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## Estimation of Solar Radiation on the Slope and its Effect on the Vegetation Distribution in the Mountainous Area

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### Abstract

In the recent years, computers can quickly analyze huge amounts of data, and this has changed some of the methods used in climatological study. The study of local climates by using grid analysis is one of these new methods which have developed with the advance of computers. The grid based analysis is highly useful for a study of local climates in the regions with complicated topography. The author used this method to analyze the local climates in mountainous areas in Hokkaido, Japan.

Relative strength of solar radiation at each 50 m×50 m grid point was calculated from the gradient and direction of slope and altitude at the point. The strength of solar radiation affected the distribution of vegetation in the area.

**Key Words:** Grid based data, Landform element, Solar radiation, Bed rock, Water stress, Vegetation.

### Introduction

The island of Hokkaido is the northernmost of Japan's islands and is characterized by wide areas which have been preserved in natural condition. Conservation and utilization of these areas are increasing and are pressing problems that must be solved before new plans of regional developments are formulated.

The character and resources of an area are utilized very differently and the analytical methods or the form of data have to be common. An analysis of numerical environmental data such as climatological, geological, topographical and biological data is a useful method to establish the relation between different kinds of environmental factors.

In this study the author estimated the relative strength of solar radiation on slopes of natural forests in the central mountainous area of Hokkaido. Geologists and biologists have claimed that the distribution of numerous types of forests in this area was due to geological factors, and a purpose of this study is determine the effect of solar radiation on the distribution of forests in the area.

### 1. Topography of the study areas

Study area (A) where the environmental factors were investigated is located

at the southern edge of the Daisetsu Mountains in Central Hokkaido, 43°15'N and 143°07'E. The area is 2.5 km from north to south and 3.0 km from east to west. A part of Lake Shikaribetsu is in the northern part and Lake Komadome is in the western part of the area. The area has two peaks, Mt. Higashinupukaushi, 1252 m, a.s.l. and Mt. Hakuun, 1187 m a.s.l. The south east end of the area is lowest, 625 m a.s.l. The annual mean temperature is 8.9°C, the monthly mean temperatures in January -5.3°C and in August 18.9°C, and the annual precipitation is 940 mm, all at the nearest meteorological station, Kamishoro, about 17 km east of the area.

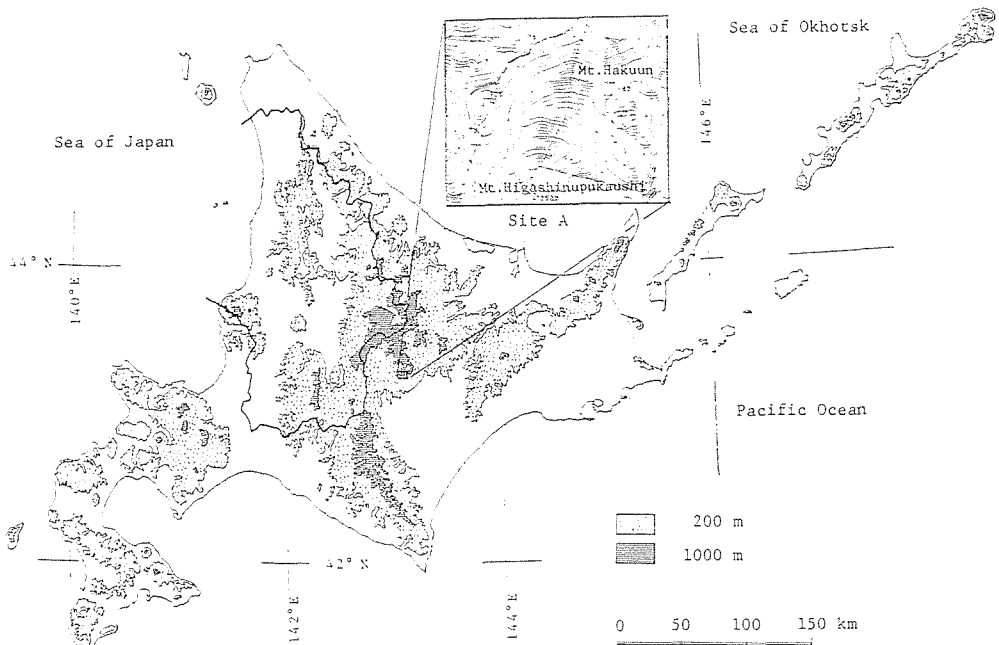


Figure 1. The topography of Hokkaido and the locations of the study area.

## 2. Methods

a) The geological and vegetation data in the study area were numerically assigned at the cross points of a 50 m grid based on geological (Figure 2) and vegetation maps (Figure 3). The landform elements such as altitude, gradient and direction of slope were also numerically determined with the same grid spacing, from a 1/5000 topographical map.

b) The intensity of solar radiation at the grid points was calculated for every hour from sunrise to sunset by Okanoue's formula (Okanoue, M., 1957).

$$I = I_0 \left[ \left\{ 1 - (\sin A \cdot \cos B \cdot \cos P + \cos A \cdot \sin P)^2 \right\}^{\frac{1}{2}} \cos(\omega t + a) \cdot \cos d \right. \\ \left. + (\sin A \cdot \sin B \cdot \cos P + \cos A \cdot \sin P) \sin d \right] \\ a = \tan^{-1} \frac{\sin A \cdot \sin B}{\cos A \cdot \cos P - \sin A \cdot \cos B \cdot \sin P} \quad (1)$$

where  $I$  is the direct solar radiation incidents upon the slope without an optical air mass;  $I_0$  is the solar constant;  $A$  is the gradient of slope;  $B$  is the direction of slope;  $P$  is the latitude;  $d$  is the declination of the sun;  $\omega$  is the angular velocity of rotation of the earth;  $t$  is the hour angle.

c) In this estimate, solar radiation is assumed to decrease to half when insolation is shaded by land. The relative strength, the ratio at each grid point to that

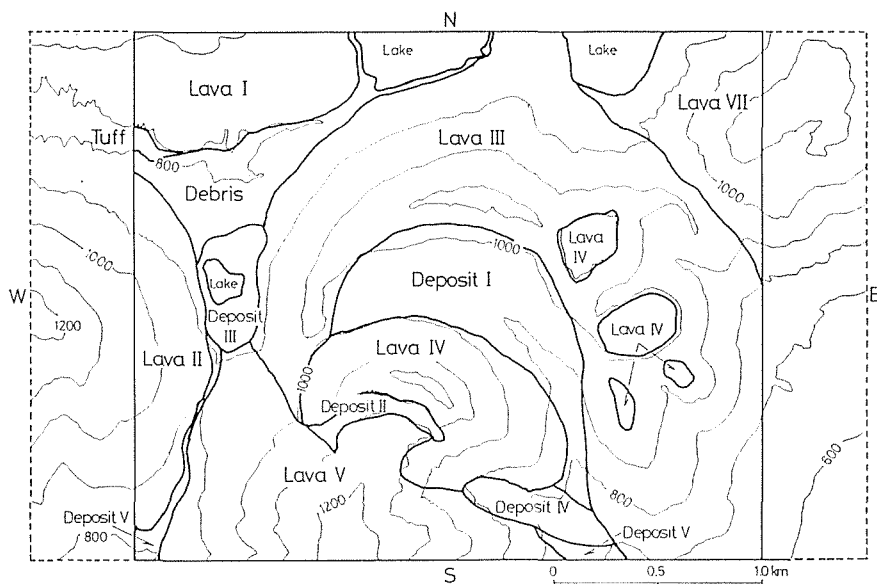


Figure 2. Geological map of the study area (OCEWSGH, 1980).

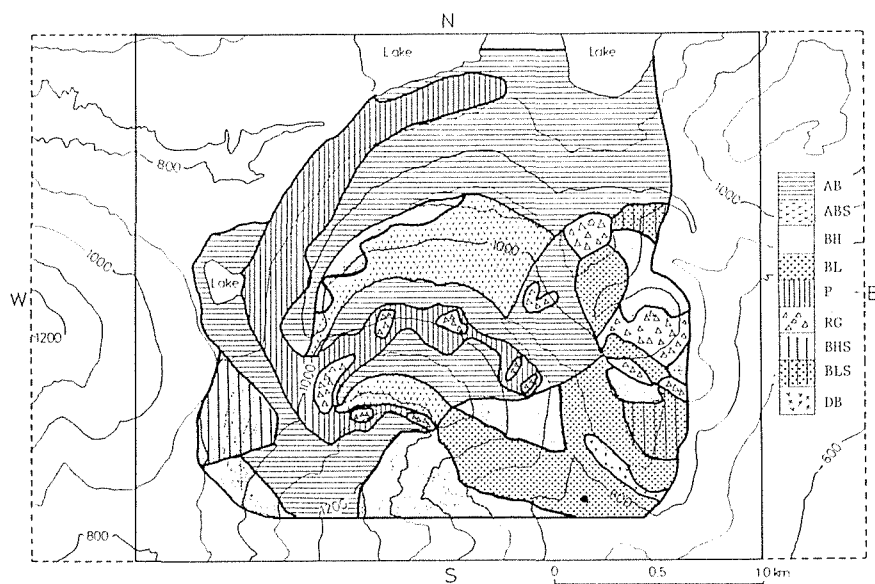


Figure 3. Vegetation map of the study area (OCEWSGH, 1980).

at an open horizontal area is used in following analysis.

### 3. Results and Discussion

#### (a) *Topographic characteristics in the study area derived from the grid data*

Mean elevation of the study area (A) is 932 m a. s. l. and the areas distribute as shown in Figure 4. The maximum gradient of slopes is 45 degrees and the mean gradient is 19.7 degrees. The areas of the different gradient are shown in Fig. 5.

#### (b) *Characteristics of bed rock distribution derived from grid data*

The bed rock in the study area is lava and pyroclastic deposits from volcanoes which were active after the Pleistocene. The bed rock of the area was classified as shown in Table 1 (OCEWSGH, 1980).

**Table 1.** Classification of bed rock and the landform elements in the study area

| Materials of bed rock                            | Area<br>(ha) | Elevation (m) |      |      | Slope (deg) |      |
|--|--------------|---------------|------|------|-------------|------|
|  |              | Mean          | Max. | Min. | Mean        | Max. |
| Water Surface                                    | 26.3         | —             | —    | —    | —           | —    |
| Welded Tuff (Tuff)                               | 1.2          | 777           | 805  | 775  | 32.4        | 45   |
| Minaminupukaushinupuri Lava (Lava I)             | 53.0         | 851           | 935  | 830  | 15.3        | 34   |
| Nishinupukaushinupuri Lava (Lava II)             | 45.3         | 943           | 1045 | 905  | 18.5        | 45   |
| Higashinupukaushinupuri<br>Somma Lava (Lava III) | 262.5        | 906           | 1190 | 625  | 21.5        | 41   |
| Pyroclastic Deposit I (Deposit I)                | 59.5         | 940           | 1050 | 735  | 20.1        | 36   |
| Higashinupukaushinupuri<br>Cone Lava (Lava IV)   | 62.9         | 1017          | 1162 | 815  | 22.2        | 39   |
| Pyroclastic Deposit II (Deposit II)              | 6.7          | 1091          | 1115 | 1090 | 17.5        | 34   |
| Higashinupukaushinupuri Lava (Lava V)            | 101.7        | 1029          | 1250 | 755  | 20.6        | 39   |
| Komadomeko Exprosion-crater                      |              |               |      |      |             |      |
| Pyroclastic Deposit (Deposit III)                | 11.8         | 871           | 905  | 880  | 14.8        | 27   |
| Pyroclastic Deposit III (Deposit IV)             | 11.6         | 807           | 975  | 710  | 20.1        | 34   |
| Hakuunsan Lava (Lava VI)                         | 19.3         | 1061          | 1180 | 960  | 23.4        | 34   |
| Tembousan Lava (Lava VII)                        | 50.6         | 967           | 1175 | 810  | 23.3        | 44   |
| Pyroclastic Flow Deposit (Deposit V)             | 6.5          | 780           | 890  | 695  | 16.1        | 27   |
| Volcanic Debris and Gravels (Debris)             | 30.8         | 819           | 905  | 800  | 13.9        | 39   |

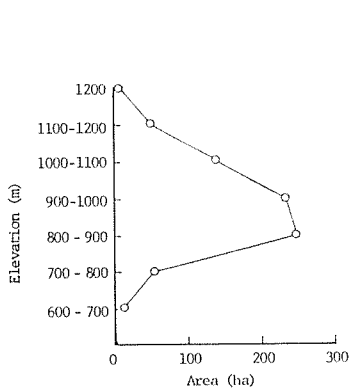
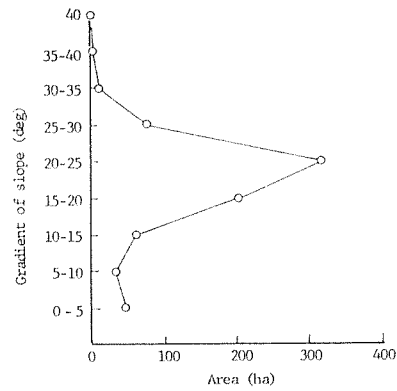
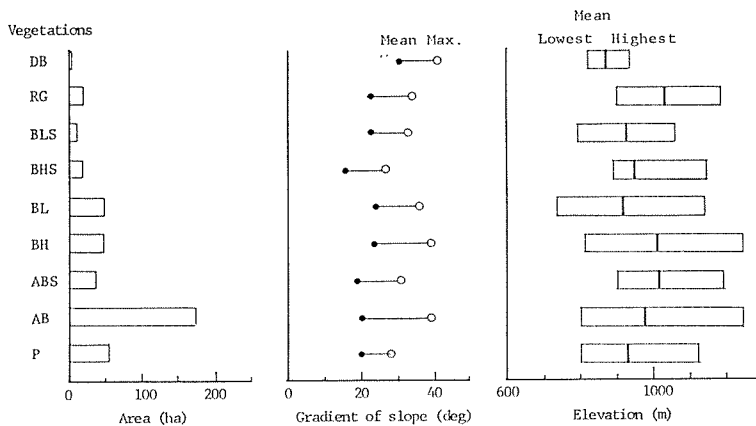
#### (c) *Characteristics of vegetation distribution derived from grid data*

The area is the southernmost part of The Daisetsu National Park. Natural coniferous forest, mixed forest and a kind of alpine flora are well conserved here. The vegetation of the area is classified as shown in Table 2.

Areas, gradient of slopes and elevation of each vegetation calculated from the grid data are shown in Figure 6. The AB forest covers the widest area, 23.3%, the P forest 7.5%, and the BL forest 6.4%. The mean gradient of 25.7% at debris slopes is the steepest in the area, followed by the BL forest 23.6%, and the BH area 23.3%. The 1033 m mean elevation of the RG area is highest, the

**Table 2.** Vegetations and landform elements in the study area

| Vegetations  |         | Area<br>(ha) | Elevation (m) |      |      | Slope (deg) |      |
|--|---------|--------------|---------------|------|------|-------------|------|
|  |         |              | Mean          | Max. | Min. | Mean        | Max. |
| Lake surface or unsurveyed area                                  | (ND)    | 329.3        | 881           | 1250 | 625  | 18.1        | 45   |
| Debris   | (DB)    | 3.4          | 872           | 935  | 820  | 25.7        | 41   |
| Rock and Gravel  | (RG)    | 20.7         | 1033          | 1180 | 900  | 23.0        | 34   |
| <i>Betula ermanii</i> Low Sparse Forest                          | (B L S) | 10.1         | 927           | 1060 | 795  | 23.1        | 33   |
| <i>Betula ermanii</i> High Sparse Forest                         | (B H S) | 19.8         | 949           | 1145 | 890  | 16.0        | 27   |
| <i>Betula ermanii</i> Low Forest                                 | (B L)   | 49.2         | 919           | 1140 | 735  | 23.6        | 36   |
| <i>Betula ermanii</i> High Forest                                | (B H)   | 48.2         | 1013          | 1245 | 815  | 23.3        | 39   |
| <i>Abies sachalinensis</i> - <i>Betula ermanii</i> Sparse Forest | (A B S) | 38.6         | 1017          | 1190 | 905  | 19.2        | 31   |
| <i>Abies sachalinensis</i> - <i>Betula ermanii</i> Forest        | (A B)   | 174.5        | 977           | 1245 | 800  | 20.1        | 39   |
| <i>Picea glehni</i> Forest                                       | (P)     | 56.2         | 931           | 1125 | 803  | 20.3        | 28   |

**Figure 4.** The number of areas at different elevation (100 m interval).**Figure 5.** The number of areas with different slope gradient.**Figure 6.** Area, gradient and elevation of land covered by vegetation.

ABS forest is 1017 m, and the BH forest is 1013 m.

(d) *Geological elements and vegetation*

Table 3 shows the areas of the different types of vegetation covering on each geological formation. The Lava III occupies the widest area, with several kinds of forest covering. The ratios of areas covered by the BL, BH, ABS, AB and P forests on the Lava III are roughly equal to the ratios of area covered by those forests in the whole study area (Table 4). The Lava V which is a secondary area, has only BHS, BH and AB forests, covering on it. This is considered to be caused by the directions of the slopes which these forests cover.

**Table 3.** Areas of vegetations on each kind of subbase

|             | DB  | RG  | BLS | BHS  | BL   | BH   | ABS  | AB   | P    |
|-------------|-----|-----|-----|------|------|------|------|------|------|
| Tuff        |     |     |     |      |      |      |      |      |      |
| Lava I      |     |     |     |      |      |      |      |      |      |
| Lava II     |     |     |     | 0.2  |      |      |      | 0.2  |      |
| Lava III    | 3.4 | 4.3 | 9.6 |      | 21.0 | 14.7 | 9.9  | 87.5 | 36.4 |
| Deposit I   |     | 2.4 |     |      | 6.0  | 2.2  | 22.2 | 23.9 | 2.9  |
| Lava IV     |     | 4.1 |     |      | 15.2 | 13.0 | 3.9  | 14.5 | 12.3 |
| Deposit II  |     | 1.2 |     |      | 0.2  |      | 2.7  | 0.7  | 1.9  |
| Lava V      |     |     |     | 18.8 |      | 11.1 |      | 26.0 | 0.5  |
| Deposit III |     |     |     |      |      |      |      | 9.4  | 2.2  |
| Deposit VI  |     |     |     |      | 3.9  | 1.9  |      |      |      |
| Lava VI     |     | 8.4 | 0.5 |      | 2.9  | 5.3  |      | 2.2  |      |
| Lava VII    |     |     |     |      |      |      |      | 8.2  |      |
| Deposit V   |     |     |     |      |      |      |      |      |      |
| Debris      |     |     |     | 0.7  |      |      |      | 1.2  |      |

**Table 4.** The ratios of area covered by BL, BH, ABS, AB and P forests on the Lava III and in the whole study area

|            |      | BL   | BH   | ABS  | AB    | P    | Total |
|------------|------|------|------|------|-------|------|-------|
| Lava III   | (ha) | 21.0 | 14.7 | 9.9  | 87.5  | 36.4 | 169.5 |
| —          | (%)  | 12.4 | 8.7  | 5.8  | 51.6  | 21.5 | 100.0 |
| Study Area | (ha) | 49.2 | 48.2 | 38.6 | 174.5 | 56.2 | 366.7 |
| —          | (%)  | 13.4 | 13.2 | 10.5 | 47.6  | 15.3 | 100.0 |

(e) *Meteorological conditions and vegetation*

Figure 7 shows the frequency of appearance of each kind of forest at different slope directions. The figure shows that there are RG areas on all directions of slopes. All forests have a dominant direction. High forest (BHS) of *Betula ermanii* sparse forests, distribute on western slopes and the low forest (BLS) on the south-eastern slopes. The *Betula ermanii* low forest (BL) distributes on the southern

slopes and the high forests (BH) on east southeast slopes. In the same manner, the sparse forests (ABS) of the *Abies sachalinensis* and *Betula ermanii* distribute on the south southwest slopes and the normal dense forests (AB) on northern slope. The *Picea glehni* forest distributes on the north-western slopes.

The forest distribution of this study area is considered to be caused by the differences in solar radiation on the slopes. To elucidate this point, the relative strengths of solar radiation at each grid point were estimated.

The relative strength of solar radiation is the ratio of solar radiation incident on the slope to that on an open horizontal surface. The relative strength of solar radiation is not very different on the different vegetations on May, June and July because the angle of the sun is high. The differences became larger on August and September because the sun is lower at this time (Table 5).

Seasonal changes in the relative strength of solar radiation on debris areas is the largest because it faces southeast, but it is very small of the RG areas because they face in many different directions. A part of the RG area is covered by lichen which prefers wet conditions. The differences in the vegetation on the RG area seems to be caused by the difference in solar radiation intensities on the slopes.

Seasonal changes in the relative strength of solar radiation for each kind of forest are shown in Figure 8. The seven types of natural forests in this area can be divided into three groups. The first group is the BLS, BL and ABS forests. Solar radiation on these forest is the strongest and increases rapidly in August and September. The second group is the BHS and BH forests, where solar radiation is not strong and

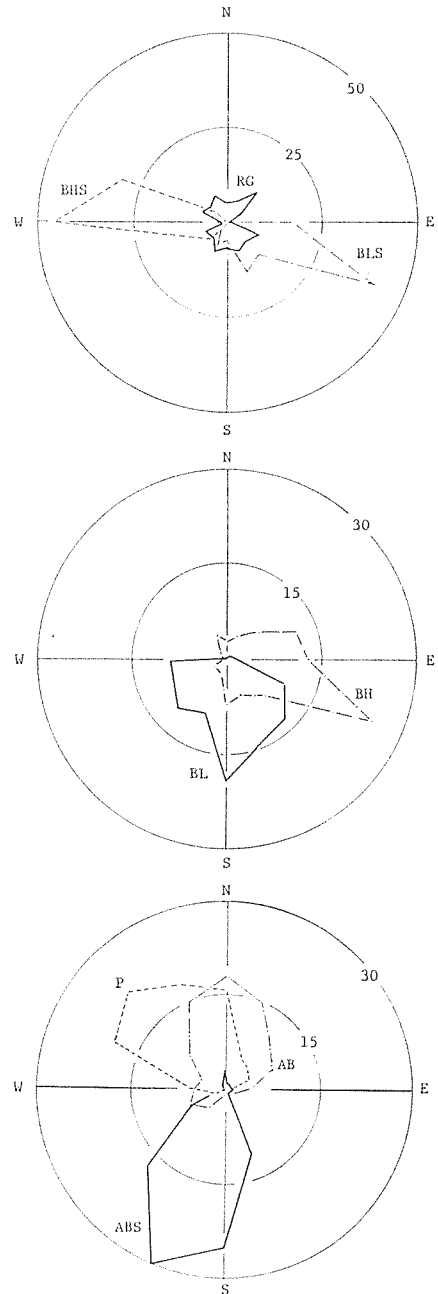


Figure 7. The incidence of forests on different directions of slopes.



**Table 5.** Relative strength of solar radiation on the vegetation type

| Vegetations | 20 May | 20 Jun. | 20 Jul. | 20 Aug. | 20 Sep. |
|-------------|--------|---------|---------|---------|---------|
| DB          | 0.88   | 0.86    | 0.87    | 0.93    | 1.03    |
| RG          | 0.81   | 0.82    | 0.81    | 0.80    | 0.82    |
| BLS         | 0.86   | 0.86    | 0.86    | 0.90    | 0.99    |
| BHS         | 0.80   | 0.80    | 0.80    | 0.79    | 0.78    |
| BL          | 0.85   | 0.83    | 0.84    | 0.90    | 1.01    |
| BH          | 0.82   | 0.82    | 0.82    | 0.81    | 0.83    |
| ABS         | 0.88   | 0.87    | 0.87    | 0.95    | 1.06    |
| AB          | 0.73   | 0.76    | 0.73    | 0.66    | 0.56    |
| P           | 0.74   | 0.76    | 0.74    | 0.67    | 0.56    |

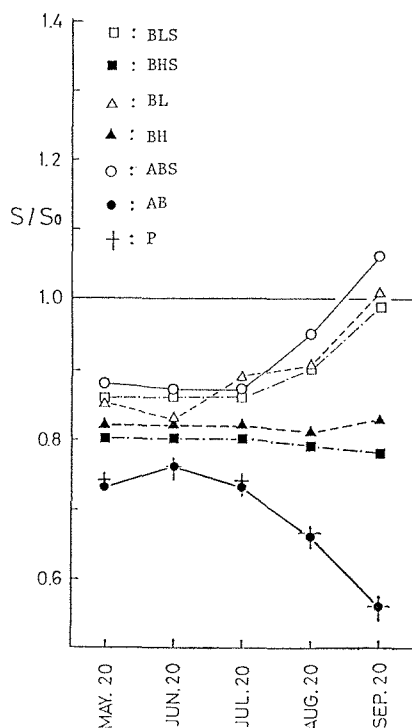
seasonal changes are small. The third group is the AB and P forests. Solar radiation on these forests is somewhat weak and decreases rapidly in August and September.

From these facts, the difference in solar radiation on the slopes play an important role in dividing vegetation types in the study area.

The water retention in the soil in this area is very poor because the soil layer is not well developed on the bed rocks which originated from volcanic lava and deposits after the Pleistocene. It is clear that water stress caused by solar radiation and poor soil retentivity are affecting on the growth of trees in the study area.

### Conclusions

The relationships between vegetation distribution, landform elements and meteorological elements was established by grid data of the study area (A) located at the southern edge of the Daisetsu Mountains. The forest vegetations were divided into three groups on the basis of the strength and the pattern of seasonal change of solar radiation on the forests. The important effect which decide the distribution of vegetation was water stress caused by solar radiation on the poor soil, not the distribution of bed rock.



**Figure 8.** Seasonal changes in the relative strength of solar radiation on the forests.

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