

## Succession of *Pinus thunbergii* forest on coastal dunes, Hitotsuba Coast, Kyushu, Japan

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*Pinus thunbergii* forest on coastal sand dunes and natural evergreen broad-leaved forest on old sand dunes were studied. The gradual change of floristic similarity among the stands seems to be a series of vegetational succession from *Pinus thunbergii* forest to *Persea thunbergii* natural forest. A considerable amount of fallen leaves (litter) has been raked up and taken out from the forest floor to use as compost. A beautiful moss carpet of *Hypnum plumaeforme* developed in the stands with no fallen leaves. The successional change in these stands is very slow and sometimes retrogressive even after the destruction of the tree canopy by the pine wilt disease.

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### Introduction

*Pinus thunbergii* forest is the most common forest vegetation on coastal dunes in the warm-temperate zone of Japan. Most of these forests have been planted artificially. They are expected both to fix the sand and to break the wind. The history of the afforestation on coastal dunes is very old. Some of them were maintained more than three hundred years under the silvicultural controls of local government. *Pinus thunbergii* seems to be the most suitable species for planting on the sand dunes, because it is very tolerant to both the drought of soil and the violent wind with salt. It also grows naturally in the coastal area. Natural *Pinus thunbergii* forest, known as *Pinus thunbergii*-*Pittosporum tobira* community (sociation) is commonly found on rocky coast (Yoshioka, 1958).

Hitotsuba Coast is one of the most famous coasts with developed pine forest in Kyushu. The oldest stand was afforested more than one hundred years ago. The afforested area is under the silvicultural control of both the Forestry Agency and the Prefectural Government. Thou-

gh it has been maintained carefully, pine wilt disease, caused by a certain Nematoda (Kiyohara & Tokushige, 1971; Mamiya & Kiyohara 1972), killed a considerable number of pine trees in the last two decades.

Coastal pine forest is very important not only as a shelter belt but also in landscaping the coast. In spite of the effort of the officers, to control the vector insect, it is difficult to preserve the pure pine forest. It is desirable to induce the artificial pine forest to a more stable forest type. This paper describes the process of vegetational succession of pine forest in Hitotsuba Coast, and refers to the principle of maintenance of it.

### Area investigated

Hitotsuba Coast is located just north of Miyazaki City, southeast of Kyushu island. The climate of this area is warm and moderate. The annual mean temperature is 16.8°C, the daily mean temperature of the hottest month (August) is 26.9°C, and that of the coldest month (January) is 6.7°C. The annual precipitation is

about 2600 mm, usually without snow.

Natural vegetation on the sand dunes of this area consists of the communities of *Ischaemum antheboroides*, *Vitex rotundifolia* and other grasses. Among these communities, 2-year-old seedlings of *Pinus thunbergii* have been planted, sometimes with *Robinia pseudoacacia*, *Elaeagnus umbellata*, and *Myrica rubra*. The density of planted seedlings may be about 10,000 per hectare. It is not easy to make well-developed forest. The forest of today is the result of such efforts as putting a wind breaker fence around the seedlings, and planting again and again. The afforested area has been expanded into 15 km long and 200–600 m wide. A considerable area of forest floor has been cleaned up by the farmers, who have raked out fallen leaves every winter for making compost for cultivating tobacco plants.

There is another type of forest on the old sand dune. It is the holy forest around a shinto shrine. It consists of *Persea thunbergii* and other evergreen broad-leaved trees. This forest seemed to be a climatic climax forest. Figure 1 shows the vegetation of the investigated area.

## Methods

Vegetational investigation was made in the summers of 1982 and 1983. Nineteen stands of *Pinus thunbergii* forest, four stands of holy forest, and one stand of natural pine forest were investigated. Braun-Blanquet cover-abundance value and sociability are estimated and recorded for each species in the recognized community layer of a stand. The vegetational data obtained were tabulated and rearranged to emphasize the successional changes. Although factor analysis and the other numerical methods supplement the table method, the final arrangement of the table is decided by the number and the ecological status of differential species.

The effect of disturbance of undergrowth by raking up the fallen leaves was considered. The development of a moss carpet of *Hypnum plumaeforme* must be correlated with the amount of fallen leaves. It is, however, very difficult to represent the intensity of raking.

## Results

Some examples of sand dune vegetation are

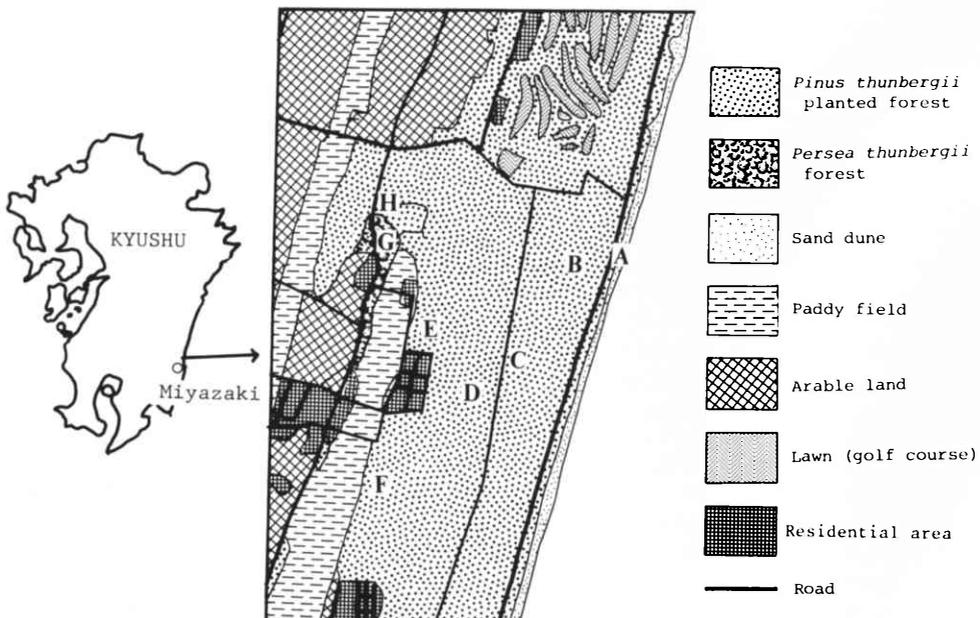


Fig. 1. Map showing the vegetation and the location of investigated stands.

A, F327. B, F254–256 and F269. C, F268 and F326. D, F259–262, F270 and F330. E, F257–258. F, F263–266. H, F267.

shown in Table 1. These communities are common in the coastal sand dunes of Kyushu (Miyawaki, 1981). The seedlings of *Pinus thunbergii* have been planted under the same circumstances. This is the starting point of the succession. The vegetation (relevé data) of *Pinus thunbergii* stands and *Persea thunbergii* stands is shown in Table 2. The arrangement of relevés and species is decided by tabular comparison (Mueller-Dombois & Ellenberg, 1974) with the aid of mathematical treatment.

#### Stand age and development of the layers

In about 20-year-old stands, pine trees have grown to about 4–5 m high, and the forest crown has been closed. No woody species is found except *Robinia pseudoacacia* planted together with the pine. The herb layer is also poor, with scattered plants of *Vitex rotundifolia*, *Ischaemum antheophorioides*, *Miscanthus sinensis*, and *Imperata cylindrica* var. *koenigii*. They are the remains of sand dune vegetation. The moss layer, consisting of *Hypnum plumaeforme*, covers 60–80 percent of the area on the sunny floor and about 10 percent on the rather dark floor.

In the stands of fifty years old, tree layer and subtree layer are differentiated. The height of the layer reaches about 10 m and 3–5 m respectively. Subtree layer consists of *Robinia pseudoacacia* and *Pinus thunbergii*. Such shrubs as *Symplocos lucida*, *Ligustrum japonicum*, *Vaccinium bracteatum* and the others have penetrated into the forest floor. *Lophatherum gracile* and *Lespedeza cuneata* have invaded the herb layer. Fallen leaves are raked up and transported out of the forest in the most of the stands every winter. H and A-horizons of soil are very thin and coverage of the moss layer is high in these stands (Figs. 2 and 4). Seedlings of tree species are not found except *Pinus thunbergii*. In the stands of more than fifty years old and with no raking of fallen leaves, the herb layer has developed and the moss layer is poor. H-horizon and A-horizon of soil is 2–3 cm and more than 5 cm thick, respectively (Figs. 3 and 5). Such perennial herbs as *Ophiopogon jaburan* and *Carex lenta* have entered.

Pine forests have been often damaged by pine wilt disease. Two types of succession are observed when the forest canopy has been broken. The one is the rapid growing of under story

Table 1. Natural vegetation of mobile sand dunes

Table number		1	2	3	4
Total cover of herb layer(%)		90	90	60	80
Height of herb layer (cm)		20	20	15	15
Area (m <sup>2</sup> )		1.0	1.0	1.0	1.0
<i>Vitex rotundifolia</i>	H	5.4	5.4		
<i>Digitaria timorensis</i>	H	+	+		
<i>Ischaemum antheophorioides</i>	H		1.2	3.4	4.4
<i>Wedelia prostrata</i>	H			3.2	2.2
<i>Carex</i> sp.	H		+		+
<i>Imperata cylindrica</i> var. <i>koenigii</i>	H	1.2			
<i>Carex kobomugi</i>	H			+	

broad-leaved species, and the other is the natural regeneration of *Pinus thunbergii* forest. The first type is found in the stands, which left as natural, have low density of pine tree and abundant undergrowth. The second type is found in the stands where the undergrowth has been affected by raking up the fallen leaves out of the forest floor. Thus, many seedlings of pine trees are found under the canopy gaps.

#### Index of successional continuum

Indexes showing the successional stage were obtained by two methods. The first one is based on the floristic composition. The constituent species are classified into the following three groups: Group A consists of the species of sand dune vegetation and man-made pine forest. Group B consists of the species of the deciduous secondary forest (deciduous *Quercus* coppice, etc.) or in natural pine forest. This is the intermediate of the groups A and C. Group C consists of the species growing in the evergreen broad-leaved forest. Others are species of low frequency.

The proportion of the group in each relevé was calculated. The total proportion of group A (IC, index of coastal pine forest flora) varies from 0.0 to 0.87. This value seems to correlate with the stand age. It may also correlate with the distance from sea. The younger stands are located nearer the sea shore than the older stands. The proportion of group B was between 0.0 and 0.33. Although the value was high in the young stands of pine forest, no more specific character is found. The proportion of groups C (IE, index of evergreen broad-leaved



**Fig. 2.** An inside view of a stand with raking. Fallen leaves (litter) are raked up and brought out of the forest in winter.



**Fig. 3.** An inside view of the stand with no raking. Shrub and herb layers are well developed.



forest flora) seem to be closely correlated with the stand age. It varies from 0.0 to 0.85. Figure 6 shows the correlation between IC and IE.

The second index is based on multivariate analysis. Factor analysis is applied to such a correlation matrix, as the correlation coefficient ( $R_{ab} = \text{Covariance}(a,b) / (\text{Standard deviation}(a) \times \text{Standard deviation}(b))$ ) and the Jaccard's similarity index ( $S_{ab} = \text{Number of common species}(a,b) / \text{Total number of species}(a,b)$ ). The calculation is based on the presence/absence data of 71 species in 21 relevés. The species found only in one releve are omitted from the consideration.

A satisfying solution of factor analysis is gotten based on the Jaccard's similarity matrix. Factor loadings of relevés that are estimated by the squared multiple correlation method and the non-iterated solution are used as the indexes. The position of each relevé on the plane including the co-ordinates of factor 1 and factor 2 is arranged in a curved line. The values of the first factor were high in the young stands and those of the second are high in the old *Pinus* stands and *Persea* stands. The values of the third factor are high in the relevés of middle-aged stands. Though the relevés were located on a line that shows an ordination of successive

change, it is not a straight line. It must be one of the faults of the numerical methods ("arch effect" of Hill and Gauch, 1980). A new axis(S) was drawn to give a 45° angle with the first and second ones. A perpendicular line was drawn to the new axis from each relevé as shown in Figure 7. The position of a relevé in the new axis can be calculated by the formula  $CS_n = f_{2n} - f_{1n}$  (value in -1.0 to 1.0). It may be thought to be "a coefficient of succession" of each stand. The same solution with the correlation coefficient is not suitable, because the position of relevés is arranged in such a strongly curved line (bell-shaped). This is not a standard application of factor analysis (Dagnelie, 1978 for example). The multivariate analysis is used only as a tool that supplements the table method.

The indexes obtained by the floristic composition were combined to a new index by the same idea as above ( $IS_n = IE_n - IC_n$ ). Figure 8 shows the close correlation of IN and CS. The floristic index of succession IS seems to be a good index to show the successional stage in the coastal pine forest. It is not an absolute value, but a relative value usable in the limited area only. The results of floristic analysis and factor analysis are shown in Table 3. The other succes-

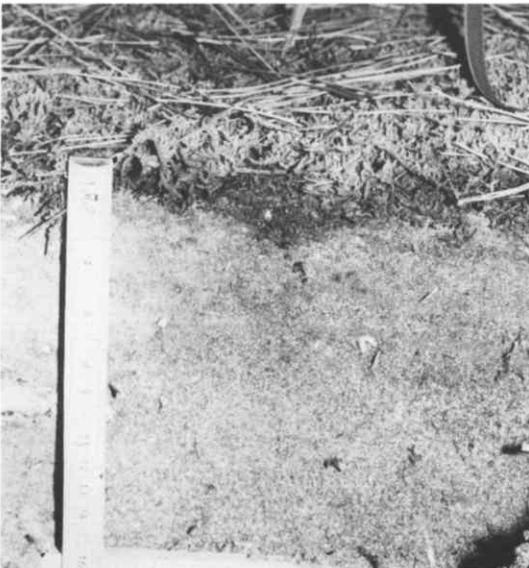


Fig. 4. A profile of soil of the stand with raking. Developed moss layer and thin H and A-horizons are shown.



Fig. 5. A profile of soil of the stand without raking. Accumulated L and F layers and developed H and A-horizons are shown.

sional indexes, such as the degree of succession that is calculated with the life span, dominance, and ground cover of component species (Numata, 1966), has been calculated. The values obtained are not appropriate, because the vegetational data used is rather qualitative than quantitative.

Based on my results, I classify the vegetation of pine forests planted on Hitotsuba Coast into following three groups.

1. Young group. The relevés of young stands containing the species of coastal vegetation (Nos. 1-5 in Table 2).

2. Middle-aged group. The relevés containing the components of the secondary evergreen broad-leaved forest (Nos. 6-10 in Table 2). The forest floor is covered by a moss, *Hypnum plumaeforme*. In these stands, the fallen leaves are raked out every winter and the growth of the shrub and herb layers are reduced.

3. Old group. The relevés containing many components of the evergreen broad-leaved forest (Nos. 11-16, in Table 2). The shrub and herb layers are well developed. The forest floor is usually covered with a grass, *Lophatherum gracile*.

The vegetation of holy forest around a shinto

shrine is broad-leaved evergreen forest, consisting of *Persea thunbergii* and *Litsea lancifolia*. It seems to be a climatic climax forest developed on the old sand dunes. The floristic composition of the natural pine forest of *Pinus densiflora* is similar to the *Persea thunbergii* forest.

## Discussion

*Pinus thunbergii* forest on sand dunes in the Hitotsuba Area seems to change to the *Persea thunbergii* forest, the same as the pine forest on the alluvial plain in central Japan (Kurauchi, 1953). Kurauchi reported that *Pinus thunbergii* forest with *Persea thunbergii* as undergrowth are found in stands of 60 to 300 years old, and the *Persea* type forest, with *Pinus thunbergii*, are found in 300-500 years old stands. The oldest planted forest in Hitotsuba coast is about 100 years old. These stands are now dominated by *Pinus thunbergii*, and the height of evergreen trees reaches to the subtree and shrub layers. This type of forest, *Pinus thunbergii*-*Persea (Machilus) thunbergii* association, is widely distributed in south western Japan (Yoshioka, 1958; Ishizuka, 1974).

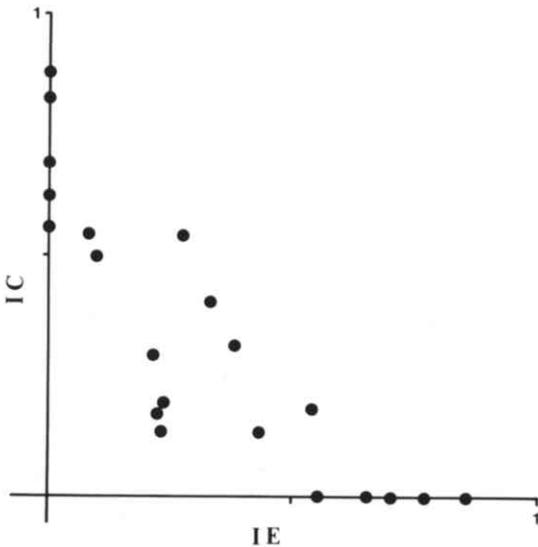


Fig. 6. Scatter diagram showing the correlation between the floristic index of coastal pine forest (IC) and the floristic index of evergreen broad-leaved forest (IE).

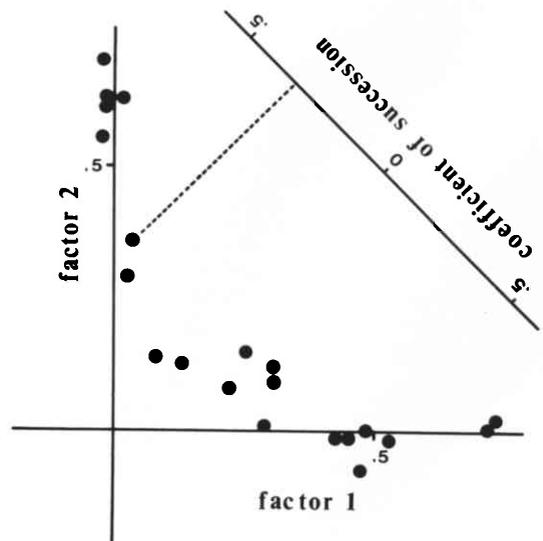


Fig. 7. Scatter diagram showing the result of factor analysis of relevés based on Jaccard's similarity index and the coefficient of succession derived from the factor loadings.

Table 3. Floristic analysis and factor analysis

Relevé	floristic index			factor loading			communality	CS****
	IC*	IE**	IS***	f1	f2	f3		
F269	0.88	0.0	-0.88	0.709	0.003	0.095	0.512	-0.706
F262	0.83	0.0	-0.83	0.721	0.021	0.075	0.525	-0.700
F255	0.56	0.0	-0.56	0.531	-0.021	0.340	0.340	-0.552
F327	0.62	0.0	-0.62	0.410	0.001	0.134	0.259	-0.490
F260	0.69	0.0	-0.69	0.448	-0.023	0.140	0.221	-0.471
F261	0.54	0.08	-0.46	0.418	-0.015	0.274	0.250	-0.433
F254	0.50	0.10	-0.40	0.465	-0.074	0.530	0.503	-0.539
F259	0.53	0.27	-0.26	0.286	0.009	0.506	0.337	-0.276
F326	0.29	0.21	-0.08	0.307	0.092	0.419	0.279	-0.215
F268	0.40	0.33	-0.07	0.310	0.116	0.537	0.398	-0.194
F330	0.19	0.23	0.04	0.127	0.121	0.482	0.263	-0.006
F329	0.17	0.22	0.05	0.217	0.081	0.436	0.243	-0.136
F258	0.31	0.38	0.07	0.249	0.146	0.492	0.326	-0.103
F270	0.13	0.23	0.10	0.078	0.137	0.537	0.314	0.059
F257	0.13	0.43	0.30	0.022	0.286	0.583	0.422	0.264
F256	0.18	0.54	0.36	0.033	0.353	0.575	0.456	0.320
F267	0.0	0.55	0.55	-0.023	0.555	0.271	0.382	0.578
F266	0.0	0.85	0.85	-0.006	0.618	0.098	0.391	0.624
F263	0.0	0.65	0.65	0.007	0.623	0.065	0.393	0.630
F265	0.0	0.70	0.70	0.020	0.629	0.153	0.419	0.609
F264	0.0	0.77	0.77	-0.015	0.703	0.096	0.504	0.718

\* index of coastal pine forest flora

\*\* index of evergreen broad-leaved forest flora

\*\*\* floristic index of succession:  $IS_n = IF_n - LC_n$

\*\*\*\* coefficient of succession:  $CS_n = f2_n - f1_n$

See the detailed explanations in text.

The matured or self-fertilized soil of the pine forest enables the indigenous species to grow in the forest floor. The progress of soil maturity in these forests is similar to Kawasaki & Tanaka (1984). In some stands, pine trees are killed by the pine wilt disease. These stands look like the scrub of broad-leaved species, and they must change to the climax forest even if it takes a long time.

The other case is observed in the pure pine stands in which fallen leaves are raked up. In these, if the tree layer is broken down, a lot of seedlings of pine trees grow up soon; then natural regeneration of pine forest is observed. It is characteristic that these stands have no herb layer, and have a well-developed moss layer. The retrogressive or cyclic succession of pine forest is closely related to the maintenance of the forest (raking). The schematic diagram of

the two courses of succession is shown in Figure 9.

It may be the principle of maintenance of the pine forest to take off the fallen leaves from the forest floor. It leaves the soil too poor for growing the broad-leaved evergreen trees. It is suitable for developing the moss layer of *Hypnum plumaeforme* and for growing the *Pinus thunbergii* seedlings. This type of forest is unstable against diseases, but very tolerant to the conditions of sand dunes. So many broad-leaf trees can invade and grow in the case when fallen leaves are left and accumulated as litter on the forest floor. It takes a long time to develop on effective shelter belt, because the growth of broad-leaved trees depends on the development of soil maturity more than does that of the pine trees. The author proposes the combination of treatments, for the sea-side half of

the afforested area and for the inside half. The first one is to allow the raking and to maintain the pure pine stands. The other is to prohibit the raking, and to introduce the broad-leaved tree species for accelerating the succession.

#### Acknowledgement

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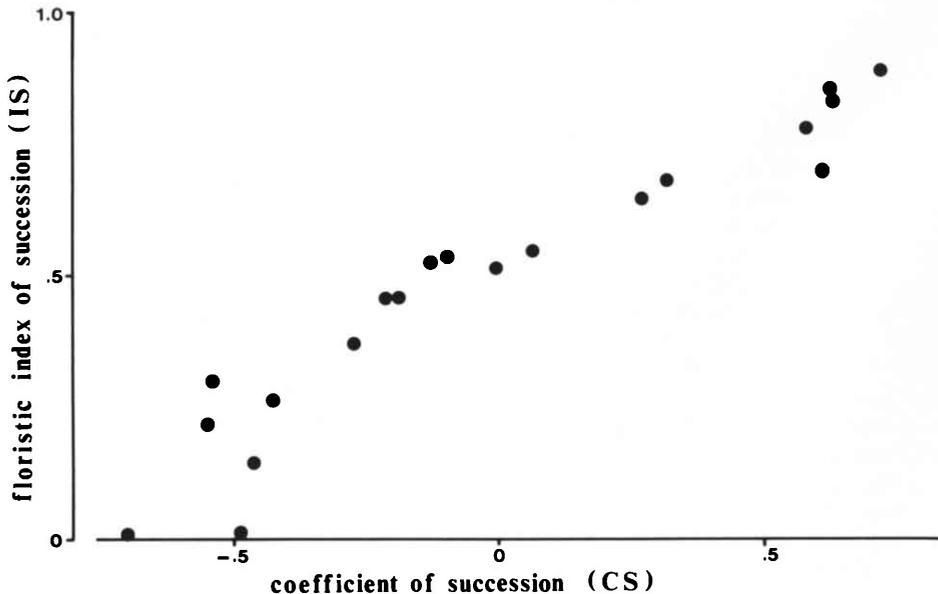


Fig. 8. Scatter diagram showing the correlation between the floristic index of succession (IS) and the coefficient of succession (CS).

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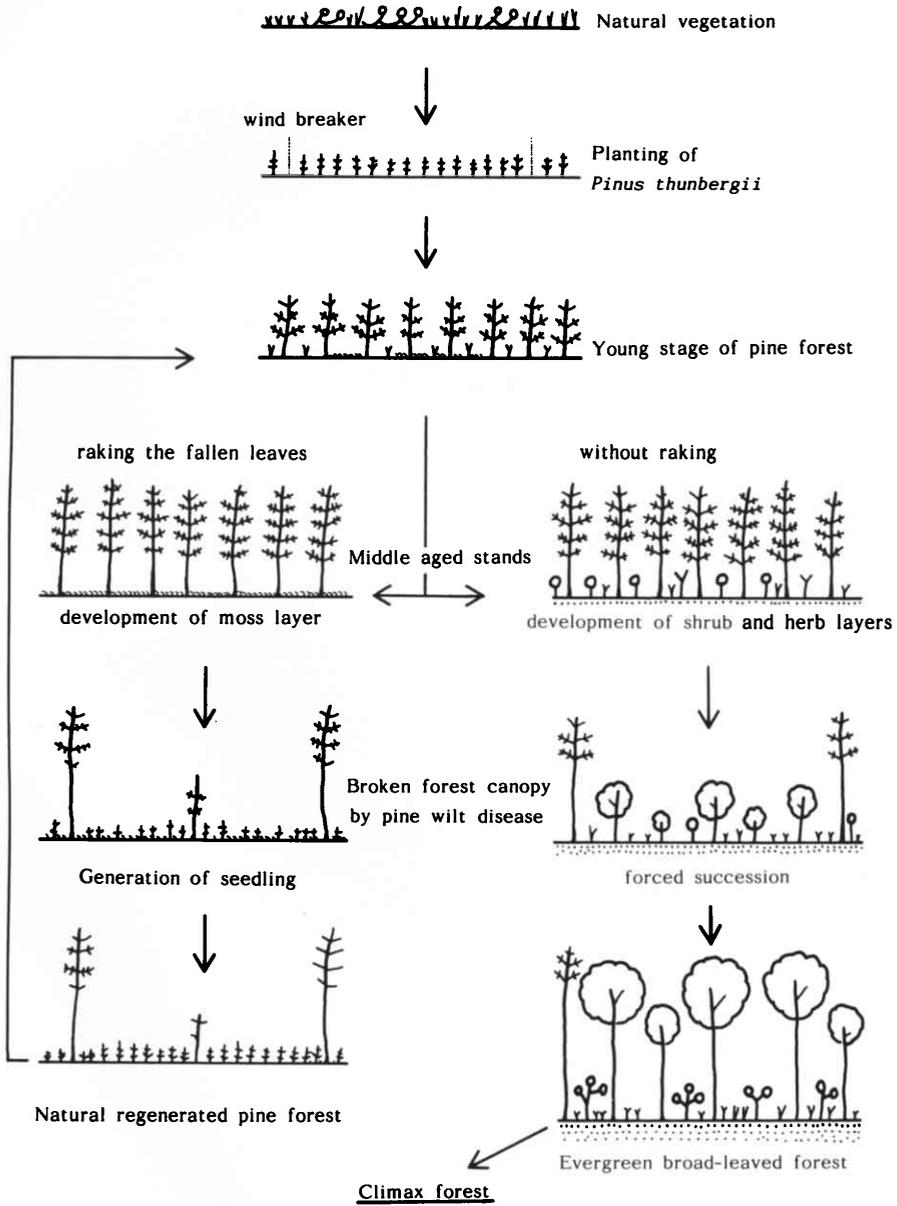


Fig. 9. Diagram showing the succession of *Pinus thunbergii* forest planted on coastal sand dunes.

埜田 宏：宮崎県一葉海岸のクロマツ林の遷移

宮崎県一葉海岸の砂丘上に植栽されたクロマツ林は最も古いもので約100年生である。近年、まつくい虫の被害が見られ、場所によっては広葉樹林化しつつある。一方、天然更新によってクロマツ林が再生している場所もある。付近の古い砂丘上に存在する社叢林の調査結果と合わせ、クロマツ植林からタブ林への遷移過程を明らかにした。

50年生以上のクロマツ林には、多数の常緑広葉樹林の要素が侵入し、階層構造が発達する。クロマツ林とタブ林の種構成の類似度は連続的であり、クロマツ林からタブ林への遷移が認められる。これは、中部地方で報告された例と同様である。多くの場所では、タバコ耕作に用いる堆肥作りのため、「落葉かき」が毎年行われている。これは、落葉の堆積と低木層、草本層の発達を妨げ、林床にハイゴケ群落を発達させる。このような林分では、

林齢にかかわらず、遷移の進行がおくれ、まつくい虫の被害により生じたギャップにはクロマツ稚樹の発生が顕著である。

Jaccardの植生類似度をもとに因子分析を行い、2つの因子負荷量から、遷移系列に直線的に対応する遷移度係数を算出した。また、林分を構成する植物の生態的位置づけから、遷移度を示す指数を得た。常緑広葉樹林要素と海岸植生要素の構成率の差が最も良い遷移度指数であった。

クロマツ植林を、まつくい虫被害に強いタブ林に誘導するためには、落葉かきを厳禁する必要がある。しかし、塩風に対する耐性、防風林としての諸機能の点ではクロマツ林が優れている。したがって、汀線側では落葉かきを行って、クロマツ林の自己修復機能を維持し、内陸側ではそれを禁止して、遷移の促進をはかることが望まれる。