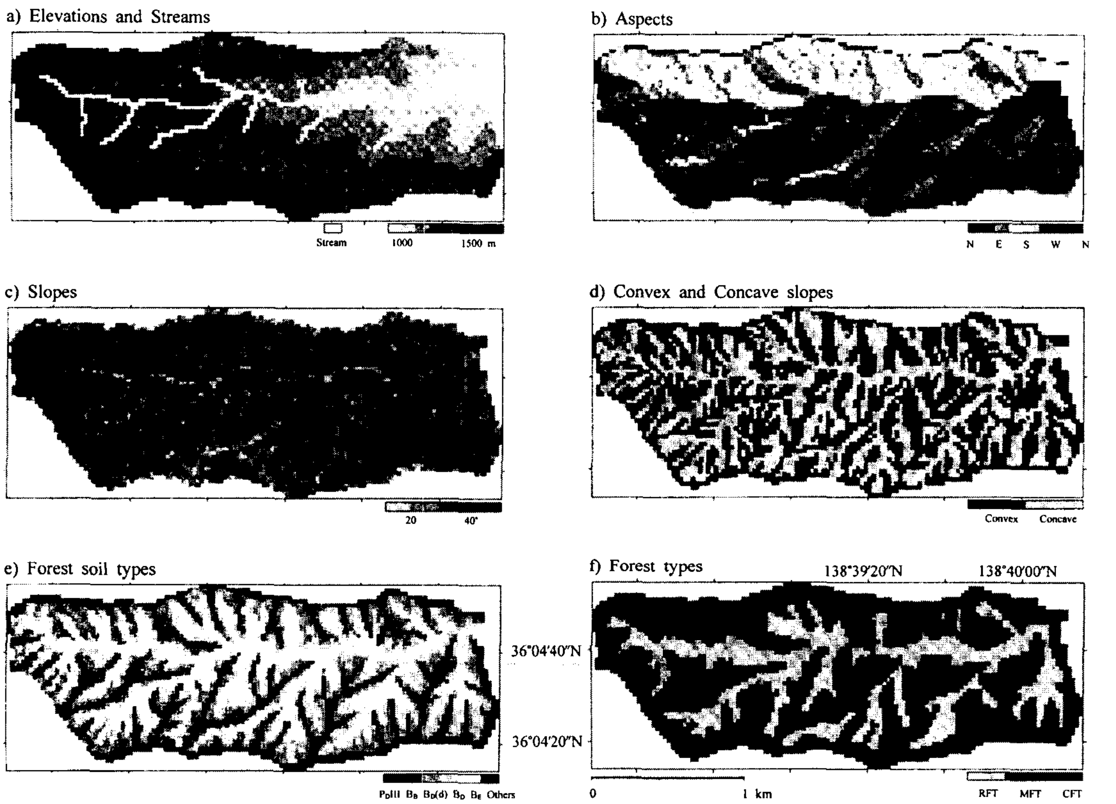

Fig. 1. Distribution maps of environmentally variable factors and forest type; RFT (the Riparian Forest Type), MFT (the Mountainside Forest Type) and CFT (the Crests Forest Type). Location of the study area (302 ha, 25 × 25 m, n = 4,843) are on surrounded crests, and elevation ranges from approximately 920 to 1,680 m.

ambiguum Dippel, etc., and understory dominated of *Acer carpinifolium* Sieb. et Zucc., *F. spaethiana*, *Carpinus cordata* Blume, *Acer japonicum* Thunb., etc.

3. Methods

Samples were collected from the areas which topographical features are found locally. The study area is located on the temperate montane zone which is mainly covered by homogeneous typical valley vegetation. Along mountainsides and ridges, however, several different types of vegetation are found. The vegetation classification was divided into three forest types by the topographic features, and mapped on 1:5000 topographic map (published by the Maebashi Forestry Office) using field locations (70% of study area, mesh of 100 m intervals, studied from July to September 1988 and from September to October 1991 and only in August 1996) and aerial photographs(1:8500 scale):

- the Riparian Forest Type (RFT): dominant trees of canopy layer consisted chiefly of *F. spaethiana* and *P. rhoifolia*, but also included *A. turbinata* and *C. japonicum*, on valleys;
- the Mountainside Forest Type (MFT): summer green deciduous broad-leaved species distributed on mountainsides and ridges consisted by *F. crenata*, *F. japonica*, *Quercus mongolica* ssp. *crispula* Blume, *Castanea crenata* Sieb. et Zucc., *Tilia japonica* (Miq.) Simonkai, *Betula* sp., etc;
- the Crests Forest Type (CFT): evergreen conifer species consisted mainly of *T. sieboldii*, *A. firma*, and included *Tsuga diversifolia* (Maxim.) Masters, *Chamaecyparis obtusa* (Sieb. et Zucc.) Endlicher, *Pinus parviflora* Sied. et Zucc., etc. on ridges.

The height ranges of elevation were assigned of the eight classes (class 1 = ≤1,000 m, class 2 = -1,100 m, class 3 = -1,200 m, class 4 = -1,300 m, class 5 = -1,400 m, class 6 = -1,500 m, class 7 = -1,600 m, class 8 = ≥ 1,600 m) by 100 m interval of 920-1,681 m.

The landforms of four variables (aspect, slope, convex and concave slopes, stream) mapped using topographical map (1:5000 scale):

- the direction of the study area was separated into eight categories (N-NE, E-NE, E-SE, S-SE, S-SW, W-SW, W-NW, N-NW);
- the slope degrees were assigned of the four classes (class 1 = ≤20, class 2 = -30, class 3 = -40, class 4 = ≥40), and sought for an angle of slope using inverse tangent function from horizontal distance to elevation distance of contour line;
- two categories of the convex and concave slopes by convert point of contour line divided;
- the stream were divided two categories by stream lying sites (presence) and absence sites (absence).

The forest soil was classified into taxonomic groups according to the Forest Soil Division (1975), and mapped based upon the results of field investigations (70% of study area, mesh of 100 m interval, studied from July to September 1988 and from September to October 1991) conducted by Forestry Agency (1962) and Maebashi Forestry Office (1974). The forest soil type was divided into following 7 groups including 1 subtype and 6 types:

- the dry slightly podzolic soil-P_DIII
- the dry brown forest soil (granular and nutty structure type)-B_B
- the weakly dried brown forest soil-B_C
- the moderately moist brown forest soil-B_D
- the moderately moist brown forest soil(drier subtype)-B_D(d)
- the slightly wetted brown forest soil-B_E
- the weakly dried black soil-B*l*c.

A database for analysis was compiled from the information which was recorded at each grid (302 ha, 25 × 25 m, n = 4,843). The relationships among 34 forest types and environmental categories of 7 environmentally variable factors (forest types, elevations, aspects, slopes, convex and concave slopes, streams, forest soil types) were analyzed by the correlations and the eigenvectors from the quantification theory 3rd family[22]. As Fig. 3 shows, the direction of an arrow indicates the environmentally variable factors while the length of an arrow indicates the strength of relationship.

4. Results

4.1 Relationship of environmentally variable factors

As shown in Fig. 1, the distribution of various landforms and forest soil types along the terran presents the complexity of their interactions in the process of determining the riparian forest environment. The gradient of the slope, in particular, appears to have a strong influence on the formation of landforms and forest soils. However, other environmentally variable factors and the gradients of slopes do not appear to be related to each other (Table 1). The gentle slopes (<30°) are distributed along ridges and valleys, forming a narrow interface while the steep slopes (>30°, 85% frequency) are randomly distributed on the mountainsides (Fig. 1, Slopes). Those slopes shape a distinctive landscape and a drainage pattern of the area. The convex slopes distributed along ridges on eroded sites (Fig. 1, Convex and Concave slopes) show a positive correlation with the elevation (Table 1). The concave slopes were mostly found on accumulated soils along the valleys at low elevations. The area of stream occupied 7% of the total area studied, and it was distributed along the concave slopes on valleys and in-

Table 1. Correlation matrix of six environment variables and forest type (34 categories) by quantification theory 3rd family in study area (303 ha, n = 4,843). The numbers in parentheses are the numbers of percentage within each variable

Categories	Aspects								Elevations (m)							
	N-NE (21.6)	E-NE (14.0)	E-SE (13.1)	S-SE (15.8)	S-SW (9.7)	W-SW (0.9)	W-NW (5.1)	N-NW (19.8)	≤1000 (2.7)	-1100 (11.1)	-1200 (17.0)	-1300 (19.7)	-1400 (22.2)	-1500 (15.4)	-1600 (9.5)	>1600 (2.4)
N-NE	~	-.212	-.204	-.228	-.172	-.048	-.122	-.261	-.049	-.067	-.048	.013	.008	.052	.067	.000
E-NE		~	-.157	-.175	-.132	-.037	-.094	-.201	-.030	-.044	-.024	-.031	-.021	.008	.082	.143
E-SE			~	-.168	-.127	-.036	-.090	-.193	-.030	.015	.010	-.022	.022	.010	-.020	-.013
S-SE				~	-.142	-.040	-.101	-.215	.079	.008	.066	-.023	.000	-.008	.010	-.053
S-SW					~	-.030	-.076	-.163	-.024	.052	.038	.040	-.035	-.049	-.023	-.024
W-SW						~	-.022	-.046	-.015	-.025	.042	-.006	-.033	-.008	.001	.089
W-NW							~	-.116	.025	.055	-.008	.059	.014	-.030	-.072	-.024
N-NW								~	.037	.023	.023	-.008	.035	-.007	-.076	-.054
≤1000									~	-.058	-.075	-.082	-.088	-.071	-.054	-.026
-1100										~	-.159	-.175	-.188	-.151	-.114	-.055
-1200											~	-.224	-.242	-.193	-.147	-.071
-1300												~	-.265	-212	-.161	-.078
-1400													~	-.229	-.173	-.084
-1500														~	-.139	-.067
-1600															~	-.051
>1600																~

	Slopes (°)				Slopes		Streams		Forest soil types							Forest types		
	≤20 (2.3)	-30 (13)	-40 (39.9)	>40 (44.8)	Convex (55.8)	Concave (44.2)	Presence (6.7)	Absence (93.3)	P_DIII (13.1)	B_B (11.6)	B_C (0.8)	B_D (24.8)	B_D(d) (26.8)	B_E (22.6)	B/c (0.4)	RFT (25.5)	MFT (63.8)	CFT (10.7)
N-NE	.008	-.031	.012	.007	.001	-.001	-.051	.051	.020	-.039	.084	.000	.026	-.033	.015	.038	-.055	.032
E-NE	.023	.047	-.011	-.028	.033	-.033	.029	-.029	-.028	-.037	-.022	.004	-.049	.103	.003	.036	-.028	-.008
E-SE	.028	.055	-.016	-.030	.011	-.011	.096	-.096	-.071	-.051	-.007	-.006	.-070	.179	-.005	-.009	.021	-.021
S-SE	-.001	.002	.020	-.021	-.006	.006	.008	-.008	-.066	-.017	-.006	.026	.026	.012	.009	-.055	.080	-.047
S-SW	-.026	-.031	.043	-.014	-.024	.024	-.032	.032	-.015	.072	-.013	.008	.060	-.112	.002	-.073	.054	.018
W-SW	.016	.025	-.034	.012	-.004	.004	-.025	.025	.058	.009	-.008	-.043	.015	-.028	.030	-.023	-.010	.048
W-NW	-.029	-.043	.005	.033	-.021	.021	-.018	.018	.048	.003	-.021	.011	.024	-.072	-.015	.057	-.048	-.005
N-NW	-.020	-.017	-.035	.051	-.004	.004	-.022	.022	.095	.074	-.032	-.024	-.009	-.089	-.023	.015	-.022	.013
≤1000	-.025	.024	.009	-.018	-.072	.072	.186	-.186	-.064	-.016	-.015	.024	-.065	.113	-.010	.121	-.084	-.041
-1100	.004	-.015	-.057	.065	-.025	.025	.124	-.124	-.072	-.010	-.031	-.003	-.057	.139	-.022	.132	-.116	-.006
-1200	-.028	-.016	-.047	.065	.031	-.031	.039	-.039	.019	-.047	-.040	.006	-.059	.089	-.028	.031	-.037	.013
-1300	-.016	-.029	-.038	.062	-.030	.030	-.025	.025	.007	-.033	-.044	.043	-.031	.023	-.031	.071	-.069	.007
-1400	.026	.015	.049	-.066	-.011	.011	-.058	.058	.073	.002	-.048	-.029	.032	-.049	-.034	-.052	.065	-.027
-1500	.012	.022	.048	-.066	.029	-.029	-.046	.046	.004	.085	-.012	.014	.032	-.081	-.027	-.067	.046	.032
-1600	.012	-.004	.053	-.053	.018	-.018	-.087	.087	-.032	.006	.242	.017	.079	-.142	.070	-.140	.123	.007
>1600	.004	.040	-.028	.000	.055	-.055	-.042	.042	.007	.023	-.014	-.068	.094	-.085	.228	-.092	.076	.012
≤20	~	-.059	-124	-.137	.023	-.023	.143	-.143	.057	.032	.018	-.077	-.038	.044	.031	.033	-.034	.006
-30		~	-.315	-.349	.084	-.084	.175	-.175	.125	.102	.091	-.151	-.063	.020	.035	.020	-.079	.095
-40			~	-.735	.056	-.056	-.051	.051	-.011	.053	-.006	-.009	-.018	-.003	.101	.019	-.019	.003
>40				~	-.119	.119	-.111	.111	-.091	-.130	-.061	.134	.072	-.024	-.037	-.042	.082	-.069
Convex					~	-1.000	-.252	.252	.195	.167	.051	-.128	.053	-.224	.029	-.336	.170	.210
Concave						~	.252	-.252	-.195	-.167	-.051	.128	-.053	.224	-.029	.336	-.170	-.210
Presence							~	1.000	-.102	-.095	-.024	-.066	-.136	.375	-.017	.389	-.293	-.093
Absence								~	.102	.095	.024	.066	.136	-.375	.017	-.389	.239	.093
P_DIII									~	-.140	-.034	-.223	-.234	-.210	-.024	-.203	-.033	.339
B_B										~	-.032	-.208	-.219	-.196	-.023	-.181	.157	.011
B_C											~	-.051	-.054	-.048	-.006	-.052	-.011	.091
B_D												~	-.347	-.310	-.036	.058	.030	-.129
B_D(d)													~	-.327	-.038	-.212	.191	.001
B_E														~	-.034	.483	-.331	-.167
B/c															~	-.037	.040	-.001
RFT																~	-.778	-.202
MFT																	~	-.459
CFT																		~

fluenced the conditions of ground water (Fig. 1, Elevations and Streams; Table 1). Landforms seem to greatly influence the distribution of forest soil type.

While the dry forest soil types (P_DIII, B_B, B_C, B*l*c; 26% frequency) show a positive correlation with high elevations, slopes of <30°, and the convex slope, the moisture soil types of B_D and B_D(d) on the mountainsides show a positive correlation with slopes of >40° (Fig. 1, Forest soil types; Table 1). On the other hand, the soil type of B_D (25% frequency) has a positive correlation with the low elevations, the concave slope, and the stream lying areas, but the soil type B_D(d) (27% frequency) was quite opposite (Fig. 1, Table 1). The wet soil type (B_E; 23% frequency) was found on the concave slope and the stream lying areas, and it has a positive correlation with low elevations and the slope of >30°. One of the noteworthy characteristics of the B_D and B_E sedimented soils was the fact that they were distributed widely along the streams in a patchy pattern (Fig. 1, Forest soil types).

In conclusion, the study results show that forest soil types, landforms, and soil moisture interact each other and form the following patters; the wet type (B_E) on valleys, the moist types (B_D, B_D(d)) on mountainsides, and the dry types on ridges.

Table 2. Vegetation of three types (Riparian Forest Type, RFT; Mountainside Forest Type, MFT; Crests Forest Type, CFT) were grid frequency (25 × 25 m, n = 4,843) of each category, and parenthesis is percentage in study area (302 ha)

Categories	RFT	MFT	CFT	Total
SUM	1236 (26)	3091 (64)	516 (11)	4843 (100)
Elevations (m)				
≤1000	74 (57)	51 (40)	4 (3)	129 (100)
-1100	224 (42)	257 (48)	54 (10)	535 (100)
-1200	235 (29)	493 (60)	95 (12)	823 (100)
-1300	303 (32)	545 (57)	106 (11)	954 (100)
-1400	229 (21)	750 (70)	98 (9)	1077 (100)
-1500	140 (19)	516 (69)	92 (12)	748 (100)
-1600	31 (7)	378 (82)	52 (11)	461 (100)
>1600	0 (0)	101 (87)	15 (13)	116 (100)
Aspects				
N-NE	300 (29)	615 (59)	131 (13)	1046 (100)
E-NE	200 (29)	411 (61)	68 (10)	679 (100)
E-SE	156 (25)	422 (66)	57 (9)	635 (100)
S-SE	153 (20)	557 (73)	56 (7)	766 (100)
S-SW	74 (16)	336 (72)	58 (12)	468 (100)
W-SW	6 (15)	24 (59)	11 (27)	41 (100)
W-NW	90 (36)	134 (54)	25 (10)	249 (100)
N-NW	257 (27)	592 (62)	110 (11)	959 (100)
Slopes (°)				
≤20	38 (35)	58 (53)	13 (12)	109 (100)
-30	175 (28)	340 (54)	115 (18)	630 (100)
-40	513 (27)	1212 (63)	208 (11)	1933 (100)
>40	510 (23)	1481 (68)	180 (8)	2171 (100)
Convex and Concave slopes				
Convex	338 (12)	1923 (71)	444 (16)	2705 (100)
Concave	898 (42)	1168 (55)	72 (3)	2138 (100)
Streams				
Presence	947 (89)	37 (11)	0 (0)	326 (100)
Absence	289 (21)	3054 (68)	516 (11)	4517 (100)
Forest soil types				
P_DIII	17 (3)	378 (60)	328 (38)	633 (100)
B_B	21 (4)	475 (85)	65 (12)	561 (100)
B_C	0 (0)	22 (58)	16 (42)	38 (100)
B_D	359 (30)	797 (66)	45 (4)	1201 (100)
B_D(d)	133 (10)	1024 (79)	139 (11)	1296 (100)
B_E	706 (64)	377 (34)	12 (1)	1095 (100)
B*l*c	0 (0)	18 (95)	1 (5)	19 (100)

4.2 Relationship between forest types and environmentally variable factors

The MFT was composed of sub-climatic vegetation and occupied over 60% of the study area (Table 2). It was distributed widely along streams and ridges except on the B_E soils and dry soils on ridges (Fig. 1, Forest types). As

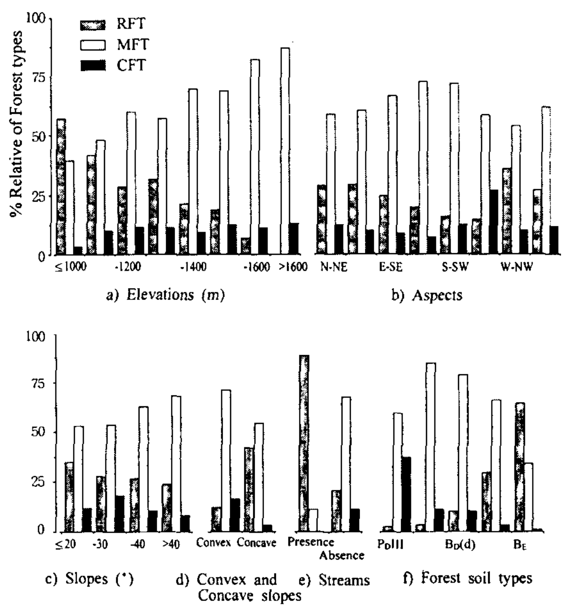

Fig. 2. Frequency distributions of Elevations, Aspects, Slopes, Convex and Concave slopes, Forest soil types and Forest types. Frequency distributions for Forest types RFT (the Riparian Forest Type), MFT (the Mountainside Forest Type) and CFT (the Crests Forest Type) of each category.

shown in Fig. 2, the distribution ration of the MFT becomes high above the elevation of 1,300 m. It raises along with the elevation while the distribution ration of the RFT shows an opposite trend. On the other hand, the distribution ration of the CFT does not seem to correlate with the elevation as it remains almost same along the ridges at all elevations except ≤1,000 m. The relationship between the distribution of forest types and the aspects was negligible (Fig. 3, Table 1). The MFT were largely relationships to the stream absence sites (Absence), the B_D and B_D(d) soils, and steep slopes of >40° (Fig. 3).

The RFT occupied 26% of the total area studied and it was found mainly on the B_D and B_E soils at the concave slopes along the streams in random and patchy manners (Fig. 1, Forest types). As shown in Fig. 2, the majority (95% frequency, Table 2) of the RFT is found at the steep slopes of >30°, but the distribution ration of the RFT in comparison with other vegetation types becomes higher towards the gentle slopes (Fig. 1 and 3). The B_E soils contained large talus gravels and topographical feature can be regarded as the main determining factors of the riparian forest (RFT) in which *F. spaethiana* and *P. rhoifolia* are dominant species[17]. The CFT occupied 11% of the total area studied and distributed mainly on P_DIII, B_B, B_D(d) soils of the convex slopes along ridges (Fig. 1, 2 and 3). Over 80% of the RFT were found on the convex slopes.

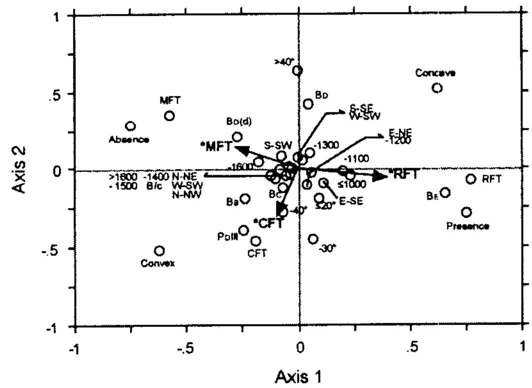

Fig. 3. Environmental variables (31 categories) and forest types (3 categories) for the first and second axes from eigenvectors by quantification theory 3rd family of study area (303 ha, n = 4,843). Elevations; ≤1000 m, -1100 m, -1200 m, -1300 m, -1400 m, -1500 m, -1600 m, ≥ 1600 m: Aspects; N-NE, E-NE, E-SE, S-SE, S-SW, W-SW, W-NW, N-NW: slopes; ≤20°, -30°, -40°, ≥40°: Convex and concave slopes; Convex, Concave: Streams; presence, absence: Forest soil types; PDIII, BB, BC, BD, BD(d), BE, Blc: Forest types; RFT (the Riparian Forest Type), MFT (the Mountainside Forest Type) and CFT (the Crests Forest Type).

5. Discussion

The study results show that the distribution pattern of the vegetation is influenced by environmentally viable factors. The MFT composed of climatic climax vegetation on convex and concave slopes was not found on the B_E soils along streams since those soils contain a considerable amount of large talus gravels. The characteristics of the topography of the area can be outlined as follows: (1) abundant concave slopes; (2) full of steep slopes >30° inclined to landslides, and V-shaped gorges; (3) frequent landslides at the gorges along streams.

The B_E soils contained large talus gravels and topographical feature can be thought as the main determining factors of the riparian forest in which *F. spaethiana* and *P. rhoifolia* are dominant species[17]. The soil formation along streams is often unstable as it is prone to vigorous natural disturbances. Disturbances such as landslides and soil erosion can be also regarded as determining factors of the riparian forest formation.

The distribution of the vegetation is directly related with the nature of soils, but the study results suggest that it can be also greatly influenced by the topographical features and disturbances. The riparian forest formation in the area where frequent natural disturbances occur can be influenced by the disturbances pattern and characteristics of the vegetational composition. In addition, a spatial and time complexity has an effect on natural regeneration and micro-topography of the area, and plays a significant role in forming a forest. In short, it can be said that the vegetational composition of the forest can be determined not only by the climatic factors but also by a pattern of natural disturbances and also an assemblage of plants which have adapted to the particular environmental conditions.

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