Habitat Segregation of the Weeds as an Indicator of the Soil Hardness*

By

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I. Introduction

It has been noted that in the study of agriculture the value of observations on weed ecology, as related to agriculture, is a vital necessity. Within recent years weed communities have received consideration as objects of study in the methods of phytosociology.[1-5]

In studying the structure of weed communities, one of the most important problems to be investigated is the habitat segregation. Weeds seem to grow in apparent disorder on the wayside, vacant ground and in other places, but when they are carefully surveyed it is clear that the habitat of each species is limited and governed by its environmental factors, even the slight differences of which apparently serve to reveal the variations of the communities.

Animal ecologists in Japan have recently considered the problem of habitat segregation and have published their observations.[6-13]

Habitat segregation has also been considered by some ecologists engaged in the study of plant communities, namely: NUMATA 1950a, b,[14-15] SUZUKI, 1952[16], KIRA, 1952[17], etc. However, as MORI, 1952[11] has pointed out the definitions of the concept of habitat segregation by these ecologists does not seem to be identical.

As a means of ecological analysis of the structure of weed communities, the phenomena of habitat segregation are divided into two types, as related to the life form of plants and its growing field. One is homogeneous habitat segregation and the other is heterogeneous habitat segregation, both of which are seen in a field at the same time, and the authors here have used the term "habitat segregation" as including both types.

BATES 1935, '37, '38, '48[18-21], DAVIES 1938[22], YOSHIOKA 1952[23], etc. have given attention to the special vegetation on footpaths, gateways, sidewalks, cart-tracks and play-grounds all of which are trodden by feet and vehicles. GUPTA G. PARMESHWAR 1933[24] researched experimentally on features of development of the under-ground and the terrestrial plant-parts, according to the soil density. Soil hardness seems to play an important role in relation

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to homogeneous* or heterogeneous habitat segregation in the weeds of cultivated field and those of roadsides. Beyond doubt, it might be supposed that the more the terrestrial parts of the weeds are trodden and crushed by men and wheels, the harder the soil under these crushed weeds becomes. Therefore, to consider on the physical conditions of the soil should not be neglected in this case.

The authors' purpose was to investigate thoroughly the relation between habitat segregation and soil hardness in vegetations developed under special artificial factors, and primary attention was focused on the heterogeneous habitat segregation of roadside vegetation including cultivated fields. Since the spring in 1951, the authors have made the investigations in Hiroshima, in the suburbs of Tokyo, and in Odawara. We used the soil hardness-tester designed by Yamanaka, and the index of soil hardness as an indicator at the localities investigated.

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II. Subject and Method of Investigation

(1) One of the investigations was performed at the footpath among the farms on the reclaimed land composed of granitic sandy soil at Takasu, Hiroshima during the spring~winter seasons of 1951, (2) the others at Oome, Tokyo in the summer of 1952 and (3) at Tomizu, Odawara in the same season, soil of the former locality is composed of so-called Kanto loam, and that of the latter is of a meadow soil (river-bed type)[25] originated from the river deposit.

To facilitate investigation, a footpath with rather clear zonal vegetation was selected, and a certain roadway was divided into more than 10 belt transects 0.1–1 m in width at each spot of 1 meter's distance. Furthermore, quadrats of 0.1–1 m^2 were set on each transect, in each of which cover degree and frequency of each species were carefully investigated with respect to its growth stage and growth form (shoot form and root form)[26] as a part in life form of the weeds, furthermore we examined the soil hardness**, pH and component of P_2O_5 and CaO*** in bed soil of the vegetation. In another case, moreover, we selected a large number of quadrats of 0.3–1 m^2 at random, and we investigated the relation between soil hardness and dominant species, the cover degree of which was more than 4.

* Details of this phenomenon will be discussed in the near future.

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Soil hardness-tester has a spiral steel-spring. And conical body was pushed straight into the ground, and then the shrink of the spring showed the soil hardness is shown by the degree of its shrinking which corresponds to the indicated value of index from 0 to 40 mm (intensity of spiral was 8 kg). The authors tried the examination five or more times in each quadrat and the read index value will be connected to theoretical value (this value shows absolute soil hardness) by means of formula or nomograph.

When the results of these investigations were collated, the index of soil hardness and its theoretical value were brought out.

III. Results of Investigation

1. Footpath in farm field at Takasu, Hiroshima.

This region is reclaimed land which was made at the mouth of the Oota river and composed of granitic, sandy soils. The flat-paths without gravel are developed in all directions of the vegetable fields or rice-fields. Each farm road is different from one another in the amount of traffic by men and vehicles according to the road's position and width. The roads which are used very frequently are barren, and vegetation is developed only on the verges of the road. On other roads where two-wheeled vehicles are passing frequently barren parts of these roads are seen only where the wheels have passed. In such manners there appears several features of vegetation according to varying degree of artificial factors. The measurement of soil hardness was always done at the earliest 2 days after rainfall, because there is a close relationship between the soil hardness and soil moisture[27].* In every case of footpaths where their width is of about 4.6 m and traffic is of a medium degree, there appears a distinct habitat segregation between growing plants (Fig. 1). The center of the road where the divisions of vegetation C and D (index of soil hardness** 23±2.1, 25±0.4) occur is dominated by *Plantago asiatica* L. and *Juncus tenuis* WILLD., *Trifolium repens* L. ranking next.

Poa annua L. had been dominant here from winter to spring, but disappeared in about the middle of May and since August *Eragrostis ferruginea* BEAUV. has been dominant. Dominant at the division of B and E (index 18±1.4, 19±1.2) was *Trifolium repens* L. mixed with *Hydrocotyle maritima* HONDA. At the division F (index 12±1.3) which occupies the edge of the road, *Erigeron canadensis* L. and *E. sumatrensis* RETZ. are dominant, and following them are such plants as *Trifolium repens* L., *Polygonum longisetum* DE BRUYN and *Gnaphalium affine* D. DON, etc. At the division A (index 9±1.4) is planted *Phaseolus vulgaris* L. and here are found the so-called

* But relative value of soil hardness is not so variable in soil which has a moisture of 5-45%.

** In the following parts of this paper "index of soil hardness" is refered to as "index".

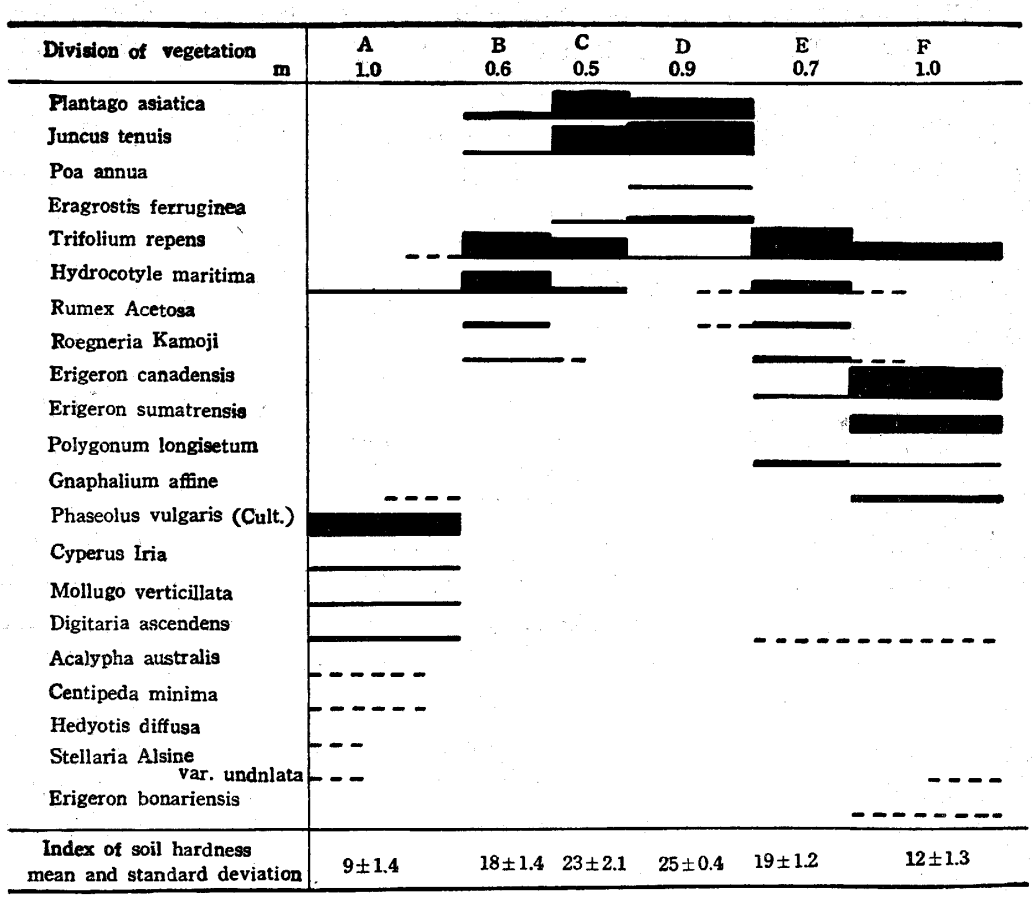

Fig. 1. Structure of the vegetation at a footpath composed of granitic sandy soil at Takasu, Hiroshima. Diagram showing average cover degree obtained from the 10 quadrats in each division.

cultivated-land weeds: *Cyperus Iria* L., *Mollugo verticillata* L., *Acalypha australis* L. and *Centipeda minima* AL. BR. et ASCH., etc.

The results of chemical analysis of soils taken at each part shows slight differences between one another. Generally speaking the pH value is rather low and it seems possibly more acidulous than in the cultivated fields (Table 1). The fact that division C shows a lower index than division D, in spite of the similarity of their vegetation, may be caused by the presence of too much soil-moisture at the time of investigation.

2. Footpath in the field at Oome, Tokyo.

As a typical representative area in this region covered with the so-called Kanto loam, some footpaths at Oome, Tokyo were investigated by the authors in August of 1952. For example, we investigated the weed vegetation on a footpath 2.5 m in width between the fields of *Ipomaea Batatas* LAM. and also the field of *Ipomaea Batatas* LAM. proper (Fig. 2). The center of the path (index 34±0.5) is almost bare and on both sides of the path, namely on B

Table 1. Analysis of granitic sandy soil from a footpath in a field at Takasu, Hiroshima.

Division of vegetation	Sampling portion	Index of soil hardness	Soil moisture	pH	P_2O_5	CaO
A	0-3 cm	9±1.4*	21.60%	4.1	20 p. p. m.	less than 0.07%
B	0-3	18±1.4	26.76	4.0	5	„
	3-5	21±0.9	14.27	4.0	100	„
	5-10	20±4.0	15.2	4.0	20	„
	15-20	11±1.0	16.45	4.0	10	„
C	0-3	23±2.1	31.48	4.0	50	0.07-0.12
	3-5	24.1±2.1	12.50	4.0	25	less than
	5-10	23±1.6	17.47	4.0	15	„
	15-20	19±1.2	20.06	4.0	1	„
D	0-3	25±0.4	19.57	4.0	20	0.07-0.12
	3-5	24±5.1	15.57	4.0	15	„
	5-10	23±2.8	18 65	4.0	20	less than
	15-20	18±2.8	18.24	4.0	25	„
E	0-3	19±1.2	26.33	4.0	8	0.07-0.12
	3-5	19±0.6	22.04	4.0	30	less than
	5-10	19±2.0	20.80	4.0	100	„
	15-20	14±0.9	24.84	4.0	20	„
F	0-3	12±1.3	22.36	4.2	50	over 0.12
	3-5	10±0.5	21.34	4.2	30	less than
	5-10	9±2.4	23.37	4.0	30	„
	15-20	10±0.7	26.14	4.0	35	„

* showing mean and standard deviation

and D (index 27±1.5, 28±2.0) *Eleusine indica* GAERTN., *Plantago asiatica* L., *Polygonum aviculare* L. and *Eragrostis ferruginea* BEAUV. are more abundant than have been observed in other places. The division A (index 18±1.1) is dominated by *Digitaria violascens* LINK which is fairly abundant also in B and D, and *Hydrocotyle maritima* HONDA is next in dominance here. At the division E (17±3.8) dominates *Digitaria ascendens* HENRY, and in the cultivated field of *Ipomaea Batatas* LAM. are more abundantly found *Digitaria ascendens* HENRY, being followed by such weeds as *Polygonum longisetum* DE BRUYN, *Oxalis corniculata* L., *Setaria viridis* BEAUV., *Euphorbia supina* RAF., *Cyperus Iria* L., etc.

The results of the authors' soil analysis (Table 2) show only a tendency that the hardness is inversely proportional to soil moisture, but pH, P_2O_5 and CaO of chemical components do not show remarkable differences except for cultivated field.

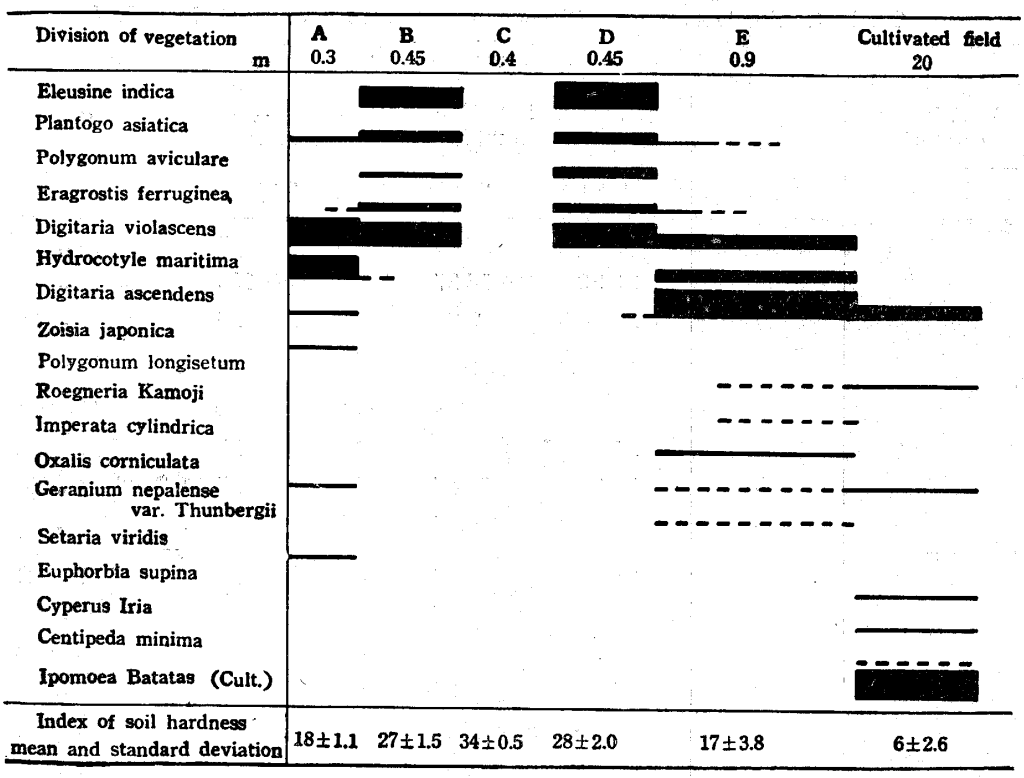

Fig. 2. Structure of the vegetation on the footpath in the field composed of so-called Kanto loam at Oome, Tokyo. Diagram showing average cover degree obtained from the 10 quadrats in each division.

Table 2. Analysis of so-called Kanto Loam from a footpath in a field at Oome, Tokyo.

Division of vegetation	A	B	C	D	E	Field of Ipomoea Batatas
Index of soil hardness	18±1.1	27±1.5	34±0.5	28±3.4	17±3.8	6±2.6
Soil moisture %	50	35.1	38.2	39.3	50	50.4
pH	5.0	5.0	5.0	5.0	5.1	5.8
P_2O_5 p. p. m.	10	10	20	30	30	60
CaO %	0.07-0.12	less than 0.07	less than 0.07	less than 0.07	0.07-0.12	over 0.12

Depth of soil sampled portion 0-5 cm.

3. Footpath in the rice-field at Tomizu, Odawara.

A footpath with the width of 2 m between rice-fields was investigated which was divided into 7 zones showing some differences of the vegetation (Fig. 3). The authors also investigated the ridge between the path and rice-field on which *Glycine Max* MERR. was cultivated. Every division of C, E, and G (index 29±1.4, 32±2.3, 28±0.6) was barren land, and both division of

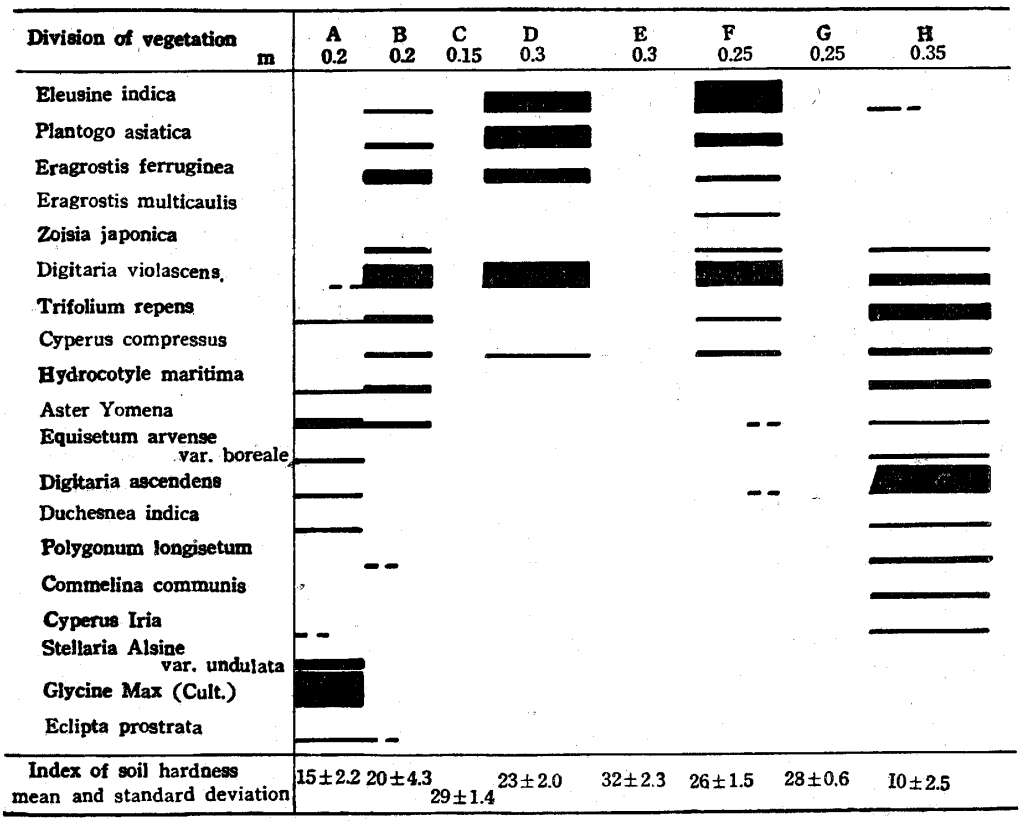

Fig. 3. Structure of the vegetation on the footpath in the ricefield composed of meadow soil (river-bed type) at Tomizu, Odawara. Diagram showing average cover degree obtained from the 10 quadrats in each division.

F (index 26±1.5) and D (23±2.0) were dominated by *Eleusine indica* GAERTN. followed by *Digitaria violascens* LINK, *Plantago asiatica* L. and *Eragrostis ferruginea* BEAUV. in quantity. The division of H (index 10±2.5) was dominated by *Digitaria ascendens* HENRY, and next were *Trifolium repens* L. and *D. violascens* LINK division of A (index 15±2.2) is a ridge of a rice-field which had been rebuilt every year, where was planted *Glycine Max* MERR. Here was a soil with large moisture-content (41.5%) and the vegetation consisted of *Stellaria Alsine* GRIMM. var. *undulata* OHWI, *Aster Yomena* KITAM., *Equisetum arvense* L. var. *boreale* RUPR., *Digitaria ascendens* HENRY and *Duchesnea indica* FOCKE, etc.

The results of the soil analysis, as in the previous one, shows that soil hardness and moisture are inversely proportional, and the differences among the zones based on other factors were not clearly found. Judging from the investigation of the relation between the soil hardness and depth of soil in every division (Fig. 4, (3)), the authors found out the great differences of hardness of each zone from the surface to 5 cm in depth, and at the depth of 10–15 cm, there was hardly found any difference.

At the above mentioned 3 regions, the authors examined the relation

Table 3. Analysis of a meadow soil (river-bed type) from a footpath in a rice-field at Tomizu, Odawara.

Depth cm	Division of vegetation	A	B	C	D	E	F	G	H
0–5	Index of soil hardness	15±2.2	20±4.3	29±1.4	23±2.0	32±2.3	26±1.5	28±1.5	10±2.5
	Soil moisture %	41.5	17.2	22.4	20.9	21.4	20.9	18.6	31.5
	pH	5.5	6.0	6.6	6.0	6.5	6.5	6.5	5.5
	P_2O_5 p. p. m.	10	10	15	15	10	20	10	10
	CaO %	0.07–0.12	less than 0.07	0.07–0.12	0.07–0.12	less than 0.07	0.07–0.12	less than 0.07	over 0.12
15–20	Index of soil hardness	20±1.0	16±0.1	20±1.0	29±0.7	28±0.7	19±0.7	18±1.0	14±4.0
	Soil moisture %	47.78	37.61	17.5	17.18	25.2	21.37	24.2	30.4
	pH	5.5	5.0	5.8	6.0	6.0	6.0	6.0	5.5
	P_2O_5 p. p. m.	20	20	10	20	50	50	10	50
	CaO %	less than 0.07	less than 0.07	0.07–0.12	less than 0.07	less than 0.07	less than 0.07	less than 0.07	less than 0.07

between soil hardness and number of species of each division (Table 4), and it was observed that the number of species tends to sudden decrease at the division with more than 25 index of soil hardness.

4. Summarized results.

At the 3 regions mentioned above, the authors picked up 350 quadrats at random in every season and measured the cover degree of vegetation and soil hardness at each quadrat. The authors attempted to determine the main growing range by the soil hardness with respect to species having a cover degree of more than 4 which the authors considered to be dominant species.

According to Fig. 5, habitat range and habitat segregation of the weeds have a pretty close relation with soil hardness. In this case, emphasis was placed on soil hardness and other environmental factors were not considered. The weeds growing in various places as treated above are distinguished into 3 groups according to the degree of soil hardness: "soft", "hard" and "very hard".

In the first group are the species growing in the habitat showing 0–11 in index of soil hardness (absolute hardness; 0–1.7 cm/kg^3), the majority of so-called cultivated land weeds such as *Stellaria neglecta*

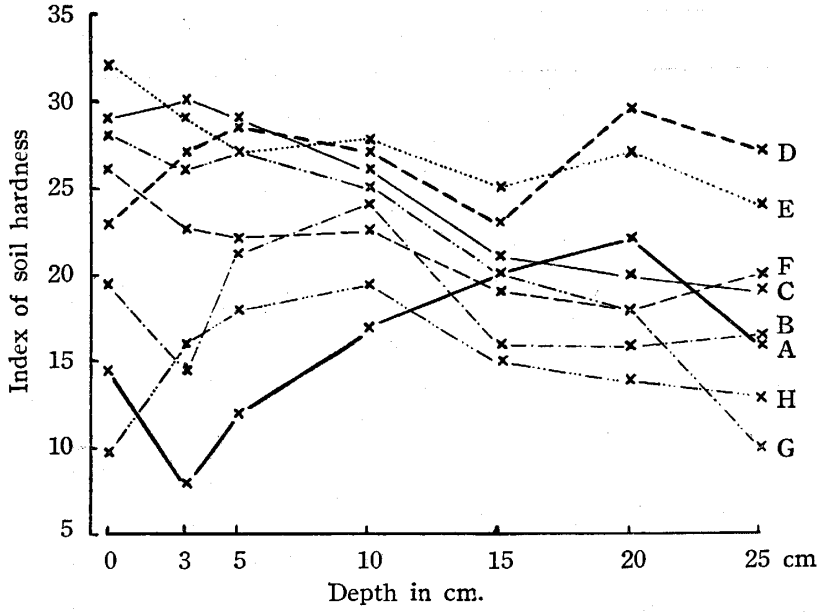

Fig. 4. Showing the relation of soil hardness owing to the depth of soil. (Tomizu, Odawara).

Table 4. Relation between soil hardness and number of species.

Index of soil hardness	6	9	10	12	15	17	18	20	23	25	26	27	28
Takasu (Hiroshima)		14		12			6, 7		6	7			
Oome (Tokyo)	7					10	7					5	5
Tomizu (Odawara)			13		11			10	5		(10)*		

* this division was adjoined to bare land

WEIHE, *Cerastium caespitosum* GILIB. var. *ianthes* HARA and *Digitaria ascendens* HENRY, etc. and in fact, the ground of less than 11 index of soil hardness is cultivated-land usually. The field showing 25–30 in index of soil hardness (absolute hardness; 28–115 cm/kg^3) is in play-grounds or central parts of footpath trodden by men and wheels, where grow a special weed vegetation composed of such species as *Eleusine indica* Gaertn., *Juncus tenuis* WILLD., *Polygonum aviculare* L., *Plantago asiatica* L., *Rumex Acetosa* L. and *Poa annua* L., etc.

When such species as *E. indica*, *J. tenuis*, *D. violascens*, *E. ferruginea* and *P. aviculare*, etc. occur on the ground of high valued index of soil hardness, they grow changing their growth form (shoot form),[26] namely they do not show erect form (E) but still caespitose form (C) or prostrate form (P) even at flowering stage. "Hard" habitat (index 11–25 absolute hardness; 1.7–28 cm/kg^3) is verge of roadway or vacant land untrodden, where many

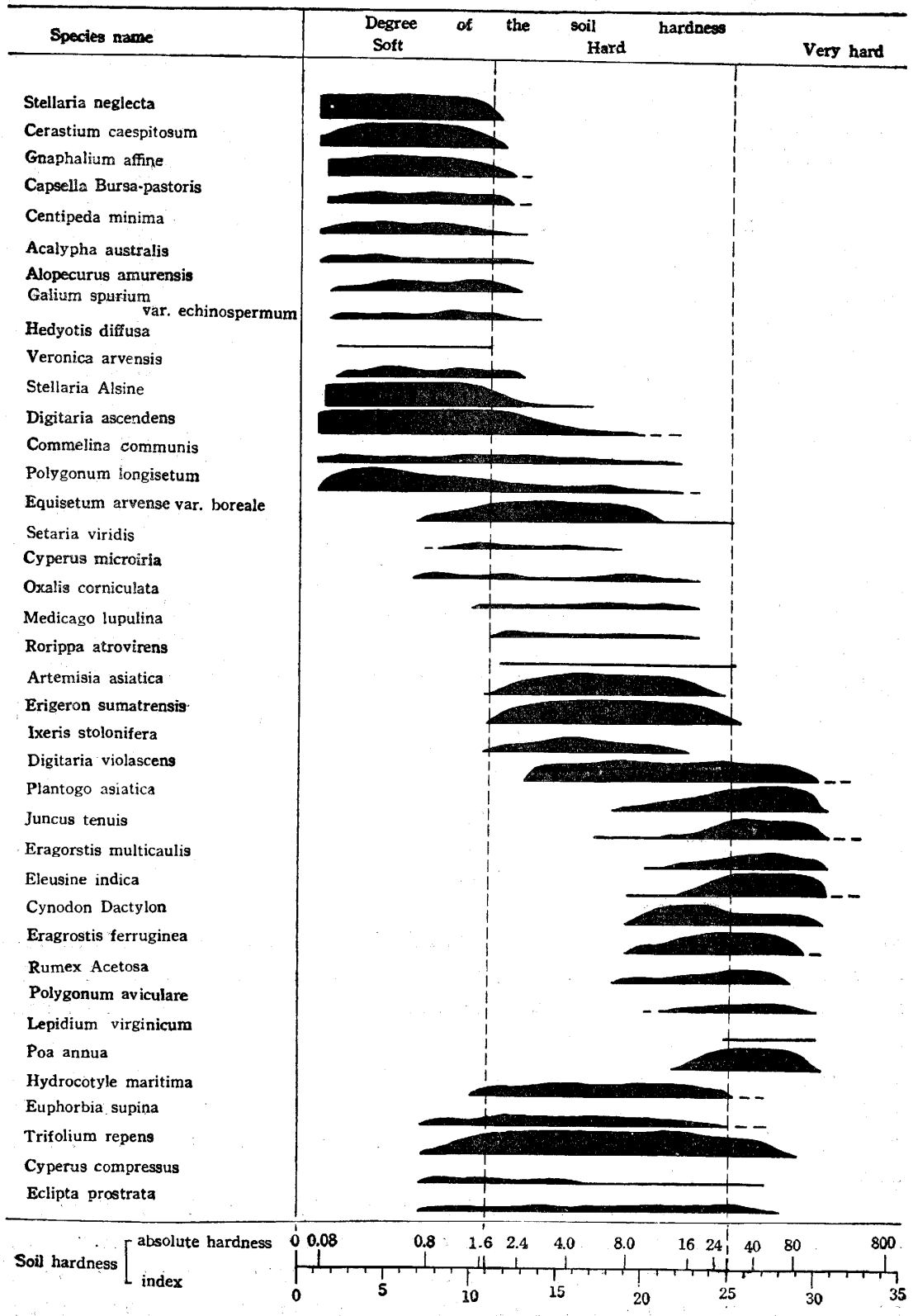

Fig. 5. Habitat range of main weeds caused by soil hardness. The diagram obtained from the 350 quadrats in various artificial stands showing average cover degree.

road-side weeds are usually found. They are *Erigeron sumatrensis, Artemisia asiatica* Nakai, *Roegneria Kamoji, Aster Yomena, Erigeron annuus* L. and *E. canadensis*, etc. Rarely, however the species which are common in "very hard" come out on the "soft" ground, but the cover degree and frequency are very small. Some species which are usually more abundant in "hard" are sometimes found in the range of "very hard" or "soft". They are such species as *Trifolium repens, Hydrocotyle maritima, Euphorbia supina* and *Cyperus compressus.* Of these species *Trifolium repens* has a wider amplitude of its habitat. This plant grows very close to the earth when it occurs on the "very hard" ground, and then internode and leaf stalk are shortened with very much smaller leaf area.

IV. Discussion

At first, in 1941 IMANISHI[6] published so-called habitat segregations of living organisms based upon his study on larva of mayflies from Japanese torrents. Later KANI 1944, '52,[7-8] and IMANISHI 1949, '51,[9-10] investigated the same phenomenon on insects in brooks and torrents, etc. and the habitat segregation became one of the most remarkable ecological theories in Japan. Animal ecologists have discussed on this problem[11-13]. In the studies of plant communities, NUMATA 1950a, b,[14-15] investigated the habitat segregation of underground parts, SUZUKI 1952,[16] of forest vegetation and KIRA 1952,[17] referred to the extensive habitat segregation. MORI 1952,[11] proposed 3 fundamental processes which differ from the view point of IMANISHI's which is based on life form.

As a method of ecological analysis of the structure of weed communities, the authors divided the habitat segregation into homogeneous and heterogeneous types in reference to the life form and growing field, the former is a phenomenon that individuals of the same species grow at different stands with different forms, and the latter is that different species grow at different stands which are close to one another with different environmental factors. In many cases of the latter life form is also different, but another case must be considered, of course.

BATES 1935, '37, '38, '48,[18-21] DAVIES 1938,[22] and YOSHIOKA 1952,[23] reported of the vegetation on the verge of roadway, footpath, cart-track and playground, which showed more special forms of growing under artificial factors. According to BRAUN-BLANQUET 1932,[28] such vegetation is very unstable and changed by the degree of artificial factors. In this case, however, the measure of the degree of artificial factors becomes a problem to solve. As above-mentioned, the authors have investigated the relationship between soil hardness and vegetations with the same method in each stand. It is evident that the habitat segregation of the vegetations on roadsides is scarcely dependent upon chemical components (pH, P_2O_5, and CaO) of weeds bed soil, because

no evidence of the difference of these character were observed. But it is clearly related to variations of index of soil hardness from the earth's surface to about 5 cm in depth. As shown in Fig. 1, 2 and 3, even by a little difference of index of soil hardness, average cover degree of each species is very sensitive in its reaction to the difference at every measured stand. The habitat segregation which is caused mainly by the soil hardness is observed more commonly on footpath, roadside, sidewalk, play-ground, etc. where the index of soil hardness is more than 20. On the edges of the road or vacant land grow erect form plants like genus *Erigeron* by reason of being untrodden by men and wheels, erect form plants in mature stage such as *Erigeron* do not occur on trodden and "very hard" ground. Farm-field under cultivations is usually fertile and under special environmental conditions such as weeding or cultivation, so here grow special species of weeds. The authors find it of interest that the habitat segregation can be analyzed by the very simple method of measuring the index of soil hardness. It is commonly accepted that weeds never select a place where they grow. However weeds are rather sensitive to their environments, even in a slight variation of them. So far as the measurement of index of soil hardness is concerned, it is now found that the habitat for each species of weed is unexpectedly restricted.

Among weeds which have their main growing ranges in "hard", some plants can alter their life forms and can invade "very hard". These plants are for instance, *Trifolium repens* L., *Euphorbia supina* FATIN. and *Eclipata prostrata* L., etc. But the others can not invade "very hard". These facts are in agreement with MORI's 1952[11] second fundamental process of habitat segregation. On the other hand, *Eleusine indica* GAERTN., *Polygonum aviculare* L., *Poa annua* L. and *Eragrostis multicaulis* STEUD., etc. which have their main growing regions in "very hard" are infrequently or never found in "hard" and "soft". Whether this fact may be solved by MORI's 1st fundamental process of habitat segregation or not must receive further study. From the habitat segregation view point of weeds, we do not find a strict difference between the 1st and 2nd fundamental process case, but it seems to us that it will be a result of the co-action of both processes.

Résumé

1. To analyze the structure of weed communities, the concept of habitat segregation is a most important problem to solve.

The phenomenon of habitat segregation of weeds was divided into two groups based on their relationship between the life form and habitat, one is homogeneous habitat segregation and the other heterogeneous habitat segregation. The first is that in which the same species occurs in different life form and a different habitat, and the second is that in which different species occurs in different habitat, and different life form in many cases.

2. Since the spring in 1951, the authors have investigated the habitat segregation of the weeds in cultivated fields and roadways, and special attention was focused on the latter. As for the measurement of soil hardness, the authors used the soil hardness-tester designed by Yamanaka.

3. As the places for the investigations we selected three regions of granitic sandy soil (at Takasu, Hiroshima), so-called Kanto loam (at Oome, Tokyo) and a meadow soil, river bed type (at Tomizu Odawara).

4. In the three regions mentioned above, the authors investigated the weed communities on fields and play-grounds, results are as follows; habitat segregation of the roadside weeds is not influenced by chemical components of their bed soils, but by soil hardness influenced by artificial factors; the treading of men and wheels.

5. Most of habitat segregation, according to the soil hardness, were of the heterogeneous habitat segregation.

6 In the three regions mentioned above, the authors investigated the average cover degree of each species and soil hardness in a large number of quadrats, and from the results the main growing range of weeds due to the soil hardness is classified into following 3 parts, that is, "soft" "hard", and "very hard". "Soft" (index of soil hardness 0–11, absolute hardness 0–1.7 cm/kg^3) to which belongs the main growing range of weeds on cultivated land. In the habitat of "very hard" of soil hardness weeds are very much trampled and pressed (index 25–30, absolute hardness 28–115 cm/kg^3, and occasionally, to index 32, at stands of more than 30 in index, the growth of weeds is very poor, and usually almost bare). For example, the tracks of wheels and the passage of the pupils on the play-ground belong to "very hard" habitat, and here the following weeds grow; *Eleusine indica* GAERTN., *Juncus tenuis* WILLD., *Polygonum aviculare* L., *Eragrostis ferruginea* BEAUV., *Poa annua* L., *Plantago asiatica* L. In Middle-valued "hard" habitat (index 11–25, absolute hardness 1.7-28 cm/kg^3), there grow most of roadside weeds. And some of the weeds on this habitat alter their life forms if they invaded the field of "very hard".

7. Each species of weeds has a different growing range and occurs in a restricted habitat segregation.

8. Moreover, soil moisture has a tendency to have an inverse value to soil hardness. The pH and chemical components of the soil such as P_2O_5 and CaO do not seem to be much of an influencing factor governing habitat segregation.

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