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Biosystematic Study of *Sedum* L. Subgenus *Aizoon* (Crassulaceae) I. Cytological and Morphological Variations of *Sedum aizoon* L. var. *floribundum* Nakai

MAKOTO AMANO

Department of Botany, University Museum, University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113

Variation in chromosome number and morphological characters of *Sedum aizoon* L. var. *floribundum* Nakai were investigated to analyze correlations between them. Geographical variation in chromosome number was also examined. Chromosome numbers of 189 individuals from 55 localities were counted as 2n=32, 33, 34, 48, 61, 64, 78, 80, 84, 85, 88, 93, 94, 95, 96, 97 and 102. In *Sedum* subgenus *Aizoon*, which has the basic number of X=8, var. *floribundum* of the species *aizoon* showed a polyploid series from tetraploid to dodecaploid. Tetraploids were found most frequently in this variety. More than two chromosome numbers were found in all the populations with 2n=61 or more. Tetraploids were mainly distributed in the eastern part of Japan, and higher polyploids (higher than hexaploid level except octaploids) were distributed in the western part of Japan.

Thirteen morphological characters were examined in 119 individuals belonging to 30 populations. The principal component analysis and the cluster analysis of these characters indicated that populations with similar chromosome numbers were not always morphologically similar. Ten morphotypes can be recognized based on the combination of chromosome number and morphological characters. Thus *S. aizoon* var. *floribundum* can be regarded as a polyploid-aneuploid complex.

Key words: Chromosomal variation — Morphological variation — Polyploid complex — *Sedum aizoon* var. *floribundum*

Sedum subgenus *Aizoon* is mainly distributed in eastern Asia. Taxonomically this subgenus is still a problematic group, with the species delimitation varying among authors. According to Ohba (1978) this subgenus contains seven species. *S. aizoon* L. is distinguished from the other six species by the nondecumbent rhizomes, the glabrous and usually annual floral stems, the alternate leaves except in the juvenile stage, and the serrate leaf margin.

In Japan *S. aizoon* L. has two varieties: var. *aizoon* and var. *floribundum* Nakai. Var. *floribundum* is distinguished from the typical variety by the thick rhizomes, the caespitose floral stems which arise from the rhizome, and the number of serrations on the margin of the leaf which is usually less than 20. Var. *floribundum* is widely distributed in Japan (Fig. 1).

Soeda (1944), Ogawa and Yuasa (1970) and Uhl and Moran (1972) showed variation in chromosome number indicating the presence of a series of polyploids and aneuploids. Ogawa and Yuasa (1970) reported 2n=32, 48, 49, 64 and 96, while, under the name of *S. kamtschaticum* in Japan and South Korea, Uhl and Moran (1972) counted them as n=16, 16+1, 32, ca 40, 48, 56 and 64. Uhl and Moran (1972) also reported different chromosome numbers (n=48-64) for the individuals from a single locality. They considered the basic number of the subgenus *Aizoon* as x=16. Ogawa and Yuasa (1970), however, counted 2n=16 for *S. sikokianum* Maxim., which belongs to this subgenus.

S. aizoon var. *floribundum* has been reported to be variable in morphological characters as well as chromosome number. In this variety Ohba (1982) noted variations in leaf shape, leaf length, stem height, existence of papilla on plant body and flower size.

It is difficult to correlate particular taxa to these counts, because the delimitation of taxa is different among different authors (e.g., Praeger, 1921; Berger, 1930; Fröderström, 1931; Borissova, 1939; Ohwi, 1953; Ohba, 1982; Fu, 1984). Variations in both chromosome number and morphological characters have suggested that var. *floribundum* is a polyploid complex. The precise study of morphological characters and their relationship to chromosome number as well as their variations within a given population has not yet been carried out in Japan. Thus, it is necessary to examine chromosome number and morphological characters within population samples in order to clarify the variations shown by this variety.

In this paper, I will first clarify the variation of chromosome number of *S. aizoon* var. *floribundum* in Japan. Secondly, I will examine the relationship between chromosome number and morphological characters among populations with different chromosome numbers. The principal component analysis and the cluster analysis using the UPGMA method are employed for these studies. The principal component analysis shows the degree of difference and discontinuity of variation among the populations. The cluster analysis shows the overall morphological similarity among the populations. Populations with the same or similar chromosome numbers are divided by the combinations of morphological characters.

Materials and Methods

The living materials of *Sedum aizoon* var. *floribundum* were collected from 55 different localities from various areas within the distribution range in Japan (Fig. 4, Table 1, also see Fig. 1). They were cultivated in a garden of University Museum, University of Tokyo, Hongo, Tokyo, for chromosome observations. In each locality, samples were collected within a ten to two hundred meter line-transect of two to three meter width. Individuals within each transect were treated as belonging to the same population.

For chromosome observation, root tips and shoot apices from the plants cultivated in the garden were used. The pretreatment was made with 0.002 M 8-hydroxyquinoline for 3 to 4 hrs. After the pretreatment they were fixed in a mixture

Table 1. List of localities

Population number	Place name	Collecting date	Habitat*	Number of** individuals
1	Senposhi, Rishiri, Rishiri, Hokkaido	1987 Aug.	S., R.	(1)
2	Kutsugata, Rishiri, Rishiri, Hokkaido	1987 Aug.	S., R.	2 (5)
3	Oshidomari, Higashirishiri, Rishiri, Hokkaido	1987 Aug.	S., R.	(3)
4	Shiundai, Kushiro, Hokkaido	1986 Jul. 29	S., G.	(2)
5	Nishikioka, Tomakomai, Hokkaido	1986 May 7	S., Sa.	(1)
6	Asamushi, Aomori, Aomori	1987 Jul. 6	S., R.	6 (6)
7	Shiriyazaki, Higashidori, Shimokita, Aomori	1986 Jun. 27	S., R.	2 (4)
8	Okuki, Hachinohe, Aomori	1986 Jun. 26	S., R.	1 (4)
9	Horinai, Fudai, Shimohei, Iwate	1986 Jun. 26	S., R.	1 (4)
10	Tomari, Rikuzentakada, Iwate	1986 Jun. 25	S., R.	3 (4)
11	Motogoya, Akiu, Natori, Miyagi	1987 Jul. 4	M., R.	8 (9)
12	Futakuchi Pass, Akiu, Natori, Miyagi	1987 May 24	M., R.	(2)
13	Toga, Oga, Akita	1986 Jun. 28	S., R.	4 (4)
14	Mt. Toko, Ouchi, Yuri, Akita	1988 May 5	M., R.	(4)
15	Oyana, Honjyo, Akita	1988 May 5	M., R.	(2)
16	Atsumi, Atsumi, Nishitagawa, Yamagata	1986 Jun. 29	S., R.	5 (6)
17	Mt. Horai, Sanpoku, Iwafune, Niigata	1988 May 4	S., R.	(1)
18	Maoroshi, Murakami, Niigata	1988 Jul.	S.	(2)
19	Iwafune, Murakami, Niigata	1986 Jun. 29	S., P.	4 (4)
20	Omi, Nishikubiki, Niigata	1988 Jul.	S.	(1)
21	Kamiichi, Nakaniikawa, Toyama	1986 May	M.	(1)
22	Shirasaki, Sosoki, Wajima, Ishikawa	1987 Mar. 29	S., R.	(2)
23	Otani, Suzu, Ishikawa	1987 Mar. 29	S., R.	3 (3)
24	Kuroshima, Monzen, Fugeshi, Ishikawa	1987 Mar. 30	S., Sa.	4 (4)
25	Mt. Namasefuji, Daigo, Kuji, Ibaraki	1986 May 5	M., R.	(5)
26	Chuzenjiko, Nikko, Tochigi	1989 Jun.	M.	(1)
27	Mt. Mitsuishi, Kimitsu, Chiba	1988 May 9	M., R.	4 (4)
28	Higashinippara, Okutama, Nishitama, Tokyo	1986 Jun. 11	M., R.	2 (5)
29	Itsukaichi, Nishitama, Tokyo	1987 Apr.	M.	(1)
30	Otomekogen, Makioka, Higashiyamanashi, Yamanashi	1988 Jul. 19	M.	5 (5)
31	Hirano, Yamanakako, Minamitsuru, Yamanashi	1986 May 25	M., R.	2 (2)
32	Mt. Mikuni, Yamanakako, Minamitsuru, Yamanashi	1988 Nov. 11	M., R.	(3)
33	Kenmarubi, Fujiyoshida, Yamanashi	1988 Sep.	M.,	(1)
34	Koyodai, Ashiwada, Minamitsuru, Yamanashi	1986 Jul. 18	M., R.	1 (1)
35	Nakanokura, Shimobe, Nishiyatsushiro, Yamanashi	1987 Jun. 8	M.	(1)
36	Ide, Minabe, Minamikoma, Yamanashi	1986 Apr.	M.	(1)

Table 1. continued

Population number	Place name	Collecting date	Habitat*	Number of** individuals
37	Minobu, Minamikoma, Yamanashi	1988 Oct.	M.	3 (3)
38	Yashajin, Nirasaki, Yamanashi	1984 Aug. 30	M.	(1)
39	Hatanagi-daiichidamu, Shizuoka, Shizuoka	1987 Nov. 18	M., R.	7 (8)
40	Mt. Tekari, Shizuoka, Shizuoka	1985 Aug.	M., R.	(1)
41	Mt. Ishimaki, Toyohashi, Aichi	1986 May	M., R.	(2)
42	Tokuyama, Ibi, Gifu	1987 Sep. 30	M.	(2)
43	Mt. Kujaku, Totsukawa, Yoshino, Nara	1988 Jul.	M., R.	4 (4)
44	Mt. Sanjyo, Tenkawa, Yoshino, Nara	1988 Jul.	M., R.	3 (4)
45	Mt. Inamura, Tenkawa, Yoshino, Nara	1988 Jul.	M., R.	(2)
46	Ajiro, Iwami, Iwami, Tottori	1989 Jun. 14	S., G.	4 (4)
47	Nakamura, Tomimasu, Yonago, Tottori	1989 Jun. 14	S., P.	3 (4)
48	Kankakei, Utsumi, Shozu, Kagawa	1986 Jul. 11	M., R.	4 (7)
49	Hoshigajyo, Utsumi, Shozu, Kagawa	1988 Oct. 21	M., R.	7 (7)
50	Mt. Tsurugi, Higashiiya, Miyoshi, Tokushima	1988 Aug. 3	M., R.	4 (4)
51	Kamitsushima, Kamiagata, Nagasaki	1986 Apr. 15	S., R.	3 (5)
52	Yabakei, Shimoge, Oita	1988 Aug.	M., R.	(1)
53	Mt. Do, Takachiho, Nishiusuki, Miyazaki	1988 Jun. 5	M., R.	6 (7)
54	Takenokawa, Itsuki, Kuma, Kumamoto	1988 Jun. 4	M., R.	7 (7)
55	Mt. Shiraiwato, Kuma, Kuma, Kumamoto	1988 Jun. 3	M., R.	7 (7)

* Letters reveal environmental condition of habitat; S.: seashore, M.: mountain, R.: on rock, G.: grassland, Sa.: on sandy soil, P.: under pine forest

** The first number is the number of individuals on which morphological measurements were made, the second number in parenthesis is the number of plants whose chromosome numbers were determined.

of ethanol and acetic acid (3 : 1) or Newcomer's fluid, and preserved in a refrigerator at 4 C. For the maceration they were incubated with 2% pectinase for 40 min. at 37–40 C after being placed in distilled water for 1 hr. They were then stained with 2% aceto-orcein for 5–12 hr., after which time they were squashed. The voucher specimens of the chromosome observation were deposited in TI (the herbarium of Faculty of Science, University of Tokyo).

Morphological characters were examined from the voucher specimens. Thirteen morphological characters of 119 individuals collected from 30 localities were examined (Fig. 2): they were leaf blade length (LBL), widest width of leaves (WWL), number of serrations on one side of leaves (NSL), length from the base to the basal point of the nearest serration of leaf (LSB), plant height (PH), described as the length between the base of stem and the attachment point of the topmost leaf, width of basal stem (WSB), length of the living part of the last year's stem (LLS), number of leaves of a stem (NL), longer node length between three serial leaves (LNL), shorter node length between

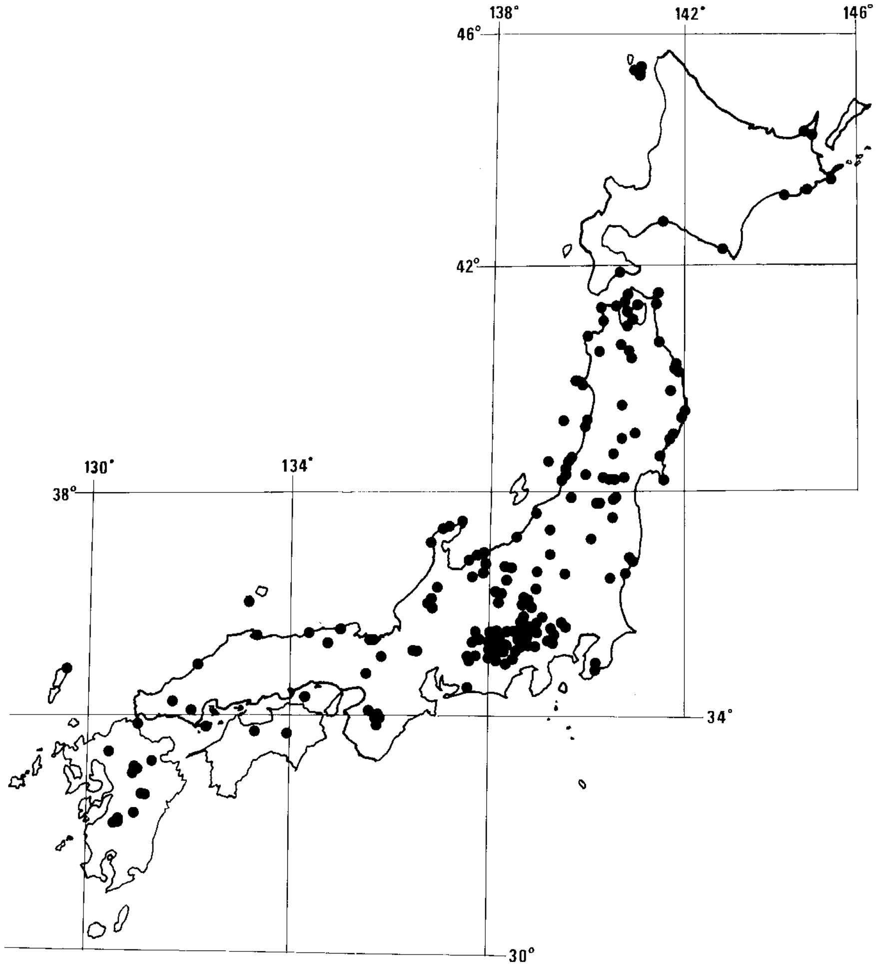

Fig. 1. Geographical distribution of *Sedum aizoon* var. *floribundum* in Japan based on herbarium specimens deposited in KYO, MAK, TI and TNS and the specimens collected for the present study.

three serial leaves (SNL), width of serration (WS), height of serration (HS) and length between the apical point of serration and the lower basal point of serration (LPS). LBL, WWL, NSL and LSB are calculated from a mean of three values measured from three different leaves of the same stem. PH, WSB, NL, LLS, LNL and SNL are based upon individual measurements. WSB is a mean of the least and the greatest diameters of a stem. The value of LLS is 0 when a shoot sprouted direct from the rhizome. WS, HS and LPS are a mean of three values measured from serrations at the middle part of the same leaf. For the cluster analysis the package program published by Kyoritsu Shuppan Co. Ltd. (1984) was used.

A distribution map (Fig. 1) was made from the data of herbarium specimens deposited in KYO (the herbarium of Faculty of Science, Kyoto University), MAK (Makino Herbarium, Faculty of Science, Tokyo Metropolitan University), TI and TNS

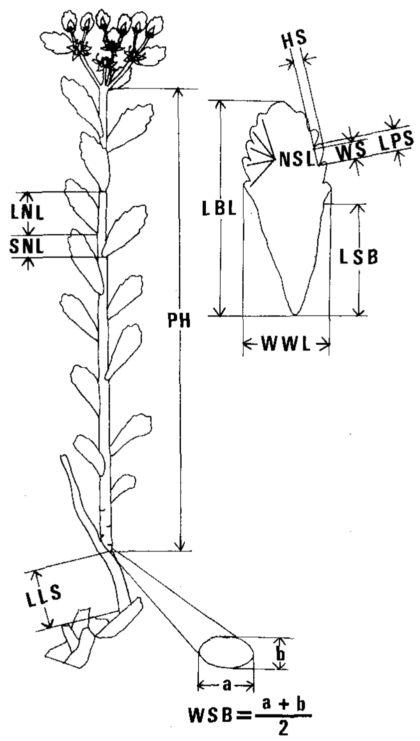

Fig. 2. Measurement of morphological characters.

(the herbarium of National Science Museum, Tokyo) as well as the materials collected for the present study.

Results

1) Chromosome numbers

Somatic chromosome numbers of 189 individuals of *S. aizoon* var. *floribundum* are listed in Table 2, and some of their chromosomes are shown in Fig. 3. Various chromosome numbers, 2n=32, 33, 34, 48, 61, 64, 78, 80, 84, 85, 88, 93, 94, 95, 96, 97 and 102, have been counted. Individuals with 2n=32 and 48 are the most prevalent with 2n=32 being found in 119 individuals belonging to 41 populations, and 2n=48 being found in 33 individuals of eight populations. The other numbers are found in the remaining 37 individuals.

Among the various chromosome numbers observed, two numbers, 2n=32 and 48, are found to be stable within many populations (Table 3). However, in four populations (Pops. 8, 11, 13 and 22) 2n=33 and 34 are observed together with 2n=32, and in one population (Pop. 11) 2n=32, 33 and 34 are observed together with 2n=48. Chromosome numbers are found to be unstable within a population consisting of individuals with higher chromosome numbers (2n=61 to 102), i.e., these populations contain individuals with different chromosome numbers.

In the five populations of Hokkaido all the individuals show 2n=32 (Fig. 4).

Table 2. Variation of chromosome number

Chromosome number	Number of individuals	Number of populations
32	119	41
33	3	3
34	3	3
48	33	8
61	1	1
64	5	1
78	1	1
80	2	1
84	2	1
85	1	1
88	6	2
93	2	1
94	1	1
95	1	1
96	4	4
97	1	1
102	4	1

Among them Pop. 5 is possibly an escape, since morphologically indistinguishable plants were cultivated at a garden nearby the locality. In Honshu the individuals with 2n=32 are also the most common number, although individuals having higher chromosome numbers are found in some populations. In the Kii Peninsula all the individuals from three populations (Pops. 43–45) show 2n=48. This number is rarely observed in the individuals from northern Honshu (Pops. 11 and 20). In Pop. 6 from northernmost Honshu all the individuals examined have 2n=64 or 61. Two individuals in the southern part of Aichi Prefecture in central Honshu also have high chromosome numbers, i.e., 2n=88 and 96.

In Shikoku and Kyushu no individual with 2n=32 is found. All the individuals in these areas have higher chromosome numbers, i.e., 2n=48 is observed in central Kyushu and 2n=78 or more in Shikoku and northern Kyushu.

2) Relationship between chromosome number and morphological characters

The populations whose morphological characters have been examined can be placed into five groups based on the variation shown by the chromosome number of each population (Table 3). Group A includes populations with 2n=32, 33 and 34, group B with 2n=48, group C with 2n=61 and 64, group D with 2n=78, 80, 84, 85 and 88 and group E with 2n=88, 93, 94, 95, 96, 97 and 102. Overlapping of variation in chromosome number is found between group D and E at 2n=88. Pop. 48 is included in group D because its variation range of chromosome number widely overlaps those of Pop. 50, belonging to the same group. Pop. 41 is included in group E because its

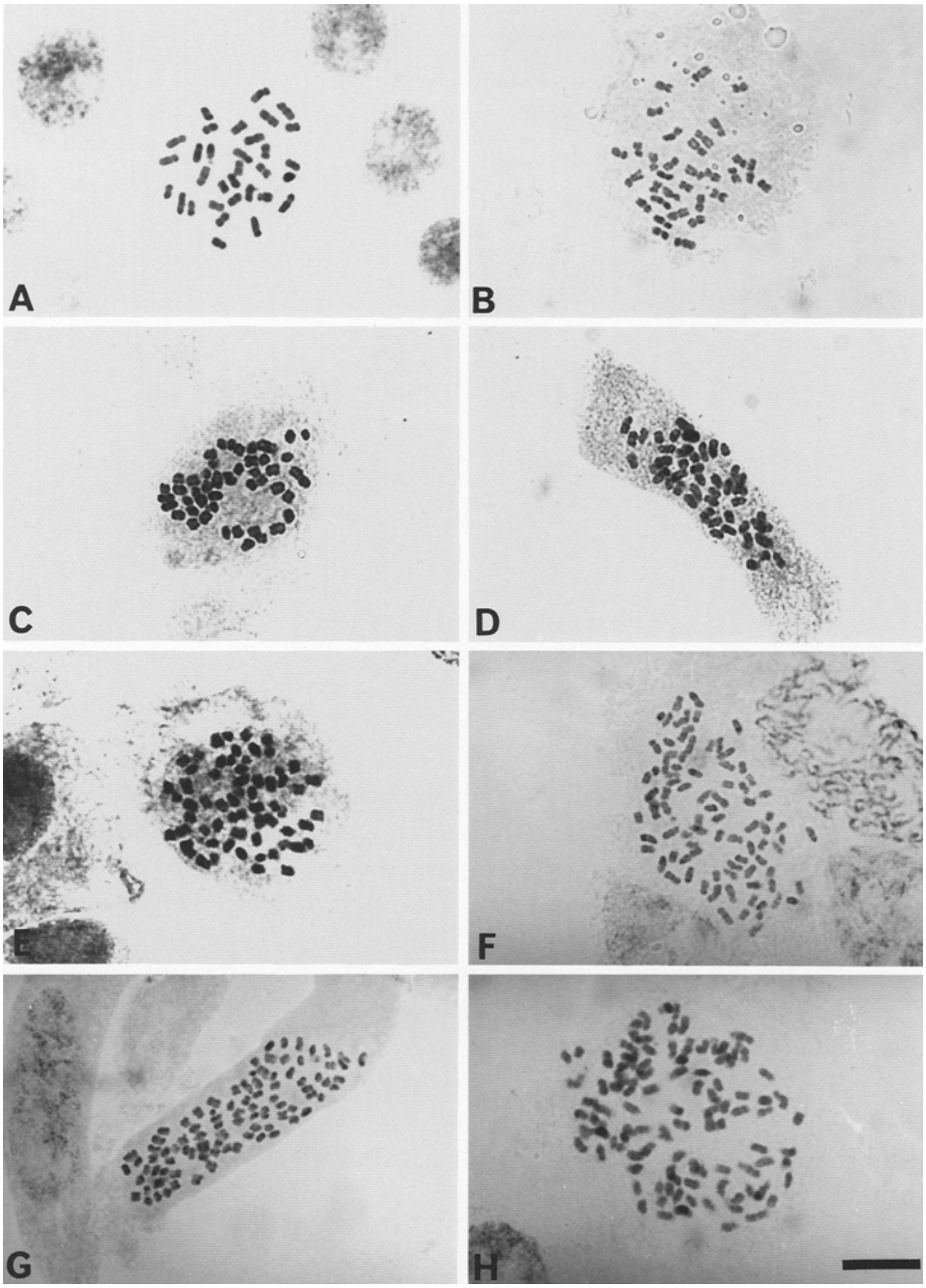

Fig. 3. Somatic chromosomes of *Sedum aizoon* var. *floribundum*.
Bar: 10 μm. A: Pop. 39 2n=32; B: Pop. 7 2n=32; C: Pop. 54 2n=48; D: Pop. 44 2n=48; E: Pop. 6 2n=64; F: Pop. 48 2n=88; G: Pop. 49 2n=95; H: Pop. 51 2n=102.

Table 3. Variation of chromosome number within population

Chromosome variation	Number of populations	Population number	Group
2n=32	37 (11)	1, 2, 3, 4, 5, 7, 9, 10, 12, 14, 15, 16, 17, 18, 19, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 41, 42, 46, 47	A
2n=32, 33	2	13, 22	A
2n=32, 34	1	8	A
2n=34	1 (1)	40	A
2n=32, 33, 34, 48	1	11	A
2n=48	7 (1)	20, 43, 44, 45, 53, 54, 55	B
2n=61, 64	1	6	C
2n=80, 84	1	50	D
2n=78, 85, 88	1	48	D
2n=88, 96	1	41	E
2n=96	1 (1)	52	E
2n=93, 94, 95, 96, 97	1	49	E
2n=96, 102	1	51	E

The number in parenthesis is the number of populations from which the chromosome number was counted in only one individual. Groups are divided by variation range of chromosome number.

variation range widely overlaps those of Pops. 49, 51 and 52. Pop. 11 is included in group A because in this population 2n=32 is the most frequently found number.

(i) Morphological similarity within and among the groups:

The principal component analysis of the thirteen morphological characters was carried out among the 119 individuals from 30 populations. Table 4 shows the cumulative variances of the first four principal components and the loadings of the thirteen characters for them.

The first four principal components cover more than 70% of the total variance. The first component accounts for 48.3% of the total variance. Characters with heavy loadings in the first component are LBL, WWL, LSB, PH, WSB, NL, LNL, SNL, HS, WS and LSP. These characters are mainly size characters: thus this component can be regarded as a general size factor. The second component accounts for 10.8% of the total variance. NSL and NL's loadings are heavy in the second component. The third component accounts for 9.7% of the total variance. Characters with heavy loadings in the third are LLS, WWL and WS. The fourth component accounts for 8.0% of the total variance. Characters with heavy loadings in the fourth component are NSL, NL and SNL.

Group A varies much both in the first and the second components, but does not show any distinct tendency (Fig. 5). Groups B and C tend to have smaller values for

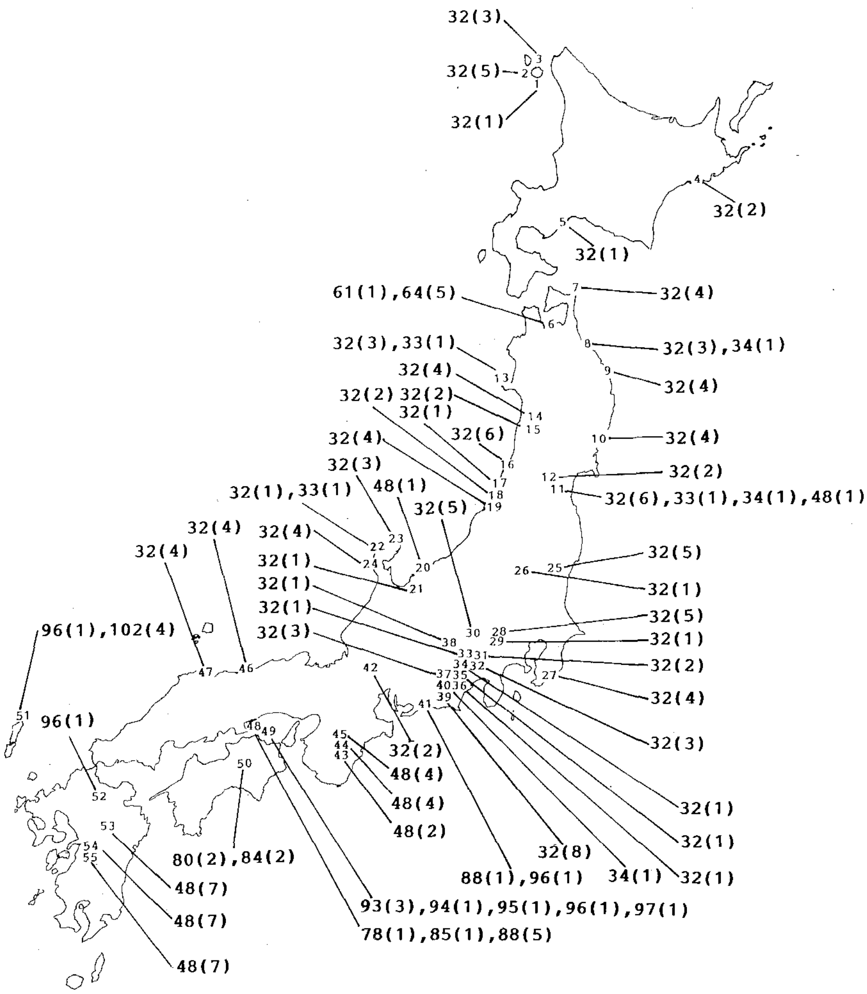

Fig. 4. Geographical variation of chromosome numbers in *Sedum aizoon* var. *floribundum*. Small numbers on land indicate population number. Numbers on the sea indicate diploid number, and those in parentheses indicate numbers of individuals whose chromosomes were counted.

both of them. Group D has a smaller value for the first component and a larger value for the second. Group E has a smaller value for the first component and an intermediate value for the second. However, the ranges of variation of these groups largely overlap with one another.

Group A also varies much both in the third and the fourth components (Fig. 6). Group B has a smaller value for the third and a larger value for the fourth component. Group C has much variation of the third, and tends to have an intermediate value for the fourth component. Group D varies much in the third component and has an intermediate value for the fourth component. Group E has intermediate values for both of them. The ranges of variation of these groups also largely overlap with one

Table 4. Cumulative variances of the first four principal components and the loadings of the thirteen characters on each principal component

Cumulative variance	C1 48%	C2 59%	C3 69%	C4 77%
Characters	Eigenvectors			
LBL	0.892	0.068	−0.121	0.102
WWL	0.715	0.363	−0.459	−0.069
NSL	0.104	0.726	−0.300	0.413
LSB	0.796	−0.161	−0.127	0.082
PH	0.811	0.308	0.354	0.044
WSB	0.732	0.283	−0.071	−0.386
LLS	−0.026	−0.151	0.657	0.151
NL	0.529	0.555	0.290	−0.470
LNL	0.777	−0.030	0.218	0.366
SNL	0.714	−0.019	0.199	0.484
HS	0.802	−0.328	0.122	−0.217
WS	0.607	−0.328	−0.428	0.071
LPS	0.848	−0.342	0.057	−0.176

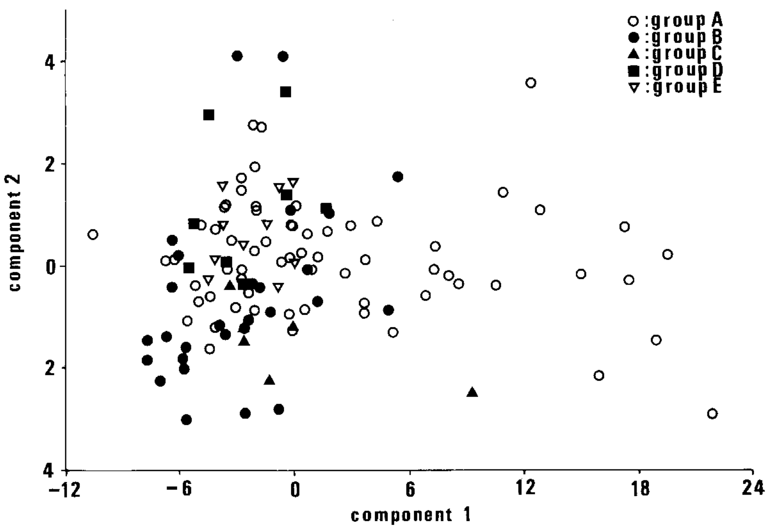

Fig. 5. Correlation of principal component 1 and 2. Each sign indicates groups recognized from chromosome numbers.

another.

As a result, individuals belonging to the same groups are not similar to one another in the morphological characters. In addition, the groups are not distinguishable from one another.

(ii) Morphological similarity and geographical distribution :

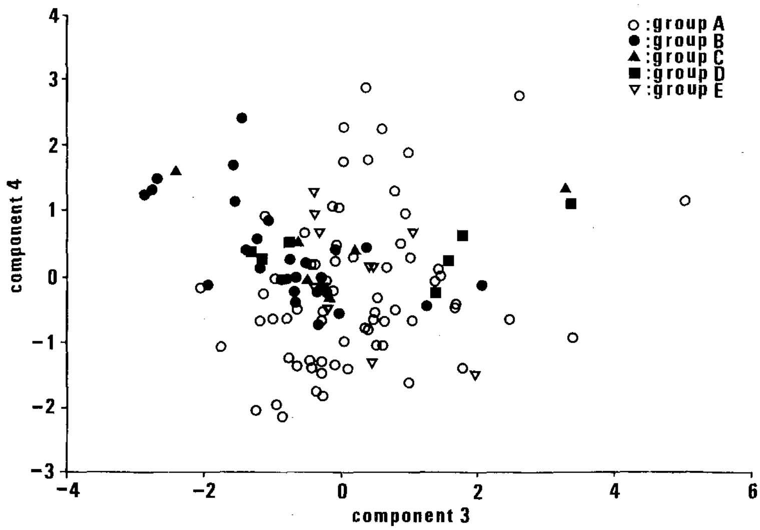

Fig. 6. Correlation of principal component 3 and 4. Each sign indicates groups recognized from chromosome numbers.

Cluster analysis is carried out for the mean values of the thirteen characters of 30 populations from different localities. Squared Euclidian distances are calculated for dissimilarity, and the UPGMA method is used for clustering. Five clusters can be recognized, if divided at the level of 400 (Fig. 7). They are designated as clusters 1, 2, 3, 4 and 5. Cluster 1 includes ten populations (Pops. 2, 9, 10, 12, 13, 16, 24, 28, 49 and 50) belonging to the groups A, D and E. Cluster 2 contains 15 populations (Pops. 6, 7, 8, 23, 27, 31, 34, 39, 43, 44, 48, 51, 53, 54 and 55) belonging to all five groups. Clusters 3 and 4 consist of a single population belonging to group A. Cluster 5 includes three populations (Pops. 19, 46 and 47) in group A. If divided at a smaller value, the populations belonging to group A tend to make compact clusters (for example, Pops. 2, 13, 9 and 16 ; Pops. 10, 28 and 12). Among the populations of group B, Pops. 43, 44 and 53 are similar to one another and also to Pop. 48 in group D. The populations belonging to groups D and E are morphologically different from each other.

The cluster analysis indicates that populations belonging to the same groups are not always morphologically similar. Moreover, populations of clusters 1 and 2 are spread throughout Japan (see Figs. 4 and 7). Cluster 5 consists of three populations ranging from Niigata Prefecture to Tottori Prefecture along the Japan Sea side of Honshu. The populations of higher polyploids (6x–12x) and those of lower polyploids within the same clusters are not close geographically.

(iii) Morphological variation within groups :

The result of the principal component analysis and the cluster analysis indicate that each group has a large amount of variation in morphological characters. Populations belonging to the same group are not always morphologically similar. When the populations within the groups are examined on combination of characters, the groups can be divided into subgroups. Tentatively, I call them morphotypes.

In group A there are slight morphological differences between seashore and mountain populations. Seashore populations (Pops. 2, 7, 8, 9, 10, 13, 16, 19, 23, 24, 46 and 47) are mainly distributed along the seashore of Hokkaido, Tohoku and Hokuriku Districts, and mountain populations (Pops. 11, 28, 30, 31, 34, 37 and 39) are found on the mountains of Tohoku, Kanto and Chubu Districts (see Table 1). The seashore populations tend to have large values for both WWL/LBL and WSB (Fig. 8): they have obovate leaves and thick stems. The mountain populations tend to have small values for both of them: they have oblong leaves and thin stems. Pop. 27 of Mt. Mitsuishi has an intermediate value for both of them. Though distributed on the seashore, Pop. 19 of Murakami has a small value for WWL/LBL and a large value for WSB: they have oblong leaves, thick stems and large plant bodies.

Populations of group B are mainly distributed on the Omine Mountains in the Kii Peninsula and the middle to southern parts of the Kyushu Mountains. Pops. 43, 44 and 53 have smaller average values of LBL, WWL, NSL, PH, WSB, NL, LNL and SNL; they have small plant bodies with serrate leaves. Pops. 54 and 55 have larger average values; they have large plant bodies with crenate leaves. The result of the cluster analysis also suggests that Pops. 43, 44 and 53 are very similar to one another in morphological characters. Thus the morphological similarity of populations within group B does not correspond to their geographical distribution.

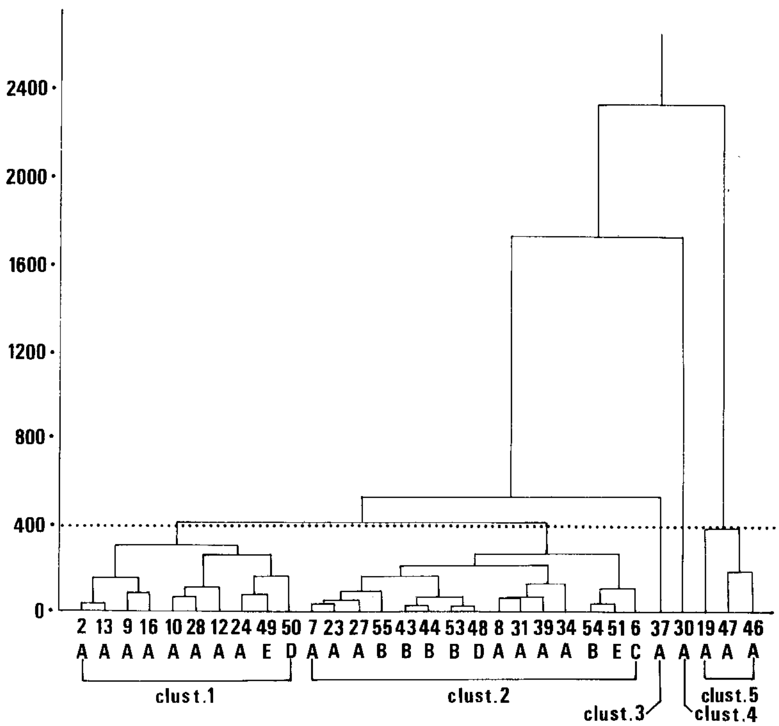

Fig. 7. Result of the cluster analysis. Numbers indicate the population number and letters indicate the group.

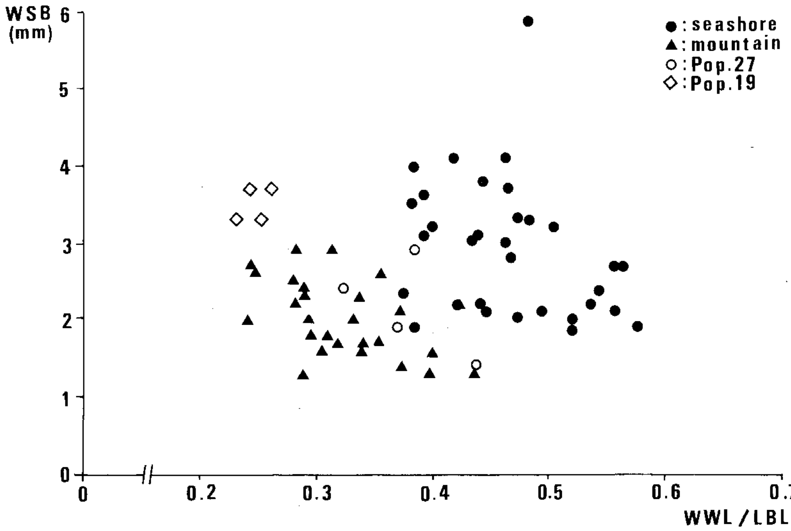

Fig. 8. Difference among populations within group A. Seashore populations include Pops. 2, 7, 8, 9, 10, 13, 16, 23, 24, 46 and 47. Mountain populations include Pops. 11, 28, 30, 31, 34, 37 and 39. WWL/LBL indicates leaf shape : small values mean obovate leaves and large values mean oblong leaves. WSB indicates thickness of stem.

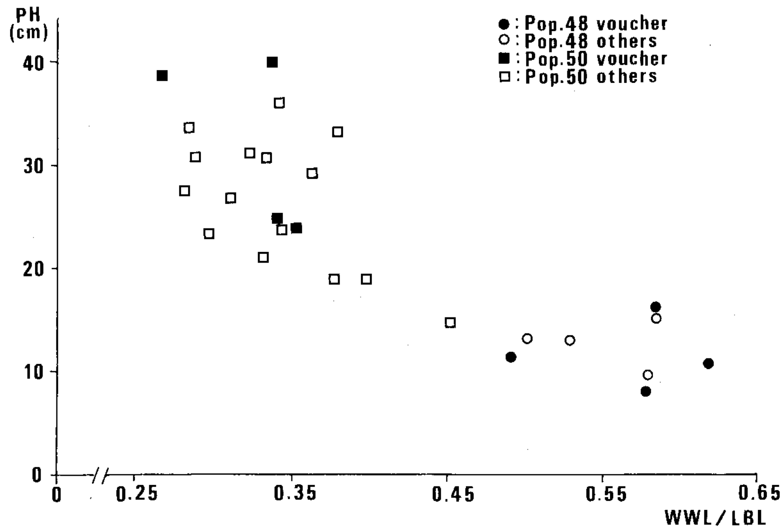

Fig. 9. Difference between populations within group D. Solid signs indicate the voucher specimens for chromosome counts, and open ones indicate other specimens. WWL/LBL indicates leaf shape : small values mean round leaves and large values mean oblong leaves. PH indicates plant height.

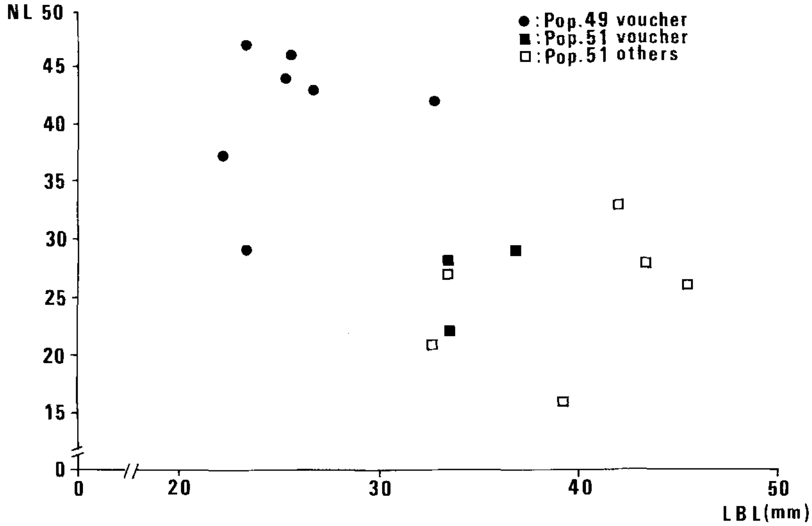

Fig. 10. Difference between populations within group E. Solid signs indicate the voucher specimens for chromosome counts, and open square indicates other specimens of Pop. 51. LBL indicates leaf length and NL is number of leaves: large values mean leafy.

Group D is distributed in Shikoku. It also has two types (Fig. 9). Pop. 48 on Kankakei has a larger value for WWL/LBL (round leaves) and a smaller value for PH (short stem) than Pop. 50 on Mt. Tsurugi.

Group E includes four populations, Pops. 41, 49, 51 and 52, and is distributed in western Japan. It has at least two types (Fig. 10). Pop. 49 on Hoshigajyo has shorter stems and a larger number of leaves than Pop. 51 on Kamitsushima. The other populations could not be analyzed because of their small sample sizes.

As a result, ten morphotypes can be recognized from the examination of morphological characters among the populations belonging to the same group. Features of each morphotype are summarized in Table 5.

Discussion

S. aizoon var. *floribundum* shows a wide range of variation in chromosome number; that is, 2n=32, 33, 34, 48, 61, 64, 78, 80, 84, 85, 88, 93, 94, 95, 96, 97 and 102. Among them 2n=32, 48, 64 and 96 were also reported by Ogawa and Yuasa (1970). Uhl and Moran (1972) regarded *S. aizoon* var. *floribundum* as *Sedum kamtschaticum* Fischer, so that their counts of *S. kamtschaticum* may include those of *S. aizoon* var. *floribundum*. Uhl and Moran's counts for the materials from Honshu and Shikoku are taken as those of *S. aizoon* var. *floribundum*, because the real *S. kamtschaticum* is distributed only from Hokkaido and the Shimokita Peninsula, the northernmost part of Honshu in Japan. Uhl and Moran (1972) reported n=16, "16+1" and 32 from the samples collected in Japan. They are identical to 2n=32, 33 and 64, respectively: the expression n=16+1 means that the plate consisted of 16 bivalents and one extra,

Table 5. Features of morphotypes recognized from combination of ploidy level and morphological characters

Type number	Ploidy level	Plant height (cm)	Leaf shape WWL/LBL	Leaf blade length (mm)	Serration of leaves	Thickness of stem (mm)	Number of leaves	Geographical distribution
1	4x	short to tall 12.7–46.7	obovate 0.40–0.55	variable 23.6–54.1	number : 5.0–7.9 shape : obtuse	thick 2.0–4.3	variable 31.0–49.5	seashore of Hokkaido and Honshu except southern pacific coast
2	4x	medium 16.2–38.2	oblong 0.28–0.37	variable 20.3–44.8	number : 5.8–10.7 shape : obtuse	thin 1.6–2.6	variable 31.6–45.6	mountains of Tohoku, Kanto and Chubu
3	4x	tall 42.0	oblong 0.25	long 65.7	number : 9.0 shape : obtuse	thick 3.5	many 54.0	seashore of Murakami
4	6x	short 7.3–11.3	oblong 0.41–0.45	short 25.4–27.9	number : 4.5–6.4 shape : obtuse	thin 1.3–1.7	several 21.0–26.3	Omine Mountains and Mt. Do
5	6x	medium 13.7–16.8	obovate 0.40–0.46	medium 30.1–39.0	number : 8.9–9.5 shape : rotundate	thin 2.0–2.3	several 24.9–32.0	Kyushu Mountains
6	8x	medium 16.4	oblong 0.33	medium 35.1	number : 5.7 shape : acute	thin 1.9	several 25.7	seashore of Asamushi
7	10x	short 12.2	round 0.44	short 28.0	number : 8.2 shape : obtuse	thin 1.5	several 27.3	a mountain of Isl. Shodo
8	10x	medium 32.1	oblong 0.33	short 29.0	number : 8.9 shape : obtuse	thin 2.2	many 46.8	Mt. Tsurugi
9	12x	medium 22.7	round 0.58	short 25.7	number : 7.0 shape : obtuse	thin 2.0	many 41.1	a mountain of Isl. Shodo
10	12x	medium 16.6	oblong 0.40	medium 34.6	number : 8.4 shape : obtuse	thin 1.3	several 26.3	seashore of Isl. Kamitsushima

All numbers are an average of populations.

probably accessory, chromosome. Uhl and Moran (1972) also reported n=16, 32, 48, 64, "5x/2 prob." and "7x/2" from the plants from South Korea. They are identical with 2n=32, 64, 96, 128, 80 and 112, respectively. They thought that the basic number was x=16, and that "5x/2 prob." and "7x/2" mean a pentaploid and a heptaploid, respectively. Thus "5x/2 prob." and "7x/2" are identical with 2n= ca. 80 and 112. Hence 2n=34, 61, 78, 84, 85, 88, 93, 94, 95, 97 and 102 can be considered as new chromosome numbers discovered in the present study.

The basic number is essential for the determination of ploidy levels, however, that of *Sedum* subgenus *Aizoon* is obscure at present. Uhl and Moran (1972) considered the basic number as x=16, however, the minimum chromosome number (2n=16) of the subgenus *Aizoon* is that of *S. sikokianum* (Ogawa and Yuasa, 1970; Amano and Ohba, in press). Therefore, x=8 is supported by the data of Ogawa and Yuasa (1970) and Amano and Ohba (in press). Thus *S. aizoon* var. *floribundum* can be said to include tetraploid, hexaploid, octaploid, decaploid, endecaploid, dodecaploid, tetradecaploid, hexadecaploid and various aneuploids. Among them hexaploid, decaploid, endecaploid, dodecaploid and tetradecaploid can not be derived directly from tetraploid by simple chromosome doubling. Longer and shorter chromosomes exist in the plates of individuals with 2n=64 (Fig. 2-F) and 2n=95 (Fig. 2-G), but they are not found in tetraploids. These facts suggest that these polyploids were formed in a complicated way.

Considering the basic number as x=8, aneuploids found in this complex are 2n=33, 34, 61, 78, 84, 85, 93, 94, 95, 97 and 102. The frequency of aneuploid is higher at higher polyploid levels. More than two chromosome numbers are found in all the populations with 2n=61 or more. Uhl and Moran (1972) also observed variation in chromosome number within the same locality. Such a variation in chromosome number is also reported in other genera, such as *Poa macrocalyx* Trautv. et Meyer (Tateoka, 1980) in Japan and *Claytonia virginica* L. (Rothwell, 1959) in U.S.A.

Sedum aizoon var. *floribundum* shows a conspicuous pattern of geographical variation of chromosome number in Japan. Tetraploids are mainly distributed in the eastern part of Japan, while the higher polyploids are distributed in more or less isolated localities of the western part of Japan. This pattern of chromosomal variation seems to be similar to that found in South Korea (Uhl and Moran, 1972). In South Korea the chromosome number of this variety seems to vary with location and includes various higher polyploids (8x–14x).

From the morphological similarity tetraploid can be considered as one of the ancestors of higher polyploids, which shows that the populations distributed in Hokkaido and the eastern part of Honshu are primitive, and that those distributed in the western part of Japan are derivative. There are several cytogeographical studies covering a large area of Japan: *Ranunculus silerifolius* Lév. (Fujishima and Kurita, 1974; Okada and Tamura, 1977), *Calamagrostis sachalinensis* Fr. Schm. (Tateoka 1974a, 1974b, 1976), *Agrostis mertensii-flaccida* complex (Tateoka, 1975), *Calamagrostis hakonensis* Franch. et Savat. (Tateoka, 1976, 1984), *Lemna paucicostata* Hegelm. (Beppu and Takimoto, 1981), *Eupatorium chinense* L. subsp. *sachalinense* (Fr. Schm.)

Kitamura var. *oppositifolium* Koidz. (Watanabe and Yahara, 1984) and *Aster ageratoides* Turcz. (Irifune *et al.*, 1985). But none of them has shown geographical variation of chromosome number similar to that found in the present study.

Chromosomal variations are regarded as mutations which are difficult to fix in a population, because mutants must confront chromosomal sterility barriers on the way to fixation (Hedrick, 1981). Small effective population size is one of the conditions favorable to the fixation of chromosomal variations including polyploidy (Wright, 1940; Hedrick, 1981). *S. aizoon* var. *floribundum* is widely distributed from Hokkaido to Kyushu in Japan, but it is distributed most abundantly in Tohoku and the mountain region of Chubu District (Fig. 1). In these regions, the density of the populations as well as the population size seems to be larger than in the other regions. Its distribution in the western part of Japan is more or less disjunct, and the population sizes seem to be small. This may be one of the reasons why polyploids are mainly distributed in the western part.

As a result of morphological and cytological researches at least ten morphotypes have been recognized: three in group A, two in group B, one in group C, two in group D and two in group E (Table 5). Various morphotypes found within the same ploidy level suggest a heterogeneous nature for *S. aizoon* var. *floribundum*. Thus, *S. aizoon* var. *floribundum* can be regarded as a polyploid-aneuploid complex, which should be clarified in further studies of this complex.

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