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CHARACTERIZATION OF TEMPERATURE ENVIRONMENT ON MIKURA-JIMA ISLAND, JAPAN CONSIDERING VEGETATION RECOVERY

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ABSTRACT: Vegetation recovery following landslides caused by typhoons has been monitored on Mikura-jima Island, Japan. Despite having a temperature profile of a warm temperate zone, Mikura-jima has many plant species representative of a cool temperature zone. Temperature environment is an essential parameter for determining the development of vegetation and flora, but little data are available for the island. In the present study, we measured atmospheric temperature by thermographs at seven different elevations (130, 300, 400, 500, 600, 700 and 800 m) over a period of 5 years (from 2013 to 2017), and we determined the warm index, cool index and rate of decline with elevation. The lapse rate along elevation gradient was 0.98 ˚C per 100 m for elevations 500 m and below, and 0.66 ˚C per 100 m for elevations 500 m and above. Warm index (W.I.) was estimated to fall below 85 at elevations over about 800 m, which allows the existence of a cool temperature zone. The re-examination of temperature environment in the present study will facilitate planning of goals and evaluation or estimation of vegetational succession on Mikura-jima Island.

Keywords: Atmospheric Temperature, Warm index, Lapse rate, Vegetation, Mikura-jima Island

1. INTRODUCTION

Vegetation recovery projects require planning of remediation activities based on monitoring data and evaluation of success at the species level. The course of remediation efforts may differ greatly from project to project and will reflect the purpose of the project. In the case of urgently needing to stabilize the base of a slope to prevent landslides near populated areas, rapid establishment of ground cover may be achieved by using exotic pasture grasses owing to their superior germination and growth compared to native plant species. However, when restoration in a natural ecosystem is not so urgently required, it is desirable to focus on establishing native plant species. The importance of native species becomes greater in isolated natural ecosystems such as solitary islands due to its vulnerability to disturbance by non-native species [1].

What determines the distribution of native species? Humidity and temperature environment, which can be measured by precipitation and atmospheric temperature, have been demonstrated to influence the distribution of vegetation in various studies [2,3]. In the 'Sino-Japanese Region' including China, the Korean peninsula and Japan, differences in atmospheric temperature are generally more critical than precipitation in determining the distribution of vegetation and flora because precipitation is abundant across this region [4]. Temperature environment is essential for determining the development of vegetation and flora [2-5] and, accordingly, it is an essential parameter for setting goals and evaluating or estimating the succession of vegetation.

The range of each plant species is determined by biomass production (i.e., photosynthesis, respiration, growth and storage), ability of survival in unfavorable seasons, as well as reproduction and competition [5]. From these points of view, several temperature indices such as the warm index (W.I.) and cool index (C.I.) [3] have often been used to characterize the habitat environment. For example, Kira [3] showed that the boundary between the cool temperature zone (deciduous broad-leaved tree forest) and a warm temperature zone (evergreen broad-leaved tree forest) is around 85 for the W.I. and -10 for the C.I. in Japan.

On Mikura-jima Island (Fig. 1), one of the solitary islands of the Izu Islands of Japan in the Pacific Ocean, vegetation recovery following landslides caused by typhoons has been monitored [6,7]. Mikura-jima Island naturally has an 'irregular' vegetation distribution, having many plant species that are representative of a cool temperature zone but that are inconsistent with the previous placement of the entire island into a warm temperature zone. This inconsistency in classification poses challenges for setting goals for vegetation recovery and evaluating the succession of vegetation.

However, little data is available on the temperature environment of Mikura-jima Island. The only temperature dataset on Mikura-jima Island was recorded for 5 years from 1960 to 1964 at the village school located at an elevation of 130 m reported by Kawamoto [8]. Mikura-jima Island is encircled by a shoreline of uninhabitable sheer sea cliffs and has a highest peak (Mt. Oyama) with an elevation of 850.9 m [9]. Since clouds and fog usually cover the high elevation area of the island (Fig. 2), it is reasonable to consider that the atmospheric temperature shows a lapse rate along the elevation gradient in humid conditions: taking a lapse rate of 0.6 ˚C per 100 m produces an estimated difference of about 4.3 ˚C in temperature and 51.6 (= 4.3 × 12) in W.I. between at the village school and the mountaintop. This empirical estimation provides an W.I. of more than 100 at the top of Mt. Oyama, which exceeds the criteria of a cool temperature zone, which is W.I. of less than 85 [10].

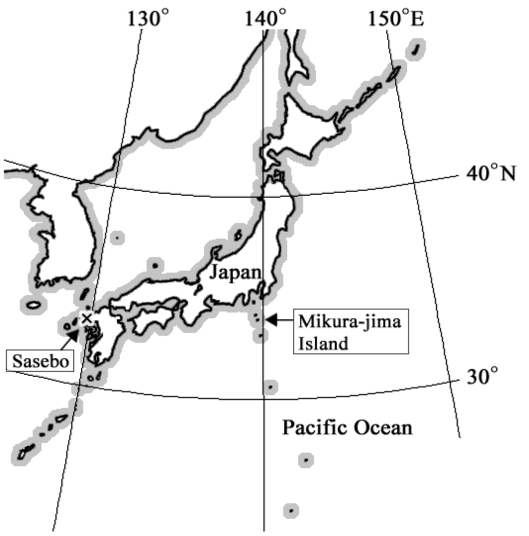

Fig. 1 Location of Mikura-jima Island, Japan with Sasebo, a city with nearly the same latitude, shown for reference

Fig. 2 Photo of Mikura-jima Island
The shoreline is made up of sea cliffs, and the high-elevation area of the island is usually covered by clouds and fog.

In the present study, atmospheric temperature is measured continuously at several points with various elevations on Mikura-jima Island. We characterize the temperature environment of Mikura-jima Island and furthermore, re-examine the relationship between the distribution of vegetation and the temperature environment.

2. METHODS

2.1 Measurement of Atmospheric Temperature

Seven points at different elevations (130, 300, 400, 500, 600, 700 and 800 m) were established for the measurement of atmospheric temperature. Among them, six points were at an elevation of 300 m or higher and are located along a path leading to the top of Mt. Oyama. The observation point at 130 m is at a village school (elementary school along with a junior high school) in a residential area.

Atmospheric temperature at each observation point was measured using a waterproof self-registering thermograph (TR-51, T AND D Corporation). The thermographs, one thermograph per observation point, were placed at the six points along a path leading to the top of Mt. Oyama in August 2012. Each was placed at a height of 1.5 to 2.0 m shaded from direct sunlight by placement under tree crowns along the path and in an instrument shelter at the village school.

Measurements were taken every hour on the hour, and the thermographs were exchanged every summer in order to collect registered data.

Measurements were continuously taken starting in August 2012 and are continually being taken as of publication of this report. In the present study, we analyzed the results of 5 years with entire-year data from 2013 to 2017.

2.2 Data Analysis

Based on the atmospheric temperature dataset, average monthly temperature and average annual temperature were calculated in each of the 5 years. From the viewpoint of the ‘irregular’ distribution of plant species in cool temperature zone, we also counted the number of days with freezing temperatures (i.e., the minimum temperature was below 0 ˚C) occurring each year.

The warm index (W.I.) at each point was calculated as follows,

$$\text{W.I.} = \Sigma\,(T - 5) \quad (\text{if } T \text{ is higher than } 5\ ˚\text{C}) \qquad (1)$$

where T is the average monthly temperature and the value of W.I. works out a positive number.

The cool index (C.I.) at each point was calculated by the similar formula to W.I.,

C.I. = Σ (T - 5) (if T is lower than 5 ˚C) (2)

and the value of C.I. gives a negative number. Equations (1) and (2) were proposed based on a general rule that plants can grow at temperatures above 5 ˚C [3].

The lapse rate along the elevation gradient was estimated by the relationship between elevation and each temperature index (average annual temperature, W.I, C.I and the number of days with freezing temperature). A simple regression model was employed to estimate the relationship, and the significance of fitness of the model was determined by an F-test based on the value of R^2.

3. RESULTS

3.1 Atmospheric Temperature

Table 1 Average monthly temperature and temperature indices by elevation on Mikura-jima Island over the period from 2013 to 2017

Month	Elevation (m)						
	130	300	400	500	600	700	800
Jan.	9.4	7.2	6.5	5.4	4.8	3.6	3.1
Feb.	9.5	7.5	6.7	5.8	5.0	4.0	3.4
Mar.	12.4	10.6	9.6	9.1	8.1	7.0	6.5
Apr.	15.7	14.2	13.1	12.3	11.6	10.7	10.2
May	19.3	18.0	16.8	16.0	15.6	14.7	14.3
Jun.	21.4	20.1	19.1	18.6	18.2	17.4	16.9
Jul.	25.5	24.3	23.1	22.4	22.3	21.4	21.0
Aug.	26.8	25.2	24.1	23.5	23.1	22.4	21.9
Sep.	24.2	22.2	21.4	20.3	20.3	19.5	19.0
Oct.	20.7	18.6	18.0	17.0	16.7	15.9	15.3
Nov.	16.5	14.3	13.7	12.7	12.2	11.2	10.7
Dec.	11.8	9.6	9.0	7.6	7.3	6.1	5.6
An.ave.	17.8	16.0	15.1	14.2	13.8	12.8	12.3
W.I.	153	132	121	111	155	96.4	91.3
C.I.	-	-	-	-	-0.2	-2.4	-3.4
DF	-	0.4	1.0	2.0	10.0	18.8	24.7

An.ave.: the average annual temperature, W.I: warm index, C.I.: cool index, and DF: days with freezing temperature (below 0 °C).

Table 1 shows the average monthly temperature, average annual temperature and temperature indices (W.I, C.I, and days with freezing temperature) by elevation over the 5-year period from 2013 to 2017. The seasonal changes in atmospheric temperature on Mikura-jima Island presented as profiles of average monthly temperature at elevations of 130, 600 and 800 m (Fig. 3) show that the coldest month was January and the warmest month was August at all elevations. All temperature parameters showed that temperatures decrease with higher elevation throughout the year. C.I. was determined to be '0' at the points at elevation lower than 600 m because the average temperature did not fall below 5 ˚C in any month.

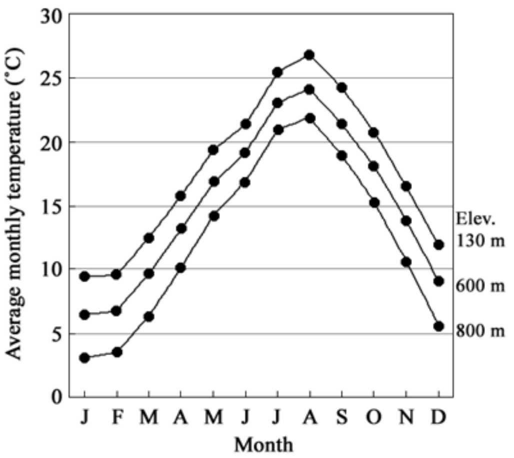

Fig. 3 Average monthly temperature in Mikura-jima Island, from 2013 to 2017

3.2 Lapse Rate along Elevation Gradient

The lapse rate along the elevation gradient is shown for average annual temperature (Fig. 4), W.I. (Fig. 5) and days with freezing temperature (Fig. 6). We excluded C.I. from this analysis because only three observation points at high elevation had observations that could be used to calculate C.I.

For average annual temperature (Fig. 4), fluctuation among years seemed small (standard error (se) = 0.42 ˚C) at each elevation point. A statistically significant regression line using all data points (R^2 =0.951, p <0.0001, F-test) was obtained:

$y = 18.5 - 0.0080\,x$ (3)

where x is elevation and y is the average annual temperature. The slope (-0.0080) indicates a lapse rate in atmospheric temperature over the elevation gradient of approximately 0.80 ˚C per 100 m.

Regression lines fitted to data for lower and upper elevations separately (dashed lines in Fig. 4) showed a significant difference in slope (p<0.005, F-test by analysis of covariance). Lapse rate for elevations 500 m and below was 0.98 ˚C per 100 m, while the lapse rate for elevations 500 m and above was 0.66 ˚C per 100 m (R^2 = 0.954 and 0.742, respectively; p <0.0001, F-test).

For W.I. (Fig. 5), variation among years was also small (se = 5.1) at each elevation. A statistically significant regression line (R^2 =0.944,

p <0.0001, F-test) was obtained as follows:

y = 160.6 - 0.091 x (4)

where x is elevation and y is W.I. The slope (-0.091) indicates a lapse rate in W.I. over the elevation gradient of approximately 9.1 per 100 m.

Breaking down the observation points by lower and upper elevation (dashed lines in Fig. 5) shows a significant difference in the slope of the regression line (p<0.0002, F-test by analysis of covariance) between lower elevations and upper elevations with a lapse rate of 11.7 per 100 m for elevations at 500 m and below and 6.5 per 100 m for elevations at 500 m and above (R^2 = 0.953 and 0.718, respectively; p <0.0001, F-test).

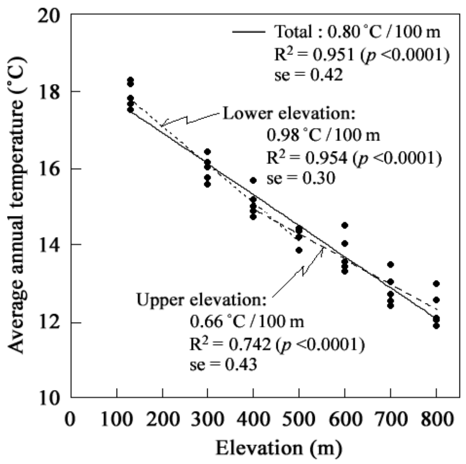

Fig. 4 Lapse rate for average annual temperature

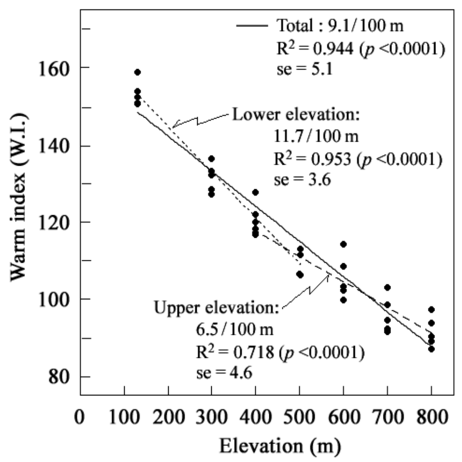

Fig. 5 Lapse rate for warm index (W.I.)

On the other hand, days with freezing temperature, or DF, showed large variation among years, especially at the points at higher elevations (Fig. 6). DF was zero or small up to elevations of 400 or 500 m and tended to increase with increasing elevation above 400 m. A statistically significant regression line was obtained for data over the elevations from 400 to 800 m (R^2 =0.717, p <0.0001, F-test):

y = 25.9 + 0.062 x (5)

where x is elevation and y is days with freezing temperature. The slope (0.062) indicates that for elevations above 400 m, there is a rate of increase of approximately 6.2 days of freezing temperature per 100 m.

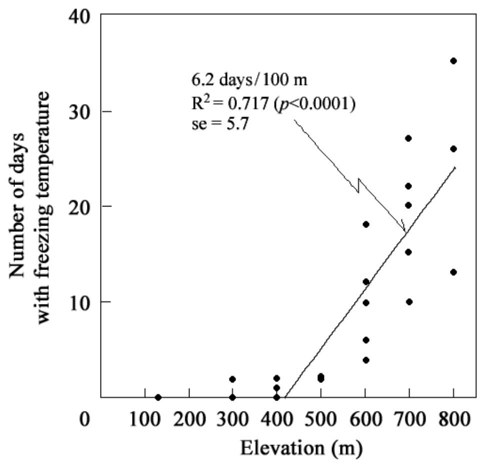

Fig. 6 Lapse rate for days with freezing temperature

4. DISCUSSION

4.1 Temperature environment in Mikura-jima Island

Over the 5 years from 2013 to 2017, the average annual temperature was 17.8 ˚C and W.I. was 153 at an observation point in the residential area of Mikura-jima Island at an elevation of 130 m.

Kawamoto (2006) reported that the annual temperature range on Mikura-jima Island was smaller (i.e., cooler in summer and warmer in winter) than in Sasebo [3], a city at nearly the same latitude (Fig. 1). From a plot of average monthly temperature on Mikura-jima Island using data collected in this study and in Sasebo city using data obtained by the Japan Meteorological Agency [11] over the same 5-year period from 2013 to 2017 (Fig. 7), we see a range in annual temperature on Mikura-jima Island of 17.4 ˚C, which is smaller than that in Sasebo City (21.0 ˚C). Further, the average monthly temperature was higher from October to April and lower from June to August on Mikura-jima Island than in Sasebo City. These data show that the temperature environment conditions on the island reported by Kawamoto [3] are as applicable in recent years as previously.

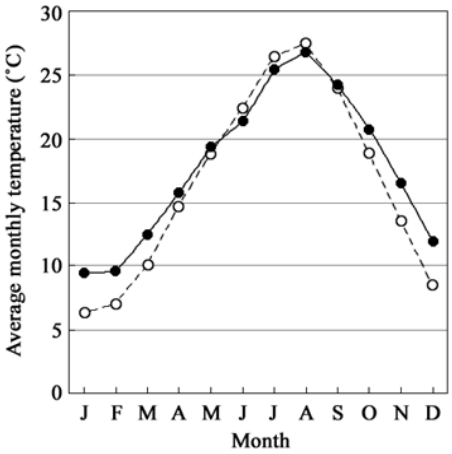

Fig. 7 Comparison of average monthly temperature between Mikura-jima Island at elevation 130 m (closed circles and solid line) measured in this study and Sasebo City (open circles and broken line) [11]. Data are averages over 5 years (2013 to 2017).

The lapse rate against elevation gradients differed between lower and higher elevations (Fig. 4 and Fig. 5). The patterns are classified as different patterns as for average annual temperature with the rate for elevations of 500 m and below of 0.98 ˚C per 100 m considered as a dry adiabatic lapse process, while the rate at elevations of 500 m and above of 0.66 ˚C per 100 m considered as a moist adiabatic lapse process [12]. These classifications are fitting with the clouds and fog that usually cover the high-elevation area of the island (Fig. 2). Other studies have also reported changes in lapse rate along the elevation gradient for other islands in Japan [13,14], but the change in the lapse rate was relatively mild on Mikura-jima Island: the moist adiabatic lapse rate at higher elevations was larger than that on Mimami-Iwo-To Island (0.47 ˚C [13] and 0.56 ˚C [14] per 100 m). We consider that this less distinct difference in lapse rate is due to the landform of Mikura-jima Island, or the strong winds that almost steadily blow up from the sea.

The regression equation on lapse rate enables us to estimate W.I. at any elevation, and conversely, to determine elevation from any W.I.. Using the regression equations in Fig. 5, we estimated the elevation corresponding to W.I. over the entire Mikura-jima Island. As W.I. is related to vegetation, the elevations with W.I. = 120 and W.I. = 85 were estimated to be at 409 ± 36 m and 895 ± 92 m, respectively (estimated elevation ± se). The lower confidence interval of W.I. = 85 involves the upper part of Mt. Oyama with elevations over 803 m, which implies that the temperature environment in Mikura-jima Island would support a cool temperature zone: W.I. can fall below 85 at elevations over about 800 m, where the days with freezing temperatures total up to about a month (Fig. 6).

4.2 Re-examination of Distribution of Vegetation

Fig. 8 shows the distribution of classes of vegetation on Mikura-jima Island by elevation with notation of W.I. The vegetation classes are as defined following Sanada [15] with the following examples (photos of charactersitc vegetation classes are shown in Fig. 9):

(a) Forest vegetation:
A: Daphniphyllo - Trochodendretum aralioidis,
B: Carci - Castanopsietum sieboldii,
C: *Castanopsis* coppice forest,
D: Hydrangeo - Alnetum sieboldianae,
E: *Alnus sieboldiana* secondary forest,
F: Euonymo - Pittosporetum tobira,
(b) Harbaceous vegetation:
G: Patrinio - Calamagrostietum insularis,
H: Sasa community,
I: Chrysanthemo - Miscanthetum condensatus,
(c) Artificial vegetation:
J: *Buxus microphylla* plantation,
K: *Cryptomeria japonica*, *Chamaecyparis obtusa* plantation.

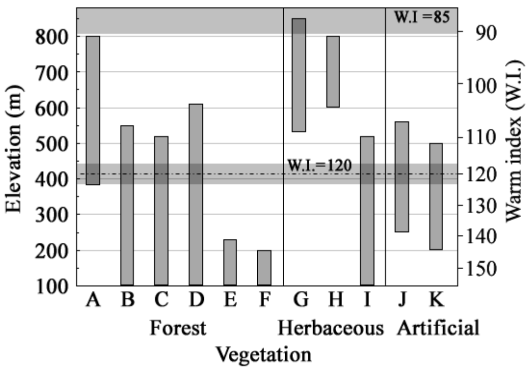

Fig. 8 Distribution of vegetation in Mikura-jima Island by elevation and estimated W.I.. A to K are the patterns of vegetation described in the text. Horizontal shading indicates confidence intervals (elevation ± se estimated by W.I.).

Compared to empirical estimations obtained by setting the lapse rate at 0.6 ˚C per 100 m, the temperature environment on Mikura-jima Island proved to be overall cooler. In particular, the distributions of Daphniphyllo - Trochodendretum aralioidis (A), Patrinio - Calamagrostietum insularis (G) and Sasa community (H) on the coastal wind-blown slopes are reasonably explained by the estimated W.I. in the present study (Fig. 8). These distributions of vegetation corresponding to W.I. were not inconsistent with those of previous reports [16,17]. In addition to the lapse rate phenomenon, shading by clouds and fog and the occurrence of freezing temperature days likely contribute to cooling the environment in the high elevation area, which appears to enable plant species representative of a cool temperature zone to grow naturally on Mikura-jima Island.

Carci - Castanopsietum sieboldii (B), a major vegetation class in low elevation area

Daphniphyllo - Trochodendretum aralioidis (A), a major vegetation class in high elevation area

Sasa community (H) in high elevation area

Fig. 9 Photos of characteristic vegetation classes in Mikura-jima Island

5. CONCLUSION

We measured the atmospheric temperature on Mikura-jima Island over a period of 5 years using thermographs placed at seven different elevations (from 130 to 800 m). Analyses of the temperature environment produced the following conclusions:

(1) Along elevation gradients, the average annual temperature ranged from 17.8 to 12.3 ˚C, and the warm index (W.I.) ranged from 153 to 91.3 on the island.

(2) The lapse rate differed between lower and upper elevations with rates of 0.98 ˚C per 100 m for elevations of 500 m and below and 0.66 ˚C per 100 m for elevations of 500 m and above.

(3) W.I. was estimated to fall below 85 at elevations over about 800 m, which would produce a cool temperature zone, which reasonably explains the distribution of vegetation patterns.

These solved the inconsistency in the distribution of plant species and vegetation. Temperature environment re-examined in the present study will facilitate the planning of the goal and the evaluation or estimation of vegetational succession on Mikura-jima Island.

It should be noted that temperature observations were not taken at elevations over 800 m (e.g., the top of Mt. Oyama), and the lapse rate above 800 m can not be confirmed to maintain the 0.66 ˚C per 100 m at elevations over 800 m. It is desirable to achieve a more precise characterization of the temperature environment in Mikura-jima Island.

6. ACKNOWLEDGMENTS

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