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# Urban Ecology in the Broader Context of Ecological Science*

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Studies in cities have been made in the fields of sociology, geography, economics, demography, etc. However, there have been relatively few studies done from the integrated ecological standpoint. Our project team aimed at clarifying the close relationships between the components and factors of an urban ecosystem, urbanization processes, and changes in human and natural environments caused by them, the effects of changed environments on man, and changes in environmental perception from the standpoint of the biocentric and anthropocentric ecosystem concepts, and others.

In this paper, these themes are discussed, with the exemplifications of the Tokyo Project and the Chiba Bay-Coast Cities Project.

## The Tokyo Project

### 1. The First Period

The period of our studies of urban ecosystems, particularly concerned with the Metropolis of Tokyo, was undertaken for seven years (1971-1977). These studies have been financially supported by the Ministry of Education, Science and Culture, within the framework of "Special Research on Basic Studies of the Natural Environment in Relation to Human Survival". The title of our studies during the first period (1971-1973) was "Fundamental Studies on the Characteristics of Urban Ecosystems" where the characteristics of the urban environment (air, soil, water, etc.), the dynamics of biotic communities under the influence of the urban environment, and changes in the human environment, etc. were studied and discussed. Some of the results up to this stage of the study have been published in a book by the author and others (Numata *et al.*, 1974).

### 2. The Second Period

In the following period of our research, since 1974, the study team was divided into seven groups concerned with the following topics: 1) air, 2) soil, 3) water, 4) vegetation, 5) animals, 6) man, and 7) modelling.

### 3. The MAB Projects and Others

In the beginning, our study was conducted along the guide lines of the basic idea of the MAB programme, particularly related to the viewpoint of "the impact of human activities on the natural environment" (cf. Detwyler *et al.*, 1972). Therefore, studies on the characteristics of the urban environment and on the life of biotic communities and human behaviour under the influence of such environment were stressed in the first period. At the same time, the MAB report of "Ecological effects of energy utilization in urban and industrial systems" (UNESCO/MAB, 1973) was issued, "Urban Ecosystem" edited by Stearns and Montag (1974) was published in the U.S.A. and an INTECOL (International Association for Ecology) journal "Urban Ecology" first approached in 1975. A task force meeting on "Integrated ecological studies of human settlements" was held in Paris by UNESCO, UNEP and INTECOL in 1975, and its report was published (UNESCO/MAB, 1976).

### 4. Workshops and Symposia

Workshops on the methodology of urban ecosystem studies were held several times in Japan in 1974, and their papers were included in our report "Studies on the Structure and Dynamics of Urban Ecosystems-1975." The author convened a symposium on "Urban ecosystems" within the framework of "The human impact on terrestrial ecosystems" at the International Conferrence of Sci

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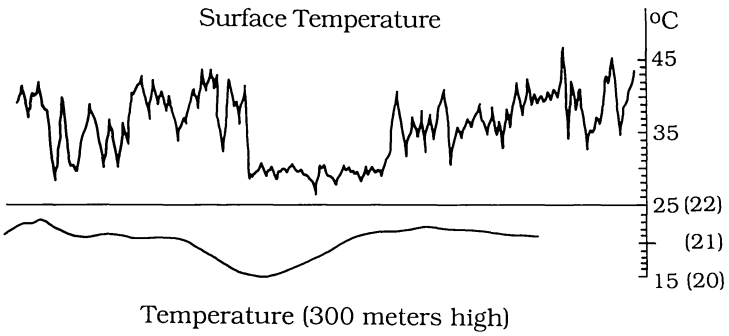


**Fig. 1.** Surface temperature in Nature Study Park (the range of lower temperature) and its Environs and distribution of wet bulb temperature (parenthized figure) in the upper sky of 300 meters high (after Tsuchiya, 1972 -Numata, 1977).

entists on the Human Environment held in Kyoto in November, 1975 sponsored by the Science Council of Japan. The proceedings (HESC Editional Committee, 1976) were published under the title "Science for Better Environment" in which the author's paper "Methodology of urban ecosystem studies" (Numata, 1976) was included.

## 5. Urban Ecosystem

The term "urban ecosystem" is used as an analogy to "natural ecosystem." Matter, energy, population and information flow into an urban ecosystem and flow out in different forms. An urban ecosystem is basically an entity composed of biotic components (plants, animals, microorganisms and man) and abiotic factors (air, water, soil, etc.), i.e. an ecologically integrated holistic entity. It is a problem in determining how to treat a city as such an entity. Of course, a city as an administrative unit is not necessarily equivalent to an urban ecosystem as such. A city is a distinct space having a clear border, whereas the borders between urban, suburban and rural areas are less clear. Needless to say, urban phenomena are also seen even in small villages these days.

## 6. Sample Areas

We have selected the Metropolis of Tokyo as a study site in order to include it in a comparison of large cities of the world. However, Tokyo has various areas with different degrees of urbanization. Therefore, six sample areas (each 9×6 sq. km) were selected, and the studies during the second period (1974-1977) have concentrated on these sample areas in order to collect various kinds of data using a mesh system.

## 7. Abiotic Factors and Biotic Components

*Urban Atmosphere.*

In relation to the urban atmosphere the temperature environment accompanying urbanization was compared for urban areas and suburbs or urban forests. The surface temperature was measured by the infrared radiation thermometer carried in the helicopter. As the results, the surface temperature at the sites of forests and ponds in the Nature Study Park which we studied for a long time and on the buildings and paved roads around the Park was quite different, and the difference was reflected to the air temperature at the height of 300m and 1000m (Fig.1). The surface temperature of the city was about 5°C higher than that of suburban areas even at night. So-called "heat-islands" were found in the old part of Tokyo.

*Urban Soil.*

Regarding urban soils, the method of evaluating soils in urban ecosystems was discussed. Soil as a part of the human environment is evaluated in relation to 1) human life and health, 2) landscape and 3) plant growth or food production. The soil in the area where urban street trees grow is weakly alkaline and has much available phosphoric acid originating in the surrounding concrete (Sukopp *et al.*, 1979). The contents of Pb and Zn in the soils close to roads were high, and those of Ca were similar in some areas. Regarding soil microorganisms, the total number of bacteria reflected the ground cover on the soil surface, and the number of gram-negative and nitrifying bacte-

ria was related to soil moisture, organic matter supply and pH.

*Urban Water.*

Regarding urban water, the hydrological and material cycles in the urban area, particularly the movement of matter due to rainfall, was examined quantitatively. Regarding water quality, the relationship between water pollution and benthic animals in the Tama River was studied, and biotic and pollution indices were calculated. According to the data, polluted water exceeding the self-purification capacity of the Tama River was always found to be discharged to the lower reaches of the River. In ponds and lakes in Tokyo, exotic hydrophytes established earlier and eutrophication proceeded more quickly than in natural lakes. The source of underground water is lost due to urbanization, and the amount as water gushing from springs is very much reduced.

*Vegetation.*

In the vegetation study group, the composition of urban forests, vigor of trees, etc. were studied for long. Weedy vegetaton in urbanized areas, particularly in the area where urban trees grow, was surveyed in relation to the life-form composition in which the ecological characteristic of the urban vegetation was identified. The number and growth of alian plants are related to the degree of human impact. In the comparison of the six sample areas, the species of planted trees in the residential area are limited in the centre of the city, whereas there are various hedges in the suburbs, but fences of stones, concrete, etc. are most popular there. The phytometer method for identifying the chemical properties of soils using growth of a liverwort (*Marchantia polymorpha*) and a moss (*Pogonatum akitense*) was very useful to test inexpensively many soil samples. The sulphur contents of the most sensitive lichen (*Parmelia tinctorum*) corresponded well to the $SO_2$ concentration of the air. Pollens, microorganisms and dust as an aerobiological factor were counted to various heights using a tower and a helicopter.

*Animals.*

In the animal study group, beetles and spiders, the macrofauna of soil animals, bird communities, dogs, cats, rats and wild mammals were studied as biotic indicators of urbanization. Particularly the retreat phenomena of some animals according to the urbanization were traced by questionnaires.

*Man.*

In the man study group, man's behavioural and anatomical changes of man corresponding to rapid environmental changes under urbanization were studied. Man as the dominant species of urban ecosystems is changing his ecological characteristics as a species of *Homo sapiens* as well as undergoing anatomical changes toward corpulence and increasing size. The residential environment affecting the health and the ways children play was compared between different districts and residential building types. As for the residential environment in relation to children's play space, detached houses are dominant in the suburbs while multistoreyed apartment are predominant in the centre of the city. The land use pattern is, of course, different in Tokyo of 1980 from that in the city of Edo (the old name of Tokyo) in 1860 (Masai, 1980). However, interestingly, the population density in Edo was much higher than expected, in fact almost similar to today. The amount of nature in Edo was much greater than in today's Tokyo. Furthermore, the study group is considering the evaluation of human space not only physically but also biologically. The biological human space concept originated from the idea on ethology.

## 8. Self-Domestication

Thus, urbanization by man→changes in air, water and soil→changes in biotic communities→ man's movement to suburban and rural areas to seek nature and place of mind, is the chain of human behaviour due to urbanization. Overmechanization and overmotorization make people yearn for deurbanization such as in O. H. Thoreau's "Walden" (1847) and in Alicia Bay Laurel's "Living on the Earth" (1970).

On the other hand, mankind gradually changes his characteristics under such circumstances. This is self-domestication by which mankind adapted to the new environment created by himself. People living in cold climate wish to live in modern apartments with heating facilities, and a social welfare policy is necessary. However, people living in the arctic lose their resistance to the cold as an adaptation, and are sometimes frostbitten. Recently, children cannot use a knife to sharpen a pencil in Japan, because they use electric sharpeners. We use an escalator or elevator instead of

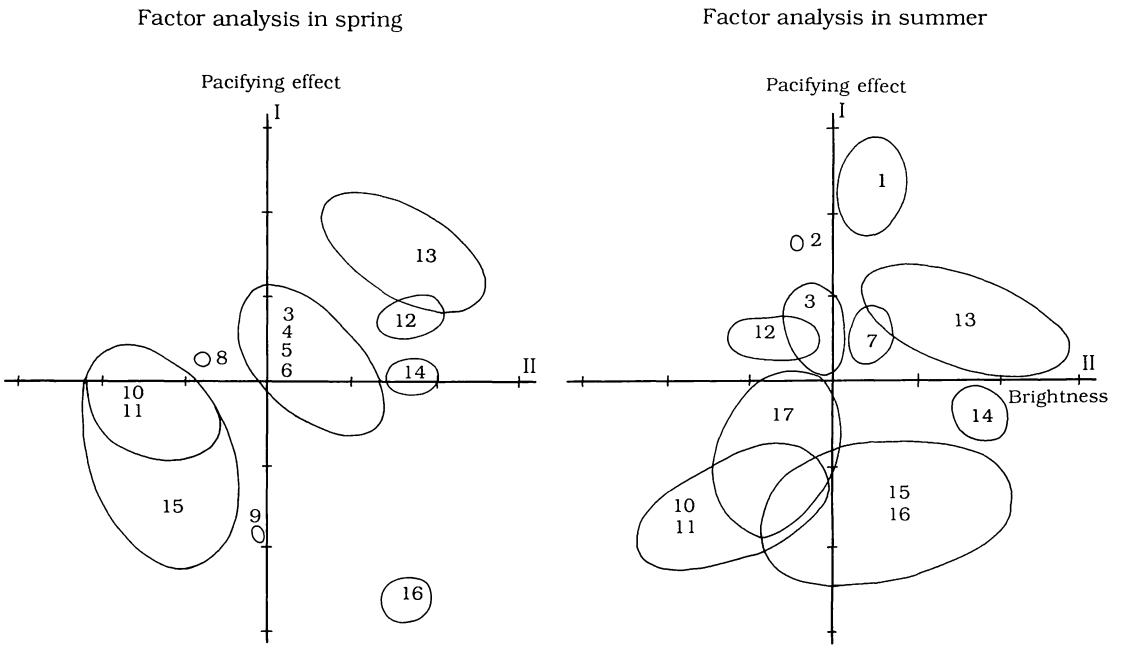


**Fig. 2.** Factor analysis of vegetation types (after Shinada, 1985). 1.*Moliniopsis japonica* community, 2.Paddy field, 3.*Quercus serrata-Castanea crenata* forest, 4.*Cericidiphyllum japonicum* forest, 5.*Fagus crenata, Fagus japonica* forest, 6.*Cornus controversa* forest, 7.*Platanus* avenue, 8.*Cryptomeria japonica* plantation (60 years), 9.*Chamaecyparis obtusa* plantation (20-30 years), 10.*Castanopsis cuspidata, Quercus acuta* forest, 11. *Quercus glauca* forest, 12.*Miscanthus sinensis* community, 13.Turfed lot, 14.Garden, 15.Mantle community, 16.Sleeve community, 17.*Abies firma* forest.

walking up the stairs, and so our walking ability may be degraded. These are all examples of self-domestication under urbanization.

### 9. Biocentric and Anthropocentric Approach

In the second and third period of our study, an anthropocentric, zoocentric and phytocentric approaches were sought. The approach is somewhat similar to "Streifzüge durch die Umwelten von Tieren und Menschen" (J. von Uexküll und G. Kriszat, 1934). It is completely opposite to the approach of the first period which focused on human impacts. It is an anthropocentric and biocentric concept. For example, the visual evaluation of nature with the semantic differential method verifies that lawns, paddy fields, street trees of *Platanus* and deciduous oak forests are ranked higher from the viewpoint of mental ease and brightness conditions (Shinada, 1985: Fig.2). Such an evaluation of vegetation was shown with factor loadings of the factor analysis. There are naturalness ratings (1-10) of vegetation adopted by the Environment Agency of Japan. This is a natural scientific rating, however, the visual evaluation is not natural scientific but socio-psychological as is the evaluation of vegetation from the human viewpoint.

### 10. Biological Time and Space

There is biological time vs. physical time as well as biological space vs. physical space. From the standpoint of the biocentric or anthropocentric concept, biological scale is very important compared with physical scale. As a popular example, inner man has a kind of biological time. An experiment to measure biological time was proposed by wound healing time (de Nouy, 1936). Nevertheless, the wound healing time is shorter in younger ages, and longer in older ages.

### 11. Man as the Leading Factor

Man as the leading factor of an anthropocentric environmental system should be considered from the different levels of the individual, family, local community, nation, region and global (*Homo sapiens*) in general. There frequently are contra-

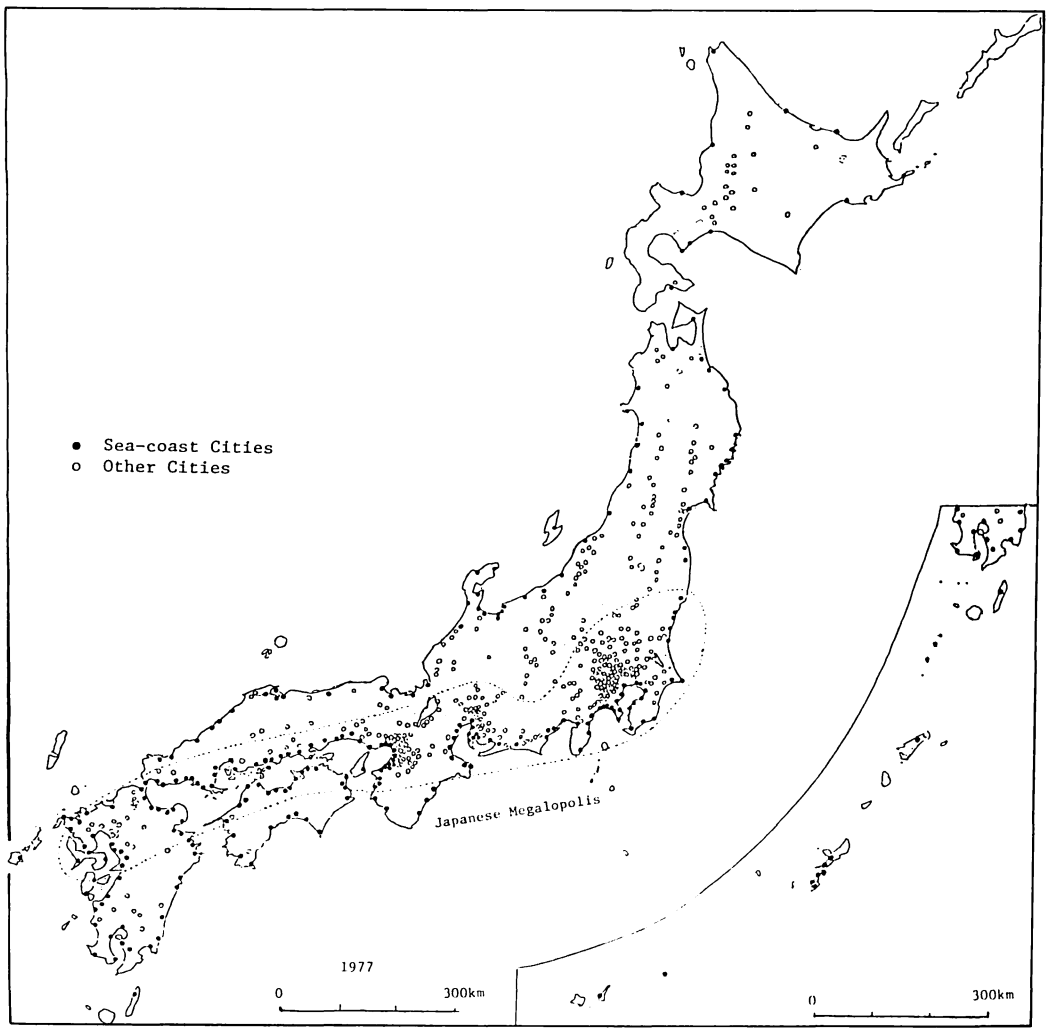


**Fig. 3.** The sea-coast and other cities in Japan (Masai, 1979).

dictions that benefit for individuals and families but do not benefit for local communities and nations. Motorcars are very convenient for individuals and families, however, they are the cause of air pollution at the level of local communities. Besides organismic levels like these, ethic goals and the happiness of human society are important in considering environmental problems. This was seen in the difficult process of finalizing the Human Environment Declaration (1972). We must deeply consider the goal of a city as a human habitat.

### The Chiba Bay-Coast Cities Project

The study area of the following period (1978-1981) is the bay-coast cities of Chiba and Ichihara which are characteristic Japanese cities the growth of which has been accompanied by industrialization located at the interface of the land and sea.

#### 1. Sea-Coast Cities

In Japan there are many large sea-coast cities such as Sendai, Tokyo, Yokohama, Nagoya, Kobe, Fukuoka, Niigata and others, and a few are inland, such as Kyoto and Sapporo (Fig.3). Many sea-coast cities are bay-coast cities. The definition of coast should be examined in relationship to this.

#### 2. Methodology

These bay-coast cities developed economically

by invited factories to locate on new coastal landfill along old sea-coast. Their effects of these industrial landfills have been very great naturally and socially. A new methodology was developed by our group for studying the structure, function and dynamics of an urban ecosystem during the former periods of the Tokyo Project. The same methodology has been applied to the Chiba Project.

### 3. The Study Area

The study area of the Chiba Project is divided into three: 1) the area functioning as the central part of the old city, 2) the area combined with the activities of large enterprises located on coastal landfill, and 3) the area having a strong rural character. A collective housing area, public parks, museums, kindergardens, hospitals, schools, etc. have been constructed as a new town on the landfill, however many of the residents there work in Tokyo. The collective housing area is similar to that of a dormitory town of Tokyo which is only 30 km away of Tokyo (Fig.4). The highways between the landfill and the old city promote independence of the new town from the mother city and unity with the Tokyo Metropolis.

### 4. The Residents

Among the inhabitants of bay-coast cities, particularly of Chiba, less than half are original residents, and the other have come from other industrial cities or have jobs in Tokyo. The awareness in the residents of these cities as their home town is not strong, and they are rather aware of their city being a dormitory town of Tokyo or of the Keiyo (Tokyo-Chiba) Industrial Zone. The affection of residents for their city is small, as is likewise the case in large cities as Tokyo and Osaka. The residents strongly desire to have good roads, drainage, open space, hospitals, libraries, department stores, supermarkets, etc. in their urban environment.

### 5. Citizens' Concern

In Chiba, their citizens' concern for pollution is very high. However, about half of the respondents to the questionnaires indicated in all elements of environmental quality except quietness that there had been no change in the past 10 years. Some of the respondents indicated that quietness (noise

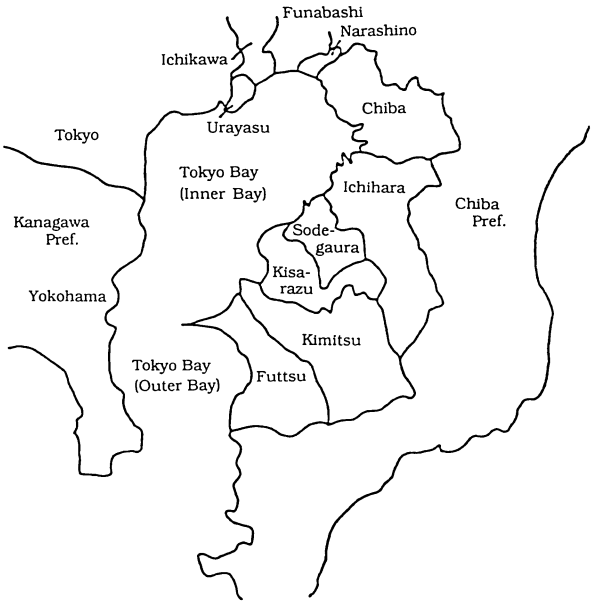


**Fig. 4.** The bay-coast cities of the Keihin (Tokyo-Yokohama) and Keiyo (Tokyo-Chiba) Industrial Zones (Numata, 1986).

and vibration), water quality, air quality, and traffic safety were getting worse, while more of them tended to evaluate traffic roads, convenience for shopping and transportation as having improved. Pollution as well as the prices of commodities and consumer's problems were considered to be the most important problems in Chiba City. Importance of pollution problems depends on the evaluation of present environmental quality and the presence of pollution victims. It differs largely from area to area. The majority of the respondents thought that the developement which might destroy natural beaches should not be permitted, and they preferred a society that emphasized environmental protection over economic growth. There was a consensus on the view of nature. More than 80 % of the respondents agreed that the balance of nature is very important, and man must live in harmony with nature in order to survive.

### 6. Environmental Perception

Environmental perception and human behaviour are closely related to population density. The evaluation of the respondents to the questionnaires indicating that they have enough open space was characteristic to areas less than 10,000/

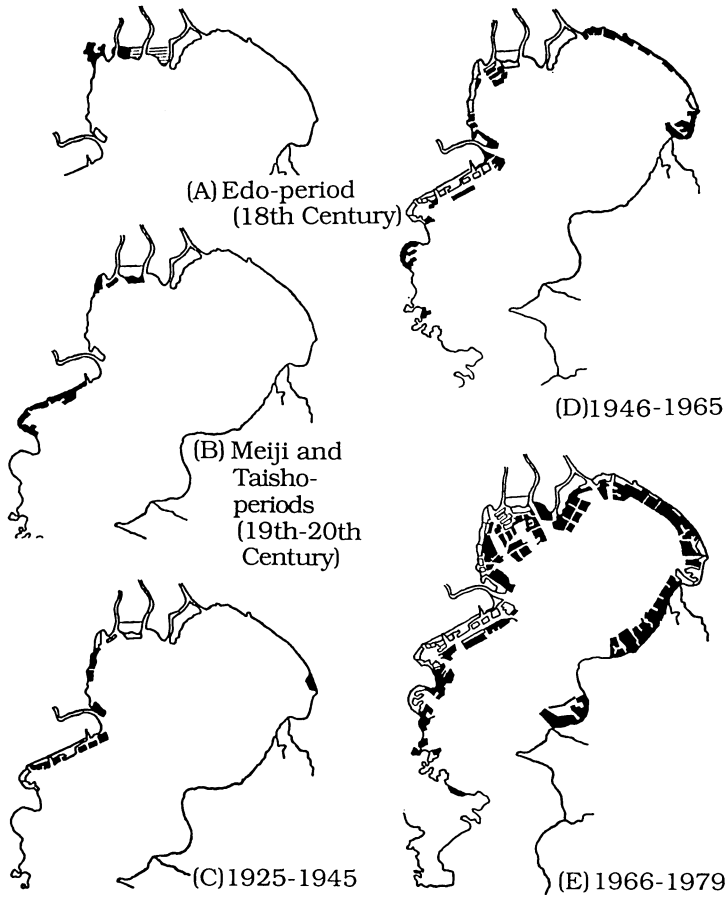


**Fig. 5.** Historical change of Tokyo Bay coastal line. Black lacquered parts are landfills (after Nippon Kagakusha Kaigi, 1979).

km² in the population density. This is a kind of physical quantity, such as mean area per capita. On the other hand, an anthropocentric biological quantity evaluated from the human standpoint is related to the dynamics of human behaviour flowing out of and into an area as an ecobiological space of a city. At the same time, increase in energy consumption, air temperature, migration of soils in relation to development, succession of urban vegetation and fauna, etc. are studied from the standpoint of anthropocentric ecosystem dynamics.

## 7. Landfill

Due to landfill along the sea-coast of Tokyo Bay, the natural sea-coast came to be covered by a high concrete sea wall, and the mud flats (where shells, crabs, lugworm, small fishes, shrimps and many other creatures were living) were lost (Fig. 5). We used to be able to swim, collect shells, fish there. Due to loss of access to the sea-coast, the "Coastal Access Right Movement" started in 1973 as an environmental right movement (Shapiro, 1980). Over 40 percent of the nation's 120 million people live and work in Japan's coastal cities, at an average population density over 30 times that of the United States. The average length of coastline per capita in Japan has been estimated to be 30 cm (Shapiro, 1984).

According to the State of Land Utilization Survey of the Shoreland (Environment Agency, 1975), cities and industrial areas make up 59.6% in Chiba Prefecture; and 80.2% in Kanagawa Prefecture (95.4% in Osaka Prefecture).

South of the Futtsu Cape bordering the inner bay from the outer bay, a branch current of the Kuroshio (warm current) flows counterclockweise, while on the other hand, a branch current

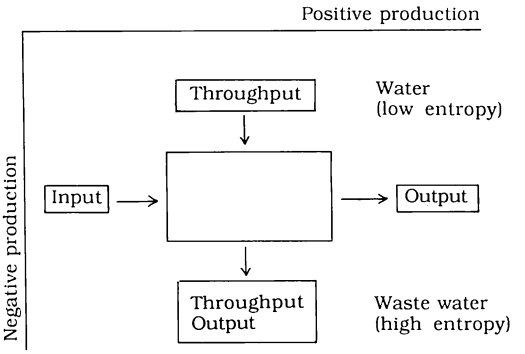


**Fig. 6.** The role of water in the positive and nagative production (Tamanoi, 1981).

**Table 1.** Total water consumption in Tokyo Metropolitan area (after Hayakawa, 1983).

| | $10^9$ton/year | % |
|---|---|---|
| Household | 0.6764 | 49.0 |
| Commercial sector | 0.2495 | 18.1 |
| Office | 0.0814 | 5.9 |
| Department store | 0.0129 | 0.9 |
| Restaurant | 0.0647 | 4.7 |
| Amusement facility | 0.0093 | 0.7 |
| Hotel | 0.0155 | 1.1 |
| Barber shop | 0.0046 | 0.3 |
| School | 0.0397 | 2.9 |
| Hospital | 0.0214 | 1.6 |
| Industrial sector*) | 0.4536 | 32.9 |
| Total | 1.3795 | 100.0 |

Notes: *) Industrial use involves city water supply, surface and underground water, etc., excepting sea water.

in the northern inner bay flows clockweise. The growth of the Futtsu sand bar westward was promoted by both currents.

## 8. Land-Water System

Changes and consequences of the land-water system in relationship to urbanization and industrialization were seen in the coastal areas of the Tokyo Bay. The countermeasures against the lowering of the water table, land subsidence, the shortage of industrial and domestic water, etc. were legal regulations against the utilization of groundwater, and the transfer of surface water from neighboring areas. Due to these measures, the water table has returned to its former position. Furthermore, saving water, particularly the recycling of water, is necessary. Industrial water

**Table 2.** Water balance in the Tokyo Metropolitan area (Hayakawa, 1984). (unit = $10^6$m$^3$/year)

| | | Inputs | Outputs |
|---|---|---|---|
| Precipitation | 932.4 | 932.4 | |
| Inflow | Water supply 1822.7<br>Industrial use 1338.1 | 3160.7 | |
| Water generated (combustion) | 21.3 | 21.3 | 21.3 |
| Evaporation (surface) | 185.8 | | 185.8 |
| Outflow | Sewerage 1813.4<br>Drain from industry 1966.8 | | 3780.2 |
| Evaporation (cooling tower) | 28.0 | | 28.0 |
| Total | | 4114.4 | 4015.3 |

is, in many cases, not input, but throughput for negative production from low entropy clean water to high entropy polluted water (Tamanoi, 1981:Fig.6). Therefore, water as a throughput should be reused as recycled water.

## 9. Citizens' Movement

The impact of industrial development and urbanization on river and coastal water can be seen by the use of bio-indicators. Measures to reduce the impacts mentioned above will be maintenance of natural mud flats, construction of man-made mud flats along the landfills, restraint of the concrete cover of rivers, and planting vegetation on man-made beaches, etc. In Chiba City, a pine forest planted on a man-made beach by the citizens themselves is successful.

## 10. Water-Oriented Approach and Suggestion to the Urban Planning

To achieve an integration of the previous stages approaches and also an integration of structure and function of an urban ecosystem has been tried through the role of water. In this case, water was considered as not only urban hydrology, but also water as a throughput. Water as a throughput is not included in products, but is mostly used in production process as potential water. This water is not a productive element, and not raw material.

Besides this, the water balance analysis (Sueishi, 1983) was proposed. That is, the regional water balance-supply and consumption is defined in three levels as follows:

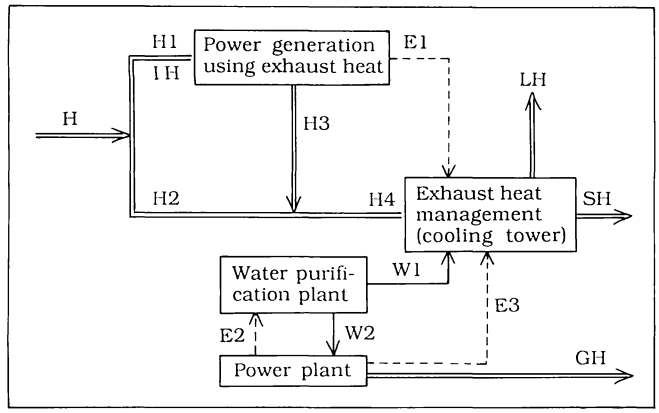


**Fig. 7.** System composition of exhaust heat management (Hayakawa *et al.*, 1986). H: Exhaust heat to be treated. H1: Exhaust heat used for power generation. IH: Enthalpy of H1. H2:(=H−H1). H3: Exhaust heat of power generation. H4:(=H2+H3). LH: Latent heat. SH:Sensible heat. E1: Generated output. E3: Purchased power used for exhaust heat management. W1: Water used for exhaust heat management. GH: Exhaust heat of power generating. E2: Electric power used for water distribution. W2: Water used for power generation.

a) Primary balance-ordinary water resource allocation to agricultural, industrial and living (for domestic and urban activity) uses. There are in-region balance and export/import across a region boundary (Tables 1, 2).

b) Secondary balance-indirect water consumption for which the final user of produced goods and services is liable. Primarily balanced agricultural and industrial waters yield generally secondary export and import caused by goods transportation.

c) Tertiary balance-indirect water consumption to accomplish the secondary water balance. Direct and indirect waters used by transportation system may be a main part of this category.

It is an attempt to reevaluate the values of goods production and human activities from the total water use of direct and indirect amounts for goods production and transportation.

From the viewpoint of throughput of water as well as input and output of water and the water balance analysis as well as urban hydrology, that the precipitation and streamflow should infiltrate to the ground and riverbed, recycling of water, water allocation and reevaluation of potential water are suggested for the urban planning. For the urban planning, such a water-oriented approach is closely related to the heat balance of a city (Fig.7).

In a word, the impact of industrial development and urbanization on the land-water system of coastal cities is seen on the atmosphere, soil, water, plants, animals, microorganisms, and man.

## Conclusion

As a conclusion, our research team has aimed at clarifying the situation and role of biotic components and abiotic factors of urban ecosystems, particularly in the Metropolis of Tokyo and the Chiba bay-coast cities from the biocentric and anthropocentric viewpoint. Then, we tried to integrate the knowledge on the structure, function and dynamics of urban ecosystems through the role of water which is not only the urban hydrology but also the throughput of water and the water balance analysis including the heat balance analysis.

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