International Journal of GEOMATE, May, 2016, Vol. 10, Issue 21, pp. 1884-1890
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

VEGETATION RECOVERY PROCESS ON LANDSLIDE STEEP SLOPE AFTER *Alnus sieboldiana* AND *Miscanthus condensatus* PLANTING WITH SIMPLE TERRACING WORK IN MIKURA-JIMA ISLAND, JAPAN

Tetsuo Okano and Teruo Arase

Faculty of Agriculture, Shinshu University, Japan

ABSTRACT: Typhoon 9512 hit the island of Mikura-jima in 1995, causing many landslides and destruction of forest vegetation. For long-term observation of vegetation change, a research plot was established on a landslide slope in 2003. A simple terrace was built on this slope, which was planted with native species (*Alnus sieboldiana* and *Miscanthus condensatus*) in 2000 to accelerate vegetation recovery. From 2003 to 2012, a vegetation survey of the plot was conducted to elucidate the vegetation recovery process at an early stage. *A. sieboldiana* grew steadily and its density of individuals decreased. The number of species gradually increased due to invasion of new seedlings from adjacent forests, i.e. *Castanopsis cuspidata*, *Persea thunbergii*. We found some differences in vegetation recovery from another research site, which is a landslide slope seeded with exotic pasture grasses by helicopter in 2002. Seeding of exotic pasture gasses prevented the establishment of trees and reduces successional velocity.

Keywords: Vegetation recovery, Species composition, Species diversity, Exotic pasture grasses

1. INTRODUCTION

Revegetation in isolated ecosystems should be carried out in ways that restore and do not disrupt the native ecosystem. In an insular ecosystem, habitat for wildlife can easily be destroyed due to disaster or development. Island ecosystems are generally rich in endemic species but tend to be homogeneous in habitat, making them vulnerable to invading species [1-3].

Mikura-jima Island is 20.58 km^2 in area, located ca. 180 km south of Tokyo, and is one of the isolated volcanic islands of the Izu islands in the Pacific Ocean off the main island of Japan. The island has sea cliffs more than 100 m in height and steep slopes less than 700 m above sea level. The highest peak, Mt. Oyama, is 850 m. The annual mean temperature is 17.9 °C and the annual precipitation is 2910 mm [3]. It is covered with natural or secondary vegetation. The main vegetation of the island is an evergreen broad-leaved forest, Carci-Castanopsietum sieboldii (Arachniodo-Castanopietum sieboldii [4]) below 500 m and Daphniphyllo-Trichodendretum aralioideae above 500 m [5].

In September 1995, Typhoon 9512 hit Mikura-jima Island (Fig. 1) and produced many landslide slopes in mature forests. The bedrock and solid soil were exposed on the landslide slopes from the surface soil being washed away. After the typhoon, vegetation recovery efforts were begun with projects to put in simple terracing to retain the soil and to transplant locality-certified seedlings of native species (*A. sieboldiana* and *M. condensatus*) [6]. On some landslide slopes, exotic pasture grasses were seeded by helicopter after the transplanting of these two species.

Seeding of herbaceous species, especially exotic pasture grasses, forms a dense, carpet-like community in the short term, and this community prevents the germination and the growth of tree species [7-9]. However, there are few studies of the influence of seeding of herbaceous species on ecological succession in isolated ecosystems. In this paper, we show clearly the effect of seeding of exotic pasture grasses on ecological succession in a mature natural forest area with data from 10 years of continuous monitoring.

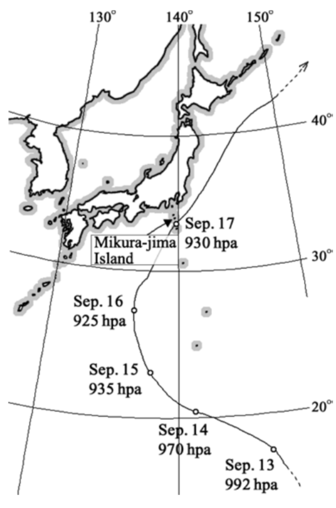

Fig. 1 Path of Typhoon 9512 [3] and location of Mikura-jima Island.

2. METHODS

2.1 Sites and monitoring plots

Two study sites were selected to examine the influence of exotic pasture grass seeding on ecological succession on landslide slopes. One was Ofunato No. 2 slope and the other was Torino-o No. 3 slope. Both slopes are located at an elevation ranging from 500 to 550 m above sea level. Slope direction and average angle are respectively NW and 37° for Ofunato No. 2, and N and 27° for Torino-o No. 3. The distance between the two sites is about 1 km.

On both slopes, landslides were caused by Typhoon 9512 (precipitation: 648.5 mm, maximum wind velocity: 67.8 m/s) in 1995. From 2000 to 2002, simple terracing was placed and *A. sieboldiana* seedlings and *M. condensatus* stumps were transplanted to each slope from other sites in the island. Planting densities of these species were 1.0 seedling per square meter for *A. sieboldiana* and 1.5 stumps per square meter for *M. condensatus*. In 2002, exotic pasture grasses (including *Agrostis stolonifera*, *Festuca* sp. and *Lespedeza cuneata*) were seeded on the Torino-o No. 3 slope.

In August 2003, two monitoring plots were established in Ofunato No. 2 (Photo 1). One was on the upper part of the slope, the other one was on the lower part of the slope, with a plot size of 62.3 m^2 and 84.0 m^2, respectively. In August 2004, one monitoring plot was established in Torino-o No. 3 (Photo 2). Plot size was 47.15 m^2. In subsequent years, growth and species composition were investigated in summer (early August).

2.2 Growth of *A. sieboldiana*

Transplanted *A. sieboldiana* was measured for plant height (H) and diameter at the base (D_0), and the parameter D_0^2H was calculated as an estimate of aboveground biomass. Since self-thinning was observed, we estimated the regression as follows:

$$1/x = a + by \tag{1}$$

where x is the tree density, y is the mean individual D_0^2H, and a and b are constants [10].

2.3 Species composition and diversity

To assess species composition, invading and regenerated trees more than 5 cm in height were investigated for each species. For ten years (Ofunato

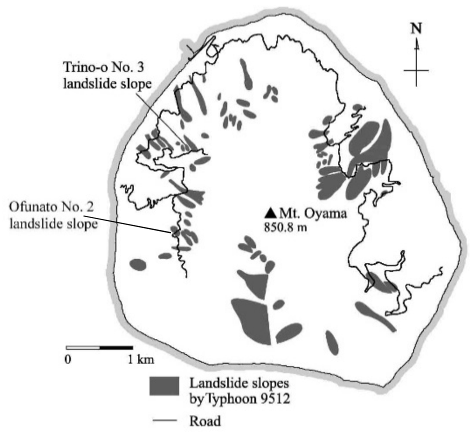

Fig. 2 Location of landslide slopes formed by Typhoon 9512 on Mikura-jima Island.

No. 2: 2003–2012, Torino-o No.3: 2004–2013), the emergence pattern was investigated thoroughly for each species, and all species were divided into several groups. Tree species diversity was indicated by the Shannon diversity index (H') [11] as follows:

$$H' = -\mathrm{SUM}[(pi) \cdot \ln (pi)] \tag{2}$$

where SUM is a summation and *pi* is the proportion of the total number of individuals that is represented by species *i*. Based on the characterized species groups and the diversity index, differences in the change in species composition over ten years was clearly observed between Ofunato No. 2 and Torino-o No. 3, indicating an influence of exotic pasture grasses on ecological succession.

3. RESULTS

3.1 Growth of *A. sieboldiana*

Figure 3 shows the growth of *A. sieboldiana* over a period of 9 years. In each of the Ofunato and Torino-o plots, a phenomenon resembling self-thinning was confirmed for *A. sieboldiana*: the mean plant density decreased yearly, while individual D_0^2H values increased. Although the mean plant density seemed to be greater and individual D_0^2H values smaller in 2004 in the Torino-o plot than the Ofunato plots, the progress of values tended to converge after several years. Analysis of co-variance detected no significant differences in the regression coefficients (F-test, p = 0.113 and 0.867 for a and b, respectively) among the three plots.

3.2 Density and number of species of invading trees

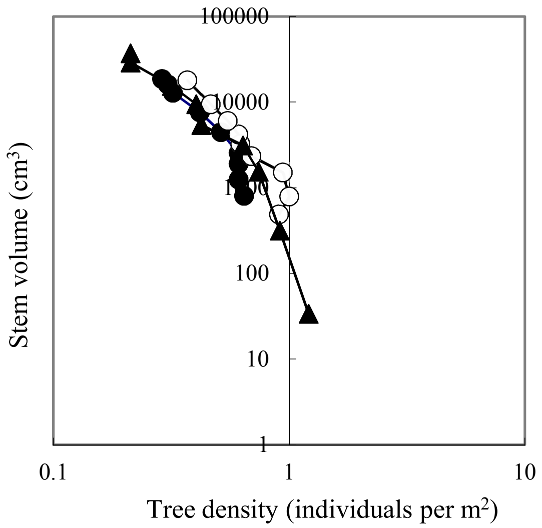

Fig. 3 Changes in the density and stem volume per individual of transplanted *Alnus sieboldiana*. Solid and open circles indicate upper and lower plot of Ofunato. Solid triangle indicates Torino-o plot.

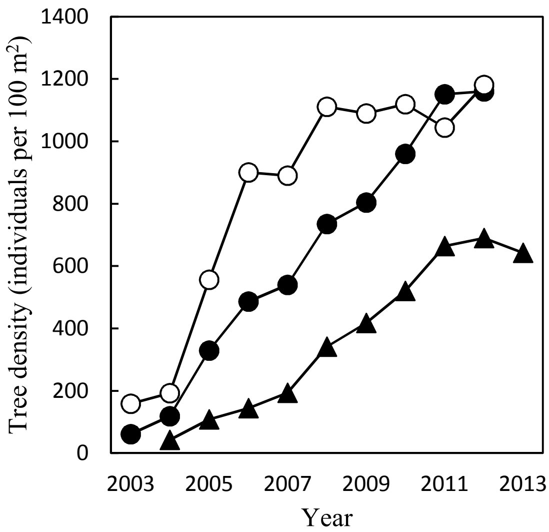

Fig. 4 Changes in the density of invading trees in each plot. Solid and open circles indicate upper and lower plot of Ofunato. Solid triangles indicate Torino-o plot.

Figure 4 shows the density per 100 m^2 of the invading trees over a period of 10 years in each plot. Until 2010, the density increased in all plots. In the lower plot of the Ofunato site, the density was higher than in the upper plot. In 2012, the density of both plots was similar, ca. 1200/100 m^2. On the other hand, until 2012, the density in the Torino-o plot was about half that in the upper plot of the Ofunato site, although the density increased. After that, the density decreased.

Figure 5 shows the number of species per plot of invading trees over a period of 10 years in each plot. The number of species indicates the species richness. These numbers increased with small fluctuations. The species richness in the Torino-o plot were about half that of the lower plot of Ofunato site. The species richness of the upper plot of the Ofunato site was in between that of the lower plot and Torino-o plot.

3.3 Species composition and diversity

Table 1 shows the species composition, the number of individuals in the study period from 2003 to 2013 and the species groups of the invading trees at each site. Thirty-nine invading tree species were confirmed and divided into four groups. Species of Group A (13 species) were present from the first year and had a tendency to increase in number yearly. Species of Group B (18 species) appeared after monitoring began. Group C (4 species) varied in tendency, increasing or decreasing in number depending on species. Group D (4 species) did not show any obvious tendencies.

At the Ofunato site, 13 species were included in Group A. Nine of these species were also growing at the Torino-o site, but only two species (*E. japonica* and *Trachelospermum asiaticum* var. *intermedium*) were included in the same group at both sites; other species, *Hydrangea involucrata* f. *idzuensis*, *Rubus trifidus* and *Stachyurus praecox* var. *matsuzakii* belonged to Group C, and *P. thunbergii*, *Rubus*

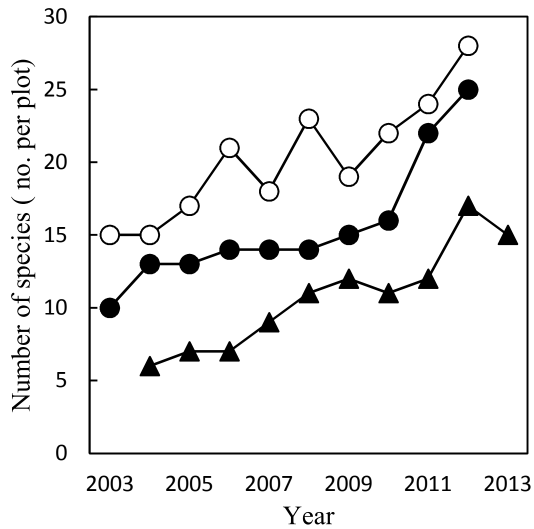

Fig. 5 Changes in the number of tree species in each plot. Solid and open circles indicate upper and lower plot of Ofunato. Solid triangles indicate Torino-o plot.

Table 1 Individual density of invading trees and species groups for each species from 2003 to 2013.

Species	Species group		Site	Year										
	Ofunato	Torino-o		2003	04	05	06	07	08	09	10	11	12	13
Castanopsis cuspidata var. *sieboldii*	A		O	2	2	2	1	1	2	2	1	2	8	
Morus kagayamai	A		O	1	0	0	1	0	0	1	1	4	4	
Persea thunbergii	A	D	O	2	6	4	4	13	12	11	12	13	16	
			T		0	0	0	0	0	0	0	0	2	0
Hydrangea involucrata f. *idzuensis*	A	C	O	4	3	2	5	14	24	37	47	59	86	
			T		0	0	0	0	2	15	15	25	15	15
Rubus trifidus	A	C	O	7	11	35	50	31	65	50	60	65	69	
			T		6	23	30	28	59	59	49	51	38	32
Rubus ribesioideus	A	D	O	25	27	41	64	151	217	244	305	297	290	
			T		6	6	15	2	4	4	8	6	21	13
Prunus lannesiana var. *speciosa*	A	D	O	3	4	10	12	16	26	37	35	41	38	
			T		2	2	0	0	0	0	0	0	0	2
Mallotus japonicus	A		O	7	6	12	12	11	14	14	20	26	28	
Eurya japonica	A	A	O	19	26	53	73	72	107	154	190	198	238	
			T		21	55	66	72	91	151	210	288	299	246
Stachyurus praecox var. *matsuzakii*	A	C	O	1	2	1	8	7	8	7	9	11	18	
			T		0	0	0	0	2	4	6	4	4	4
Styrax japonica var. jippei-kawamurae	A		O	1	1	1	1	2	3	2	3	5	4	
Trachelospermum asiaticum var. *intermedium*	A	A	O	2	3	7	10	11	23	23	27	79	93	
			T		0	8	11	4	23	8	36	93	68	91
Callicarapa japonica var. *luxurians*	A	D	O	0	3	2	5	2	3	4	5	10	8	
			T		2	0	0	0	2	2	2	2	2	2
Podocarpus macrophullus	B		O	0	0	0	1	1	1	0	1	1	3	
Ficus erecta	B		O	0	0	0	0	0	0	0	0	0	1	
Akebia trifoliata	B		O	0	0	0	0	0	0	0	0	0	0	
Rubus buergeri	B	B	O	0	0	0	0	0	1	0	1	4	3	
			T		0	0	0	21	21	34	19	51	108	153
Ilex crenata var. *hachijoensis*	B	B	O	0	0	0	1	0	0	0	0	2	2	
			T		0	0	0	0	0	0	0	0	2	4
Ilex integra Thunb.	B	B	O	0	0	0	0	0	0	0	0	1	0	
Microtropis japonica			T		0	0	0	0	0	0	0	0	2	2
Euonymus japonicus		B	T		0	0	0	2	2	2	2	2	2	2
Elaeocarpus sylvestris var. *ellipticus*	B		O	0	0	0	0	0	1	1	1	1	1	
Camellia japonica	B	B	O	0	0	0	0	0	0	0	1	1	2	
			T		0	0	0	0	0	0	0	0	2	0
Cleyera japonica	B		O	0	0	0	0	0	1	0	0	0	1	
Dendropanax trifidus	B		O	0	0	0	1	0	0	0	0	0	3	
Cornus controversa	B		O	0	0	0	0	0	0	0	0	1	0	
Ardisia japonica	B	B	O	0	0	0	0	0	0	0	0	0	1	
			T		0	0	0	0	0	0	0	0	2	0
Ardisia crenata	B	B	O	0	0	0	0	0	0	0	0	1	6	
			T		0	0	0	0	0	0	0	2	2	0
Symplocos prunifolia	B		O	0	0	0	0	0	0	0	0	1	1	
Osmanthus insularis	B		O	0	0	0	0	0	1	1	1	1	19	
Clerodendrum izuinsulae		B	T		0	0	0	0	0	0	0	0	0	2
Alnus sieboldiana	C	C	O	11	17	188	266	195	160	147	82	51	32	
			T		0	2	4	8	11	8	0	0	0	0
Hydrangea macrophylla f. *normalis*	C	C	O	11	17	30	83	100	141	127	159	155	138	
			T		0	0	13	53	123	125	168	131	112	68
Hydrangea involucrata	C		O	0	2	3	2	1	2	0	0	0	0	
Weigela coraeensis var. *fragrans*	C	C	O	13	24	49	91	84	110	83	76	64	58	
			T		0	0	0	0	0	4	0	0	0	0
Illicium religiosum	D		O	0	0	0	0	0	1	0	0	0	0	
Buxus microphylla f. *major*	D		O	1	2	1	2	2	1	1	1	1	1	
Elaeagnus macrophylla	D		O	1	1	1	1	2	1	1	2	2	1	
Damnacanthus major		D	T		4	11	6	2	0	0	4	6	6	6

Site O: Ofunato, T: Torino-o.

ribesioideus, *Prunus lannesiana* var. *speciosa* and *Callicarpa japonica* var. *luxurians* belonged to Group D. Group B included 18 species (Ofunato: 15 species, Torino-o: 8 species). Most species of this group germinated in 2011 or 2012; only 5 species were found at both sites, *Rubus buergeri*, *Ilex crenata* var. *hachijoensis*, *C. japonica*, *Ardisia japonica* and *Ardisia crenata*. Group C included 4 species (Ofunato: 4 species, Torino-o: 3 species). A clear peak in the number of *A. sieboldiana* was noted only at the Ofunato site in 2006. A peak in the individual density of *Hydrangea macrophylla* f. *normalis* was noted in 2010 at both sites. A clear peak of *Weigela coraeensis* var. *fragrans* density was noted only at the Ofunato site in 2008. Group D included 4 species (Ofunato: 3 species, Torino-o: 1 species). Fluctuation in the density of *Buxus microphylla* f. *major* was small and constant after 2008, whereas the density of *Elaeagnus macrophylla* and *Damnacanthus major* continued to fluctuate.

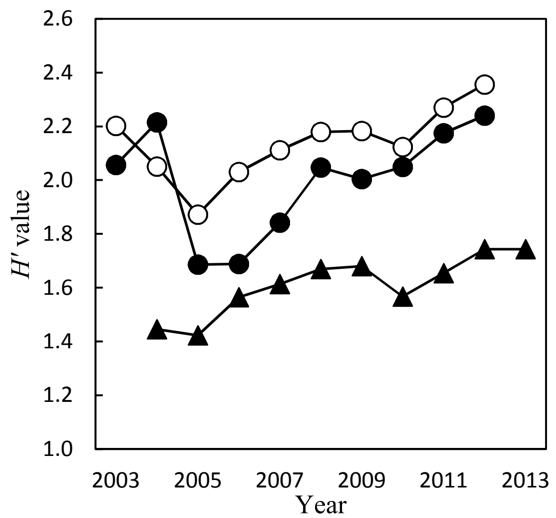

Fig. 6 Changes in tree species diversity (H') in each plot. Solid and open circles indicate upper and lower plot of Ofunato. Solid triangles indicate Torino-o plot.

Photo 1 Physiognomical change in Ofunato site from 2003 (upper) to 2012 (lower).

Photo 2 Physiognomical change in Torino-o site from 2004 (upper) to 2013 (lower). Covered with exotic pasture grasses in 2004.

3.4 Tree species diversity

Figure 6 shows the tree species diversity (H') over a period of 10 years in each plot. H' values of all plots decreased in 2005. This phenomenon was remarkable in the upper plot of the Ofunato site. After that, H' values of all plots increased with small fluctuations. In 2012, the Ofunato plots reached H' values greater than 2.2, but the value for Torino-o was less than 1.8. Therefore, tree species diversity of recovered vegetation at the Ofunato site was higher than at the Torino-o site.

4. DISCUSSION

For *A. sieboldiana*, the tree density decreased yearly, while the individual D_0^2H values increased (Figure 3). Although the mean plant density seemed to be greater and the individual D_0^2H value smaller in 2004 in the Torino-o plot than the Ofunato plots, these values tended to converge after several years. There are allometric relationships between stem size and biomass of each organ (stem, branch and leaf) in *A. sieboldiana* [12]. The dry weight of leaves per unit area of *A. sieboldiana* in each plot would be nearly equal because no significant differences were noticed among plots in tree density and individual D_0^2H values. Therefore, we concluded that the light environment under *A. sieboldiana* canopies did not differ remarkably among the three plots.

The density of invading trees in the three plots increased yearly, but the density in the Torino-o plot was lower than in other plots (Figure 4). The coverage percentage of exotic pasture grasses was more than 80% in 2004. The percentage decreased rapidly to less than 40% by 2008 and to less than 5% in 2011 [3]. This phenomenon indicated that interference by exotic pasture grasses didn't affect the germination of invading seeds or growth of seedlings after 2008. On the other hand, mean plant height of *M. condensatus* increased and tended toward a plateau in 2008 (ca. 170–200 cm) [3]. Therefore, the establishment of invading trees might be prevented by existing exotic pasture grass communities in the initial stage, and by *M. condensatus* communities in the next stage. The extent of changes in number of species was similar to the changes in invading tree density in the survey plots. The increasing number of species might be affected by the community dynamics of exotic pasture grasses and *M. condensatus*.

Species composition could be characterized by defining A, B and C species groups (Table 1). *C. cuspidata* var. *sieboldii*, *P. thunbergii*, *E. japonica*, *Styrax japonica* var. *jippei-kawamurae* and *T. asiaticum* var. *intermedium*, assigned to Group A in the Ofunato plot, were more frequent tree species in mature natural forests on Mikura-jima island [5], [13], [14]. The former three species in particular were abundant in mature forest stands adjacent to the Ofunato and Torino-o landslide slope sites. Other species in this group were mid-successional deciduous trees or shrubs with a wide distribution on Mikura-jima island. *H. involucrata* f. *idzuensis*, *R. trifidus* and *S. praecox* var. *matsuzakii* increased and often later decreased in individual density at the Torino-o site. The density of *P. thunbergii*, *R. ribesioideus*, *P. lannesiana* var. *speciosa*, and *C. japonica* var. *luxurians* were lower at the Torino-o site than the Ofunato site. The characteristic behavior of these seven species suggests that the expansion of exotic pasture grasses or the *M. condensatus* community prevented germination or growth of the invading tree species. Most of the species in Group B were evergreen broad-leaved and late-successional species occurring in mature natural forests on Mikura-jima island. The number of species at the Torino-o site (8 species) was smaller than at the Ofunato site (15 species). The difference of species composition between plots may be relate to the speed of ecological succession. At the present time, the successional change to the mature stage at the Torino-o site will be slower than at the Ofunato site. It is expected that the number of species represented in Group C, including *A. sieboldiana*, will decrease because these are pioneer species.

The trend in tree species diversity on both landslide slopes was similar to changes in the tree density and the number of species. However, the *H'* values of all plots decreased remarkably in the Ofunato plots in 2005 (Figure 6), although the number of species increased. This decrease was caused by a change in evenness of the species composition. Due to a rapid increase in the number of individual *A. sieboldiana* seedlings, evenness declined.

5. CONCLUSION

The seeding of exotic pasture grasses prevents the establishment of trees that invade landslide slopes from adjacent mature forests. Moreover, ecological successional velocity will be reduced due to the dominance of exotic pasture grasses and *M. condensatus*. When soil erosion is controlled by simple terracing, the seeding of exotic pasture grasses is unnecessary for recovery of the native vegetation.

6. ACKNOWLEDGEMENTS

The authors would like to thank the staff of Mikura-jima Village office and Mr. Masayuki Hino for their friendly assistance, Dr. Susumu Inoue for his scientific advice on species identification and Mr. Tadao Hiraoka for his unfailing support.

7. REFERENCES

[1] Loop LL, Hamann O and Stone CP, "Comparative conservation biology of oceanic archipelagoes – Hawaii and the Galapagos", Bio Science, Vol. 38, 1988, pp. 272-282.

[2] Ono M, Wildlife in solitary island. Tokyo: Iwanami Shoten, 1994, 239 pp.

[3] Arase T and Okano T, "Influence of fertilization on native plants and exotic pasture grasses on the fascined landslide slopes in Mikura-jima Island, Japan", GEOMATE, Vol. 8, June. 2015, pp. 1316-1322.

[4] Miyawaki A, Vegetation of Japan Kanto. Tokyo: Shibundo, 1986, 641 pp.

[5] Ohba T, "Die Vegatation von Mikura-Insel leight 200km südlich von Tokyo", Bull. of Kanagawa Prefectural Museum, Vol. 1(4), Feb. 1971, pp.25-53.

[6] Kyoju no Kai ed., Saving earth (1) Practices to restore nature in Mikura-jima Island. Tokyo: Kyoju no Kai, 2004, 48 pp.

[7] Yoshida H, "Stratificational revegetation of arboreous plant community by deeding method", J. of the Japanese Society of Revegetation Technology, Vol. 24, Nov. 1998, 90-98.

[8] Arase T, Okano T, Kimura T and Inoue S, "Influence of seedling exotic pasture grasses on the vegetation recovery of landslide slopes formed by typhoon 9512 in Mikura-jima Island, Izu Islands, Japan", J. of the Japanese Society of Revegetation Technology, Vol. 35, Feb., 2010, pp. 448-461.

[9] Holl KD, Loik ME, Lin EH and Samuels IA, "Tropical montane forest restoration in Costa Rica: overcoming barriers to dispersal and establishment", Restoration Ecology, Vol. 8, 2000, pp.339-349.

[10] Yoda K, Forest ecology. Tokyo: Tsukiji Shokan, 1971, 331 pp.

[11] Shannon CE, "A mathematical theory of communication", Bell System Technical Journal, Vol. 27, 1948, pp. 379-423.

[12] Saito H, "Some features of dry-matter production in a young Alnus siebodiana community on dumped detritus with special reference to reproductive parts", Japanese J. of Forest Society, Vol. 72, 1990, pp. 208-215.

[13] Kamijo T, Isogai T, Hoshino Y and Hakamada H, "Altitudinal zonation and structure of warm-temperate forests on Mikura-jima Island, Izu Islands, Japan", Vegetation Science, Vol. 18, 2001, pp.13-22.

[14] Hoshino Y, Nozaki R, Isogai T, Maesako Y, Kamijo T, Kobayashi H and Watabe Y, "Studies for ecology Island Mikura-jima Area", Report of Pro Natura Fund, http://www.nacsj.or.jp/pn/houkoku/h01-08/h05-no03.html.

International Journal of GEOMATE, May, 2016, Vol. 10, Issue 21, pp. 1884-1890

MS No. 5177 received on July 19, 2015 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in Jan 2017 if the discussion is received by July 2016.
Corresponding Author: Tetsuo Okano