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A Study of Urban Ecosystems Based on the Concepts of Landscape Ecology and Vegetation Dynamics*

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Introductory remarks : urban ecosystem studies by our project team and their background

During the IBP Period (1964-1974) in which some 600 biological scientists participated, the ecosystem approach progressed repidly in studies of terrestrial and aquatic communities. At that time, I was responsible for the study of grassland productivity and conservation of terrestrial communities. After that, the IBP was succeeded internationally to the MAB (=Man and the Biosphere) Program of UNESCO. Against this background, a Grant-in-Aid from the Japanese Ministry of Education, Science and Culture was awarded for the Special Research Project "Basic Approaches to the Environment in Relationship to Human Survival." Urban ecosystem studies organized by myself, particularly on bay-coast cities of the Keiyo (Tokyo-Chiba) Industrial Zone facing Tokyo Bay, have been included within this framework from 1978 to 1987. I have had another project on the effect of urbanization and industrialization on the biota and on biotic communities of coastal cities in Chiba until now since 1975.

On the other hand, the first report of the Expert Panel of MAB Project No. 11 : Ecological Effects of Energy Utilization in Urban and Industrial Systems was issued in 1973 (UNESCO, 1973), and the Task Force for integrated ecological studies on human settlements, within the framework of Project 11 (UNESCO, 1975), was organized by UNESCO and UNEP. I participated in the above-mentioned Conference in Paris in 1975 and strongly felt the influence of the United Nations Conference on the Human Environment (1972) and the United Nations Conference on Habitat (1974), particularly in regards to integrated ecological studies. After that, the reports of the Planning Meeting with emphasis on industrialized settlements (UNESCO, 1977) and that of the Task Force on methods and concepts for studying man-environment interactions (UNESCO, 1983) were issued. Also, MAB Technical Note 12 : An integrative ecological approach to the study of human settlements (UNESCO, 1979), and Technical Note 14 : Approaches to the study of the environmental implications of contemporary urbanization (UNESCO, 1983) were issued. During this period, research teams on urban ecosystems were formed and obtained good results in the U.S.A., Australia, Germany, Belgium, Mexico and Italy as well as in Japan.

Early publications on urban ecology include the following : "The City as a Life System" (Ecological Society of Australia, ed., 1972), "The Ecology of a City. The Case of Hong Kong" (Boyden et al., 1981), "Urbanization and Environment. The physical Geography of the City" (Detwyler and Marcus, eds., 1972), "The Urban Ecosystem. Holistic Approach" (Sterns and Montag, eds., 1974) as a project of the Ecological Society of America, and "Wildlife in an Urbanizing Environbment" (Progulske, ed., 1974) as the proceedings of a symposium in U.S.A. Perloff's "The Quality of the Urban Envionment" (1969) can also be included.

"L'Écosystême Urbain. Application a l'Agglomératon Bruxellois" (L'Agglomération de Bruxelles, 1975) was issued by a symposium held by Brussels City in which I participated. Harrison and Gibson's "Man in the Urban Environment" (1976), Vester's "Urban Systems in Crisis" (1976),

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"Nature Area for City People" (Johnston, 1990), etc. were published in books one after another, while "Desarrollo Urbano" (Carmona, ed., 1981) of Mexico was a Governmental Report. In the same year, the Pacific Science 4th Inter-Congress was held in Singapore, with the theme "Pacific Cities in the Eighties". At the session on Urban Ecology, I and others in our research group read papers on our urban ecosystem studies (Numata, 1981). The Institute of Environmental Research, Chulalongkorn University, has conducted urban ecological studies for a long time, and issued a report "Changes in the Suburban Area North of Bangkok Metropolis. An Intergrated Ecological Study" (Chulalongkorn Univ., Institute of environmental Research, 1986). Recently we have had two books by Sukopp (1991) and Deelstra and Yanitzky (1991).

In our urban ecosystem studies, the impact of urbanization and industrialization on the components of an ecosystem, such as air, water, soil, plants and vegetation, animals, human behaviour and health , etc., were separately studied in the first stage (1971-1973). This is the so-called "action" (influence of external conditions) analysis as defined by Clements (1916), who was the first to write on "action and effect" in relationship to the causes of plant succession. This stage of our research was characterized as multidisciplinary but was not sufficiently interdisciplinary, and thus, not intergrated.

In the secont stage (1974-1977) we tried to do biocentric and anthropocentric (particulary phytocentric) interdisciplinary and transdisciplinary approaches. Studies of the impact of the urban environment on plants and vegetation (= environmental action on plants and vegetation) are easy to understand and familiar to a plant ecologist ; however, phytocentric, interdisciplinary studies on the influences of plants and vegetation on animals and man and their environment are not. This is so called "reaction" analysis defined by Clements (1916), who stated that "the term reaction is understood to be the effect which a plant or a community exerts upon its habitat". Along this line, "Forest Influences" was written by Kittredge (1948), who stated that "Forest influences may be defined for most purposes to include all effects resulting from the presence of a forest or scrub upon climate, soil water runoff, stream flow, floods, erosion, and soil productivity". "Environmental Measurement and Interpretation" by Platt and Griffiths (1964) is also related to the phytocentric concept. The phytocentric approach to the relationship between plants and environment was conducted by Clements and Goldsmith (1924), using their phytometer method in which "The plant's judgment as to efficient factors" was needed.

In the third stage of our research (1978-1980) the integration of the structure, function and dynamics of urban ecosystems was the goal. For that , we focused our study on the role of water, not only urban hydrology but also the role of water as a throughput and as related to increasing entropy. Water in the production process (input and output) and water as a throughput are tools of integration.

Table 1. Biocentric and anthropocentric viewpoints.

I. Biocentric viewpoint

1. Phytocentric viewpoint

   e.g. Phytosociological classification of associations
   Naturalness rating for vegetation
   Successional sequence based on dominant plant's autecological characteristics

2. Zoocentric viewpont

   e.g. Vegetation mapping from the viewpoint of wild animals (e.g. Japanese monkey) different from a usual vegetation map

II. Anthropocentric viewpoint

   e.g. Land use mapping
   Sustainable utilization of natural resources
   Evaluation and conservation of nature

Table 2. Structure of anthropocentric ecosystem.

Human Being (Individual Communities) Regional Society v.s. Global Society	
Biotic Components	Abiotic Components
Plants (Vegetation)	Air
Animals	Water
Microorganisms	Soil
	Light

These multidisciplinary-interdisciplinary-integrated studies based on the biocentric and/or anthropocentric concept characterize our ecological approaches to urban ecosystem studies (Numata et al., 1974 ; Müller, 1979). In the fourth stage (1981-1983) we aimed at a comprehensive study in the bay-coast cities of which there are many examples in Japan, surrounded by the sea. We applied our methodology to elucidate the structure, function and dynamics of such cities on the basis of the first to third-stage studies.

Now we are in the fifth stage (since 1983), where the relationship of such ecological studies to urban planning and management is being considered. Urban planning and management itself is not our target, but our urban ecosystem studies should suggest various ideas for it.

Biocentric and anthropocentric approaches

Ecolgy was established as a biological science with the idea of a science of the natural homes of organisms (Tansley, 1923). He said "ecology is a science of the field, treating organisms as they grow in nature". It is sometimes defined as "scientific natural history" (Elton, 1927), "ecosystem approach based on matter and energy" (Lindeman, 1942), "systems ecological approach based on mathematical modeling and simulation" (Van Dyne, 1969) and others.

In my ecological studies, I established first the biocentric and anthropocentric viewpoint (Table 1) in the ecosystem concept (Numata, 1953) and later stressed the anthropocentric viewpoint (Table 2) in urban ecological research (Numata, 1983).

According to Naveh and Lieberman (1984), landscape ecology is an interdisciplinary and global science of human ecosystems. The role of human beings in an ecosystem composed of producer, consumer, decomposer and abiotic components is not so big. Landscape ecology

Table 3. Relationships of general ecology and applied ecology to technologies.

General	Applied	Technological
General Ecology	Biological Production Ecology	Production Technology
	Agro-Ecology	Agriculture
	Forest Ecology	Silviculture
	Fish Ecology	Fisheries
	Feral Ecology	Feral Production
	Pasture Ecology	Animal Husbandry
	Diagnostic Ecology	Diagnostic Technology
	Condition and Trend Judgment	Bio-Indicators
	Diagnosis of Grassland Production and Health	
	Diagnosis of Forest Production and Health	
	Conservation Ecology	Bio-Management Technology
	Bio-Diversity	Pasture Management
	Sustainability	Wildlife Management
	Conservation Ethics	Pest Control
		Weed Control
		Pollution Control
		Soil Conservation
		Practice in Nature Conservation
		Designation of Nature Reserves
	Landscape Ecology	Landscape Design and Architecture
	Ecology of Man Nature/Culture Relationship	Landscape Planning and Management
	Ecology of Five Senses	

evaluates adequately the human role in an ecosystem. On the other hand, phytocentric and zoocentric approaches are also used in landscape ecology, as well as the anthropocentric approach. Landscape ecology is applied ecology as a bridge between general ecology and landscape planning and management (Table 3).

I discussed the relationship among general ecology, applied ecology and technical fields (Numata, 1954), before the Journal of Applied Ecology was first issued in 1964. Applied ecology is the application of methodology and concepts in general ecology to specific problems in technical fields, such as landscape ecology vs. landscape architecture.

On the other hand, ecology is divied into (1) macro-ecology of the population/community level, (2) meso-ecology of the individual/ethological level, and (3) micro-ecology of molecular/cellular/functional level. Landscape ecolgy is macro-ecology, particularly on the basis of visual forms on lands, or also the aquascape in water. In the case of the sense of hearing, it is called the soundscape (Schafer, 1977). The landscape can be called visuoscape, as opposed the soundcape, but landscape in a broad sense will include both.

The basis of landscape ecology was laid by Alexander von Humboldt (1808) in his Grundformen or Hauptformen composing the physiognomy of vegetation. His Grundformen developed later in two directions: (1) Griesebach's representative taxonomic forms such as banana form, palm form, etc., and (2) Raunkiaer's life forms (dormancy forms), chamaephyte, hemicryptophyte, etc. I use the growth forms and migrule forms (disseminule forms and radicoid forms; Numata, 1947) as well as the dormancy forms.

As the method of landscape ecology, I use species composition, life-form spectra, dispersion pattern, the degree and rate of succession, etc. particularly for the plant part of the landscape (Numata, 1990).

The Concepts of landscape ecology

The object of such studies does not need to be limited to cities. Recently, the method of landscape ecology is also used as regional ecosystems. The landscape has been considered in geography, urban and regional planning, landscape design and engineering. Besides these there are two new books on landscape ecology. One of them is by Z. Naveh and A. S. Lieberman (1984): "Landscape Ecology. Theory and Application". Naveh says that the notion of landscape ecology as an interdisciplinary science deals with the interrelation between human society and its living space. A holistic landscape-ecological approach contributes to dynamic conservation planning, management and education on a regional and global ecological basis. It is a principle for environmental conservation and management useful for scientists, educators and decision-makers.

According to the foreword by A. M. Schultz (in Naveh and Lieberman, 1984), the name "landscape ecology" is established, the field is recognized, justifications are no longer necessary, and disagreements on what belongs and what does not are slight. However, its concepts have not been so firmly settled yet. North America is said to be in a similar situation, because there, changes in landscape resulting from human activities are still relatively small. In this respect, the necessity of landscape ecology may be very great in a small land crowded with people, like Japan. In a word, the task of landscape ecology is to clarify the role of human influences for environmental conservation and management within the total human ecosystem and to contribute to evaluating the environment and exemplifying the practice of conservation and management.

F. E. Egler (1984) said in the epilogue of the book by Naveh and Liebermann (1984) that Tansley defined ecosystem as an integrated unit composed not only of plants and animals but also of the climate, soil and other aspects of the environment (except man). I pointed out several times similar issues on the concept of ecosystems (Numata, 1976a). Naveh's basic concept is man-and his total-environment ecosystem, as a way to clarify the principles of the man-nature system through landscape changes. It is human ecosystemology based on the landscape.

Man is included in models of ecosystems, but his role is relatively small as a consumer. Actually, however, man is not only a consumer but is also a producer and decomposer. In our study of urban ecosystms (Numata, 1976b) my standpoint is biocentric and anthropocentric approach to an intergrated research. At the Fourth International

Table 4. Vegetation naturalness rating.

Degree of Naturalness	Land Use
1	Urban, housing areas
2	Farmlands
3	Orchard, tea and mulberry plantations
4	Shortgrass grasslands
5	Tallgrass grasslands
6	Afforested lands
7	Secondary forests
8	Secondary forest close to climax forests
9	Climax forests
10	Climax grassland such as alpine meadows

Table 5. Degree-of-Succession (DS) Classes of Natural and Semi-natural Vegatation.

DS Classes	Natural and Semi-natural Vegetation
1	Pioneer and weed communities
2	Shortgrass-type grasslands
3	Tallgrass-type grasslands
4	Secondary forests
5	Climax forests

Congress of Ecology, Syracuse, New York, in 1986, a symposium was held on the theme "Landscape Ecology in Transdisciplinary Science", and there were two other symposia on "The Role of Landscape Heterogeneity in the Spread of Disturbance" in February 1986 and one on "Biotic Impoverishment" in October 1986 in the United States.

The other new book on landscape ecology is "Landscape Ecology" by R. T. T. Forman and M. Godron, also published in 1986. In the preface, landscape ecology is described exploring a heterogeneous combination of ecosystems - such as woods, meadows, marshes, corridors, and villages - their structures, functions, and changes. It points out how the landscape progressed from the wilderness to urban landscapes, and focuses on (1) the distribution patterns of landscape elements or ecosystems ; (2) the flows of animals, plants, energy, mineral nutrients and water along these elements ; and (3) the ecological changes in the landscape mosaic over time. When we focus on the heterogeneity of a landscape, we feel how intertwined its ecological systems are. The future of the field will be catalyzed by basic ecologists and by geographers, wildlife biologists, foresters, planners and landscape architects, agricultural scientists, and others.

The basic ideas of the two books by Naveh and Lieberman and by Forman and Godron are very similar in some points and are also common to my ecological concepts (Numata, 1953). Besides these books, Egler's (1977) "The Nature of Vegetation. Its Management and Mismanagement" mentioned above, and Kenfield's (1966) "The Wild Gardener in the Wild Landscape : The Art of Naturalistic Landscaping" are ecologically interesting. In addition to this, Biogeographica Vol. 16, "Landscape Ecology", in honour of Prof. Dr. J. Schmithüsen (1979), "Biologie der Kulturlandschaft" (Tischler, 1980), and "Landscape Heterogeneity and Disturbance" (Turner, 1987) are noticeable for our studies.

Urban areas as seen from DS (degree of succession) and seral stage classes

The landscape is originally a visual object with its surrounding conditions. Philosopher T. Watsuji (1939) characterized Central Europe as a pastureland which is in a seral stage of retrogressive succession, within the beech climax forest area. The pastureland for grazing of domestic animals is a characteristic of the actual landscape which makes up the European man-environment system. However, the potential landscape there (potential natural vegetation or climax vegetation) is a beech forest, i. e. a beech zone or deciduous broad-leaved forest zone. The land has the potential to develop beech forest, but now it is pasture (man-made or semi-natural pasture).

The Environment Agency of Japan (1976) adopted a vegetation naturalness rating (Table 4) in "The First National State-of-the-Environment Survey". This is mostly in a sequence from the pionner to the climax stage, but this is not equal to the degree of importance of vegetation for preservation. When we remove man-made vegetation from Table 4, the naturalness rating of natural and semi-natural vegetation is considered as the degree-of-succession (DS) classes (Table 5).

The degree-of-succession classes can be expressed with factor loadings in a factor analysis of the evaluation of the visual environment (Shinada and Tachibana, 1975), as shown in Table 6. Here the relationship between vegetation types

Table 6. DS classes of vegetation types and evaluation of the visual environment by the factor loading in a factor analysis for two axes on the mental ease and the atmospheric brightness in the summer.

DS Classes	Mental Ease	Atmospheric Brightness
1	1.0	1.5
2	1.0	0
3	0.3	0.5
4	−0.5	−1
5	−1	−1

and the evaluation of the visual environment is roughly expressed. However, not only vegetation types but also the ground cover and seasonal aspects, etc., show different factor loadings.

The degree of succession (DS) of the seral stages of secondary succession in the warm-temperate evergreen broad-leaved (laurel-leaved) forest region is shown in Table 7. The legend of the actual vegetation map (1/50000) of Chiba (1984) in the Third National State-of-the-Environment Survey (Environment Agency of Japan, 1984) are also described. The legend items correspond to seral stages with similar DS, but natural vegetation types (from 8 to 10 ; see Table 7) are not found on that vegetation map.

I compared maps of potential natural vegetation (1/25000) and actual vegetation (1/25000) of Chiba City (Miyawaki and Suzuki, 1974). At that time, 1 km-wide belt transects from the coastline inland in the central part of Chiba City were compared on the two maps. The sequence of potential natural vegetation is 3-8-9-10 (cf. Table 7). Table 7 is based on an orthosere in secondary succession on mesic loamy soil. In the legend of the map of potential natural vegetation, there are coastal dune plant communities (DS=300), a *Miscanthus sacchariflorus* community (DS=500), and *Euonymus japonicus-Pittosporum tobira* scrub (DS=800) which correspond to the stages from 1 to 10 in Table 7. On the map of actual vegetation, the sequence from the coastline inland is 1-2-6-9-10 for 9 km. The area of 9-10, apart from the coastline covers all of the map of potential vegetation, but is of many very irregularly shaped small patches on the map of actual vegetation. Nevertheless, the seral stage class of vegetation there is similar to 9-10. The potential vegetation of 3-8 near the coast decreases in DS and is degraded in seral-stage classes from 3 down to 1 or 2, and from 8 down to 6.

After that, belt transects were implemented using a map of actual vegetation (1/50000) produced by the Environment Agency of Japan (1984 ; Figs 1, 4). The 1 km-wide belt transects were : (I) from the Chiba Station area eastward, (II) 5 km south of (I), and (III) 10 km south of (I). These three belt transects from west (the coast) to east consist of continuous 1 km quadrats (Table

Table 7. The degree of succession (DS) of seral stages, from pioneer to the climax, and legend of the vegetation map of Chiba.

Seral Stage Classes	DS	Legend on the Vegetation Map
1. Bare areas	0	Landfills, man-made lands, urban districts
2. *Ambrosia artemisiifolia* communities	100	Roadside weeds, farmland weed communities, paddy-field communities
3. *Erigeron annuus* communities	150	〃
4. *Solidago altissima* communities	300	Man-made grasslands, fallow paddy fields
5. *Miscanthus sinensis* communities	500	*Phragmites communis* communities
6. *Pinus densiflora- P. thunbergii* forest; *Quercus acutissima-Q. serrata-Carpinus tschonoski* forests	1000	*Pinus* plantations, *Q. serrata* forests, bamboo forests, housing areas covered with rich green environment
7. *Cyclobalanopsis glauca* forests	2500	*Cryptomeria japonica-Chamaecyparis obtusa* plantations
8. *Persea thunbergii* forests	3000	
9. *Castanopsis cuspidata* var. *sieboldii* forests	5000	
10. *Cyclobalanopsis* spp. forests	7000	

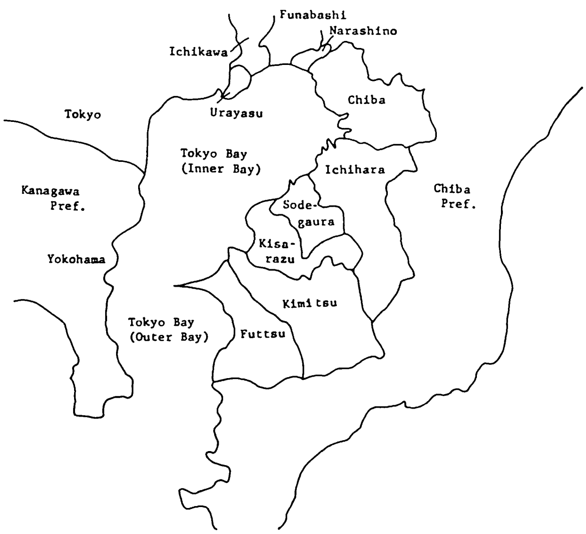

Fig. 1. The bayshore cities of the Keiyo Industrial Zone (Numata, 1990).

8). The 1/50000 vegetation map is better for understanding the rough tendency than the 1/25000 map, but vegetation areas of less than 1 mm^2 on the map ($50x50\ m^2$) are neglected in the former, while fragmental vegetation of 8, 9 and 10, recognized in the latter map, disappeared, and only 6 (*Quercus serrata* forests, pine plantations, bamboo forests, and housing areas covered with rich plant material used as decoration) and 7 (*Cryptomeria japonica*, *Chamaecyparis obtusa* plantations) are recogized. One of the characteristics of Japanese bayshore cities is that the urban district (1) extends far from the seaside, buried under landfills, to 9-15 km inland (Table 8).

Further detailed studies have not yet been carried out, but if the seral-stage classes shown in Table 7 and the evaluation of visual environment shown in Table 6 are applied to the distribution of vegetation on the vegetation maps or on landsat photographs with a 10-year interval, it may be possible to trace the changes in urban environment with the concept of landscape ecology.

The topographic map (Fig 2), the present state of agricultual lands (Fig. 3), and the schematic green-axis map (Fig. 4) will be helpful in understanding the outline of the green belts of Chiba

Table 8. Seral stage classes (see Table 7) of the 1 km^2 quadrats in the 1 km-wide belt transect (from west to east) in Chiba and Ichihara (— is sea) in the summer. (See text)

Serial number of quadrats from the coast	I*	II**	III***
1	—	—	2—3
2	—	—	2—3
3	2—3	—	2—3
4	2—3	—	4
5	2—3	—	2—3, 5
6	2—3	5	5
7	4	2—3	4
8	2—3	5	2—3, 6
9	1	2—3	4, 5
10	1	2—3	4
11	1, 2—3	1, 2—3	1, 2—3
12	1, 2—3	1, 4	1, 6
13	1, 6	2—3, 6	2—3
14	1, 2—3	6	1, 2—3
15	2—3, 7	1, 2—3	6
16	6	2—3, 4	2—3, 6
17	1, 6	2—3	2—3
18	2—3, 7	2—3, 6	4, 7
19	2—3, 6	2—3, 7	6
20	2—3, 6	2—3, 6	2—3
21	2—3, 7	2—3, 4, 6	2—3, 6

* from the Chiba Station area eastward
** 5 km south of I
*** 10 km south of I

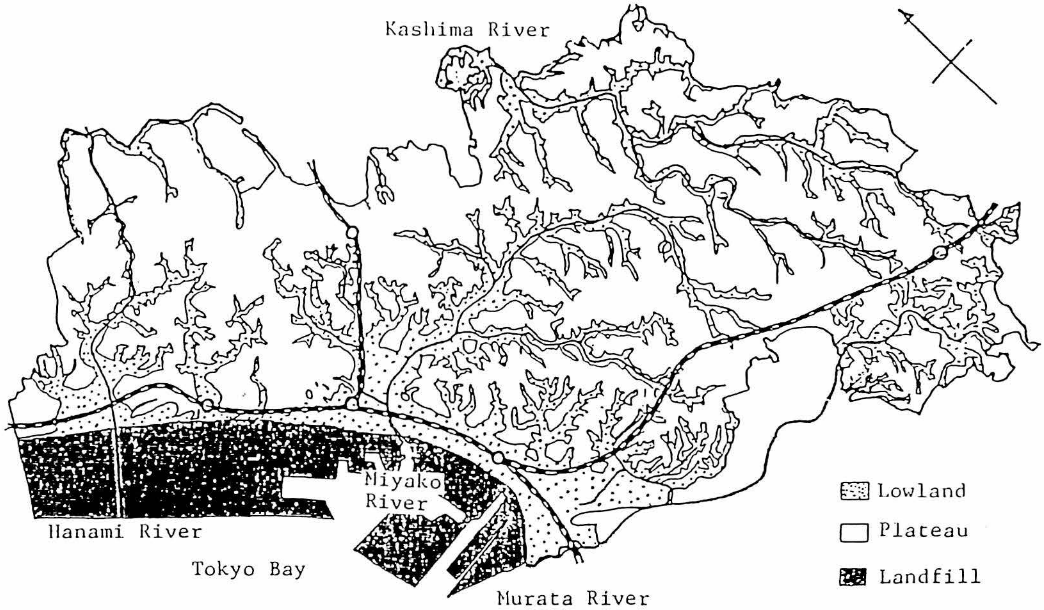

Fig. 2. Topographical Map of Chiba City (Chiba City, 1984).

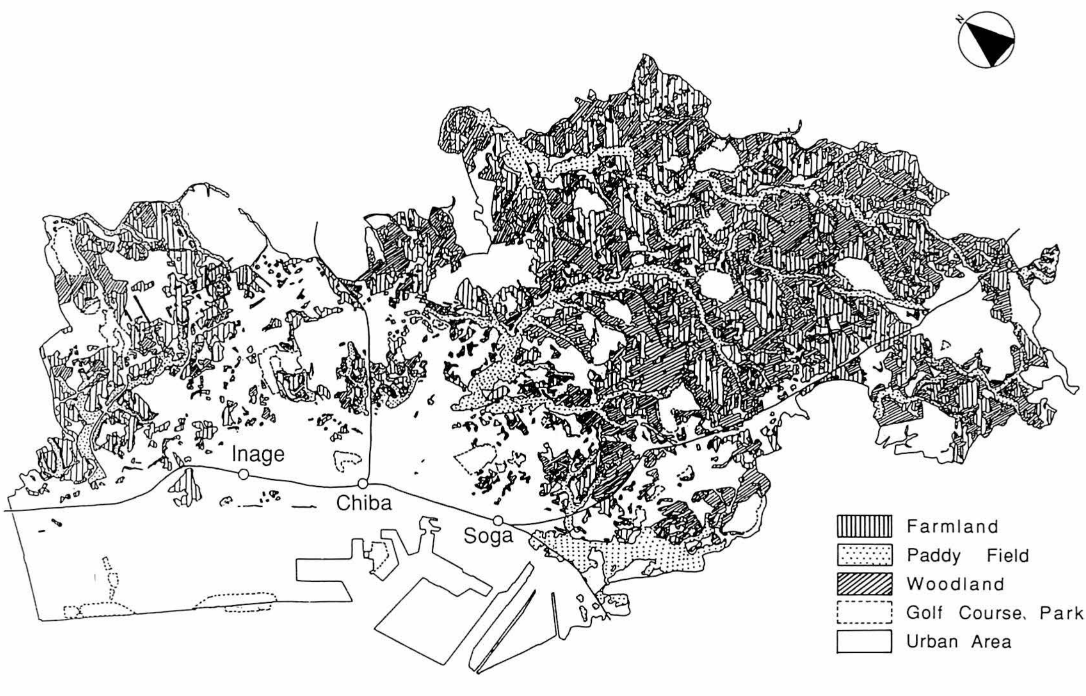

Fig. 3. Present state of green cover and urban area of Chiba City (Chiba City, 1990).

Table 9. Agricultural lands, housing areas and population of Chiba city.

	Paddy Fields	Farmlands	Woodlands	Total 1—3	Housing Area	Population
1973	2,392 ha	5,317 ha	5,364 ha	13,073 ha	4,742 ha	584,868
1983	1,892	4,578	4,953	11,423	6,420	772,447
83—73	−500	−739	−441	−1,650	+1,678	+187,579
$\frac{83-73}{73} \times 100$	−20.9%	−13.7%	−8.3%	−12.6%	+35.4%	+32.1%

City. The legends used there are roughly as follows ; urban ares : 1, paddy field and farmlands : 2-3, and woodlands : 6-10 based on the seral-stage classes (Numata, 1987, Tables, 7, 8). The green plan was developed based on the topographic map and the present state of agricultural lands. The green belts in this figure (Fig. 4) are mainly composed of fragmental woodlands, historical sites and parks.

The decrease in the area of green cover (paddy fields, farmlands and woodlands) is shown in relationship to the increase in the housing area and population (Table 9). We can understand the general trend of green cover as shown in Table 9, but it is difficult to comprehend precisely the change in vegetational cover. Besides this, the distribution of lowlands, plateaus, and landfills are shown in the city area. The distribution of landscape type can be understood by combining topography and the seral stages of succession. In this way, the direction to establish "a city of green and water," the goal of Chiba City planning, will be strengthened.

According to a survey of the life-forms of planted trees in the residential area of Chiba City (Ootomo and Iizumi, 1982 ; Table 10), 55 tree species were observed in early urbanized Shiomigaoka-machi. Of these, *Pinus thunbergii* was dominant, but there were also many individuals of *Castanopsis cuspidata* var. *sieboldii*, *Juniperus chinensis* var. *kaizuka*, *Podocarpus macrophyllus* and *Ilex integra*. Fifty-eight tree species were observed in Inaoka-machi, of which *Juniperus* was dominant and *Pinus* was next, followed by *Castanopsis*, *Diospyros kaki*, and *Acer* spp. There were 44 tree species in Omiyadai, a new housing development, and in Nishitsuga there were 48 species of which *Juniperus* was dominant

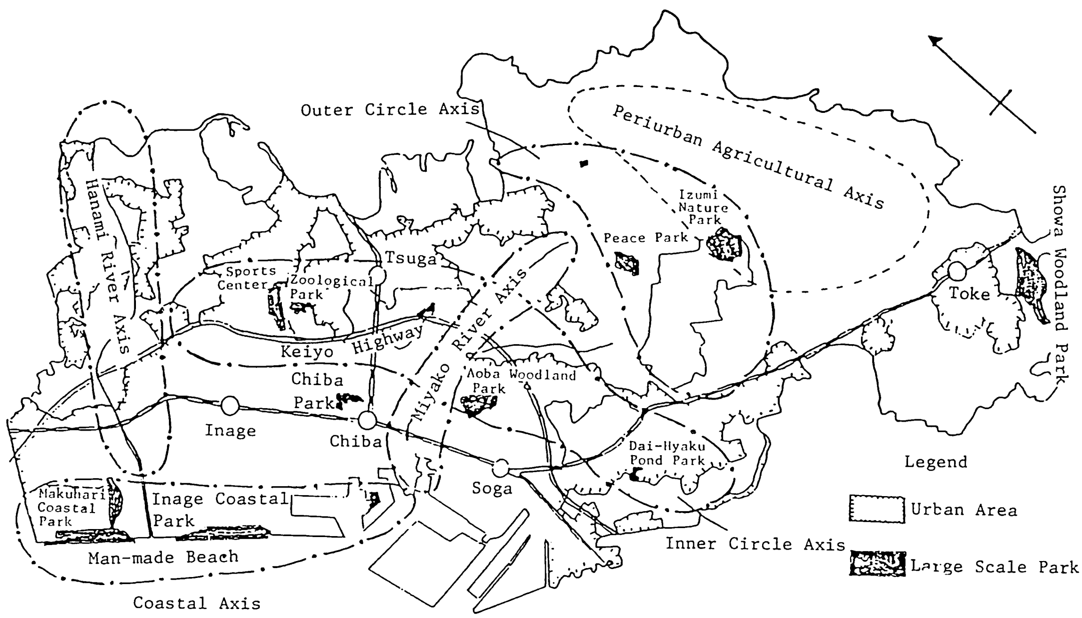

Fig. 4. Schematic green axes of Chiba City (Chiba City, 1984).

Table 10. The life-form ratio of planted trees in four residential areas of Chiba City (Ootomo and Iizumi, 1982). EC: evergreen conifers, EB: evergreen broad-leaved trees, DB: deciduous broad-leaved trees.

	The number of species (%)				The number of trees (%)			
	Shiomigaoka	Inaoka	Omiyadai	Nishitsuga	Shiomigaoka	Inaoka	Omiyadai	Nishitsuga
EC	21.8	19.0	22.7	18.7	42.2	44.3	57.9	50.1
EB	45.5	36.2	47.7	50.0	45.1	33.3	23.7	29.4
DB	32.5	44.8	29.6	31.3	12.7	22.4	18.4	20.5
No. of species	55	58	44	48				
No. of individuals					574	501	451	562

followed by *Podocarpus*, *Chamaecyparis obtusa*, *Ch. pisifera*, *Camellia japonica*, and *Pinus* which are similar in the new housing development of Ichihara City. The Life-forms of tree species in the residential area of Chiba City are shown in Table 10.

The number of trees will affect the landscape of the residential areas by providing green environment, but it is interesting that the number of species (%) is remarkably different from the number of trees (%). The proportion of deciduous broad-leaved trees (=DB) is high in Sendai in the northern part of Japan, and this corresponds to that of evergreen broad-leaved trees (=EB) in Chiba. The number of individuals of DB trees is small, but the number of DB species is large in Chiba, showing that the climate of Chiba belongs to the warm-temperate region. Despite this, the people like deciduous trees.

Such man-planted vegetation includes garden plants, hedges, street trees, shrine and temple plants, park plants, man-made forests and lawns. The species, combinations of species and their stratified structure are important. Natural and semi-natural vegetation includes preserved woodlands, shrine and temple forests, abandoned fields, and grasslands on vacant land. Identifying their distribution pattern in the urban area will help to clarify a regional characteristic, as well as the various other approaches mentioned above.

Vegetation changes due to urbanization as measured by DS and RS

The Nature Conservation Section of the Environment Department of Chiba Prefecture planned a Basic Survey for Nature Conservation in the Southern Boso Peninsula of the Prefecture (Chaired by Numata) and made a Vegetation-Change Chart (1/25000) based on aerial photographs taken in 1977 and 1987 and on vegetation maps (Table 11). The area of vegetation change was measured using a minimal unit of 1 ha. Vegetation changes and their causes were classified as shown in Table 12. As a result, 5,815.5 ha (34.3 %) of the vegetation of the entire investigated area of 6 cities, 9 towns and 1 village (169,502 ha) were found to have changed. Of this, vegetation change due to urbanization (1,432.2 ha) was the greatest (24.6 %). Such urbanization was concentrated in large coastal cities, such as Ichihara, Kisarazu and Kimitsu. Vegetation change in Ichihara City was the greatest, with 50.3 % of the total area having changed, 41.1 % of which was caused by the expansion of urbanized areas.

Round numbers of DS (Degree of Succession) were given for each type of original and present vegetation, and the progressive succession rates (+RS) and retrogressive succession rates (-RS) per year are given in Table 12 (Numata, 1982). Vegetation changes are mostly retrogressive except for plantations, natural succession and landfills. The value of RS/year multiplied by the occupied area (%) shows the landscape changes in terms of DS. In sum, RS x Area (%) is 2076-4863=-2787, reflecting the degradation of ecosystems in coastal cities. This fact is shown more clearly by comparing DS x Area Rate between 1977 and 1987, and also RS/10 years x Area Rate (Table 13).

Conclusion and summary

The Environment Agency of Japan (1976) has made a vegetation map using the vegetation naturalness rating (1-10). The urban area was 3.

Table 11. The area ratios (%) of the present land use as related to changes* in vegetation types over a period of 10 years, in five coastal cities facing Tokyo Bay.

Land Use	Ichihara	Kimitsu	Kisarazu	Futtsu	Tateyama
Urban vegetation	41.1	13.1	56.3	3.3	39.0
Golf course	46.1	15.3	26.8	0.5	0
Quarry	5.5	15.0	0	7.4	12.9
Dam	1.2	8.0	0	2.6	0
Landfill	0	0.6	0	47.7	0
Felling site	2.5	17.7	7.3	13.1	12.5
Conifer plantation	3.1	24.1	3.5	24.1	29.2
Coppice	0.5	6.3	6.1	1.3	6.4

* Cause of vegetation change. A—E: increased human impact, F—G: forestry, H: normal secondary succession.

Table 12. Vegetation change of five coastal cities in the southern half of the Boso Peninsula over a period of 10 years (Chiba Pref, 1987), modified by some data on DS and RS (Numata, 1982).

Area	Original State	DS	Present State	DS	RS*	Area (%)	RS × Area*
A	Grassland	500	Urbanized	100	−40	24.8	−992
B	Coppice	1,000	Golf courses	300	−70	21.8	−1,526
C	Grass field on rocks	1,200	Quarry	0	−20	8.5	−170
D	Coppice	1,000	Dam	0	−100	2.7	−270
E	Sea	0	Landfill	200	+20	9.3	+186
F	Conifer plantation	2,000	Felled site	500	−150	12.7	−1,905
G	Coppice	1,000	Conifer plantation	2,000	+100	17.6	+1,760
H	Grassland	500	Coppice	1,000	+50	2.6	+130
Total		6,200		4,100	−210	100	−2,787

* Progressive (+), retogressive succession rate (−) per year.

Table 13. DS × area ratio and RS × area ratio. (See areas in Tables 11 and 12)

Area	1977 DS × area ratio	1987 DS × area ratio	RS/10 yr × area ratio
A	12,400	2,480	−9,920
B	21,800	6,540	−15,260
C	1,700	0	−1,700
D	2,700	0	−2,700
E	0	1,860	+1,860
F	25,400	6,350	−19,050
G	17,600	35,200	+17,600
H	1,300	2,600	+1,300
Total	82,900	55,030	−27,870

9 % in 1976 and 4.3 % in 1989, as an average for the whole country. I devised DS (degree of succession) and RS (rate of succession) to quantify the progression and retrogression of succession. After that, DS classes (1-5) were proposed. Every vegetation type in the Chiba City area was shown with a DS value. The areal percentages of various vegetation types in the five cities facing Tokyo Bay were investigated for ten years. The vegetation change for ten years is mostly due to urbanization and construction of golf courses. DS x areal ratio and RS/10 years x areal ratio indicate similar vegetation change. The progression of urbanization is also expressed by the Landsat figures of the same area in 1977 and 1987. On the other hand, comparison of the old and new land-use maps and vegetation maps is followed by calculation of the DS, RS and their areal ratios.

The rate and area of urbanization is known by these data.

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