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Geomorphological Environment for Vegetation in East Asia

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Abstract The geomorphological environment for vegetation in East Asia was examined from three landform aspects; 'distribution', 'morphology' and 'function'. 'Distribution' refers to that of surface altitude. Mountains and lowlands produce regional differences in rainfall, temperature, wind, sunshine, water, soil and other factors, which all affect vegetation growth. These differences cause regional variety of vegetation. High mountains, extensive lowlands and wide straits act as barriers or corridors for vegetation migration through climatic changes. There are many geomorphological barriers or corridors in East Asia. 'Morphology' refers to the shape of the land surface. Fine texture and complex landform configurations create a composite environment, inducing a mosaic distribution of vegetation. The composite environment also provides various niches for plants, making the flora more complex. Landforms in East Asia show fine texture due to intense dissection by high rainfall. 'Function' refers to the movement of surface materials due to geomorphological processes such as slope failures, landslides and flooding. Bare land densely and frequently created by erosion and deposition accelerates vegetation migration and also induces a composite vegetation with various stages of succession. Movement of surface materials rich in seeds and fruit also accelerates vegetation migration. East Asia has some of the highest erosion rates in the world, contributing to the mosaic distribution of vegetation.

Key words: geomorphological environment, distribution of altitude, morphology of land surface, function of landforms, barrier, corridor.

The surface of the earth shows marked regional variations in the physical and chemical environment due to regional differences in geomorphological, geological, climatic and hydrologic conditions. These regional variations create differences in the indigenous flora and fauna. The earth's environment has changed through geological time, and this has been accompanied by migration of plant and animal habitats, and changes in their life style and even species. Thus, the current life style and geographical distribution of plants and animals reflect the combined results of both their adaptation to the present environment and adjustment to historical changes in the environment. Landforms produce the conditions necessary for plants and animals to survive, and significantly affect their growth and life styles. Changes in landforms thus induce the alterations of species and communities. In this paper, the geomorphological environment for vegetation in East Asia, focusing especially on areas covered with the laurel-leaved forests, is examined on the macro-scale.

Geoecosystem and Geomorphological Effects on Vegetation

Landforms have both direct and indirect effects on vegetation. Landform properties such as surface gradient, sediment types, sediment structures and the chemical composition of surface materials (soil nutrition) affect vegetation directly. Landform attributes such as elevation, slope aspect, undulation and arrangement control the surface climate under the influence of temperature, rainfall, snow accumulation, wind and sunshine. For example, temperature decreases with increasing altitude at a rate of 0.5–0.6°C/100 m. Thus, the existence of high mountains produces various climatic conditions. Through

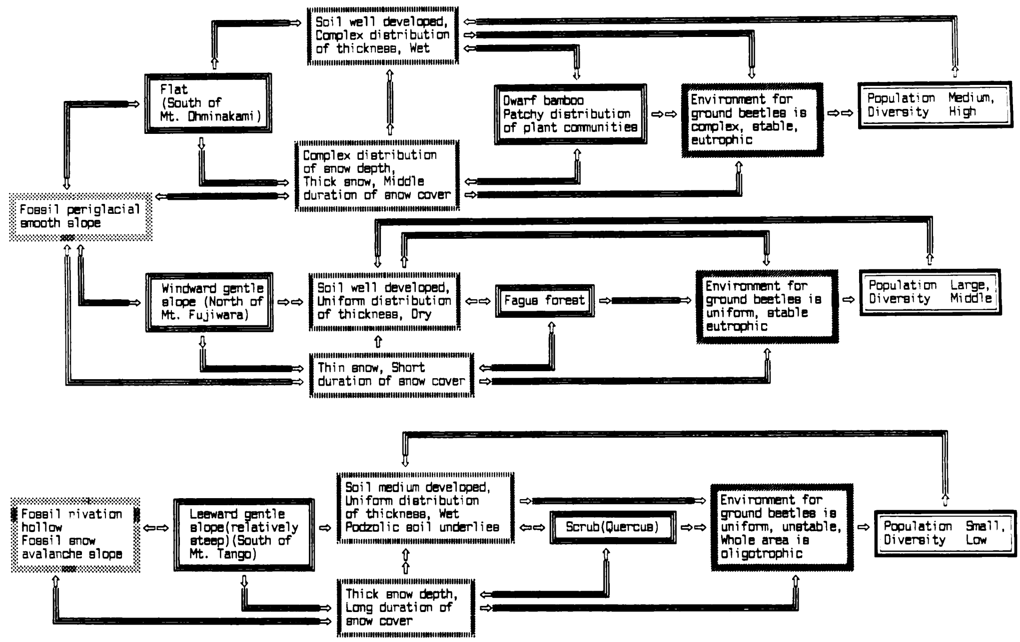

Fig. 1. Examples of geoecosystem showing the chains of interactions among landforms, soils, climate, plants and animals (ground beetle) observed in the Tonegawa-Genryubu nature conservation area, at an altitude of about 1,700 m above the sea level, central Japan (after Ohmori *et al.*, 1987).

the influence on surface climate, landforms have an indirect but significant effect on vegetation.

Examples observed in a mountain area in central Japan are shown in Fig. 1 (Ohmori *et al.*, 1987), where surface conditions of gradient, soil and snow accumulation vary with landform types. The differences in surface conditions induce different plant communities. The combination of surface conditions and vegetation types provides different conditions for ground beetles. On the other hand, the population and diversity of the beetles conversely affect soil development, which controls plant communities. The plant communities affect snow accumulation, which in turn induces different landform types.

As shown above, action and reaction among landforms, climate, soils, plants and animals show a complex cycle known as a "geoecosystem", which is a feedback system. It is difficult, therefore, to distinguish whether the direct or indirect effects of landforms on vegetation are effective in the field. Because the two effects are interrelated, the integrated effects of landforms on vegetation should be considered from a comprehensive viewpoint.

Geomorphological Framework of East Asia

The laurel-leaved forests of East Asia are distributed from the south and east flanks of the Himalaya Range to the low mountains of southwestern Japan, via central and southern China. In this area, large mountain blocks higher than 3,000 m above the sea level—the Himalaya Range and the Tibetan Plateau—stand to the west (Fig. 2). To the east of these mountain blocks, mountains higher than 1,000 m a.s.l. stretch like a wall from north to south. In the western part of Central East Asia, plains lower than 200 m a.s.l. such as the Dongbei (Northeast) Plains, Huabei (North China) Plains, Chang-Jiang Zhong You (Chang-Jiang Middle Reach) Plains, Chang-Jiang Xia You (Chang-Jiang Lower Reach) Plains and Yang-Hu Plains, exist. The eastern part of Central East Asia is bordered by the Sea of Japan, Yellow Sea and East China Sea. The island arcs of Japan and Taiwan with many volcanos stretch along the eastern margin of East Asia. The terrains

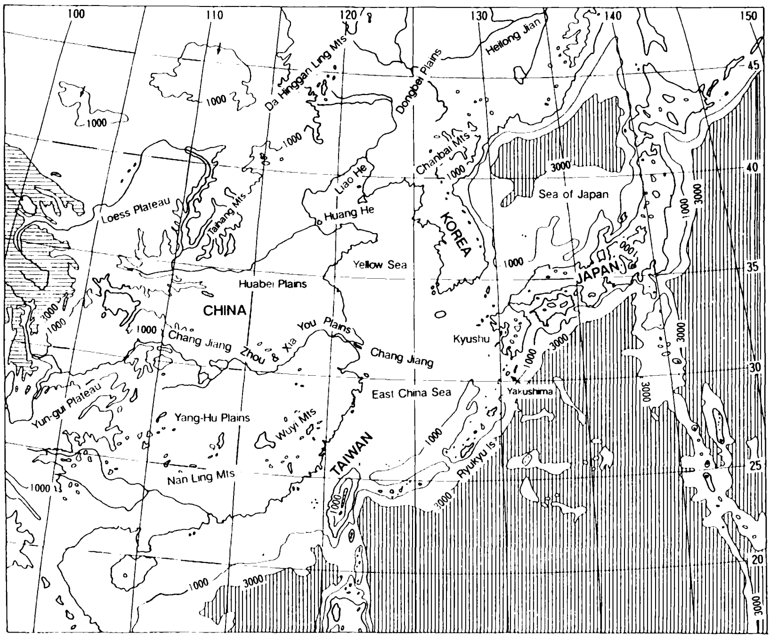

Fig. 2. Distribution of mountains, lowlands and sea in East Asia. Contours are given in meters.

Table 1. Characteristics of stepwise multiple regression equation for the estimation of mean temperatures in Japan (after Yanagimachi and Ohmori, 1991).

Month	N	Partial regression coefficients				Constant	r	Standard error (°C)
		Altitude	Latitude	Longitude	Inland index			
January	30	−0.00629	−1.41247	0.19720		26.3319	0.9908	0.80
February	30	−0.00634	−1.31369	0.14871		29.4948	0.9882	0.90
March	30	−0.00624	−1.11280			46.1721	0.9899	0.83
April	30	−0.00611	−0.98078			47.6299	0.9893	0.81
May	31	−0.00599	−0.89457		0.01652	48.3235	0.9881	0.80
June	31	−0.00551	−0.65670		0.00947	44.0777	0.9875	0.72
July	37	−0.00501	−0.49948			42.1077	0.9855	0.75
August	37	−0.00515	−0.39341			39.2700	0.9871	0.71
September	33	−0.00532	−0.86049	0.13329		34.2543	0.9899	0.66
October	31	−0.00551	−1.00302	0.20667		23.7898	0.9914	0.63
November	30	−0.00605	−1.34352	0.23924		26.7292	0.9922	0.69
December	30	−0.00634	−1.58511	0.38232		9.7557	0.9749	1.32
Winter	30	−0.00633	−1.36694	0.17712		27.4847	0.9914	0.77
Summer	38	−0.00503	−0.44944			40.7437	0.9902	0.63
Year	30	−0.00582	−1.00462	0.12215		33.0961	0.9938	0.56

* The multiple regression equation estimating annual mean temperature is shown in the text.
N: Station numbers used for regression analysis, r: Correlation coefficient.

classified by macro-scale landform types show differences in surface undulation, soil and water storage, and the arrangement of the landforms accentuates the regional differences in rainfall and temperature. In Japan, temperature decreases with increase in latitude at a rate of about 1.0°C/1°, and increases with increase in longitude at a rate of about 0.1°C/1° (Table 1; Yanagimachi and Ohmori, 1991). For example, annual mean temperature (τ, °C) is given by the equation:

$$\tau = 33.096 - 0.0058\theta - 1.0046\phi + 0.1222\lambda$$

where θ is altitude (m), ϕ is latitude (°N) and λ is longitude (°E). As shown above, geographical location itself governs the standard temperature of the terrain for an extensive area such as East Asia.

Geomorphological Characteristics of Vegetation

The characteristics of landforms can be examined from three aspects: 'distribution', 'morphology' and 'function'.

1. Distribution

'Distribution' refers to the distribution of surface altitude. Because each landform type has its own pattern of altitudinal distribution, it can be said that 'distribution' indicates the distribution of landform types, including land and sea distribution. How does the distribution—mountains and lowlands, or land and sea—control vegetation growth and distribution?

1-1. Distribution of mountains and lowlands.

Distribution of mountains and lowlands affects the distribution of soil, temperature, rainfall and water, and causes regional variations in plant species, vegetation growth and distribution.

i. Distribution of surface geology, soil and water conditions.

Mountains consist of bedrock, weathered materials and thin soil. On steep slopes, surfaces are generally well drained, resulting in lower soil fertility and quick alternation of dry and wet conditions synchronized with rainfall fluctuation. In contrast, lowlands consist of thick deposits of fine sediments. On gentle slopes, surfaces are poorly drained, producing fertile and wet conditions for vegetation habitats. The differences in soil depth, fertility and soil water produce variations in plant growth and species. Especially, on flood plains along large rivers such as the Heilong-Jiang (Amur), the Liao-He, Huang-He and Chang-Jiang, the presence of swamps and lakes and the frequent occurrence of floods have a marked effect on the distribution of plant communities and vegetation types.

ii. Effect on temperature.

Ridges on high mountains are low in temperature in contrast with the high temperature found at the foot of mountains as described in the previous section. The altitude with an annual mean temperature of 10°C is, for example, 2,200 m a.s.l. in Taiwan (122°E, 25°N), 1,300 m a.s.l. in the Wuyi Mountains (120°E, 30°N) and 1,000 m a.s.l. in Kyushu (131°E, 33°N). Deciduous broad-leaved trees such as *Fagus* and *Lepidobalanus* stand in a zone with an annual mean temperature from about 10 to 4°C, whereas evergreen broad-leaved forests consisting of laurel-leaved trees such as *Cyclobalanopsis*, *Castanopsis* and *Cinnamomum* generally require an annual mean temperature higher than about 10°C in Japan (Ohmori and Yanagimachi, 1988). Thus it is difficult for plants living at the foot of mountains with a high temperature to migrate across high mountains. On the other hand, alpine and sub-alpine or montane plants can migrate through the corridors over high ridges, although they cannot cross lowlands, which act as continental straits for alpine and sub-alpine plants.

The conditions of the barriers and corridors have changed with climatic alterations. During glacial periods, temperature was several degrees C lower than at present. This would have been a good chance for alpine and sub-alpine plants, and even for montane plants, to expand their habitats through the widened cold areas. On the other hand, during the Hypsithermal period, temperature was 2 or 3 degrees C higher than at present. Some species living on mountain ridges might have lost their habitats as a result, becoming locally extinction (Ohmori and Yanagimachi, 1991).

Mountains higher than 1,000 m a.s.l. such as the Da Hinggan Ling Mountains, the Loess Plateau and Yun-gui Plateau stretch north to south along the western margin of East Asia (Fig. 2). The Changbai Mountains and the Wuyi Mountains stand in Central East Asia. The backbone ranges in Japan and Taiwan at the eastern margin of East Asia are also higher than 1,000 m a.s.l. These mountains and their paired lowlands, which stretch north to south, would be primary barriers or corridors of temperature for vegetation migration.

iii. Effect on rainfall.

Orographically enhanced precipitation

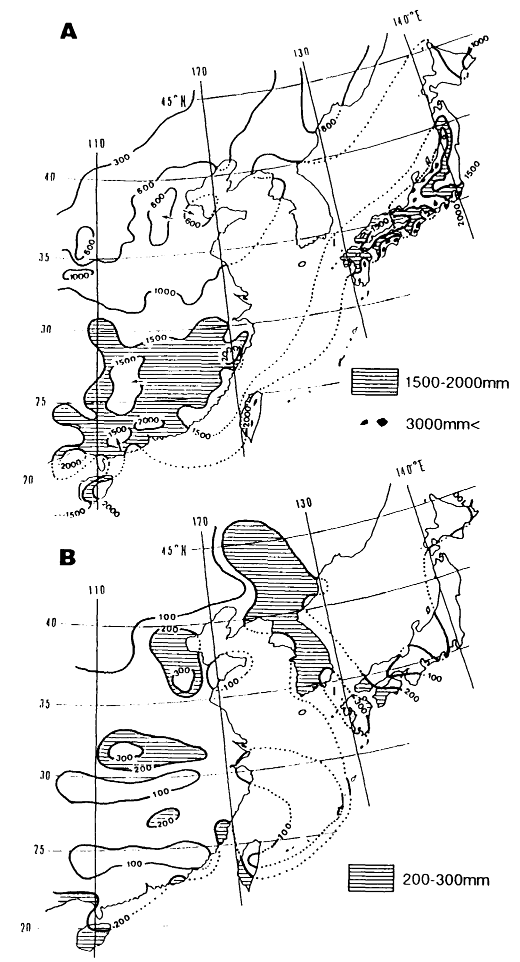

Fig. 3. Annual (A) and July (B) rainfall showing regional variation in distribution (from Central Bureau of Meteorologiy, China, 1979).

causes relatively high rainfall on the windward flank of mountains, where wet environments appear. In contrast, on the leeward flank and hinterland of the mountains, rainfall is low, providing dry conditions. Thus, the arrangement of mountains and lowlands significantly accentuates rainfall distribution. When dry or wet areas extend connectively as a belt, the dry or wet belt act as a corridor or barrier. The Wuyi and Nan-Ling Mountains in southern China and the Changbai Mountains at the base of the Korean Peninsula would be the barriers or corridors of rainfall for vegetation migration (Fig. 3; Central Bureau of Meteorology, China, 1979).

1–2. Distribution of land and sea.

Sea generally acts as a barrier for vegetation migration, although some plants use the ocean currents to expand their distribution. When a strait is narrow, even if it is deep, vegetation tends to cross it. On the other hand, a wide strait is a significant barrier to vegetation migration, even if it is shallow. The presence of a number of straits would make rapid expansion of vegetation distribution less probable. The Taiwan Strait between Taiwan Island and Continent Asia is shallow but considerably wide, and it is not easy for vegetation to cross. There are also many straits in the Japanese Archipelago. The individual straits are narrow, and do not create barriers for vegetation migration, although some of them could be barriers from the viewpoint of probability. On the other hand, the sea level has changed according to alternations of glacial and interglacial periods. Viewed from changes in sea level, the depth of a strait has a significant effect on the distribution of land and sea, causing the appearance or disappearance of straits and land bridges. During the climax phase of the Last Glacial period about 18,000 years ago, the sea level was around 100 m lower than at present, and most of the continental shelf was exposed (Fig. 4). Taiwan Island was connected to the continent by a land bridge, as were many of the islands of Japan. However, the Ryukyu Islands were composed of independent small islands. As shown above, mountains, lowlands and the sea can each act as a barrier or corridor for the migration of vegetation. These barriers and corridors have changed in extent through times of climatic change. These changes in extension have in turn caused the regional variations in plant species and vegetation distribution.

2. Morphology

'Morphology' refers to the shape of the land surface; plan figures of individual landform types, the association of various landform types, and the composition of surface undulation. The sunny sides of ridges provide dry conditions, and the shady sides wet conditions. Rainfall and wind are affected by the aspect and arrangement of slopes. Thus, the fine texture of surface undulation and the

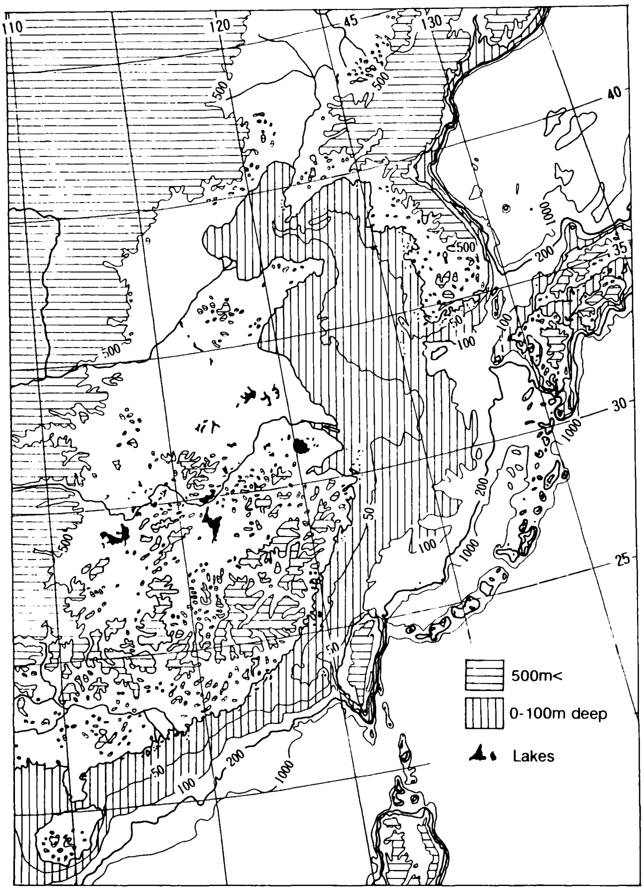

Fig. 4. Landforms in East Asia showing the fine texture of mountains and coast lines. Continental shelves shallower than about 100 m emerged during the climax phase of the Last Glacial period.

complex configuration of ridges and valleys produce a composite environment with local variations, supporting complex vegetation. Because composite landforms produce various environments, plants can easily find the right niches or escape locations when climatic changes occur.

2–1. Coast lines.

The coast lines of East Asia show complex features where ria coasts and small islands are widely distributed (Fig. 4). They have local variations in the environment with different rocks, soils, slope aspects, slope angles and climate. A patched distribution of vegetation such as mangrove swamps, bamboo groves, palm forests and various types of evergreen broad-leaved forests is seen.

2–2. Landform texture of mountains.

Mountains in East Asia are deeply dissected and show a complex relief structure.

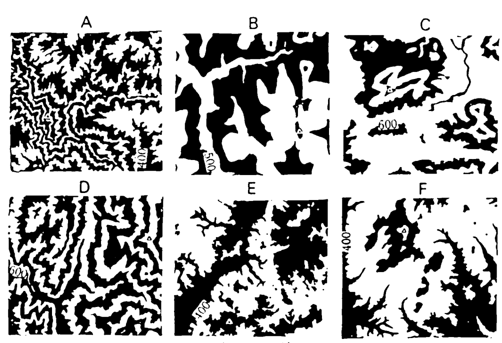

Fig. 5. Examples of configuration patterns showing differences in texture. A: Sumatra Island (5° 15′N, 95°30′E), B: Bendeleben (65°34′N, 164°09′ W), C: Kirchdorf an der Krems (47°52′N, 14°12′E), D: Ohgawara, central Japan (35°35′N, 138°03′E), E: Shobara, southwestern Japan (34°55′N, 138°08′ E), F: Niupu, northern Japan (44°34′N, 142°40′E). Every other contour interval of 200 m is indicated in black (after Sakaguchi *et al.*, 1976).

Differences in landform texture with latitude are shown in Fig. 5 (Sakaguchi *et al.*, 1976), where every other contour interval of 200 m is indicated in black. Mountains in the tropical region show fine texture due to intense water erosion (A in Fig. 5), whereas those in the boreal and sub-boreal regions show smoother landforms due to glacial and periglacial processes (B and C in Fig. 5). Mountains in the temperate regions with high rainfall are considerably dissected by water erosion and show a fine texture, as in the landforms of Japan (D, E and F in Fig. 5). The Taiwan, Nan-Ling, Wuyi, Taihang and Changbai Mountains also have fine texture. They create complex environments, inducing a conspicuously mosaic distribution of vegetation types. Considering a wide area 100× 100 km, the complexity in the distribution of vegetation types in East Asia would be among the highest in the world.

3. Function

'Function' refers to types and rates of surface material movements. It includes geomorphological processes of erosion and deposition such as debris flow, landslides, soil erosion, floods and volcanism. Active geomorphological processes accentuate the distribution of vegetation types and accelerate vegetation migration.

3-1. Bare land.

Bare land created by landslides, floods and volcanism initialize a sequence of vegetation succession. On areas of bare land of different ages, various stages of succession appear, making the vegetation composition complex. Bare land can also be a front of vegetation

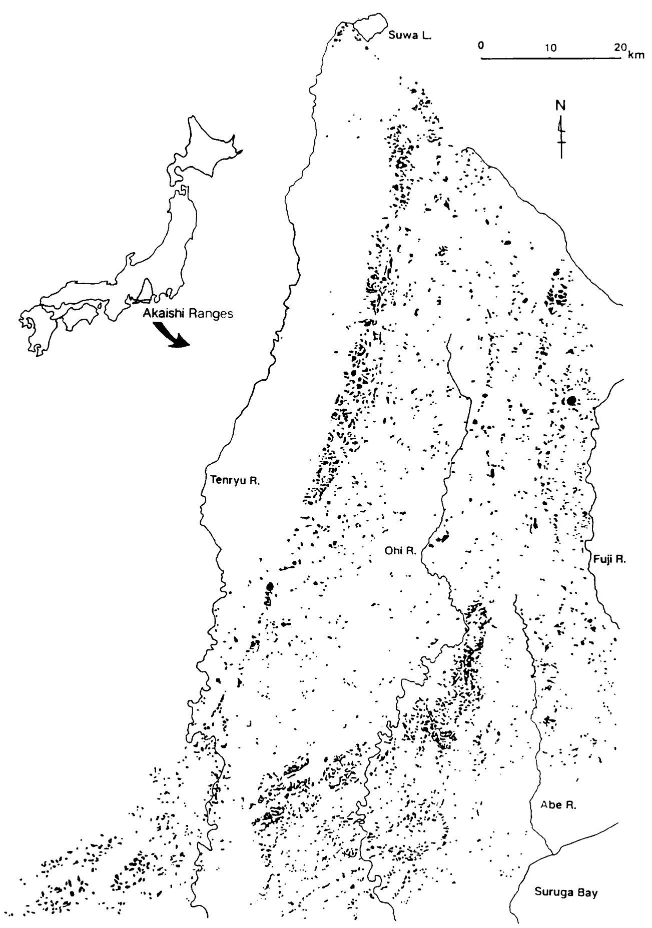

Fig. 6. Distribution of 3,424 landslide masses with areas larger than about 10,000 m^2 in the Akaishi Range, central Japan (after Ohmori and Sugai, 1994).

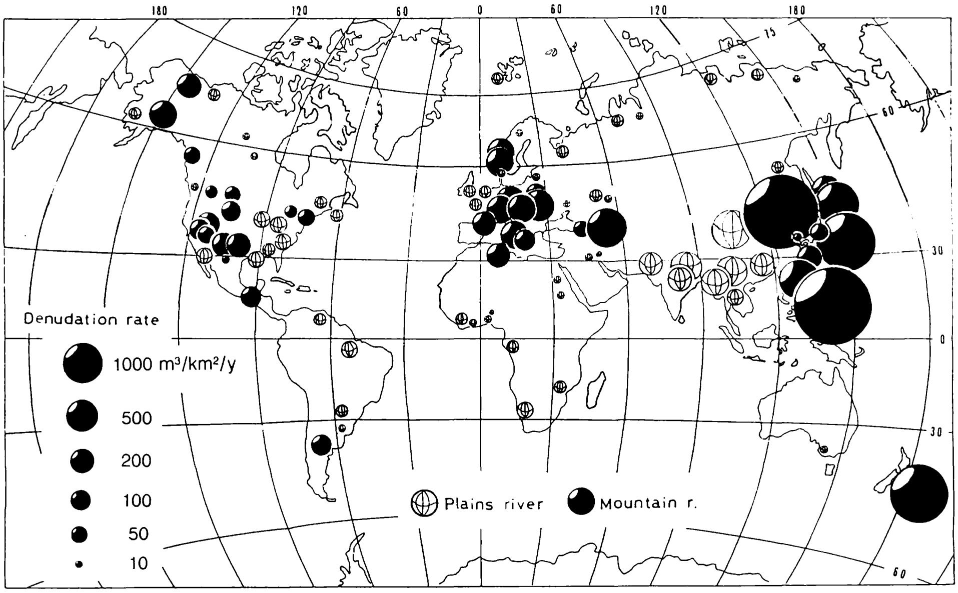

Fig. 7. Distribution of erosion (denudation) rates of drainage basins in the world, showing high rates in East and Southeast Asia due to heavy rainfall (after Ohmori, 1983b).

migration when climatic change occurs. Bare land created in forests composed of plants which have flourished under previous climatic conditions is easily invaded by plants which are adapted to the new environment. Frequent creation of bare land gives vegetation an opportunity to alternate and migrate quickly.

Figure 6 shows the distribution of 3,424 landslide masses with areas larger than 10,000 m^2 in the Akaishi Range, central Japan (Ohmori and Sugai, 1994; Sugai *et al.*, 1994; Ohmori and Sugai, 1995). Landslides occupy about 8% of the area of the range (Sugai *et al.*, 1994) and the mean volume of landslide masses in 1 km^2 is about 4,000,000 m^3 (Ohmori and Sugai, 1995). The erosion rate of the ranges is about 1,000 $m^3/km^2/y$ (Ohmori, 1983a). Thus, the surfaces of the ranges are roughly estimated to be uncovered about every 4,000 years, although the steeply sloping surfaces would have a shorter cycle of regeneration and the gently sloping surfaces might be stable for a longer period. Surfaces with different ages of generation support various vegetation types in the Akaishi Range. On Yakushima Island to the south of Kyushu, the interval of regeneration of mountain slopes is estimated to be about 1,000 years (Iso, 1984). This short interval is due to the extremely high annual rainfall exceeding 3,000 mm.

In the mountains of East Asia, the situation is similar to that in the Japanese mountains. Debris avalanches and landslides occur frequently and widely due to heavy rainfall, in spite of the high vegetation cover ratio. The dense and frequent occurrence of bare land would induce not only composite vegetation types but also rapid adaptation of vegetation to the environment newly created by climatic change.

3–2. Distribution of seeds.

Seeds of plants, not only trees but also herbs, are distributed over land surfaces and mixed with surface materials. They can be transported to distant places far from the original ones by geomorphological processes such as soil erosion, slope failure and flooding. Thus, active erosion and deposition of soil rich in seeds contribute more to vegetation migration than in areas with less active geomorphological processes. East Asia has among the highest erosion rates in the world (Fig. 7; Yoshikawa, 1974; Li, 1976; Ohmori, 1978, 1983b; Summerfield, 1991). The active erosion in mountains and the frequent occurrence of floods in lowlands, both of which also produce bare land, accelerate vegetation migration and the adaptation of vegetation to the current environment.

Conclusions

The geomorphological environment for vegetation in East Asia was examined from three aspects: 'distribution', 'morphology' and 'function'. 'Distribution' refers to the distribution of surface altitude. In East Asia, high mountains and extensive lowlands are distributed alternately, and produce various soils, temperature, rainfall and water which affect vegetation growth and distribution. Mountains and lowlands act as barriers or corridors for vegetation migration when climatic change occurs. During the alternation of glacial and interglacial periods in the Quaternary, Japan and Taiwan were connected to the continent by land bridges during glacial periods, and were islands isolated by straits during interglacial periods. With the various conditions created by 'distribution', plant species and vegetation types are very complex in East Asia.

'Morphology' refers to the shape of the land surfaces. Fine texture and the composite arrangement of ridges and ravines produce a complex distribution of soil, water, sunshine, temperature, rainfall and wind, providing a complex environment for vegetation. Landforms in East Asia show fine texture due to intense dissection by high rainfall. This creates a mosaic distribution of vegetation and provides niches for plants when climatic change occurs, resulting in a highly complex distribution of vegetation types.

'Function' refers to the movement of surface materials by erosion and deposition processes such as soil erosion, slope failure, landslides and flooding. Erosion and deposition create bare land which initializes a sequence of vegetation succession and also provides frontal areas for vegetation migration. The frequent occurrence of bare land might accelerate vegetation migration and induce complex vegetation with various stages of succession. Active movement of surface materials containing many seeds would also accelerate vegetation migration. Active erosion in mountains and frequent occurrence of floods in lowlands in East Asia contribute to vegetation migration and adaptation of vegetation to the environment.

The micro-scale effects of landforms on vegetation have been studied for many cases (e.g. Kikuchi and Miura, 1991; Sakai and Ohsawa, 1994; Shimada, 1994; Sakai, 1995; Hara *et al*., 1996). For the macro-scale landform effects on vegetation, there have been few studies except for those on landforms such as straits and land bridges that have affected vegetation migration for a long time since the Mesozoic era. It has been noted by Ohmori and Yanagimachi (1991) that even in a short period such as the Holocene, some plant species might have disappeared from some mountains in Japan due to patchy distribution of high mountains. The lack of *Abies mariesii*, a sub-alpine conifer, on some high mountains in Japan could be caused by the disappearance of thermal conditions suitable for the species due to the increase in temperature in the Hypsithermal. Once a species has disappeared from an isolated mountain, it is difficult for it to become re-established, because the path through which the species migrates does not always recover even if thermal conditions become suitable again on the higher part of the mountain due to climatic cooling. The geomorphological environment for vegetation examined here was mostly deduced from the palaeogeography, landforms, flora and vegetation types of East Asia. It is desirable to promote suitable studies of the macro-scale landform effects on vegetation for further understanding of the vegetation in East Asia.

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東アジアの植生に対する地形環境

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地球の表面の地質や地形，気候や水分の分布は地域的に大きく異なっている．そうした地表条件の違いに応じて植物の種が異なり，また，異なった生活が営まれている．一方，地表条件は時代とともに変化してきた．それに応じて植物は移動し，あるいは，生活様式

を変化させた．したがって，現在見られる植物の生活様式や分布の違いの多くは，現在の地表条件に対する適応と，過去の変化に対する順応が重なり合った結果とみなすことができる．地形は多くの植物にとっての生活の舞台であり，地形の性格は植物の生活様式や分布に少なからぬ影響を与えている．本稿では東アジアの植物の生育や分布に影響を与えている地形環境について考えてみた．

地形は植生に対して直接影響を与える場合と間接的に影響を与える場合がある．前者は，傾斜や表層地質（土壌）などの地形条件が植物の生育や分布を規定する場合である．地形の違いは土地の安定・不安定，栄養や水分の違いをもたらし，それに応じて植物の種や生育状態が異なる．後者は，地形が気候に影響を与え，その気候が植生に影響を与える場合である．地表付近の気温や降水，日射，風あるいは積雪などは高度や斜面方位あるいは，凹凸の状態などによって大きく異なり，植物の生育や分布に大きな影響を与えている．植生に対し地形の直接的影響が強いのか，間接的影響が強いのかを明確に区分することはむずかしい．東アジアというマクロスケールでは，両者を込みにして考える方が「環境」としての地形の性格を理解しやすい．

地形の性格は「分布」,「形態」,「機能」という３つの側面から見ることができる．３つの側面はそれぞれが，直接に，また，気候への影響を通して間接的に植生に影響を与えている．「分布」とは海陸の分布を含めた地表面高度の地域分布をさす．山地や低地の偏った分布は土壌や降水量，気温の偏った分布をもたらし，植生の偏った分布を引き起こす．また，気候変動などに伴う植物の移動に対して，山地や低地，海峡はバリアー（障害物）やコリダー（回廊）の役割を果たす．東アジアでは，山地，低地，海峡が交互に分布し，植生の分布を複雑にさせるとともに，あちこちに地形的バリアーやコリダーをつくりだしている．「形態」とは地表面の凹凸の形や各種の地形の輪郭をさす．形態が複雑であればあるほど，多様な環境が出現し，植生は複雑になる．また，多様な環境が出現するため，環境変化があった場合，植物は「逃げ場」を見つけやすい．東アジアではリアス海岸が発達し，また世界的に多い降水量のため，山地は細かく開析され，多様で複雑な地形環境をつくり出している．「機能」とは地表物質の動きをさし，土壌侵蝕や崖崩れ，地滑りあるいは河川の氾濫などを意味する．山地での崩壊や低地での洪水などによる地表の裸地化は植生の遷移を初期化させる．したがって崖崩れや洪水などがあちこちで頻繁に起こる地域では，異なった遷移段階の植生が出現し，植生分布が複雑になる．また，裸地は植生が移動する際の進出拠点となりやすく，多数の裸地の出現は植生の移動を容易にさせる．さらに，種子を含んだ土壌の侵蝕と下流での堆積は植生の移動を加速させる．東アジアは侵蝕速度が世界で最も大きな地域の一つであり，洪水の頻発する地域でもある．