Scientific research on urban forests created with the Miyawaki method around the world

The Miyawaki method has been scientifically tested and monitored by several research centers for over 40 years. Urban Forests has chosen to compile a series of scientific articles on the subject published until June 2021. Our hope is that this documentation will advance the debate objectively and deconstruct negative criticisms based on opinions only. In this way, it should be possible for everyone to adopt a serene, positive and constructive attitude towards the worldwide enthusiasm for Miyawaki forests.

[Image of people planting trees]

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Click on the link to know more: https://jise.jp/ENG/ENmiyawaki.html

Reports published by Urban Forests

The Miyawaki Method, data and concepts (2020)

Scientific references are given at the bottom of the report.

Miyawaki method and Science (2021)
http://urban-forests.com/miyawaki-method-and-science-2021-by-urban-forests/

Scientific publications by European research centres


Citizen Science and Determining Biodiversity in Tiny Forest Zaanstad (2018), study carried out by Wageningen University in the Netherlands. Download report on https://edepot.wur.nl/446911

Scientific publications on projects using the Miyawaki method

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Creative Ecology: Restoration of Native Forests by Native Trees

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Ecological devastation is becoming a serious problem locally to globally, in proportion as people seek affluent living circumstances. Environmental devastation originated mainly from nature exploitation and construction of cities and industrial institutions with non-biological materials. Humans have ignored the rules of nature, biodiversity and coexistence.

One of the best measures we can take anywhere, in order to restore ecosystems indigenous to each region and to maintain global environments, including disaster prevention and CO₂ absorption, is to restore native, multi-stratal forests following an ecological method.

I would like to refer to the experimental reforestation projects based on ecological studies and their results at about 550 locations throughout Japan and in Southeast Asia, South America, and China. We have proved that it is possible to restore quasi-natural multi-stratal forest ecosystems in 20 to 30 years if we take the ecological method.

1. Introduction

Until recently there were two kinds of tree planting. One involves monocultures of needle-leaved trees or fast-growing exotic species for the purpose of producing lumber. Of course producing lumber is an important business, but monocultures of species unsuited to the habitat, soil and climate will need maintenance, such as weeding and cutting off lower branches, for at least 20 years. Those conifers and exotic species are generally shallow-rooted and highly vulnerable to strong winds, heavy rain and dry air [1]. What is worse, many pine woods throughout Japan are damaged by forest fires and so called pine worms, and cedars (Cryptomeria japonica) cause pollen allergies which many people are suffering from every spring [2].

The other kind of planting is tree planting for beautification. Some examples of this are Japanese gardens, miniature gardens, and bonsai, dwarf trees, which can be said to be enhanced to the most typical Japanese culture. In the Edo era, the Emperor’s domains were covered with fine nearly-natural forests, and common people who envied them began to imitate and enjoy nature in and around their own small houses. They were apparently beautiful but cost a lot for maintenance. Recently decorative tree-and flower-planting campaigns are popular in towns and cities [3]. We see many parks dotted with adult trees planted on the lawn. These plantings may be good to delight citizens’ eyes. They not only need a lot of maintenance, however, but also are insufficient to protect environments and prevent disasters [2].

It will be a third planting method based on ecological studies that is indispensable to restore green environments, to prevent disasters, and to sustain local to global environments [4–6]. Through thorough vegetation-ecological field surveys, we grasp the potential natural vegetation of the area. Following the results of field surveys, we carry out what we call, restoration of “native forests by native trees” [7]. This reforestation is one of the most solid measures to restore environments of the earth locally to globally, with our gaze fixed upon the coming 21st and 22nd centuries [8, 9].

The green surface of a multi-stratal forest of the potential natural vegetation is about thirty times as large as that of a mono-stratal lawn, which needs periodic maintenance. As for absorbing and accumulating CO₂ multi-stratal native forests have a much larger capacity than do lawns.

When colonies, villages and towns were constructed in Japan, our ancestors usually grew forests indigenous to the region around shrines or temples, which are called Chinju-no-mori. Our method of reforestation “Native forests by native trees” is based on this traditional Japanese “Chinju-no-mori” and ecology, a new synthetic science that integrates biocenoses and environment [1, 2].

In the 1960s we started determination and systematization of phytosociological community units through steady ecological field investigations throughout Japan. Then we made maps of the actual vegetation of Japan, which can be used as diagnoses of natural environments, and middle-scaled (1/500,000) potential natural vegetation maps of Japan, which can be used as ecological scenarios for restoration of green environments [10].

We choose the main tree species and their companion species from the potential natural vegetation of the area, collect acorns of those species, grow the seedlings in pots until the root system fully develops, and mix and plant them closely together following the system of natural forests. This is the way we succeeded in restoring forests at about 550 locations in Japan.

We applied this ecological method to reforestation in Malaysia in Southeast Asia, in Brazil and Chile in South America, and in some parts of China, and found each of them successful. We believe that to continue carrying out reforestation projects based on ecology on a global scale must be essential for our future wholesome environments.
2. Method

The tree species must be chosen from the forest communities of the region in order to restore multi-stratal natural or quasi-natural forests. If the main tree species are badly chosen, it will be difficult to regenerate native forests which develop as time goes by. In the plant communities, if the top is authentic, the followers are also real, just like in human society.

For the proper choice of species, we first make a through field vegetation investigation of the area, especially in shrine and temple forests, old house forests, natural forests remaining on slopes, and substitute vegetation changed by various human impacts. The results of the investigations obtained in this way are called relevés, which are equivalent to a census of green environments [3, 4, 11].

Next, we decide local community units by tableau work comparing relevés and grouping similar species combinations. Then we compare them with community units investigated and systematized in other parts of the world and see the species combinations. When we see species combinations, we find high-fidelity species for particular communities. These species are called character species. We decide phytosociological units based on the character species. We compare phytosociological units widely from natural forests to secondary communities, and decide "associations", basic units of a plant community system, which can be applied to worldwide vegetation science. Likewise, we group the units into alliances, orders and classes by species combinations. In this way the hierarchical vegetation community system is decided [7].

Vegetation maps are drawn so that even non-experts in vegetation can understand the vegetation community units and their distribution. The present distributions of vegetation communities are drawn onto actual vegetation maps, which work as vegetation-ecological diagnoses not only for pure scientific purposes but also for the purpose of new utilization of land and decisions whether reforestation is needed [12].

There is another concept of vegetation, i.e. the potential natural vegetation [13]. Without any human impact, what vegetation could the land hold as the sum total of natural environments? The potential natural vegetation indicates the potential capacity of the land, theoretically considered, as to what vegetation it can sustain. To decide the potential natural vegetation, we investigate remaining natural vegetation and compare it with various secondary vegetation types from the factors of time and space. We also investigate the soil profile, topography and land utilization and put these together to grasp the potential natural vegetation [14].

Potential natural vegetation maps are essential for each ecological study field and are significant as ecological diagnoses for restoration of green environments. We found it possible to restore native green environments, multi-stratal forests, by choosing the main species from the potential natural vegetation of the area and planting them mixed and densely with as many companion species as possible [8].

The main tree species from the potential natural vegetation are generally deep- and straight-rooted and have been said to be difficult to transplant. We solved the problem by planting potted seedlings. We first collect seeds, that is, acorns. We germinate the seeds, move the seedlings to pots when two or three leaves have sprouted, and cultivate them until the root groups fill the containers and seedlings grow 30 to 50 centimeters high. It takes one-and-a-half years to two years in the temperate climate zone where most cities of Japan and the United States are located. In the tropical rain forest zone, where Borneo and Brazil lie, it takes only six to eight months to complete the growth of the potted seedlings [15].

Then we adjust the soil conditions of the planting site. Topsoil is usually washed away both in Japanese urban areas and on tropical barren land, from shifting cultivation and forest felling. Therefore it is necessary to recover 20 to 30 centimeter-deep topsoil by mixing the soil of the region and compost from organic materials such as fallen leaves, mowed grass and so on.

Next we plant potted seedlings of the main tree species from the potential natural vegetation along with companion species according to the system of natural forests. Dense and mixed planting of two or three seedlings per square meter will be appropriate.

Mulching with organic materials such as rice straw is needed in order to prevent soil erosion and moisture loss after planting. For two or three years after planting, we have to cut or pull weeds and utilize them as mulching material by leaving them around the young trees. In about three years the trees grow 2 to 3 meters high, and the crown covering the forest floor comes to keep the sunlight from coming in. Consequently very few weeds can grow. This is how nature manages itself through natural selection. Three years after planting, the site basically becomes maintenance free.

Dense and mixed planting of community species of indigenous forests will need no watering, insecticides or herbicides, with some exceptions. Natural management is the best management [7].

3. Experiments and Results

3.1 Internal reforestation

Since 1973 we have been forming environment protection forests around newly built ironworks and power stations in cooperation with far sighted Japanese corporations such as Nippon Steel Corp., Tokyo Electric Power Co., Kansai Electric Power Co., Honda Engineering Co., Toray Textile Co., Mitsubishi Estate Co., Mitsubishi Corp., JUSCO EASON Group, and so on. In the latter half of the 1970s municipalities like Kanagawa Pref., Okayama Pref., Nagano Pref., Nara Pref., Yokohama City, Mikawa City, and Nagoya City, as well as the central government including the Ministry of Construction, began to ask us to regenerate native forests with native trees. The planting sites range 3,000 kms from Hokkaido in the north to Okinawa in the south. As of August 1998, we have restored native forests at about 550 locations, each of which is successful (Fig. 2, Color plates 1, 2, 5~8).
Why is it indispensable to plant trees in so many places around the infrastructure? To this question the Great Hanshin Earthquake on January 17, 1995, gave us a definite answer.

We made field investigations right after the earthquake. Structures built of iron and cement, including modern buildings and some parts of elevated highways and Shinkansen railways, were destroyed easily, and some of them burst into flames. They had cost tens of billions of yen and involved the latest techniques. We believed they were the strongest structures, but non-biological materials showed weakness against such disasters, which hit us once in some hundred years (Color plate 3).

On the other hand, not a tree of the main component
of the potential natural vegetation fell. Where evergreen broad-leaved trees from laurel forests were planted in a line, fire was stopped. They proved to have a fire prevention function in many places (Color plate 4).

In the earthquake many houses were destroyed and levelled to the ground. Many of the nearly 6,000 victims were crushed to death under their houses. Some houses had evergreen trees around them in spite of their shade and falling leaves. These trees stopped the falling roofs and pillars, and made openings in the rubble. The people living

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**Photo 1** Ecological planting around Gobo thermal power plant of Kansai Electric Power Co. on a manmade island in the Pacific Ocean (July, 1983).
**Photo 2** Same place after 12 years (December, 1995). The trees have now grown much higher.
**Photo 3** Disastrous earthquake hit Hanshin District (January 17, 1995).
**Photo 4** A fire was stopped by a line of evergreen Oak trees (Quercus glauca), main species from the potential natural vegetation.
**Photo 5** Planting along Shin-shonan Bypass by primary school students.
**Photo 6** 1,200 primary school children planting seedlings along the Kashihara Bypass (March, 1982).
**Photo 7** Same place after 14 years (July, 1996).
**Photo 8** 20,000 seedlings planted by 2,000 people around the Shirakawa Dam, Nara Prefecture. Prof. H. Sano (right) and Madame Elisabeth Sano (center), participating in the planting festival (author left) (April, 1996).
**Photo 9** The first planting festival at the site in Bintulu, Sarawak, Malaysia. 6,000 seedlings planted by 2000 people (July 15, 1991).
**Photo 10** Same place after 4 years (January 16, 1995). At present the trees have grown higher.
**Photo 11** The first planting festival to regenerate tropical lowland forests near Belém, Brazilian Amazon (May 18, 1992).
**Photo 12** Same place after 4 years.
**Photo 13** Planting 14 species of seedlings from native tree species including Nothofagus trees in Concepción, Chile (May 26, 1992).
**Photo 14** Same place after 4 years (February 2, 1996).
there could probably escape from the dread of death through the openings.

Lately the Ministry of Construction is beginning to plant seedlings from the potential natural vegetation along expressways, under the so-called Miyawaki Method based on the ecological scenario (Color plate 5). School children led by their teachers plant seedlings as a part of the regular curriculum [1].

If these programs had started in Kobe ten years before the earthquake, the planted seedlings would have grown to form a forest belt about 10 m high. Then the drivers might not have lost their lives when the expressway was destroyed, through softer landing on the forest.

This is another example of reforestation along the expressway. In Nara Prefecture construction of the Kashihara Bypass met with opposition of the inhabitants and was suspended for ten years. Some advocated a greenery campaign to plant seedlings along the expressway as a way out. On March 13, 1982, school children planted seedlings following the ecological method (Color plate 6). Sixteen years have passed since then. Many of those children graduated from school and got married during the period. When they come back to their home town, they probably see the forest belt (Color plate 7). When their own children become primary school students, they will surely take them to the forest and say, "The seedlings I planted with my hands when I was as old as you are now have grown to this great forest."

The staff in the civil engineering bureau in Nara Prefectural Government knew the case of Kashihara Bypass and held a planting festival around Ohta Dam. 2,000 people, including the Governor of Nara Prefecture, planted 20,000 seedlings from the potential natural vegetation. Prof. Sano and his wife as well as many students of Nara Institute of Science and Technology took part in the festival and planted with sweat on their brows (Color plate 8). I would like people in Nara Prefecture to keep watching the growth of the seedlings with a scientific eye and love towards life.

3.2 Restoration of tropical rain forests in Southeast Asia

In 1978 we began vegetation field investigations in Indonesia (Borneo), Thailand, and Malaysia, from mangrove forests along the seawast to tropical rainforests, tropical dry forests and laurel forests in the mountains in Thailand [16, 17]. Based on the results of the investigations, we began a joint restoration project with Mitsubishi Corp. and the University of Agriculture, Malaysia in 1990. The planting site was 800 ha of barren land on the Bintulu campus of the university, Sarawak State (northeast Borneo) [15].

Restoration of tropical rainforests has been considered to be quite difficult, and it was usual to plant rapid-growing species such as Eucalyptus from Australia, and long-leaf pine, Pinus taeda from America, and Acacia mangium. These exotic rapid-growing species grow very fast at the beginning. Since they grow in a monosummer, however, they are highly vulnerable to dry air, strong wind and insect damage. Reforestation with these species is not always successful.

We chose the main tree species from the potential natural vegetation of the area, Dipterocarpaceae, including Hopea, Shorea, and Dipterocarpus. We also planted as many companion species of the tropical rainforest communities as possible, in order to follow the natural biodiversity. This may be the newest method of reforestation in the world. We have planted 91 species from the potential natural vegetation in all (Table 1) [18].

I would like to show the case of Plot 203 of the Bintulu reforestation as one example. There we had a lot of difficulty in the first stage of growth.

On July 15, 1991, we and 2,000 participants dug 6,000 small holes with our hands and planted 6,000 seedlings. The record of their growth is represented in Fig. 3 and Color plates 9 and 10. The survival rates of the individuals and the groups in six years are shown in Fig. 4. During the first few years tenacious grass seeds came out and we cut them and covered the forest floor with them for supplementary mulching. After three years the plantation basically required no maintenance. It is six years since the planting, and the trees have grown steadily to reach 6 m to 10 m high. Every year after the first planting 30-80 volunteers from Japan and people from Malaysia participate in the planting festival in Bintulu. Until now 330,000 seedlings have been planted on 50 ha of land. We can see them developing into quasi-natural forests [19].

Adopting the same method, we have succeeded in restoring disaster-preventing, environment-protecting forests around newly built shopping centers backed by JUSCO in Kuala Lumpur, Melaka, Ipoh (Malaysia), and Bangkok (Thailand). The forests restored in urban and peri-urban areas are highly valued by local people.

The royal family of Thailand had a lot of interest in ecological reforestation, and we started planting dry Dipterocarpus and other species from the potential natural vegetation along the boundary between western Thailand and Myanmar. We named the joint work the Royal Princess Sirindhorn Project.

3.3 Examples in South America

In December 1990 we started an experimental regeneration project for lowland tropical forests in collaboration with Pará Agricultural University in Belem, northern Brazil. We collected 92 species mostly from the potential natural vegetation, including the main species Virola, and made potted seedlings with fully developed root systems. This project was backed by EIDAI do Brazil Madeiras S.A. and Mitsubishi Corp. The first planting festival was held on May 18, 1992, attended by the Mayor of Belém, Mr. and Mrs. Murazumi, Japanese Ambassador extraordinary and plenipotentiary to Brazil, President of Pará Agricultural University, and many other people (Color plate 11). After that every year we continually plant seedlings at planting festivals. They grow steadily and some individuals reach 10 m to 15 m high in five years (Color plate 12).

At this site we made haste in planting and intentionally mixed indigenous species and rapid-growing pioneer species. Rapid-growing species, including Barsa, grew very
<table>
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<th>No.</th>
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Table 1 (continued)

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Fig. 3 Growth curve in height on PQ 203 in Bintulu, Sarawak, Malaysia.

Fig. 4 Survival rate with passage time on PQ 203 in Bintulu, Sarawak, Malaysia.
fast, but because of their shallow root systems some of them fell in the strong wind and received some other damage. They also made shade over the indigenous species like *Virola*, which were growing more slowly. In conclusion it is the best and the most secure method to mix and plant species from the potential natural vegetation following the system of natural forests, just as we did in Japan and Southeast Asia.

In Concepción, Chile, we practiced reforestation by mixed, dense planting of 14 species of *Nothofagus*. Though it was said to be difficult to restore native forests in the area because of dry air in summer and overgrazing, we have found that native forests can be restored if we take sufficient care for the first several years after planting (Color plates 13 and 14).

### 3.4 Reforestation in China

Forest devastation is quite serious around the Great Wall, the more than 2000-year-old structure stretching 2,600 km, which is called the symbol of the civilization of Great China. Several projects have been tried but were not necessarily successful.

We began field investigations to understand the potential natural vegetation around the Great Wall, in cooperation with the People's Government of Beijing and AEON Environment Foundation of Japan. We collected 80,000–1,000,000 acorns of indigenous species, including *Quercus mongolica*, and germinated them to grow seedlings in pots. On July 4, 1998, the first planting festival was held, with the help of 1,400 volunteers from Japan and about 1,200 volunteers from China. Chinese people took the trouble of digging 175,000 60 cm³ holes in the

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**Fig. 5** Comparison between our new succession theory and classical theory (Laurel forest area in Japan) [14].
TOPOGRAPHY

CLIMATE

Tropical rainforest ex. Meranti forests

SOIL

 Substitute vegetation finally bare land

\[ \text{20 cm topsoil added} \]
\[ \text{Young seedlings of main tree species of P.N.V.} \]
\[ \text{Densely mixed plantation} \]

Annual herb comm. Ageratum conyzoides-Crascocephalum crepidioides comm.

\[ \downarrow \text{ca. 2–10 years} \]

Perennial herb comm. Ischaemum-Melastoma comm.

\[ \downarrow \text{ca. 10–15 years} \]

Shrubby comm. Dillenia scrub

\[ \downarrow \text{ca. 15–50 years} \]

Tolerant-tree young forests

\[ \downarrow \text{ca. 40–50 years} \]

Intolerant tree forest Macaranga-Ficus comm.

\[ \downarrow \text{ca. 200–300 years?} \]

Tolerant forests

Tropical rainforests with Meranti, etc.

Climax forests Dauerensellschaft

Classical succession theory

New succession theory

Fig. 6 Comparison between our new succession theory and classical theory (Case in Bintulu, Sarawak, Malaysia).

Several hundred years for reforestation is too long for us, however, because we live in a world where industry and urbanization are developing very rapidly. We tried ecological reforestation by recovering topsoil and planting seedlings in pots with fully developed root systems directly from the terminal vegetation in succession, that is, the potential natural vegetation. It is proved here that multistratal quasi-natural forests can be built in 15–20 years in Japan and 40–50 years in Southeast Asia by ecological reforestation based on the system of natural forests. Among 550 locations of our planting throughout Japan we don’t see a single failure. We succeeded in restoration of native forests from in cold-temperate zone to in tropical forest zone.

550 locations is far from enough when we consider the whole 380,000 km² land of Japan, much more on a global scale. We all should set to restoration and recreation of global environments in every place in the world by the ecotechnological method. We can start at once, following the rules of biocenosises. Farsighted top managers of administrations, corporations, and communities can be general directors. Scientists write ecological scenarios for environment restoration. Citizens are the main characters on the stage. All the people on the earth share the work in a sweat for the sound future of human beings.

Ecology was originally viewed as a science of discovery and played the role of critic when environmental pollution occurred in the 1970s. Now ecology should be creative in order to restore environments and build better living conditions. We expect all scientists in the world to see our results positively and to begin to help make new affluent circumstances for the future in their own area. We hope to struggle together for creative ecology.

Acknowledgements

I had learned the concept of the potential natural vegetation for two and a half years since 1958, from Prof. Reinhold Tüxen, the then Director of Bundesamt für Vegetationskartierung in then West Germany. After coming back to Japan I began vegetation field investigations with the knowhow in the 1970s when the Japanese economy rapidly grew. Since then many farsighted international and domestic corporations, Ministries including the Ministry of Education, governors and mayors of local public bodies, and so many citizens have been working with us. I would like to express my gratitude to every one of them.

References


Forest reconstruction as ecological engineering

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ABSTRACT

Land restoration involves reconstruction of the native biota in a sustainable form. If reconstruction involves deliberate manipulation of biological organisms and the physical–chemical environment to achieve specific human goals, it qualifies as ecological engineering. Restoration which uses natural processes to achieve endpoints which are unpredictable but can be accepted because they are “natural” is not ecological engineering. In Japan a system of forest reconstruction has been developed which is based on knowledge of the potential vegetation of a site, knowledge of the methods of germination and growth of the species which compose the mature vegetation and a method of site preparation and planting. This ecological engineering approach has been used on 285 sites, in a variety of habitats, to form dense stands of vegetation to hide industrial complexes, control visual, noise and chemical pollution, stabilize soil and beaches and provide urban green space. The technique has also been used to restore tropical rain forest.

INTRODUCTION

The land is frequently disturbed by human activities. While ecological engineering-informed land management can reduce disturbance to the environment of a site, in many situations such as road and industrial construction, it is difficult or impossible to avoid substantial impacts. In these circumstances it is necessary to reestablish and restore the ecological systems in order to reduce erosion, recreate greenness, reduce noise and air pollution and reestablish habitat for organisms.

Land restoration is a subfield of applied ecology (Cairns, 1988) and has developed a variety of methods for rebuilding ecosystems on disturbed sites. Frequently, these methods replicate the processes of natural recovery, called ecological succession, on disturbed land. Indeed, in situations where there is adequate time and the site can be protected from further disturbance, merely allowing the natural processes of recovery to operate undisturbed by human intervention is a viable strategy. But the cost is time.
In temperate forest regions recovery of the site and the reestablishment of mature ecological systems will probably require from 100 to 200 years to restore the life forms and incorporate a relatively large percentage of the potential species in physically small areas. In large areas the rate of recovery may be much slower (Golley, 1965). In tropical rain forests, the equivalent time may exceed 500 years.

In many situations it is not possible or desirable to wait for natural recovery. In these instances the process of reestablishment of ecological systems must be accomplished through direct human management.

In either natural or managed restoration four steps are required. First, the disseminules of the species used in restoration must be transported to the site. Second, these disseminules must germinate if they are plants or become established if they are animals. Germination and establishment was called ecesis by Clements in his classic study of the process of ecological succession (Clements, 1916). Third, the organisms must grow, compete for resources and resist herbivory and predation. In this stage they also begin to react on the physical-chemical environment and alter the rates of water movement and erosion of the surface soil. Finally, the biota must store sufficient nutrients to reproduce.

In the ordinary process of succession each species goes through these four steps. Many species can not maintain themselves in competition with other species in the new environment. The sequential replacement of species and the change in life form from low-growing herbs and grasses to shrubs to trees in humid temperate regions led ecologists to call this restoration process succession. Succession has been a central focus in American ecology (Golley, 1977); studies of succession have not been as important in those countries where disturbance has been less ubiquitous. Further, in extreme environments, such as deserts, succession does not occur as such. The species that initially invade and live on these sites form the mature natural vegetation.

Restoration ecology and ecological engineering differ from conventional vegetation management of civil engineering because they employ the native biota of the region in rebuilding ecosystems. In the approach we are promoting ecological knowledge of the biology, and ecology of the biota is used to select species with the appropriate properties for reconstruction of vegetation. Restoration ecologists also utilize the natural processes of succession and direct it or change its rate.

Because ecological knowledge of species performance may be inadequate, civil engineers often resort to using exotic or domesticated species which are well known biologically and economically in restoration projects. They also use fertilization and irrigation to assure that the site is covered quickly and erosion is stopped. On severe steep slopes the danger of failure
may be so great that the civil engineer chooses to use steel and concrete to stabilize the soil rather than risk slumping.

These comments imply a definition of ecological engineering which requires further elaboration. Engineering involves manipulation of materials to construct objects and processes following a design or plan to serve specific human purposes. Design is not by chance, nor is it bricolage (Levi-Strauss, 1962). The materials used in engineering may be natural organisms, which have evolved and been selected for specific niches, or the materials may be human-made, such as iron and concrete. In contrast, ecological science, as in restoration ecology, is the study of the interactions of living organisms and their environment. Applied ecology and restoration ecology try to design with nature, using ecological processes to achieve ecological communities like those which evolve naturally under the processes of evolution, adaptation and development.

Within engineering the activities may be placed on a gradient from ecological engineering at one end and conventional civil engineering at the other. The gradient describes the tendency to use natural evolved materials in ecologically recognizable ecosystems, versus the tendency to use human-made materials in human designs to overcome what are conceived to be natural obstacles. The contrast between using native plant materials on roadcuts versus concrete and steel illustrates the extremes of this hypothetical gradient. Obviously, all kinds of compromises between the extremes are employed in real-life engineering activities.

Thus, restoration ecology forms a contrast with ecological engineering, but the contrast is less extreme than the contrast between ecological and civil engineering. In this case the restoration ecologist tries to direct and manage natural processes of recovery to obtain vegetation patterns that fit the expected regional patterns for the site. The objective is to restore the natural, bioregional ecological communities to something like a former condition. Ecological engineering, in contrast, is directly and intentionally manipulating natural materials for specific purposes within human-made designs. The ecological engineer is not letting "nature take its course" but is acting as an engineer informed by and knowledgable of ecological systems. The ecological engineer uses the information of basic ecological science in solving specific technical problems of human society.

In this paper we describe an ecological engineering technique that was developed by the senior author and has been used on over 285 sites on the Japanese archipelago. This method qualifies as an ecological engineering technique because it uses knowledge of the ecology and biology of native Japanese species and the potential vegetation of Japan to build engineering systems which hold soil, reduce pollution, provide visual screening, and reduce noise. It is anticipated that these engineered systems will eventually
replicate the mature ecosystems of the site without going through the lengthy process of succession. In that case the engineered systems will be converted into permanent adapted ecosystems. These techniques are now being extended to tropical rain forest in Malaysia, Brazil, and *Nothofagus* forest in Chile.

THE RECONSTRUCTION METHOD

The method employed by the Miyawaki team (Miyawaki, 1988) is based on three kinds of information:

1. knowledge of the potential natural vegetation on the site;
2. an understanding of the germination and establishment biology of the dominant species of the potential natural vegetation; and
3. methods of planting large numbers of seedlings in prepared seedbeds at the site.

Each of these points will be described.

*The potential vegetation:* Potential vegetation is a concept of vegetation science, developed in Europe by Tuxen (1956). It does not imply an ecological climax, in the sense of Clements (1916) or a climax as a steady-state, in current American ecological terminology. Potential vegetation is an abstract concept of a vegetation made up of the plant species present in remnants of the plant cover, without human influence. The vegetation scientist studies patches of natural vegetation and, through understanding the relations of species to each other and the physical conditions of the site, reconstructs the potential patterns. The potential patterns give the ecological engineer an endpoint or a design goal to guide reconstruction.

Knowledge of the potential vegetation of Japan is based on a long-term, intense study of the potential and actual vegetation by Miyawaki and associates (Miyawaki and Fujiwara, 1988). During the 1970s, Japan was mapped in a hierarchical system of plant communities (Fig. 1), identifying the association, alliance, order, class, as well as lower order units such as subassociations and variants. These descriptions were based on species observed on plant relevees using the conventional methods of vegetation science (Miyawaki et al., 1978, 1983). The number of maps that have been published from this research exceeds 900. The vegetation of Japan also is described in a series of volumes which presents the data obtained by thousands of relevees in tables, maps, verbal and photographic descriptions (for example, Miyawaki, 1980).

The technical work underlying these descriptive texts was based on field examination of the actual vegetation and the remnants of mature vegeta-
tion that still exist in Japan around Shinto shrines, Buddhist temples, and villages throughout the country. These pieces of natural vegetation vary in size and composition and they have been influenced by centuries of human activity. Nevertheless, they represent patterns of premodern Japanese vegetation. They exist even in the urban area of Tokyo. Before 1950 there were relatively few maps of the vegetation of Japan, but beginning in 1967, maps of potential vegetation began to be constructed for the country using these remaining stands of vegetation and ecophysiological knowledge of the relation of species to environmental factors which could be determined in the field (Miyawaki, 1985). In addition to maps of potential vegetation, the actual vegetation occurring in each region has also been studied and maps on a scale of 1:200,000 have been prepared for the Cultural Agency of the Japanese Ministry of Education, Science and Culture (1969–1976) and the Japanese Environmental Agency (1975–1977). More-detailed maps at a scale of 1:50,000 also have been prepared for the Japanese Environment Agency since 1985.

The consequence of this vegetation science analysis of Japanese potential and actual vegetation is that reconstruction activity can be directed to specific goals which fit the climate, soil and geological characteristics of the site (Fig. 2). The species of the potential vegetation can be selected for planting and the naturally occurring plant community can be reconstructed with considerable confidence. The background of knowledge of potential and actual vegetation reduces the role of chance in land reconstruction. It also avoids the need to use exotic vegetation in a project.

Forest reconstruction is based on the canopy trees and it is assumed that understory plants and animals will reinvade the site as the canopy develops, eventually recreating an ecological system. This assumption has not been adequately tested. The only other group of organisms that has been investigated has been the soil fauna (Miyawaki et al., 1977; Aoki and Harada, 1985). The soil fauna of restored communities begins to show species abundance and diversity characteristic of the potential community after the canopy has developed and become closed (Fig. 3). But this is an area of research requiring more attention.

Germination and establishment biology: Reconstruction of the vegetation requires that seeds be collected from specimen plants, germinated in nurseries and grown in containers for 1–2 years. The major objective is to grow seedlings with strong root systems because the root system is the key to successful survival of the plantings and the stabilization of the soil.
Japan is a country where gardening and horticultural knowledge has a long and deep history. Methods of growing the dominant and even rare species are relatively well understood. Forests have been reconstructed on a large scale, as for example around the Meiji Shrine in Tokyo, and to the uninitiated eye these appear to be natural stands. This traditional knowledge coupled with modern botanical scientific studies of the physiology of species provides the background needed to establish nurseries for growing

Fig. 3. Establishment of the soil fauna in restored forests of different ages. The shrine forest represents a stable forest type. Based on Aoki and Harada (1985).
the tens of thousands of seedlings needed in a large project. Seedlings are grown in pots and planted when they are 2 years old.

*The planting process:* The planting process is a unique environmental education experience for the local community. The steps for reconstruction (Fig. 2) involve site preparation, planting, and a post-planting survey. Site preparation usually involves surface plowing of the site to create low mounds of loose soil which will provide the surface for planting and prevent flooding of seedlings during the frequent rains which are a feature of the Japanese environment. On construction sites where the top soil has been reserved, 20 to 30 cm of top soil are returned to the site. Straw and organic fertilizer may be applied to the mounds if soil analyses indicate that an amendment is required. If the planting is on a steep slope, temporary planting beds are constructed of bamboo (Fig. 4). The area on the planting mounds is divided by cord into approximately 1-m squares and three planting holes are located in each square.

Planting of seedlings occurs during a planting festival, including local authorities, families, school children and guests. These ceremonies include

Fig. 4. Construction of earth berms, held in place by bamboo revetments, for tree planting on steep slopes. This Japanese example is designed to revegetate a steep cut-bank on a highway construction project.
Fig. 5. Mulched and recently planted forest designed to shield an industrial facility in Japan.

comments on environmental awareness, and the value of forests. The festival participants are instructed on how to plant trees and then they are invited to select seedlings from tanks of water and plant the seedlings in the prepared holes in the squares on the site. The species of trees are provided to the planters in the approximate proportions they occur in the potential vegetation. However, there is no attempt made to have the planters arrange these in a natural pattern in the planting beds. The large number of trees seedlings and individual planters automatically results in complex patterns of trees.

Presence of local or regional authorities, adults and children all planting trees together is recorded by the press and supports the feeling of local community action. Through these festivals the people of the area identify with the forests they have planted and expand their environmental awareness. Thus, the engineering process also yields social results that feed-back on the project and enhance its overall success.

Following the planting ceremony straw mulch is placed around the seedlings (Fig. 5). This is the final technical step in the operation and no further management or maintenance is required. A slogan describes the effect of cessation of further input – “no management is good management”. Even so, survival of seedlings is frequently over 90% and is
sometimes as high as 99% in the first year. Growth of stem height is usually double the planting height in the first year. This rate of growth continues for several years so that a closed canopy is achieved in about 5 years. As the stems grow, the canopy is raised in height (Fig. 6). Natural competition between species takes place and some individuals are eliminated from the populations as the canopy becomes closed.

This planting technique also has been used in unusual locations and in industrial applications. Unusual locations include cliff faces and beach front sites. As was shown in Fig. 4, on a cliff face it is necessary to construct bamboo basket-like planting beds along the cliff face to hold the soil for planting. As the trees become established their roots enter cracks in the rock, leaving a rock-face community on extremely steep slopes. This system also is effective in controlling soil movement on steep road cuts. On a beach front site exposed to periodic overflow of sea water the naturally adapted species are planted more closely (five per square meter) and are irrigated the first year to assure their establishment in the sandy and rocky substrate. Thereafter, a dense stand develops into a characteristic beach front dune complex and holds the site even under considerable disturbance. Industrial applications usually are designed to shield buildings or machinery from roads and housing developments and reduce noise and air
DISCUSSION

The Miyawaki reconstruction technique originally was designed for reconstruction of broad-leaved forests on small sites in Japan. In these locations rainfall is adequate year around. The object is to provide rapid revegetation to reduce visual, noise, or chemical pollution, erosion control, or urban green areas on relatively small and often highly valuable sites. Examples include industrial plants of Nippon Steel Company, Kansai Electric Power Company, and revegetation of man-made islands in Tokyo Bay. If the soil has been scraped, as in a large construction project, then fertilization of the soil in the prepared beds is required. Otherwise the main inputs are the seedlings, site preparation, and mulching. In difficult locations, for example on cliff faces within the broad-leaved forest region, site preparation and fertilization may increase the costs of reconstruction.

This technique requires a relatively large initial capital investment, but maintenance costs after the project is planted are essentially nil. It is difficult to calculate the economic costs because values differ greatly from country to country. In Japan seedlings are produced at a cost of about 400 to 500 yen (or roughly US$2.00) per plant. At this expense it would require about US$60,000 per hectare for restoration in the United States. Clearly this expense can be borne only by industry or government, for very critical areas. In comparison, in the southern United States pine seedlings are grown in nurseries for 0.5–1 cents per plant and the costs of the seedlings in replanting pine land is about 5 to 7% of the total costs (Donald Marx, USFS, pers. commun.). Hardwood seedlings may cost up to 4 cents per plant. Clearly, there is a considerable cost of the reconstruction operation, although conversion of costs from Japanese to USA currency is difficult to determine.

This technique has also been applied outside the broad-leaved forest region of Japan. Applications include northern forests on Hokkaido and beach front sites near Yokohama. Recently, it has been successfully extended to Diptocarp rain forest sites in Sarawak where over 300,000 seedlings were planted in 1992, to Amazonian rain forest in Brazil and to Nothofagus forest in Chile.

It is important to note that this ecological engineering technique is not designed to recreate natural ecosystems. While natural ecosystems may ultimately evolve on an engineered site, the goal of the process is to create dense stands of forest vegetation quickly. These stands serve specific
purposes, such as shielding industrial complexes from housing districts. The use of species characteristic of the native vegetation means that no further management is required after the trees are planted. The species are adapted to the environmental conditions of the site and to the competitive relations among the elements of the vegetation. While this process requires a substantial initial investment, there is little or no maintenance cost, a high likelihood of success and rapid achievement of the objectives. In those circumstances where a dense vegetation stand is required, this well-tested technique qualifies as a viable alternative for land managers and civil engineers. Its use is not restricted to Japan, but a knowledge base of plant biology and ecology is required before it can be applied in other countries successfully.

REFERENCES


Restoration of living environment based on vegetation ecology: Theory and practice

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The foundation of ecological restoration is how to preserve biocoenoses (i.e. functional ecosystems) and how to restore and reconstruct them where they were destroyed. One of the most important challenges is the restoration of complex, multilayer forests representing the potential natural vegetation. Native forests have functions in disaster mitigation and environmental protection, as well as providing the basis of existence for local people and maintaining gene pools for the future. Through vegetation surveys in Japan and South-east Asia, we have established basic principles in vegetation-ecological restoration of forests. We have been restoring expected disaster-mitigation and environmental protection forests, as experimental reforestation projects, since the 1970s at more than 750 sites throughout the 3000 km long Japanese Archipelago, and since the 1980s in parts of South-east Asia, China and South America. The restoration movement has spread from a local activity to a global movement. We aim for the sustainable development of human society through ecological restoration of living environments.

Key words: chinju-no-mori; ecological restoration; native forest by native trees; potential natural vegetation; restoration practice.

Introduction

Natural environments have been devastated and destroyed worldwide by recent rapid development, urbanization and industrialization. It is no exaggeration to say that the basis of human life is now threatened (Miyawaki 1982a,b).

We ecologists have been giving warnings against the devastation of nature through study results, and have produced some good effects. Besides criticism, however, we should contribute to the wholesome development of human society by active concern for nature restoration and reconstruction (Miyawaki 1975, 1981). Species and taxa that have already become extinct because of the destruction of nature are impossible to restore. Plant communities that have been destroyed are also generally quite difficult or sometimes impossible to restore (Miyawaki 2001). Therefore, it is fundamental that existing species and communities are protected and preserved and those that have been destroyed by human impact should be restored and reconstructed. However, the mere deceptive appearance of vegetation restoration should be avoided. It is essential to restore natural vegetation of combined native species in accordance with the potential abilities of the habitat, and to try to restore the whole ecosystem specific to a region (Miyawaki 1992).

Vegetation, a basic component of ecosystems, can often be restored after ecological research and adequate vegetation field surveys, although some systems, like raised bogs, are quite difficult to restore once they are destroyed (Miyawaki & Fujimori 1970).

Vegetation-ecological restoration has various methods according to its purpose and the objects treated, for example, grassland and shrub vegetation. So-called ‘Satoyama’ – seral secondary forests or substitute forests – should be restored, and lawn areas can also be constructed for the recreation and refreshment of citizens. However, it is most important to restore and reconstruct natural or quasi-natural multilayer forests, which save the lives of local people, the cultures originating in each district, and gene pools for following generations. They also have diverse functions in disaster mitigation and environmental protection (Miyawaki 1999).

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This paper is about restoration of these natural or quasi-natural forests. We aim at sustainable development of human society and ecological restoration of living environments through reforestation based on field investigations, where we understand the structures and systems of indigenous forests.

**Methods**

A thorough vegetation field survey is carried out on the objective site. We determine the phytosociological community units of many plant communities in the region from our investigation of the remaining natural vegetation and substitute vegetation. We then represent them onto a map of the actual vegetation. We determine the potential natural vegetation (Tüxen 1956) of the region from the remaining natural vegetation and its relationship to the substitute vegetation there, and draw this onto a potential natural vegetation map. Each unit of potential natural vegetation consists of species combinations. From this we are able to find the main tree species of the native plant communities of the region (Miyawaki 1999, Fig. 1).

We collect and germinate seeds of these tree species. Bare seedlings from the potential natural vegetation are difficult to transplant because they are deep- and tap-rooted. We grow them in pots until their root systems...
fully develop in containers. We prepare as many kinds of potted seedlings of the main and companion species as possible, then mix and plant them densely according to the system of natural forests. After planting we mulch with rice straw and other organic materials. Mulching prevents soil dryness even if it doesn’t rain for a month. It prevents soil erosion on steep slopes and even under heavy rainfall. It prevents weed growth. It protects seedlings against cold. It works as manure after materials get decomposed.

In many cases of ecological planting weeding is needed for the first 3 years. Weeded grass should be laid on the forest floor as added mulching. After that there is generally no need for maintenance. Young trees grow steadily through natural selection as time goes by (Miyawaki et al. 1993).

Results

Japan

With the field investigation of laurel forests on Amami Island in 1963 (Miyawaki & Ohba 1963), we started field investigations in every vegetation type of Japan, from natural vegetation of remaining forests to farmland and grassland impacted most by humans, with the assistance of Ministry of Education, farsighted local governments and private companies. From the data of investigations we drew actual vegetation maps to show the distribution of local vegetation, and potential natural vegetation maps (Miyawaki 1979, 1990).


Utilizing actual vegetation maps for diagnosis of the present green environments and potential natural vegetation maps for the scenario of reforestation, we tried to reconstruct forests where native forests were lost. The first company that asked us to reconstruct green environments was Nippon Steel Corporation. We made field surveys around their nine ironworks, determined the potential natural vegetation of each region and restored native forests. Since then we have been grappling with the restoration of green environments based on ecological knowledge (Miyawaki 1975).

The number of ecological plantations until February 2003 is 769. The plantation sites range from Hokkaido to Okinawa, from reclaimed land along the sea to a collapsed highway site 1900 m a.s.l. and from the laurel forest (Camellia japonicae) zone to the summertime broad-leaved forest (Fagetacea crenatae) zone (Miyawaki 1996, 1998; Fig. 2).

For example, Aeon Group (one of the biggest shopping center developers in Japan) held planting festivals around their 349 new shopping centers all over Japan from 1989 to 2002. The citizens planted 4 257 000 seedlings during these festivals. On the average one person planted 20 seedlings in 1 h. The results of these ecological plantations based on a vegetation-scientific scenario are quite good. Seedlings that were only 30–50 cm high when planted grew to 7 m high after 10 years, higher than 10 m after 15 years, and form so-called anti-disaster environment protection forests (Miyawaki 1989a; Miyawaki & Golley 1993).

According to our research, the main tree species of the potential natural vegetation in the C. japonicae region are Persea thunbergii in coastal areas, Castanopsis cuspidata var. sieboldii on ridges, evergreen Quercus (Cyclobalanopsis) spp. including Q. myrsinaefolia, Q. glauca, Q. salicina and Q. acuta in inland areas. Q. gilva and Q. sessifoliae are also the potential natural vegetation south of the Chubu district, Honshu, Q. miyagii, Q. glauca var. amamiana on Amami, Okinawa, and Bischofia javanica, Beilschmiedia erythrophloia in coastal areas of the subtropical zone (Miyawaki et al. 1980, 89).

As mantle communities at the forest edge, Pittosporum tobira, Rhaphiolepis umbellata, Q. phillyraeoides and others are planted in coastal areas, and Camellia sasangua var. hiemalis, Gardenia jasminoides f. grandiflora and Rhododendron spp. in inland areas. The function of a mantle community along the forest edge is preservation of the forest and beautification by seasonal flowers between the forest and the open landscape (Miyawaki et al. 1979; Miyawaki et al. 1983; Miyawaki 1997, 1998).

Dense, mixed planting of 30–50 species of the potential natural vegetation is in accordance with the system of natural forests, and enables a multilayer forest to grow after 15–20 years by the peculiarity of planted species. At some planting sites, however, even after ecological dense, mixed planting, adequate natural selection is not seen until 10–15 years after planting and some tall trees have thin stems compared to their height. This problem will be solved in time.

South-east Asia

Since 1978 we have been researching in the tropical rainforest zone of Malaysia, Thailand and Indonesia. The study results show that natural forests were completely destroyed in many areas because of slash-and-burn farming, felling trees and oil palm farming. Slash-and-burn farming over a large area has destroyed every tree within a forest and it takes quite a long time to see a forest naturally restored. Sometimes it is nearly impossible (Miyawaki 1982c, 1989b, 1993).
For reforestation on bare land at Bintulu, Sarawak, on Borneo Island, we chose *Hopea* spp. and *Shorea* spp. from the potential natural vegetation, not exotic species, such as, *Eucalyptus* spp. and *Acacia mangium*.

For 10 years we collected seeds of 92 species from the potential natural vegetation including 41 species from *Dipterocarpacea*, cultivated potted seedlings with fully developed root systems, and mixed and planted them ecologically (Miyawaki 1991). Twelve years have passed since the first planting. Through weeding for the first 3 years and solid natural selection after that, seedlings grew steadily into a splendid quasi-natural forest (Miyawaki & Meguro 2000; Fig. 3). Ecological planting is carried out every year with the help of volunteers from Japan and local students and citizens. At present several phases of tree growth can be seen at the sites of 50 ha.
For restoration of Amazonian lowland tropical forest, we began field investigations in 1991 around Belém, Brazil. This area is called ‘the green lung of the earth’. We held the first planting festival in May 1992. Every year since then we have been planting seedlings in cooperation with citizens.

**Discussion**

According to Clements’ succession theory it will take 150–200 years in Japan to restore a native forest from barren land and many scientists presume it will take more than 300 years in tropical zones like Borneo and the Amazon (Clements 1916). But a period of more than 100 years is too long for us. Nature restoration in a shorter period is required. We should not stick to the secondary progressive succession.

Field surveys have told us it is not climate conditions but soil conditions that matter. At sites with poor soil, we make retaining walls on slopes to lay soil, organic material and fallen leaves. Bare lands should be covered with as much topsoil as possible. Many planted seedlings are the main components and companions of the potential natural vegetation (i.e. terminal vegetation) not pioneer or intermediate species. We make potted seedlings of these species, with well-developed root systems, and mix and plant them densely following the system of natural forests (Miyawaki 1999; Fig. 4).

In this way we have succeeded in restoring quasinatural forests in 15–20 years in every region of Japan.

One example of reforestation in South-east Asia is an experimental greening project at Bintulu, Sarawak in Malaysia. Planted seedlings have now grown into a 12–14 m high forest in 10 years. We calculated the wood volume and the amount of carbon dioxide sequestered per year per hectare in the reconstructed forest. We also compared the figures with those of a restored forest on a man-made island, Ohgishima, Japan. The result was that the figures at Bintulu were much higher than in Japan (Miyawaki & Meguro 2000; Fig. 5). Restoration of tropical rainforests is most effective for conservation of the global environment (Miyawaki & Abe 2002).

In Belém in the Brazilian Amazon, we began field investigations in 1991 and held the first tree-planting festival in May 1992, when the Earth Summit was held in Rio de Janeiro. We planted fast-growing and intermediate species in addition to *Virola surinamensis*, *Tabebuia serratifolia* and other main tree species of the potential natural vegetation for two reasons. One is that we couldn’t carry out adequate vegetation surveys because of a limited preparatory period. The other is that it is an established theory that planting pioneer species is the key to a successful reforestation from bare land. The number of planted tree species was 50 (finally 92).

Fast-growing species like *Balsa; Ochroma pyramidale* and *Boleira; Joannesia princeps*, were 6 m high in 1994, 2 years after planting; 10 m high in 1996, 4 years after planting; and 15 m high in 1998, 6 years after planting. d.b.h. measured up to 20–30 cm. The trees had grown magnificently, and the physiognomy was a quasinatural forest. However, in the field investigation of
Fig. 4. Comparison between new and classical succession theory in laurel forest area of Japan.
There may be criticism that planting potted seedlings in a vast area is costly. The solution to this problem is getting local citizens to collect seeds, to make potted seedlings and to plant them as leading participants. We ecologists write scientific scenarios for reforestation. Administrative institutions and private companies work as behind-the-scene directors. This is how we have restored quasi-natural forests in Japan, Asia and South America.

These forests of complex multilayer communities have disaster-mitigation and environmental protection functions in each region. In the Great Hanshin Earthquake, which hit the Kobe district, western Japan in January 1995, there was no damage to trees in Japanese traditional temple forests, the potential natural vegetation, however, huge structures made of non-living materials collapsed, including elevated railways, highways and tall buildings (Miyawaki 1998). On a global scale, natural forests help to avoid global warming by absorbing carbon dioxide. Restoration and regeneration of ecologically diverse forests is inevitable for citizens in every region to survive in the next century, and the next millennium.

References


Restoration of Natural Environment by Creation of Environmental Protection Forests in Urban Areas*

Growth and development of environmental protection forests on the Yokohama National University campus—

Akira MIYAWAKI** and Kazue FUJIWARA**

 SYNOPSIS

The creation of environmental protection forests is a basic ecological method for restoring the natural environment in urban areas which are utilized intensively and are dominated by non-biological materials and several forms of energy (Miyawaki 1982, Miyawaki, et al. 1987). The result of "Ecological greenery planting: Tree planting" shows that seedlings of 0.5m height grew to 9m and developed into true environmental protection forests over a period of 11 years. Maintenance was not required after the first two or three years. These forests developed gradually into multi-stratal communities by means of an ecological equivalent of "natural selection". The understorey develops later than the canopy, but it was seen that the development of these ecosystems and the restoration of natural conditions were proceeding.

1. Environmental protection forest planted with native tree species

Forests are the most stable type of natural ecosystem, given suitable moisture, temperature, and soil conditions. Forests are composed of multiple layers of trees, shrubs, and ground herbs. Forests also have an "underground ecosystem" of soil animals which decompose the litter. The campus of Yokohama National University supports evergreen broad-leaved forests with

* Contribution from the Department of Vegetation Science, Institute of Environmental Science and Technology, Yokohama National Universitu No. 201.
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Quercus myrsinaefolia, Quercus glauca, Persea thunbergi, Castanopsis cuspidata var. sieboldii, etc. (Miyawaki et al. 1972). Evergreen broad-leaved forests, as multi-layer communities, embody the most stable sort of "naturalness". In urban areas, evergreen broad-leaved coppice forests are an easy and effective way to create natural forest conditions. We have examined creation of natural forests since 1982 (Miyawaki 1982, Miyawaki et al. 1983, etc.). Important keys are: 1) recovery of the topsoil, 2) selection of appropriate species, 3) dense initial planting, and 4) use of pot seedlings with well developed root systems.

In this report we present a survey of environmental protection forests at Yokohama National University, which are eight and 12 years old. We measured growth and development of each tree in permanent quadrats (height, diameter at breast height (DBH), and understorey species). Soil mites were surveyed by J. Aoki.

2. Purpose of the Research

It is necessary to use "living construction materials" to develop environments for healthy human living in urban areas, which are otherwise mostly constructed of artificial materials. Forest ecosystems are the most important living construction material. We should introduce the theory of developing multi-layer, balanced forests and seek the results of ecological vegetation science. We establish a method to restore naturalness in urban areas.

3. Survey method and location

Three environmental protection forests on the campus of Yokohama National University were selected for study. One forest is 12 years old, the other two are eight years old. In them, 10 permanent quadrats of 25m each were installed for estimating the height and DBH of each tree and for surveying by phytosociology. Height and DBH were plotted graphically for comparison.

Fig. 1 Location of survey points.
Table 1 Division of the survey area

<table>
<thead>
<tr>
<th>Environment type</th>
<th>natural forest</th>
<th>environmental protection forests</th>
<th>landscape garden area</th>
<th>lawn area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main plants</td>
<td>Castanopsis cuspidata var. sieboldii</td>
<td>evergreen broad-leaved trees</td>
<td>Betula platyphylla</td>
<td>Prunus jedoensis</td>
</tr>
<tr>
<td>Quadrat number</td>
<td>UA</td>
<td>UB-1</td>
<td>UB-2</td>
<td>UB-3</td>
</tr>
<tr>
<td>Location</td>
<td>west side of Institute of Env. Sci. &amp; Tech.</td>
<td>north side of Inst. of Env. Sci. &amp; Tech.</td>
<td>west of main gate of YNU</td>
<td>north of central open area</td>
</tr>
</tbody>
</table>

Fig. 2. Environmental protection forest UB-1, planted in May 1976 on the north side of the Institute of Environmental Science and Technology.
of the growth of each tree. Then phytosociological surveys were conducted on a *Castanopsis cuspidata* var. *sieboldii* forest (west side of the Institute of Environmental Science and Technology) as a natural forest, as well as *Betula platyphylla*, *Zelkova serrata-Prunus yedoensis*, and *Zelkova serrata-Rhododendron* plantation areas as examples of “landscaping” (or “landscape gardening”), for comparison of the soil mites of natural forests and garden–planning areas. The survey method used was that of Braun–Blanquet (1964; Fujiwara 1987).

4. Results

In the environmental forests surveyed, the growth of the trees was different at each site (Figs. 2–5). The environmental protection forest on the north side of the Institute of Environmental Science and Technology, which is 12 years old, was planted as pot seedlings 0.5–1.2m tall and with well developed root systems, two individuals per m², in May 1976 (UB-1, Fig. 2). UB-2 and UB-3 were planted in March 1980 (Fig. 3, 4), UB-2 with two individuals per m² and UB-3 with one individual per m². UB-1 shows the best growth, while UB-3 is worse than UB-2 (Fig. 5–9). Comparing the forest composition (Fig. 10) of natural forest, environmental protection forest, and landscape gardening, one sees that natural forest develops a four–layer structure already and becomes a stable forest. The UB-1 environmental protection forest has not yet developed enough. The UB-2 environmental protection forest has developed about the same as UB-1, UB-

Fig. 3. Environmental protection forest UB-2, planted March 1980 to the west of the main gate of Yokohama National University.
Fig. 4. Interior of environmental protection forest UB-2.

Fig. 5. Environmental protection forest UB-3, north of the central open area.
Fig. 6  Relationship of tree height and diameter at breast height (DBH), in forest UB-1.

Fig. 7  Relationship of tree height and DBH in forest UB-2.

Fig. 8  Relationship of tree height and DBH in forest UB-3.

Fig. 9  Relationship of tree height and DBH in all three environmental protection forests.
Environmental Protection Forests (UB-1 and UB-2) and their Vegetation Coverage

Fig. 10 Vegetation cover of each forest layer in the permanent quadrats.

- Evergreen
- Semi-Evergreen
- Deciduous

3 still has open space in its canopy. Although UB-2 and UB-3 forests are the same age, the UB-2 forest was constructed on a slope and UB-3 on a flat area. The site of UB-3 has especially bad drainage, and its density of seedlings is different. UB-3 was planted with one individual per m². The lawn area UD is quite different from other areas. From Figure 6, it is understood that UC1-3 have about the same composition. Based on the survey results of mites by J. Aoki (1988), UC1-3 have six special species which do not live in UB1-3 or UD. UB1-2 have nine special species which are common to natural forests. UB-3 has only one. The natural forest has 13 characteristic species.

5. Conclusion

From the results and comparison with data in 1983 (Fujiwara 1983), the following points are concluded:

1. When environmental protection forests are constructed, it is necessary to restore the topsoil, select pot seedlings with well developed root systems, plant densely, and provide good drainage.

2. Mixed plantations with many species planted densely lead to good growth because of differences in crown space.

3. Over 10 years, the environmental protection forests planted on the basis of criteria in 1) and 2) were thinned naturally, by inter-plant competition.

4. Ten years, however, are not enough to develop and restore natural forests completely. Such forests are still young. It is possible to make the forests develop faster by additional planting of some native species of shrubs and herbs in the understorey of the environmental protection forests.

5. Environmental protection forests grow up and surpass the "landscape gardening" trees within three to five years. Environmental protection forests also spread their vegetative cover resulting from the dense planting of seedlings much more than the "landscape-gardening" or lawn areas.
Thus, the best effect is produced by creating green corridors by means of environmental protection forests satisfying points 1)-5) for restoration of natural conditions in urban areas.

References


Restoration of urban green environments based on the theories of vegetation ecology

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Abstract

Modern cities and industrial areas are standardized, built of non-biological materials such as iron, cement and petrochemicals. The most desirable life for citizens should be both mentally and physically sound, which are the basis of existence for all lives. A multistratal forest is estimated to have 25–30 times the green surface area monostratal grass. With underground organic compounds, multistratal forests also contribute to the reduction of CO₂. Building facilities can be completed in short term with economic backing. But it takes biological time to regenerate a multistratal forest using living green construction materials. It is urgent to start the restoration and reconstruction of native green environments immediately. To form green environments of multistructure using plants, it is necessary to systematize the data from field investigations and to follow the scientific scenario based on potential natural vegetation. We propose the restoration of native forests, which function as disaster-prevention and environmental-preservation forests in urban and pre-urban areas. Native forests grow well with no management. With the ecological technique 600 sites have been successfully revegetated in the Japanese Archipelago, in Malaysia, Melaka, Kuala Lumpur, and Bangkok in Southeast Asia, and in Belem, Brazil, and Concepcion, Chile in South America. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Restoration; Potential natural vegetation; Multistratal forests; Green environments; Ecological scenario; Ecotechnology

1. Environmental problems are the issue of life

The focus of environmental protection is on how to protect life. To protect human life means to protect plant communities, since human beings are living on the earth as consumers of plants.

As for CO₂ problems it may not be possible to reduce this use to zero, but it is possible to minimize concentrations in the air. It is green plants that fix carbon. Forests, especially multi-stratified native forests with native trees, are said to have 25–30 times the green surface area of monosтратal grass like lawns. Forests have different functions, including wood production and decoration. But the newest and most important function is ecotechnological reforestation (Miyawaki, 1975, 1981, 1982a, 1989, 1993, 1996, 1997; Miyawaki et al., 1979, 1987; Miyawaki and Golley, 1993) and restoration of green environments in urban industrial complexes and around transportation facilities etc.

2. Ecotechnology and its vegetation-ecological approach

Vegetation science is the study of plant communities and their environment, including the influence of human activities in both temporal and spatial dimensions (Miyawaki, 1980–1988). Vegetation ecology is a field within the natural sciences and has been studied as a pure science until recently. But today the pure scientific method is not enough to maintain the development of human life. The knowledge and the perspective of ecotechnology, which is integrated ecology and technology, is inevitable.

Ecotechnology is a large field. Its vegetation-ecological approach is to build multistratal greenery to meet the potential power of the area. The goal of the vegetation ecological approach is to create real green environments as the basis of human existence (Miyawaki, 1989, 1993; Miyawaki, et al., 1993; Miyawaki and Golley, 1993; Miyawaki, 1996).

3. Afforestation based on knowledge of potential natural vegetation

In order to create ecotechnologically sound environments, field surveys are most fundamental (Miyawaki, 1981, 1982b, 1993). Potential natural vegetation is identified by remaining natural vegetation which can be judged by a few remaining native trees in the field (Tüxen, 1956), and additionally by considering the form of the land use and comparing soil profiles.

Building native forests with the functions of environmental protection and disaster prevention based on potential natural vegetation is the most important goal of ecotechnology we consider.
4. Experiment projects and the results of ecological reforestation based on potential natural vegetation

4.1. Japanese Archipelago

In 1960 we began field investigations of actual existing vegetation and potential natural vegetation for the purpose of both theoretical studies of the vegetation and preparation for restoration of green environments in various industrial/urban areas in Japan, stretching 3000 km from north to south. In the 1970s environmental destruction had come to be a social problem. We planned to utilize natural vegetation to improve the environment and to reduce pollution. Fortunately, farsighted Japanese enterprises such as Nippon Steel Corporation, Tokyo Electric Power Company, Kansai Electric Power Company, Honda, Mitsui Real Estate Corporation, Mitsubishi Corporation, Torei Company and many others, offered to help us to build environmental protection forests around ironworks, power plants, factories and new towns (Fig. 1) (Miyawaki et al., 1983; Miyawaki, 1993).

Since the 1980s, with the cooperation of local government agencies and government offices, including the Ministry of Construction, we have built environmental protection forests along highways and rivers, and around harbors, dams, airports, new towns, shopping areas, schools and houses. We have succeeded in ecological reforestation of about 600 locations. Included in the reforested areas are reclaimed lands of Tokyo Bay and Osaka Bay, Hokkaido in the cool temperate zone, and mountain highways at 1000 m above sea level, where it was once said to take more than 300 years to form native multistratal forests. We cultivated seedlings in pots

Fig. 1. Twenty years after planting 30–50 cm high pot-seedlings of Persea thunbergii, castanopsis cuspidata var. sieboldii, etc., the plants grew 16–18 m high to constitute a peripheral environmental and disaster-prevention forest around the industrial site in Japan, (May 1993).
Fig. 2. Primary-school students (1300) plating seedlings of evergreen *Quercus glauca*, *Q. gilva*, *Q. myrsinaefolia*, *Q. salicina*, *Castanopsis cuspidata* var. sieboldii, *C. japonica* and others. They are all main tree species of potential natural vegetation along the Kashiwara by-pass road. (Nara National Road Office, Ministry of Construction, March 10, 1982). After 14 years the tree canopy was 11 m high (June 28, 1996).

until they grew to 30–50 cm and their roots were adequately developed. Three years after dense, mixed ecological planting there was no further need for human-based management; nature began to manage itself. Multistratal environmental protection forests in the experimental areas have reached 20 m in height over the last 23 years (Fig. 2).

On January 17, 1995, a strong earthquake hit the Kobe area in western Japan. Not only buildings of iron or cement, but also some parts of elevated highways and Shinkansen (bullet-train) railways were instantly destroyed. But according to our investigations after the earthquake, no trees of the main component of the potential natural vegetation fell. The natural vegetation includes the species *Quercus glauca*, *Camellia japonica* and *Hex integra*, in laurel forests (*Camellietea japonicae* forests) in and around Kobe. Furthermore, theses species functioned in fire prevention. Where there was a line of such trees 1–2 m wide, fire was stopped (Fig. 3). Natural vegetation also helped to save many lives. Nearly 6000 people were crushed to death under houses, which were levelled to the ground. But these kinds of trees stopped falling roofs and pillars and made openings in the rubble, through which the people living there could probably escape.

This tragic earthquake has proved that native environmental protection forests based on ecotechnology also function as disaster-prevention forests by saving human life and property.
4.2. Southeast Asia

The knowledge we gained at 600 locations throughout Japan (Fig. 4) was also of practical use in Southeast Asia. In 1978, we began vegetation ecological studies in Southeast Asia. In Bintulu, Sarawak, Malaysia, native rain forests had been slashed. In July 1992 we planted 23000 potted seedlings of 91 species mainly from the natural tropical rain forests, with the help of the Malaysia Agriculture University (Miyawaki, 1992). We continued to plant native trees each year and by 1996 the number of planted seedlings reached 350000. These results suggest that we could regenerate tropical rain forests by the ecotechnological methods (Fig. 5).

As for environmental forests in towns, the seedlings from potential natural vegetation, such as *Hopea*, *Shorea*, *Diptocarpus* and *Balanopsis* were planted in 2–3 m-wide belts around shopping centers and on the slopes behind the centers in Kuala Lumpur, Melaka, and Bangkok, Thailand. They grew into 5–7 m-high forests within 4 years, and provide environmental-protection and disaster-prevention forests in towns.

4.3. Brazil and Chile in South America

In a joint project with Para Agricultural University, we also succeeded in restoration of lowland tropical rain forests in Belem at the mouth region of the Amazon in Brazil. This area is called the green lung of the world. We raised 150000 seedlings from the most abundant trees like *Virola*, in pots. In May 1992, we held the first international sapling planting festival, at which time 1300 people gathered and planted 6000 saplings (Fig. 6). The saplings have grown 6–10 m-high within 4 years.

Fig. 3. Flames were stopped by only 1–2 m wide tree strips of evergreen *Quercus* spp. and other potential natural vegetation in the great earthquake of Kobe, Western Japan (January 17, 1995).
years (Fig. 7). This project of restoring lowland tropical forests in the Amazon is now held every year.

In Concepcion, Chile, we attempted to reforest Nothofagus forests corresponding to Japanese *Fagus crenata* forests. Backed by the local companies and government

Fig. 4. Location of recently built ‘environmental and disaster-prevention forests’ in Japan, October 1996.

Fig. 5. Growing curve of main tree species in Bintulu, Sarawak (Borneo). Plot 203.
Fig. 6. The first international planting festival based on the vegetation ecological scenario, in Belem, May 22, 1992. This Amazonian tropical re-forestation project was a cooperative project with ECAP, Eidai do Brazil, YNU and JISE, sponsored by EDB and MC. After 4 years the trees grew 7–8 m high.

offices, we had the first planting in May, 1992. Four years later, we could see well grown, 4 m-high native forests with native trees.

5. Challenge to green forest environments around the Great Wall

We began ecotechnological research to reforest around the Great Wall with the help of the Beijing government, in August 1996. We also expect the support of the Chinese Ecological Association and Chinese Academy of Sciences. We fully understand that it will not be easy to bring this project to success. But please consider

Fig. 7. Growing curve of main tree species. All are indigenous to the Belem region (Belem/Brazil).
that the area around the Great Wall was once covered with forests of *Quercus mongolica* accompanied by summergreen broad-leaved trees including some conifer trees. The Great wall is one of the most splendid legacies of mankind in the world. The reforestation around it can be said to be for the future of mankind.

The ability or research field of an individual alone cannot bring the success of environmental restoration on a global scale. It is mandate for each researcher, government, company, and citizen in particular to cooperate and support the project from their own standpoint. Fortunately, China, which has the oldest history and civilization in Eastern Asia, and Japan join hands with other environmental restoration of the earth. I expect your heated arguments on ecoengineering. And I do hope you will work together with us and these movements of reforestation will spread throughout the world from here.

References


The Japanese and Chinju-no-mori*
Tsunami-protecting forest after the Great East Japan Earthquake 2011**

Akira Miyawaki, Yokohama, Japan

with 32 photos and 2 figures

Abstract: A great earthquake hit the Tohoku District, eastern Japan, on March 11th 2011. This Great East Japan Earthquake including a great tsunami that followed claimed the lives of about 20,000 people, though we made best possible prediction and preparation for natural disasters with full use of the newest science and technologies. Tide prevention forests of pine trees alone did not serve the purpose, but not a tree from the local potential natural vegetation fell in the earthquake and the tsunami. In order to survive in such flat areas, it is essential to build high coastal levees with native forests of indigenous tree species. Most of the debris from disaster areas is ecologically an earth resource. After removing poisonous materials, debris should be utilized to make well aerated mounds along the 300km-long coasts of disaster areas. Saplings of native tree species with fully developed root systems are planted mixed and densely on the mounds. They will grow to form tsunami-preventing native forests a “Great Wall of Forests”. This afforestation on embankments should spread as a government project and a national movement.

Keywords: tsunami, debris, potential natural vegetation, Great East Japan Earthquake 2011

Civilization, science, technology, and natural disaster

It is said that humans appeared on the earth about five million years ago and survived in forests, accepting abundant blessings from nature over most of that time. Forests were the basis of human existence (Miyawaki 2004). Humans made tools out of stones, bronze and iron, and because of their extremely developed cerebral cortex they acquired the ability to memorize, to think, to accumulate knowledge, and to judge in a comprehensive and systematic fashion. They developed civilizations that included science and technology. On the other hand, they kept destroying natural forests.

At present, by utilizing such extreme resources as atomic energy, we live a convenient and materially affluent life that our ancestors could never imagine. We live, so to speak, under the best of conditions.

In terms of prediction and preparation for natural disasters, we take the best possible measures by using the newest science and technologies. Kamaishi City, which suffered much damage due to tsunami in the past, completed a concrete breakwater 63 meters deep, 2 km long, 20 meters wide, and 8 meters high above sea level. However, on March 11th, 2011, it could not withstand the power of the great tsunami and was destroyed. The Great East Japan Earthquake claimed the lives of about 20,000 people (Miyawaki 2011). Otsuchi Town is bordered on the north by Kamaishi and had a population of around 16,000. By the Earthquake and the great tsunami, 1,276 people including the Mayor and executive officials were victimized (803 dead, 473 missing as of Nov. 2011) (Photo 1). We have realized natural threats are sometimes beyond the capability of humans to resist, and that life is most precious.

Functions of native forests

The course of life on the earth continues from about 4 billion years ago to the present, and we live now as a milestone on the road of life extending far into the future. Native forests of native trees are the green bed for our genetic resources.

Native forests are multi-stratal, each consisting of an overstory tree layer, an understory tree layer, a shrub layer, a herbaceous layer and usually a moss layer. The total green surface area is 30 times greater than that of a single-layer grass lawn. In the earth’s ecosystems, green
vegetation is the only producer, and indigenous forests with multiple layers are the basis of existence for all animals, including humans, which are also consumers.

Forests of evergreen broad-leaved trees with deep tap-roots (Photo 2) have various functions in environmental protection and disaster mitigation. They also sustain biodiversity and reduce global warming by absorbing carbon dioxide in the atmosphere and fixing carbon in biomass.

Indigenous forests throughout the world, however, have been destroyed through hundreds of years of logging, overgrazing, extensive farming and rapid urbanization. The Japanese have also cut down trees and destroyed forests to make farmland and houses. On the other hand, our ancestors always preserved, protected and built native forests nearby when they constructed villages and towns. These are the chinju-no-mori (Photo 3) (Miyawaki 2000) that Japan can be proud to show off to the world. Recently, though, the number of chinju-no-mori has dropped rapidly. For instance, only 40 such forests out of 2850 remain in Kanagawa Prefecture, the capital of which is Yokohama, with a population of 3.6 million people (Miyawaki et al. 1979).

**Trees in natural disasters**

We have been conducting field vegetation surveys in devastated areas since soon after the Great East Japan Earthquake. Monoculture forests of black pine (*Pinus thunbergii*) or red pine (*Pinus densiflora*) trees along the coast of the Sendai Plain and other disaster areas were almost completely destroyed (Photo 4), and some trees were carried inland by the second and third waves, extending the damage by bumping into people, houses and cars.

On the other hand, indigenous tree species of the chinju-no-mori in Minamisanriku Town and Otsuchi Town survived the disaster. Trees from the local potential natural vegetation (Tüxen 1956) on steep slopes, including *Persea thunbergii*, *Camellia japonica* and *Euonymus japonicus*, did not fall down, although the soil was washed away and their large roots were exposed (Photo 2, 5).

Forty years ago, at Kamaishi Steel Plant of Nippon Steel Corporation, we planted saplings of indigenous tree species in order to make quasi-natural forests, following an ecological method (Miyawaki 1973). Trees along the sea were cut down when they constructed a new harbor, but they left the forest further inland. After the Great Earthquake, trees of *Quercus myrsinacea*folia higher than 10 meters stood firmly (Photo 6), together with their young trees and other evergreen broad-leaved tree species, including *Camellia japonica* and *Euonymus japonicus*. The “real thing” endures severe conditions and holds out for a long time.

**Debris as an earth resource**

Central and local governments have problems dealing with debris from the Great Earthquake. They are carrying it to many other communities to burn. It contains lots of wood, and CO₂ is emitted when it is burned, which contributes to global warming.

Poisonous materials in the debris should be removed. What can be used should be taken away to use. All that remains is an earth resource. According to our surveys, more than 90% is woody debris from furniture or building materials plus concrete lumps from house foundations (Photo 8). These hold many memories of family history and victims.

I suggest creating native forests by utilizing the debris filled with memories of local people. We dig deep long
1. Everything was destroyed due to the Great East Japan Earthquake and the tsunami that followed on March 11th, 2011. (Otsuchi Town, Iwate Pref.) (provided by Jiji Press).

2. Root systems of Persea thunbergii which withstood the pressure of the Great Tsunami (Minamisanriku Town, Miyagi Pref.).

3. Chinju-no-mori facing the Japan Sea. (Wakasa Bay, Fukui Pref.).

4. Trees of black pine (Pinus thunbergii) and red pine (P. densiflora) fallen in the Great Tsunami (Sendai Plain).

5. An old tree of Persea thunbergii of a small Chinju-no-mori survived in the Tsunami (Minamisanriku Town, Miyagi Pref.).

6. Trees of evergreen Oak (Quercus myrsinaefolia) survived in the Great Tsunami. (Kamaishi Works, Nippon Steel Corp. (April, 2011).
Photo 7–12: 7. Environment-protection disaster-mitigation forest at Kimitsu Ironworks, Nippon Steel Corp., located on the shore of the Tokyo Bay. 8. Disaster debris is an earth resource. After removing poisonous and indecomposable matters, debris should be used to make mounds for reforestation by mixing with soil. 9. Scrap wood at the site of Eidai Brazil near Belén. This is an earth resource. 10. Scrap wood was buried to make a plantation mound. 11. Citizens planted saplings with delight at Belén, Brazil (1996). 12. 10 years later tress formed a 12 meter high forest.
Photo 13–18: 13. The planting site near the main gate of the new campus of Yokohama National University. We made lattice work, added topsoil and planted saplings of indigenous tree species (1979). 14. 20 years later, a 15 meter high quasi natural forest was formed in the campus. 15. Yokohama City Sewage Plant located close to the sea. Potted saplings planted on the mound built of construction debris and soil. 16. Same place 2 years later. (Prof. K. Fujiwara and Prof. E. O. Box following up on the tree growth). 17. About 10 years later, the trees grow to form a forest with a function of weakening the power of tidal waves and tsunami. 18. Hirohata Works, Nippon Steel Corp., Hyogo Prefecture. A mound formed in the reforestation site.
Photo 19–24: 19. Same place 10 years later. 20. Ohgishima Thermal Plant, Tokyo Electric Power Co. Saplings planted on the reclamation site in the Tokyo Bay. 21. 10 years later an environment-protection disaster-mitigation forest was formed. 22. Gobo Thermal Plant, Kansai Electric Power Co. (Head Office, Osaka). The site for plantation around the Thermal Plant on a man-made island. (March 1984, Wakayama Pref.). Potted saplings from the local potential natural vegetation, including *Persea thunbergii*, *Castanopsis cuspidata var. sieboldii*, and *Quercus glauca*, were planted mixed and densely here. 23. Same place at present (Dec. 15 2012). A boundary environment protection forest with functions of disaster mitigation and tide prevention is formed. 24. Inside of the forest of Photo 23.
trenches along the coast in disaster areas, put the debris and soil into these holes to make mounds (the higher, the better), and plant saplings of many main and companion tree species from the local potential natural vegetation. Mounds consisting of mixed soil and debris are well aerated, and trees grow well, because their roots also breathe under the ground (Miyawaki 2011, 2012).

The forests grown on the mounds will function as green embankments protecting life and property of local people from great tsunami. If all the debris is used up in building 100 m-wide 22 m-high mounds on the 300 km of affected coastline, then the debris accounts for no more than 4.8% of the total amount of soil in the mounds (Fig. 1), according to calculations by a retired senior official from the Construction and Transport Ministry and others.

Poisonous materials must be removed from the debris. The law that requires incineration disposal of general waste, including household garbage, was enacted at the beginning of 1970s. However, burning is the easiest way ecologically.

About 20 years ago, we already made plantation mounds by mixing wood refuse and soil as an experimental project at Belém, Brazilian Amazon. Trees planted on the mounds grew steadily, and now multi-stratal quasi-natural forests are formed (Miyawaki & Abe 2004) (Photo 9, 10, 11, 12).

Reforestation as national movement

Fortunately, former Prime Minister Morihiro Hosokawa (Photo 29, right person), who once joined in our reforestation project as the governor of Kumamoto Prefecture, Kyushu, cooperates actively in the implementation plan to build green embankments by utilizing the debris from the disaster areas.

We talked to the then Prime Minister Noda, as well as to former Minister Hirano of the Reconstruction Agency, and to former Minister Hosono for the Environment, about our proposal for making green embankments. They listened attentively but things have not gone forward, probably because the administrative system is too big and complex. In the meantime, debris, the useful earth resource, is being burned. It is quite effective to mix debris in order to aerate soil.

In our reforestation we do not use high-cost adult trees. We plant 30 cm tall saplings of the main and companion tree species from the local potential natural vegetation, which you can see surviving in chinju-no-mori. Saplings grow rapidly in mixed dense plantations based on the rule of natural forests.

The choice of native tree species to plant is most important. Monocultures of pine trees are weak in disaster prevention. As plants evolved, 300 million years ago was the age of the Pteridophytes (ferns and similar), which were buried in the earth during the next glacial age and became our present-day fossil fuels. Next was the time of the Gymnosperms, including cycads, ginkgos, and need-
le-leaved coniferous trees like Cryptomeria japonica and Pinus spp. Today is the age of the angiosperms (flowering plants) since about 150 million years ago.

Woody vegetation of angiosperms includes evergreen broad-leaved trees (laurel trees) with deep taproots, which grow in areas southwest of the Kanto District with the Tokyo metropolitan district up to 800 meters above sea level, and northward along the Pacific coast to around Kamaishi and Otshuchi of Iwate Prefecture, and even to southern Akita Prefecture on the Japan Sea coast. The main tree species in these areas are Persea thunbergii, Quercus acuta, Q. salicina, Q. myrsinifolia, Q. glauca, and Camellia japonica, plus Castanopsis cuspidata var. sieboldii in southern areas i.e. phytosociologically Camellietea japonicae (Miyawaiki & Ohba 1963) region.

We choose these main tree species for ecological reforestation. To support the main tall trees, we also choose shorter trees and arborescent species, such as Neolitsea sericea, Ilex integra, Myrica rubra, Dendropanax trifidus, Aucuba japonica, Fatsia japonica and Eurya japonica. Along the coasts we plant tree species strong against salty winds such as Pittosporum tobira, Rhaphiolepis umbellata, Eurya emarginata and Euonymus japonica.

We spend six months to one year nursing potted seedlings of these tree species until their root systems are fully developed, and then plant the resulting saplings in dense mixes according to the rule of natural forests. After three years, weeding is unnecessary. By natural selection, the trees grow about 10 meters tall in 10 years, and 20 meters tall in 20 years, to form a disaster-preventing and environment-protection forest of native trees (Miyawaki 2012, Photo 7 and others).

Some actual cases are shown in Photos: I. Yokohama National University (Photo 13, 14). II. Yokohama City Sewage Plant close to seashore (Photo 15, 16, 179. III. Hirohata Works, Nippon Steel Corporation (Photo 18, 19). IV. Ohgishima Thermal Plant, Tokyo Electric Power Company (Photo 20, 21). V. Gobo Thermal Plant, Kansai Electric Power Company (Photo 22, 23, 24).

We plant three saplings per square meter. This means that 90 million potted saplings will be needed to build forests on the 300 km-long 100 m-wide mounds along the coasts of the disaster areas. Of course we cannot plant all at once. We start where we can.
The first ecological planting in disaster areas, mixing debris with soil in a mound, was carried out at Kitakami Junior High School in Ishinomaki City, Miyagi Prefecture in May, 2011 (Photo 25, 26). Two months later, we also planted saplings of native tree species in Sendai, but in this project debris was not utilized. If the growth conditions compared, are compared the former is much better.

In 2012, planting festivals were held in Otsuchi Town (Photo 27, 28) and Iwanuma City (Photo 29, 30), governed by farsighted, decisive mayors. Volunteers from all over Japan planted saplings with the former Prime Minister, Mr. Hosokawa (Photo 29, right person). These saplings are now growing steadily, and 20-30 years later quasi-natural forests will be formed just like forests at Gobo Thermal Plant of Kansai Electric Co. and at Kimitsu Ironworks of Nippon Steel Corp. regenerated by using the Miyawaki Method (Photo 31, 32). Our hope is that the afforestation on embankments in disaster areas will spread as a government project and a national movement.

“Forests of Heisei” to the world

In the midst of Tokyo, there is a splendid dense laurel forest. This forest is located at Meiji Shrine which was built in 1920 to honor the Meiji Emperor who led Japan to become a modern nation after the long national isolation. The forest was built from around 1915 based on a grand design of people involved at that time to make an eternal forest on the premises. They chose native broad-leaved tree species and planted 100,000 trees given from all over Japan. In 50 years a quasi-natural forest was formed. At present 170,000 trees of 245 species are growing in 700,000 m² (Miyawaki et al. 1980).

The Great Wall of Forests on the 300 km-long embankment in the disaster areas of Tohoku district protects the lives of local people (Fig. 2), gives learning opportunities and relaxation time to visitors from home and abroad, and provides a feature of the regional landscape. These forests coexist with the local economy through selective cutting and selling after 80–120 years, and will survive thousands of years through the replacement of individuals until the next glacial age comes. We would like to build Forests of ‘Heisei’, the Great Wall of Forests. Heisei represents the era of the present Emperor.

For 40 years I have been planting saplings of indigenous tree species at more than 1700 sites in Japan and overseas, with local people in cooperation with farsighted companies, governments and various other groups. At each site the saplings grew to form forests that save the lives of people.

I hope all of the Japanese people plant small saplings with their own hands in order to protect their own lives and those of their loved ones, and to preserve the lush verdure of Japan. I wish to spread the know-how and the results of this ecological reforestation to the whole world.

References

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A. Miyawaki
Effectiveness of the Miyawaki method in Mediterranean forest restoration programs

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Abstract In the 1980s, Professor Akira Miyawaki introduced a new and innovative reforestation approach in Japan with the challenge to restore indigenous ecosystems, and maintaining global environments, including disaster prevention and carbon dioxide (CO$_2$) mitigation. Here, natural vegetation successional stages (from bare soil to mature forest) are practically forced and reproduced, accelerating natural successional times. The Miyawaki method has been applied in the Far East, Malaysia, and South America; results have been very impressive, allowing quick environmental restorations of strongly degraded areas. However, these applications have always been made on sites characterized by high precipitation. The same method has never been used in a Mediterranean context distinguished by summer aridity and risk of desertification. A first test was carried out by the University of Tuscia, Department of Forest and Environment (DAF), 11 years ago in Sardinia (Italy) on an area where traditional reforestation methods had failed. For an appropriate Miyawaki application on this site, the original method was modified while maintaining its theoretical principles. Results obtained 2 and 11 years after planting are positive: having compared the traditional reforestation techniques, plant biodiversity using the Miyawaki method appears very high, and the new coenosis (plant community) was able to evolve without further operative support after planting. Therefore, the implementation of supplementary technique along with cost reduction might provide a new and innovative tool to foresters and ecological engineering experts for Mediterranean environmental reforestation program.

Keywords Ecological restoration · Potential natural vegetation · Ecotechnology · Reforestation practices comparison · Mediterranean environment

Introduction

Global climatic changes, together with recent rapid urbanization and industrialization, have been the main anthropogenic effects worldwide in destroying natural environments and increasing risk of desertification. They suggest the need for performing more environmental conservation activity, as well as using innovative environmental recovery activities. In the last two decades, scientists have developed new insights both in theoretical and in practical actions for restoration and reconstruction of natural ecosystems (Clewell and Aronson 2007; Falk et al. 2006; Jordan et al. 1987; Perrow and Davy 2002a, b; Soulé 1980; Miyawaki 1975, 1981). Natural restoration is strictly related to increased sustainability and includes rehabilitation of ecosystem functions, enlargement of specific ecosystems, and enhancement of biodiversity restoration (Stanturf John and Madsen 2004). At the ecological level, restoration is also defined as “an intentional activity that initiates or accelerates recovery of an ecosystem with respect to its health, integrity and sustainability” (Aronson et al. 2002).

Degraded plant communities are generally quite difficult or sometimes impossible to restore (Van Diggelen and Marrs 2003). More than 200 years of reforestation practice has demonstrated that forest recovery takes a very long
time, frequently with unsatisfying results. Nowadays, it is possible to plant plantations of several species, but the transition from the simple plantation to a forest community able to evolve and sustain itself, according to the natural successional pattern, is still a rare event (for Italy, cf. Bellarosa et al. 1996). On the other hand, the mere superficial appearance of vegetation restoration should be avoided. It is essential to restore the natural vegetation using a combination of native species that conform to the potential trend of the habitat and to try to restore the whole specific ecosystem of a region (Miyawaki 1992).

In a natural forest cycle, as Clements (1916) described, annual plants on barren land are succeeded by perennial grass, sun-tolerant shrubs, light-demanding, fast-growing trees, and finally natural forests; each step may require decades, and the climax vegetation could be formed after two centuries or more (Connell and Slatyer 1977) (Fig. 1a). Currently, most forest reforestation programs adopt a scheme of planting one or more early successional species; after successful establishment, they are gradually replaced by intermediate species (either naturally or by planting), until late successional species arise. This pattern tries to simulate natural processes of ecological succession, from pioneer species to climax vegetation. However, it requires several silvicultural practices and normally takes a long time (Fig. 1b).

Taking several hundred years to complete the process of forest restoration is too long for us; because we live in a world where industry and urbanization are developing very rapidly, improvement of an alternative reforestation technique that reduces these times could be a useful tool (Miyawaki 1999). One reliable forest restoration method is the “native forests by native trees,” based on the vegetation–ecological theories (Miyawaki 1993a, b, 1996, 1998b; Miyawaki and Golley 1993; Miyawaki et al. 1993; Padilla and Pugnaire 2006) proposed by Prof. Akira Miyawaki and applied first in Japan. According to this method, restoring native green environments, multilayer forests, and natural biocoenosis is possible, and well-developed ecosystems can be quickly established because of the simultaneous use of intermediate and late successional species in plantations (Fig. 1c). The Miyawaki method involves surveying the potential natural vegetation (sensu Tüxen 1956) of the area to be reforested and recovering topsoil to a depth of 20–30 cm by mixing the soil and a compost from organic materials, such as fallen leaves, mowed grass, etc. In this way, the time of the natural process of soil evolution, established by the vegetational succession itself, is reduced.

The potential natural vegetation indicates the potential capacity of the land, theoretically considered, as to which vegetation it can sustain (Miyawaki 1992). Tree species must be chosen from the forest communities of the region in order to restore multilayer natural or quasinatural forests. For a correct choice, based on reconstructing the potential natural vegetation, several analyses (e.g., phytosociological investigation) are required. Detection of the soil profile, topography, and land utilization can improve our grasp of the potential natural vegetation. After these field surveys, all intermediate and late successional species are mixed and densely planted, with as many companion species as possible (Kelty 2006; Miyawaki 1998a), and soil between them is mulched. Mulching is needed to prevent soil dryness, erosion on steep slopes even with heavy rainfall, weed growth, protect seedlings against cold, and as manure as materials decompose (Miyawaki 2004). In fact, biocoenotic relationships involve autoregulations between species, favoring a dynamic equilibrium and avoiding any further silvicultural practice and need no insecticides or herbicides (with some exceptions). Indeed, in the Miyawaki method, the principles of self-organized criticality and cooperation theories have been essentially applied (Bak et al. 1988; Callaway 1997; Camazine et al. 2003; Padilla and Pugnaire 2006; Sachs et al. 2004). It has

*Fig. 1 Successional stages as would follow in natural conditions (a), adopting traditional reforestation methods (b) and the Miyawaki method (c)*
been demonstrated that multilayer quasinatural forests can be built in 15–20 years in Japan and 40–50 years in Southeast Asia by ecological reforestation based on the system of natural forests. Results obtained by application of the Miyawaki method in about 550 locations in Japan, as well as in Malaysia, Southeast Asia, Brazil, Chile, and in some areas of China, were found to be successful, allowing quick environmental restorations of strongly degraded areas (Miyawaki 1989, Miyawaki 1999).

Until now, the Miyawaki method has been applied in countries characterized by cold-temperate and tropical climatic regimes, which do not experience summer aridity stress and potential risk of desertification (increased by global change). Thus, the Mediterranean context could be considered an interesting test to assure the effectiveness of such a method in other important biomes, even with high biodiversity hotspots. This paper represents the first test of reforestation practices in the Mediterranean Basin using the Miyawaki method. It also offers a comparison between traditional methods and the proposed one, because the test has been carried out on target sites where traditional reforestation approaches are widely used but have mostly failed.

Materials and methods

Experiment locations and descriptions

On May 1997, we planted two experimental plots at the Municipality of Pattada (North Sardinia) on sites 2 km from each other in a straight line (Fig. 2 shows approximate location of the fields using a Digital Elevation Model with ESRI ArcMap 9.1 GIS software). In this area, reforestation programs have been periodically conducted with traditional methods since 1905, mainly using *Pinus pinaster* Aiton (maritime pine), *Pinus halepensis* Miller (Aleppo pine), *Cedrus atlantica* (Endl.) Carrière (Atlas cedar), *Quercus suber* L. (cork oak), *Quercus pubescens* Willd. (downy oak), and *Castanea sativa* Miller (sweet chestnut). Techniques involved planting along contour lines after forming gradoni or terraces by subsoiling, or along the maximum slope with subsoiling and holes.

To test the Miyawaki method, an experimental plot (named site A) of 4,500 m² was established at Sos Vanzos close to an artificial lake at 760 m a.s.l. Plot preparation consisted of brush clearing and tillage in order to shape 13 strips 3.5 m wide (Fig. 3a shows the planting scheme with

![Fig. 2 Location of the study areas. Black solid circle and square indicate, respectively, site A and site B; white solid circles show reforested areas with traditional methods used as comparison.](image-url)
different mulching operations). Potted tree seedlings were planted at a density of approximately 8,600 plants/hectare. A second plot (site B) of 1,000 m$^2$ is near Uca de s’abba lughida at 885 m a.s.l. (Fig. 3b shows mulched strips and plant density used). The preparation was similar to site A but covered the entire plot. Here seedlings were planted at a density of approximately 21,000 plants/hectare ca.

A description of the natural environment was carried out before implantation in order to check the potential natural vegetation and to proceed with species selection. Table 1 shows the main site characteristics as results of the field survey, and Fig. 4 compares the Mediterranean climate pattern with others where the Miyawaki method was successful. The data refers to 21 years of records, and the Walter and Lieth 1960 diagrams were obtained using the climatol statistical package implemented in R 2.7.1 for Linux (Guijarro 2009). Phytosociological analysis was carried out and a check-list of spontaneous species, with percentage of presence, is reported in Table 2. From this investigation, it was assumed that a mixed forest with Quercus ilex L. (holm oak), Quercus suber L., Quercus pubescens Willd., and Ilex aquifolium L. (common holly) represented the natural potential vegetation for the area. On both plots, seeds were collected from nearby natural forest stands and germinated in four greenhouses owned by the Regional Forest Directorate of Sardinia. After two or three leaves had sprouted, seedlings were cultivated in plastic bags for 1 year. Table 3 shows the species used on site A and site B, selected according to the natural phytocoenoses.

After planting, mulching with straw, green material (Navarro-Cerrillo et al. 2009) as Trifolium subterraneum L. (in site A), and sawdust (in sites A and B) were applied. Several changes from the original Miyawaki method were introduced on sites A and B in order to better test its effectiveness to local environmental conditions. The first 20–30 cm of native soil was labored, and no new soil was

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**Table 1** Site description (topographic, surrounding land cover and natural vegetation characteristics)

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<th>Site A</th>
<th>Site B</th>
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<tr>
<td>Localite</td>
<td>Sos Vanzos</td>
<td>Uca de s’abba lughida</td>
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<td>Mean height (cm)</td>
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added; some autochthonous early-successional species (e.g. *Pinus pinaster* L. and shrubs) were planted together with late-successional ones to improve plant community resilience (Castro et al. 2002, 2004; Gómez-Aparicio et al. 2004; Lortie et al. 2004); mulching was provided using different types of material, as mentioned above, instead of using only straw.

**Data collection and analysis**

To estimate the efficiency of this adapted Miyawaki method to Mediterranean environments, as well as the relationships in terms of interspecific competition, three surveys were performed in both experimental plots: in September 1998, April 1999 and, 10 years later, March 2009. GPS plant position, height ($h$) and DBH (diameter at breast height) >3 cm were collected for each individual. Moreover, mortality percentage trend and relative frequency (defined as number of individuals from each species by total number of plants) were computed. Comparisons were done with two nearby coeval sites where traditional reforestation techniques were applied to better understand the differences in plants growth, forest composition, and vegetation cover in percentage. The first one (conventionally named R15, 452 m$^2$) is a 15-year-old stand north of site A in a flat area, with *Pinus pinaster* L. and *Quercus ilex* L. planted in holes, with a spontaneous shrub layer of *Arbutus unedo* L., *Phyllirea latifolia* L., and *Erica arborea* L.; a conventional 12-m-radius sampling area was selected for recording height and diameter of all plants. The other plot (named G15, 400 m$^2$) with the same age of R15, approximately east of site B, belongs to a gradoni reforested site with *Pinus pinaster* L., *Quercus ilex* L., *Rosmarinus officinalis* L., and the natural presence of *Arbutus unedo* L., *Phyllirea latifolia* L. and *Erica arborea* L. In this case, due to the position of the site, i.e., along the mountainside with slope greater than 30%, a 4 × 100-m transect was set up following the contour line.

**Results**

Comparison between experimental plots

After planting on May 1997, plots were monitored and percent mortality was calculated for each species. On site A, 1,450 of 1,723 plants survived 1 year after planting; after 2 years, this number was reduced to 1,327, and after
Table 2  Major spontaneous species composition outside experimental fields according to Braun-Blanquet (1928)

<table>
<thead>
<tr>
<th>Species</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Allium roseum L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Anagallis arvensis L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Anthemis arvensis L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Anthoxanthum odoratum L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Aphanes boniaciensis (Buser) Holub</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arumis unedo L.</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Artemisia sp.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Asphodelus microcarpus Salzm. et Viv.</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>Avena barbata L.</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Briza maxima L.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Briza minor L.</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bromus hordaceus L.</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Bromus sp.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cerastium sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cistus incanus L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cistus monspeliensis L.</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Cistus salvifolius L.</td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td>Crepis sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cynosurus cristatus L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cytisus villosus Pourret</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Daphne gnidium L.</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>Delphinium halteratum S. et S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echium vulgare L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erica arborea L.</td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td>Erica scoparia L.</td>
<td>4</td>
<td>+</td>
</tr>
<tr>
<td>Erodium botryus (Cav.) Bertol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genista corsica (Loisel.) DC.</td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td>Geranium colouminum L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Geranium molle L.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Halimium halmifolium (Lo.) Willk.</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Helianthemum sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypericum perforatum L. subsp veronense (Schrank) Fröhlich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lathyrus angulatus L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lavandula stoechas L.</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>Linum bienne Miller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lotus subiflorus Lag.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lupinus micranthus Guss.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ornithopus compressus L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancratium illyricum L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phyllirea angustifolia L.</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Plantago lanceolata L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polygala vulgaris L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ranunculus flabellatus Desf.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Rumex acetostella L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanguisorba minor Scop.</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Sedum caeruleum L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedum stellatum L.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
12 years, 672 individuals were still alive (mortality rates equal to 15.84%, 22.98%, and 61%, respectively). Site B showed higher rates of mortality except from the first survey: in 1998, the number of plants that had survived was 1,920; the next year we counted 1,385, and in 2009 there were 336, with mortality percentages of 10.24%, 35.25%, and 84.29%, respectively. Note that in site A, 20 species survived but Salvia officinalis L., a shrub species of secondary importance, did not. On site B, a significant loss of subordinate species has occurred since 1999, and a consequent decrease of plant diversity (nine species of 23) was observed. The main forest species survived, i.e., maritime pine and the oak group, thus maintaining the possibility of achieving intermediate and terminal vegetation stages. Moreover, the presence of Prunus spinosa L. was observed as an autochthonous species. It has to be kept in mind that on the same site, other reforestation programs with traditional methods still failed, mainly due to a relevant water stagnation. Compared with site A, the success obtained on site B was less evident, as confirmed by Fig. 5, where histograms of mortality percentages are reported.

Further comparisons regard the role played by each species in the plant community as a result of interspecific competition and natural evolution of vegetation (Padilla and Pugnaire 2006). By monitoring the number and height of individuals per species, it was possible to analyze their position in terms of relevance within the experimental plots. A K index defined as $h \times v$ shows a quali-quantitative picture of vegetation dynamism, pointing out which species constitute both the upper layer and the understory. Comparisons were possible between sites A and B, as illustrated in Fig. 6 and Table 4. Diameter was not considered as a parameter for comparison because most species, except for maritime pine, showed mean DBH values < 3 cm.

On both plots, the role of Pinus pinaster L. is undoubtedly the dominant representative of the early-successional species. Mean height was 433.24 cm on site A, around 2.5 times greater than cork oak (the second species in order of significance), whereas a mean of 325.5 cm was registered on site B where it towers above the remaining species. Also, the $K$ index values for Pinus pinaster are much higher than the other species, emphasizing the importance of this species on both plots. In fact, $K$ refers to an overstory layer distinguished only by this species, as abundant and relevant in terms of number of individuals and growth performance. Because of its ability to establish in such ecological contexts, maritime pine is also found in other traditional reforestation programs all over Sardinia. Some differences in biodiversity richness of the experimental plots were recorded within the forest understory: on site A, the oak group is present with holm, pubescent, and cork oak, along with their secondary early successional species, such as Spartium junceum L., Arbutus unedo L., and Rosmarinus officinalis L., whereas on site B, intermediate species are represented only by cork oak and holm oak in a simpler plant community.

Comparison of the Miyawaki method with traditional reforestation techniques

Estimating the effectiveness of the Miyawaki method needs a comparison with other reforestation practices traditionally applied on the same ecological context, mainly focused on

<table>
<thead>
<tr>
<th>Species</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senecio vulgaris L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Serapias lingua L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Sheradia arvensis L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Silene gallica L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Silene sp.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stachys glutinosa L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Trifolium strictum L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Trifolium subterraneum L.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Tuberaria guttata (L.) Fourn.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Vicia sp.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Vicia tenaxissima (Bieb) Sch. et Th.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Viola corsica Nyman subsp limbarae Merxm. et Lippert</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Vulpia muralis (Kunth) Nees</td>
<td>+</td>
<td>4</td>
</tr>
</tbody>
</table>

A Arboreal, B shrub, C herbaceous layers. Abundance of each species is represented by six class coverage [<1% (+); 1–20% (1); 20–40% (2); 40–60% (3); 60–80% (4); 80–100% (5)].

### Table 2 continued

<table>
<thead>
<tr>
<th>Species</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senecio vulgaris L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Serapias lingua L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Sheradia arvensis L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Silene gallica L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Silene sp.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stachys glutinosa L.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Trifolium strictum L.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Trifolium subterraneum L.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Tuberaria guttata (L.) Fourn.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Vicia sp.</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Vicia tenaxissima (Bieb) Sch. et Th.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Viola corsica Nyman subsp limbarae Merxm. et Lippert</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Vulpia muralis (Kunth) Nees</td>
<td>+</td>
<td>4</td>
</tr>
</tbody>
</table>
growth performance of selected species. Table 5 describes the species composition of two selected plots with traditional reforestation techniques as result of test areas performed, in comparison with the Miyawaki ones. It is important to note that the majority of reforested sites in the area have been planned using traditional techniques; thus, the plots we have selected for comparison should be considered as a significant sample of a wider scenario.

Both R15 and G15 show an abundant presence of spontaneous shrub species, including *Arbutus unedo*, *Erica arborea*, and *Phyllirea latifolia*, whereas maritime pine forms the overstory layer with a density of 242 plants/ha in R15 and 175 plants/ha in G15 instead of 1,040 and 800 plants/ha recorded on sites A and B. The vegetation structure is simple in both cases, and associated planted species are represented only by holm oak (354 and 200 plants/ha, respectively) and other secondary species, such as *Rosmarinus officinalis* and *Cedrus atlantica* (a non-autochthonous species used on G15). Except for *Pinus pineaster*, the growth performance of secondary species, measured by plant density and mean height (including holm oak), is severely influenced by the massive presence of spontaneous shrub species that apply a strong competition. Shared investigated species reveal different vegetative condition and growth performance depending on local constraints. Mean and theoretical annual increase of height (Fig. 7) indicate a good affirmation of maritime pine on site A, site B, and G15, whereas on R15, it suffers competition by *Arbutus unedo*, partially balanced by difference in species density (44 plants/ha of *Arbutus unedo* against 242 plants/ha of *Pinus pineaster*). Although mean height of species common to all study areas does not differ significantly, plant density on site A is around four times higher than on R15 and five times on G15, whereas on site B, maritime pine densities are 3 and 4.5 times higher than on traditional reforested plots were observed.

**Table 3** List of selected species planted in Miyawaki experimental fields (total number of individuals per plot and relative percentage)

<table>
<thead>
<tr>
<th>Species</th>
<th>Acronym</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acer monspessulanum</em> L.</td>
<td>AM</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td><em>Arbutus unedo</em> L.</td>
<td>AU</td>
<td>50</td>
<td>11</td>
</tr>
<tr>
<td><em>Castanea sativa</em> Mill.</td>
<td>CS</td>
<td>42</td>
<td>–</td>
</tr>
<tr>
<td><em>Celtis australis</em> L.</td>
<td>CA</td>
<td>22</td>
<td>37</td>
</tr>
<tr>
<td><em>Fraxinus ornus</em> L.</td>
<td>FO</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td><em>Ilex aquifolium</em> L.</td>
<td>IA</td>
<td>112</td>
<td>125</td>
</tr>
<tr>
<td><em>Juniperus oxycedrus</em> L.</td>
<td>JO</td>
<td>–</td>
<td>45</td>
</tr>
<tr>
<td><em>Laurus nobilis</em> L.</td>
<td>LN</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td><em>Ligustrum vulgare</em> L.</td>
<td>LV</td>
<td>126</td>
<td>13</td>
</tr>
<tr>
<td><em>Malus domestica</em> Borkh.</td>
<td>MD</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td><em>Myrtus communis</em> L.</td>
<td>MC</td>
<td>19</td>
<td>95</td>
</tr>
<tr>
<td><em>Phyllirea angustifolia</em> L.</td>
<td>PA</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td><em>Phyllirea latifolia</em> L.</td>
<td>PL</td>
<td>–</td>
<td>203</td>
</tr>
<tr>
<td><em>Pinus pinaster</em> L.</td>
<td>PP</td>
<td>273</td>
<td>155</td>
</tr>
<tr>
<td><em>Pyrus communis</em> L.</td>
<td>PC</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td><em>Quercus ilex</em> L.</td>
<td>QI</td>
<td>300</td>
<td>394</td>
</tr>
<tr>
<td><em>Quercus pubescens</em> Willd.</td>
<td>QP</td>
<td>268</td>
<td>93</td>
</tr>
<tr>
<td><em>Quercus suber</em> L.</td>
<td>QS</td>
<td>11</td>
<td>621</td>
</tr>
<tr>
<td><em>Rosmarinus officinalis</em> L.</td>
<td>RO</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td><em>Salvia officinalis</em> L.</td>
<td>SO</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><em>Sorbus terminalis</em> (L.) Crantz</td>
<td>ST</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td><em>Spartium junceum</em> L.</td>
<td>SJ</td>
<td>53</td>
<td>21</td>
</tr>
<tr>
<td><em>Taxus baccata</em> L.</td>
<td>TB</td>
<td>251</td>
<td>126</td>
</tr>
<tr>
<td><em>Thymus vulgaris</em> L.</td>
<td>TV</td>
<td>–</td>
<td>24</td>
</tr>
<tr>
<td><em>Viburnum tinus</em> L.</td>
<td>VT</td>
<td>58</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>1723</td>
<td>2139</td>
</tr>
</tbody>
</table>

**Discussion and conclusions**

A large debate concerning naturalistic silviculture, naturalization of degraded forests, and landscape restoration...
has recently arisen (de Dios et al. 2007; Falk et al. 2006; Jordan et al. 1987; Perrow and Davy 2002a; Romano 1986; Van Andel and Aronson 2006; Walker and del Moral 2003), that provides interesting theoretical principles that can be tested through practical actions (Clewell and Aronson 2007; Padilla and Pugnaire 2006; Perrow and

---

### Table 4

<table>
<thead>
<tr>
<th>Species</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>$h \pm$ (SD)</td>
</tr>
<tr>
<td><strong>Acer monspessulanum</strong> L.</td>
<td>2</td>
<td>40.00 ± (14.14)</td>
</tr>
<tr>
<td><strong>Arbutus unedo</strong> L.</td>
<td>41</td>
<td>32.68 ± (4.15)</td>
</tr>
<tr>
<td><strong>Castanea sativa</strong> Mill.</td>
<td>1</td>
<td>10 0.15</td>
</tr>
<tr>
<td><strong>Celtis australis</strong> L.</td>
<td>3</td>
<td>26.67 ± (28.86)</td>
</tr>
<tr>
<td><strong>Fraxinus ornus</strong> L.</td>
<td>1</td>
<td>250 0.15</td>
</tr>
<tr>
<td><strong>Ilex aquifolium</strong> L.</td>
<td>23</td>
<td>45.22 ± (30.57)</td>
</tr>
<tr>
<td><strong>Juniperus oxycedrus</strong> L.</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Laurus nobilis</strong> L.</td>
<td>3</td>
<td>30.00 ± (17.32)</td>
</tr>
<tr>
<td><strong>Ligustrum vulgare</strong> L.</td>
<td>29</td>
<td>32.76 ± (52.64)</td>
</tr>
<tr>
<td><strong>Malus domestica</strong> Borkh.</td>
<td>7</td>
<td>100 ± (45.46)</td>
</tr>
<tr>
<td><strong>Myrtus communis</strong> L.</td>
<td>1</td>
<td>10 0.15</td>
</tr>
<tr>
<td><strong>Phyllirea angustifolia</strong> L.</td>
<td>1</td>
<td>70 0.15</td>
</tr>
<tr>
<td><strong>Phyllirea latifolia</strong> L.</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Pinus pinaster</strong> L.</td>
<td>208</td>
<td>433.24 ± (143.6)</td>
</tr>
<tr>
<td><strong>Pyrus communis</strong> L.</td>
<td>10</td>
<td>71 ± (65.06)</td>
</tr>
<tr>
<td><strong>Quercus ilex</strong> L.</td>
<td>159</td>
<td>34.15 ± (32.11)</td>
</tr>
<tr>
<td><strong>Quercus pubescens</strong> Willd.</td>
<td>116</td>
<td>23.62 ± (27.55)</td>
</tr>
<tr>
<td><strong>Quercus suber</strong> L.</td>
<td>7</td>
<td>174.29 ± (49.61)</td>
</tr>
<tr>
<td><strong>Rosmarinus officinalis</strong> L.</td>
<td>15</td>
<td>89.33 ± (33.9)</td>
</tr>
<tr>
<td><strong>Salvia officinalis</strong> L.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Sorbus terminalis</strong> (L.) Crantz</td>
<td>4</td>
<td>35 ± (50)</td>
</tr>
<tr>
<td><strong>Spartium junceum</strong> L.</td>
<td>29</td>
<td>110.69 ± (62.16)</td>
</tr>
<tr>
<td><strong>Taxus baccata</strong> L.</td>
<td>9</td>
<td>33.33 ± (38.08)</td>
</tr>
<tr>
<td><strong>Thymus vulgaris</strong> L.</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Viburnum tinus</strong> L.</td>
<td>3</td>
<td>10 ± 0</td>
</tr>
</tbody>
</table>

Dashes indicate species not planted, and zero values refer to planted species that did not survive in 2009

---

**Fig. 6** $K$ index recorded during field surveys in site A (histogram a) and site B (histogram b) as key index of interspecific competition and species relevance within coenosis. Values for maritime pine are shown up to the black bar to better represent the other values using an appropriate y-axis scale. X-axis labels refer to the acronyms in Table 3.
In the Mediterranean Basin, the environment has been modified and exploited by humans over the course of thousands of years. In particular, forests have experienced many processes that have led to degradation and consequent soil loss as reported since the fourth century B.C. by Plato in Critias. Also, because of these age-old anthropogenic impacts, in the last two centuries, all reforestation methods adopted in Mediterranean countries demonstrated that a long time is need to get a complete environmental restoration.

The Miyawaki method could offer a quicker and more effective reforestation approach in the Mediterranean environment, adopting naturalistic theoretical principles not previously tested in Mediterranean Europe, which has the additional challenge of a seasonal climate characterized by summer aridity compounded in several cases by winter cold, and also by thin soils. Here we provide a comparison between the Miyawaki method and two other reforestation methods (gradoni and holes) traditionally applied in Mediterranean countries. The results showed a more rapid development of trees on the Miyawaki plots, in particular, early-successional species. The benefits over previous methods are remarkable and comparable with those obtained by Miyawaki in Asia and South America. At the same time, some of the changes made in this study to better fit the method to the Mediterranean environment seem to be particularly useful. First, we used tillage to improve soil water storage over the winter and reduce water stress during the summer. Summer aridity implies the soil would be able to stock winter rainfalls in order to allow the plants avoiding water stress of the next season. This outcome has been achieved using tillage; such action is necessary and should be enough, even if it would be possible to get a better performance by adding compost or local soil. Mulching with green material does not seem effective (Navarro-Cerrillo et al. 2009), whereas mulching with dry material has been useful. Moreover, avoiding clearing all brush is opportune for the Mediterranean environment, in contrast with some studies (cf. Bernetti 1995; Goor and Barney 1968; Metro et al. 1978; Molina et al. 1989; Weber 1977), as well as adopting the plantation in worked strips. Nowadays, benefits of this method are acknowledged by several authors (cf. Schirone et al. 2004).

Table 5 Description of species on the traditional reforestation plots and comparison with the Miyawaki ones

<table>
<thead>
<tr>
<th>Name of species</th>
<th>Number/plot</th>
<th>Relative frequency [%]</th>
<th>Height ± standard deviation (SD)</th>
<th>Number of individuals/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbutus unedo</td>
<td>2</td>
<td>61</td>
<td>41 ± 0.39 (35.75)</td>
<td>200</td>
</tr>
<tr>
<td>Cedrus atlantica</td>
<td>6</td>
<td>27.2</td>
<td>32.68 ± 4.15 (41.69)</td>
<td>1000</td>
</tr>
<tr>
<td>Erica arborea</td>
<td>45</td>
<td>65</td>
<td>53.56 ± 24.62 (12.78)</td>
<td>1000</td>
</tr>
<tr>
<td>Pinus pinaster</td>
<td>11</td>
<td>75</td>
<td>53.96 ± 8.36 (7.297)</td>
<td>1000</td>
</tr>
<tr>
<td>Phyllirea latifolia</td>
<td>10</td>
<td>65</td>
<td>53.96 ± 8.64 (35.98)</td>
<td>1000</td>
</tr>
<tr>
<td>Quercus ilex</td>
<td>11</td>
<td>75</td>
<td>53.96 ± 8.36 (7.297)</td>
<td>1000</td>
</tr>
<tr>
<td>Rosmarinus officinalis</td>
<td>3</td>
<td>15</td>
<td>53.96 ± 8.36 (7.297)</td>
<td>1000</td>
</tr>
</tbody>
</table>

Bolded numerals in Number/plot column (number of plants/plot) show the values of unplanted species, superscript symbols in each row indicate significant pairwise tests at 0.05 alpha probability level.
results support the effectiveness of alternative applicable approaches in the Mediterranean area. In fact, low plant density has been traditionally retained as appropriate in arid and semiarid environments in order to avoid competition for water resources between plants (Caramalli 1973; Bernetti 1995), but it is now evident that cooperative processes, e.g., mutual shading, prevail over competitive processes (Callaway 1997). High plant density also reduces the impact of acorn predators, thus encouraging oak regeneration, i.e., the main late-successional forest species in Mediterranean environments (Gómez et al. 2003). In addition, excellent plant stock remains fundamental for planting success in harsh environments (Palacios et al. 2009).

Finally, these results could offer a chance to introduce a new method into the Mediterranean context that is able to reduce the time for a complete environmental restoration. An economic analysis might be performed to estimate the costs of postplanting silvicultural practices with traditional reforestation methods and compare them with the Miyawaki method. Indeed, labor need is high, and planting costs are quite expensive because of the high plant density required. On the other hand, no human care, such as weeding or thinning, is needed after planting, and undergrowth with late-successional species are immediately on site (Miyawaki 1998a, Miyawaki 1999). If this new approach turns out to be more expensive, then it will be important to take measures to make it economically advantageous. In any case, if the high costs of the Miyawaki method were still not competitive with the traditional techniques on a large scale, the forest quality achieved would make it a noteworthy tool for protected areas and natural parks (Reque 2008), where traditional plantings are not easily accepted because of their aesthetic and ecological impacts.

Acknowledgments We are indebted to Regional Forest Directorate of Sardinia for conceding the logistic support. Special thanks to Dr. Carmine Sau and Dr. Francesco Mazzocchi for their valuable help and commitment on the field work performed in Pattada Municipality.

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調査研究報告 Research Report

幼苗植栽技術で創出した樹林における自然間引き—長野県上田市日置電機緑地の植栽後 27 年目の事例—

吉野知明 1・武田 進 2

エスペックミック株式会社 1 日置電機株式会社 2

Tomoaki YOSHINO and Susumu TAKEDA: Decreased density from self-thinning in a 27-year-old stand after a “seedling dense planting”: The case of the HIOKI E.E. CORPORATION, Ueda City, Nagano Prefecture

キーワード: 植栽密度、枯死率、コナラ、シラカシ、種組成

Key words: planting density, mortal ratio, Quercus serrata, Quercus myrsinaefolia, species composition

Ⅰ．はじめに

日置電機株式会社は、長野県上田市に本社工場をもつ電気計測器メーカーである。小高い丘の上にある本社工場は、HIOKI フォレストビルズと名づけられ（日置電機株式会社, 1987）。今日では、社屋は高さ10mを超える樹林に囲まれている（図1，写真1，写真2）。この樹林は、1988年に工事がようになった場所に移転した際に、幼苗植栽技術を用いて創出されたものである。

幼苗植栽技術とは1970年代以降の工場、空港港湾道路などの大規模な緑化に用いられはじめた植栽技法であり、1990年代にはエコロジー緑化と称され、各地で植栽に用いられるようになった。その特徴としては、植栽基盤の造成を十分に行い、そこに自然植生や郷土樹種のコンテナ苗木を密植することにより、短期間で大面积の樹林を作ることとなっている（財団法人日本緑化センター, 1997）。この植栽技術では、幼苗（樹高50cm内外の苗）を高密度（2～3本/㎡）で植栽し、競争させる数年をかけて枝葉の密生した樹林を作ることが可能である。

一方、この技術を導入する際には、しばしば植栽直後の高い植栽密度が問題視され（前中, 1989）、間伐の必要性や、放置した場合に自然間引きがいつ頃生じるのかについて議論になることがある。しかし、その生育状況や立木密度がどのように変化しているのかについては、特に経過数年の長い事例では基礎的な見解が十分に得られていないのが実情である。

図1．幼苗植栽技術を用いて創出された樹林、および調査区の位置

Fig. 1. Location of Hioki E.E. Corporation woody area and survey plots
幼苗植栽技術技術には半世紀近い歴史があるが、植栽から時間が経過するに従って、その植栽の記憶が薄れ、植栽時の記録や植栽そのものが失われてしまった事例も少なくない。幸い本実例では、植栽時の情報が残されており、植栽20年目となる2008年と植栽27年目となる201年5の2回、この樹林を調査する機会を得た。そこで本稿では植栽27年が経過した樹林の形成状況を報告するとともに（写真2）その間に生じた樹林内の変化、特に自然間引きによる立木密度の変化について報告したい。

II. 調査地および方法

1. 対象地

日置電機株式会社は長野県西部の上田市に位置し、標高は470mである。気象統計によると1981年～2010年までの平均気温は11.9℃、年間降雨量は890.8mm（気象庁、http://www.jma.go.jp/jma/menu/menureport.html）、暖かさの指数WIは96.3℃・月、寒さの指数CIは14.1℃・月である（データは気象庁ホームページ掲載値に基づく）。敷地面積は75,000㎡、この内、緑地面積は19,000㎡である（図1: 日置電機株式会社植栽委員会、1998）。

2. 植栽

1987年5月21日から土地造成工事が開始され、1988年5月21日に57,000本の苗木が日置電機社員、工事関係者約600名により植栽された。植栽に先立って機能別に次の4つの植栽ゾーンが設定された（日置電機株式会社植栽委員会、1998）。

1) 本命植栽ゾーン12,000㎡
2) マント・ソデゾーン3,600㎡
3) 花木を中心とした美観ゾーン1,000㎡
4) 斜面の既存林を活かした既存林ゾーン1,900㎡

植栽樹種は39種類であり（表1）、植栽ゾーンにより使い分けられた。

本命植栽ゾーンにはシラカシ、コナラ、ケヤキなどの高木性の常緑樹や落葉樹が、マント・ソデゾーンおよび美観ゾーンにはニシキギ、シモツケ、ヤマツツジなどの花木・低木がそれぞれ配植された。既存林ゾーンには高・中木種の苗木が補植的に植栽された。

植栽に用いた苗木はいずれもポット容器で栽培された苗高40～50cm程度の苗木（ポット苗）であった。

植栽密度は、本命植栽ゾーンは2本/m²、マント・ソデゾーンは6本/m²、美観ゾーンは9本/m²、既存林ゾーンは原状に合わせて、およそ0.5～2本/m²で植栽された。

3. 樹林調査

樹林の形成状況を記録するために2008年9月16日に樹林内の2箇所に調査区Q1とQ2を設定した（図1）。Q1は落葉広葉樹を主体とした西向き斜面上の樹林で、調査区サイズは斜面方向12m、幅10mである。

Q2は落葉広葉樹を主体とするも林内にシラカシが目立つ樹林で、北東向き斜面上にあり、調査区サイズは斜面方向8m、幅8mである。いずれも本命植栽ゾーン内に設定した。

樹林調査では、調査区内に生育する樹高1.3m以
上の全ての樹木に対し、番号を割り付け、樹高と胸高直徑を計測した。併せて、樹木内の様子をスケッチし、簡易な植生調査を実施した。調査は植栽から20年が経過する2008年9月16日17日植栽から27年が経過する2015年5月23日〜26日に実施した。なお、2008年調査では1988年の植栽地全体を踏査し、植栽樹種39種の生態状況について簡易把握を行なった。

表1. 植栽樹種一覧
Table1. List of planted tree species

| 区分 | 常緑 | 高木種 | 中木種 | 低木種 | 合計
|------|------|--------|--------|--------|------|
| 落葉 | 常緑 | 高木種 | 中木種 | 低木種 | 合計
| 落葉 |  |  |  |  |  |

<table>
<thead>
<tr>
<th>分区</th>
<th>常緑</th>
<th>树種名</th>
<th>植栽本数</th>
</tr>
</thead>
<tbody>
<tr>
<td>常緑</td>
<td>シラカシ</td>
<td>5,398</td>
<td></td>
</tr>
<tr>
<td>ウラシロガシ</td>
<td>1,444</td>
<td></td>
<td></td>
</tr>
<tr>
<td>高木種</td>
<td>コナラ</td>
<td>4,207</td>
<td></td>
</tr>
<tr>
<td>ケヤキ</td>
<td>2,887</td>
<td></td>
<td></td>
</tr>
<tr>
<td>エノキ</td>
<td>1,444</td>
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<td></td>
</tr>
<tr>
<td>落葉</td>
<td>アキニレ</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>ヤマモミジ</td>
<td>2,888</td>
<td></td>
<td></td>
</tr>
<tr>
<td>シデンキ</td>
<td>755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ホオノキ</td>
<td>189</td>
<td></td>
<td></td>
</tr>
<tr>
<td>中木種</td>
<td>ソヨゴ</td>
<td>1,255</td>
<td></td>
</tr>
<tr>
<td>ヤブツバキ</td>
<td>342</td>
<td></td>
<td></td>
</tr>
<tr>
<td>落葉</td>
<td>ヤマザクラ</td>
<td>1,255</td>
<td></td>
</tr>
<tr>
<td>ナナカマド</td>
<td>480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヤマポウシ</td>
<td>1,255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>コブシ</td>
<td>1,255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ナツツバキ</td>
<td>755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>エゴノキ</td>
<td>755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>低木種</td>
<td>イヌツツ</td>
<td>481</td>
<td></td>
</tr>
<tr>
<td>アベリア</td>
<td>481</td>
<td></td>
<td></td>
</tr>
<tr>
<td>アセビ</td>
<td>342</td>
<td></td>
<td></td>
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<tr>
<td>エリュウツリハ</td>
<td>342</td>
<td></td>
<td></td>
</tr>
<tr>
<td>落葉</td>
<td>コデマリ</td>
<td>3,402</td>
<td></td>
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<tr>
<td>ニンキギ</td>
<td>3,401</td>
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<td></td>
</tr>
<tr>
<td>ポケ</td>
<td>2,717</td>
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<td></td>
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<tr>
<td>ヤブツキ</td>
<td>2,482</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ユキヤナギ</td>
<td>855</td>
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<td></td>
</tr>
<tr>
<td>カマツカ</td>
<td>755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ムラサキシキブ</td>
<td>2,717</td>
<td></td>
<td></td>
</tr>
<tr>
<td>レンギョウ</td>
<td>2,717</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヒウガミズキ</td>
<td>2,717</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ドウダンツツジ</td>
<td>2,104</td>
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<td></td>
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<tr>
<td>ヤマツツジ</td>
<td>2,104</td>
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<td></td>
</tr>
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<td>レンゲツツジ</td>
<td>481</td>
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</tr>
<tr>
<td>タニウツギ</td>
<td>1,123</td>
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<td></td>
</tr>
<tr>
<td>ガマズミ</td>
<td>684</td>
<td></td>
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</tr>
<tr>
<td>シモツケ</td>
<td>481</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ムグル</td>
<td>855</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヤマハギ</td>
<td>684</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ハナズオウ</td>
<td>342</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39種</td>
<td>合計植栽本数</td>
<td>57,061</td>
<td></td>
</tr>
</tbody>
</table>

### Ⅲ. 結果

#### 1. 立木密度

表2に調査区Q1とQ2の樹高1.3m以上の立木密度を示す。Q1とQ2の2008年時点の立木密度は0.56本/㎡と0.50本/㎡、2015年では、それぞれ0.49本/㎡と0.45本/㎡であった。

当初の植栽密度は2本/㎡で植栽されていることから、植栽から20年が経過する2008年時点の立木密度は、植栽時の4分の1に減少していることが明らかとなった。植栽から20年目から27年目にしての7年間では、Q1では7本減少、Q2では3本減少しているが、立木密度は0.054本/㎡の減少にとどまり、この7年の減少速度（2調査区の平均で0.0079本/㎡・yr）は、20年目までの減少速度（2調査区の平均で0.0735本/㎡・yr）と比較し、微減であった。

表2. 2調査区における立木本数と立木密度
Table2. Number and density of woody individuals in each plot

<table>
<thead>
<tr>
<th>調査区</th>
<th>調査区面積 (㎡)</th>
<th>2008年植栽後20年経過</th>
<th>2015年植栽後27年経過</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>立木本数 (H≧1.3m)</td>
<td>密度 (本/㎡)</td>
</tr>
<tr>
<td>Q1</td>
<td>120</td>
<td>67</td>
<td>0.56</td>
</tr>
<tr>
<td>Q2</td>
<td>64</td>
<td>32</td>
<td>0.50</td>
</tr>
</tbody>
</table>

#### 2. 種組成の変化

表3に植栽当初の植栽比率と、2008年と2015年のQ1とQ2の立木本数と木木本数中の構成比率を示す。植栽時には、Q1、Q2ともに高木9種と中木8種の合計17種が植栽されていたと想定される。植栽から20年が経過する2008年に調査区で確認された種数は2つの調査区を合わせて11種であった。植栽された樹種のうち、ウラシロガシ、エノキ、アキニレ、シデノキ、ホオノキ、ヤブツバキ、ナナカマド、コブシ、ナツツバキ、エゴノキの10種は確認されず、その代わりに植栽樹種に含まれていなかったミツナラ、ムクノキ、クスギ、カマツカの4種が新たに記録された。

2008年に植栽地全体を対象とし、植栽した樹種の生残状況を選ぶ測したが、ホオノキとナツツバキの2種は生残を確認することができなかった。ヤブツバキは林縁の低木が生い茂った中ののみ点在、コブシとエゴノキは林縁部で生残木が散見される程度であり、これら3種はごく少数しか生残していなかった。ウラジ
ロガシは南側の野球グラウンドに沿った樹林帯の低木層から高木層に比較的多く残存する。それ以外の植栽地ではほとんど確認されなかった。アキレは南西角の植栽帯で生殖個体を確認できたが、それ以外の植栽地では確認できなかった。シデノキ（確認されたのはアカシデ）は植栽帯の複数個所で植林の低木層構成種として確認されたが、生育良好な個体は確認できなかった。ナナカマドは林縁部で生育良好な個体が残存していたが、樹林内で生殖個体はほとんど確認されなかった。これら 4 種は、生殖箇所が限られているといえる。生残が確認されなかった 2 種を含むこれらの 9 種については、20 年の間に調査区内において枯れ、衰退した可能性が高いと思われる。

エノキについては、植栽に由来する個体は確認されなかった。一方で、エノキと葉の似るムクノキが樹林内に多数混生していることから、エノキとムクノキを取って扱って植栽されたものと考えられる。また、新たに確認されたミズナラとクヌギについては、コナラと同様に成長しており、コナラ苗に混入したものと考えられる。

2008 年時点の立木本数中の構成比率では、17 種の植栽樹種のうち、シラカシとコナラは当初の植栽比率よりも高い構成比率となっており、植栽から 20 年間で良好に定着したと考えられる。また、ヤマボウシ、ヤマザクラ、ケヤキについても構成比率はほぼ同程度であり、比較的良く成長していると考えられる。

2015 年時点の立木本数中の構成比率では、シラカシの比率がさらに高くなる一方で、2008 年構成比率が高かったコナラの比率が減少する結果となった。立木本数においてもコナラは 10 本減少、ミズナラが 2 本減少しており、両種で枯れ倒れが進んでいた。

表 3. 1988 年植栽時と 2008 年、2015 年における樹種組成および立木本数とその構成比率

<table>
<thead>
<tr>
<th>植栽樹種</th>
<th>植栽 本数</th>
<th>植栽 比率</th>
<th>2008年 立木本数</th>
<th>2008年 構成比率</th>
<th>2015年 立木本数</th>
<th>2015年 構成比率</th>
</tr>
</thead>
<tbody>
<tr>
<td>植栽树種</td>
<td>構成比率</td>
<td>2008年</td>
<td>2008年</td>
<td>合計</td>
<td>2015年</td>
<td>2015年</td>
</tr>
<tr>
<td>シラカシ</td>
<td>5,398</td>
<td>20%</td>
<td>22</td>
<td>14</td>
<td>36</td>
<td>36%</td>
</tr>
<tr>
<td>ウラシロガシ</td>
<td>1,444</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>コナラ</td>
<td>4,207</td>
<td>16%</td>
<td>16</td>
<td>10</td>
<td>26</td>
<td>26%</td>
</tr>
<tr>
<td>ケヤキ</td>
<td>2,887</td>
<td>11%</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>9%</td>
</tr>
<tr>
<td>エノキ</td>
<td>1,444</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>アキレ</td>
<td>30</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヤマモミジ</td>
<td>2,888</td>
<td>11%</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2%</td>
</tr>
<tr>
<td>シデノキ</td>
<td>755</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ホオノキ</td>
<td>189</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ソヨゴ</td>
<td>1,255</td>
<td>5%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>ヤプツバキ</td>
<td>342</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヤマザクラ</td>
<td>1,255</td>
<td>5%</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4%</td>
</tr>
<tr>
<td>ナナカマド</td>
<td>480</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ヤマボウシ</td>
<td>1,255</td>
<td>5%</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5%</td>
</tr>
<tr>
<td>コプシ</td>
<td>1,255</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ナツツバキ</td>
<td>755</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>エゴノキ</td>
<td>755</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>植栽時混合樹種</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ミズナラ</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5%</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>ムクノキ</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>7%</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>クヌギ</td>
<td>1</td>
<td>1</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>カマツカ</td>
<td>3</td>
<td>3</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ネズミサシ</td>
<td>1</td>
<td>1</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

合計 26,594 | 67 | 32 | 99 | 100% | 60 | 29 | 89 | 100% |
3. 樹高と胸高直径

表4に2008年と2015年の樹高1.3m以上の主要な樹種8種の平均樹高と平均胸高直径を示す。8種のうち7種はQ1、Q2に、ヤマザクラはQ1のみに生育していた。8種のうち、コナラ、ケヤキ、ミズナラ、ヤマザクラは2008年時点で平均樹高が8.3～9.8mとなっており、4種の落葉樹が高木層を形成していた。次いで、亜高木層にムクノキ、シラカシ、低木層にヤマポウシ、ヤマモミジが生育している。胸高直径についても樹高の高い4種が太く、亜高木層、低木層を構成する種になるにつれ細くなった。植栽当初は大差のない苗であるが、20年を経過ごとに、成長に差が生じ、階層構造が形成されたといえる。この階層構造は2015年においても同様であった。

2008年と2015年の比較では、コナラ、ミズナラは平均で樹高が2.6m以上伸長し、胸高直径も3.5cm以上膨大し、8種の中で最大数の成長量を示した。対照的にヤマポウシ、ヤマモミジは平均で樹高の増加が0.2～0.3m、胸高直径の増加が0.1～0.3cmと小さく、7年間で目立った変化は生じていなかった。

表4. 2008年と2015年における平均樹高と平均胸高直径
Table 4. Mean tree height and mean diameter at breast height (DBH) in both study years

<table>
<thead>
<tr>
<th>樹種名</th>
<th>計測個体数</th>
<th>平均樹高 (m)</th>
<th>平均胸高直径 (cm)</th>
<th>2008年</th>
<th>2015年</th>
</tr>
</thead>
<tbody>
<tr>
<td>コナラ</td>
<td>28 (16)</td>
<td>9.5</td>
<td>12.1</td>
<td>10.1</td>
<td>13.8</td>
</tr>
<tr>
<td>ケヤキ</td>
<td>9</td>
<td>9.7</td>
<td>11.6</td>
<td>10.8</td>
<td>12.1</td>
</tr>
<tr>
<td>ミズナラ</td>
<td>5 (3)</td>
<td>8.3</td>
<td>11.4</td>
<td>11.0</td>
<td>16.1</td>
</tr>
<tr>
<td>ヤマザクラ</td>
<td>4</td>
<td>9.8</td>
<td>10.6</td>
<td>14.7</td>
<td>16.2</td>
</tr>
<tr>
<td>ムクノキ</td>
<td>7</td>
<td>7.5</td>
<td>8.7</td>
<td>8.3</td>
<td>8.6</td>
</tr>
<tr>
<td>シラカシ</td>
<td>36</td>
<td>4.7</td>
<td>5.5</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td>ヤマポウシ</td>
<td>5</td>
<td>3.5</td>
<td>3.8</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>ヤマモミジ</td>
<td>2</td>
<td>2.5</td>
<td>2.7</td>
<td>2.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

* 丸括弧内の数字は2015年の計測個体数で、2008年と異なる場合のみ表示

4. コナラの枯死・衰退

2015年の調査では、2008年に記録された渓木14個体が枯死あるいは消滅していた。その内訳はコナラ10個体、ミズナラ2個体、クスギ、ツヨギが1個体ずつであった。

図2に、高木層を形成し、成長量の大きいコナラ、ケヤキ、ミズナラおよびヤマザクラの主要4種について、2008年と2015年の樹高を個体ごとに比較して示す。コナラとミズナラでは、2008年時点で相対的に樹高の高いものは成長し、相対的に樹高の低かったものは、成長が鈍く、一部が枯死し、記録から脱落していることが分かる。樹高が低い個体は、上層の樹木に遮られ、枝葉に十分な光が当たらず、衰弱、枯死に至ったものと考えられる。ケヤキでは枯死は生じていなかったが、樹高の低い個体は樹高成長が鈍い傾向があった。ヤマザクラでは個体数が4個体と少なく、判らない出来なかった。

IV. 考察

1. 立木密度の減少はいつ頃生じるか

幼苗植栽技術における立木密度の経年変化の調査事例としては、目黒ら（2005）による神奈川県川崎市の埋立地に創出されたタブノキ、スダジなどを含む森林12種からなる環境保全林の間伐効果の研究がある。この研究では、1984年に1本/㎡で植栽された無間伐区で、その11年後の1995年に0.99本/㎡、植栽19年後の2004年に0.56本/㎡と減少する結果が示されている。

植栽11年後までは立木密度は大きく変化しないという目黒ら（2005）の結果は、前中（1989）の指摘とはほぼ一致している。一方、植栽後19年が経過した時点で立木密度がほぼ半減していたという結果と、本事例植栽時2本/㎡であったものが20年経過時0.50～0.56本/㎡に激減したことの結果から、幼苗植栽技術における立木密度の減少は植栽後20年までの間に生じるものと考えられる。

2. 立木密度の減少プロセス

目黒ら（2005）の事例では、構成種のうち、良好に残存する種（スダジ）と脱落する種（タブノキ）が確認されている。本事例においても植栽された高木種17種のうち9種は、20年間で何らかの原因により調査区に残存し、植栽区から消失したと考えられる。幼苗植栽技術における立木密度の減少の仕組みを示すとして、複数植栽されている樹種のうち一部の樹種が、土地の気象条件や土壤条件に適合できず脱落する可能性が示唆される。著者が取り組んだ他の幼苗植栽の事例では、夏季の高温乾燥、冬季の凍害、病虫害等の影響により特定の樹種が衰退、脱落するこ
図2. 主要4樹種の2008年・2015年樹高の個体別比較
個体の配列は2008年の樹高順
Fig.2. Comparison of heights of individual trees of four principal species in 2008 and 2015.
Data are arranged in decreasing order of tree height within a species in 2008.

とが観察されている。
また、今回は2008年〜2015年に相対的に樹高の低いコナラがまとまって枯死する結果が得られた。ここに示されている立木密度の減少は、林冠を構成するコナラのうち、樹高のやや低い個体の枯死、消失に由来するものであった。高密度に植栽された林木では、徐々に劣勢な個体が枯死することが知られているが（玉井、1989）、幼苗植栽技術では、植栽後20年以上が経過し、数種の優占種により高さ10mほどに達する林冠が形成される段階においても強く作用していると考えられる。

幼苗植栽技術における立木密度の減少については、多数植栽された樹種のうち、一部の植栽樹種が脱落するプロセスと、同一樹種の間で生育の劣る個体が衰退するプロセスの二つの自然間引きが作用していることが示唆された。幼苗植栽については、長期的なモニタリング事例が少ないため、当初からしっかりとした調査デザインを掲げた調査事例を増やし、検討していく必要があるといえる。

3. 今後の課題
幼苗植栽技術を用いた森づくりについては、立木密度の他に、（1）密植したことにより徒長した樹形になるのではないかという論点や、（2）隣接の森などの発達した森林植生をモデルにしているが、図2の個体の発達状況や階層構造はどのように再現されているかという論点が浮上する。本研究においても今後は、調査対象を広げるとともに、周辺樹林や到達目標となる樹林と比較を行い、幼苗植栽技術のより適切な活用方法を模索したい。

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東京．

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Sustainable Management of Urban Green Environments: Challenges and Opportunities

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Chapter 18
Sustainable Management of Urban Green Environments: Challenges and Opportunities

Samuel Kiboi, Kazue Fujiwara, and Patrick Mutiso

Abstract Urban green areas not only provide aesthetic qualities but also provide important ecosystem services in ever-shrinking habitats, and therefore need sustainable management practices. The western and northwestern parts of Nairobi are within an upland dry forest that stretched from Karura to Ngong forests with a characteristic vegetation composition. Much of that vegetation has been replaced by exotic species and, over time, the original indigenous tree species composition may be lost. No previous studies have profiled the local vegetation structure in Kenya and then used this knowledge to restore the urban green environment. We carried out studies in Karura and Ngong forests and used 16 carefully selected species to recreate a natural forest using the ‘Miyawaki method’ at the College of Biological and Physical Sciences of the University of Nairobi. In just 16 months the species have established extremely well, with the best performing species (Ehretia cymosa) growing to more than 210 cm from just about 43 cm. We expect to recreate a quasi-natural forest and use such studies and methods to restore urban green environments in Kenya.

Keywords Natural green environment restoration • Upland dry forests • Urban forest ecosystem services • Urban vegetation • Vegetation structure of Nairobi
18.1 Introduction

Urban green environments in developing countries especially are under constant pressures resulting from rapid urbanization, which can be sometimes unplanned. The greatest challenge today is to manage the environment in a sustainable way whilst offering pleasant surroundings for the urban dweller, and at the same time maintaining some natural areas. Nairobi, for example, has been ranked among the top ten cities in the world that have the biggest declines in liveability over 5 years with a score of −2.9 % according to the latest Global Liveability Survey of 140 cities worldwide (Economist Intelligence Unit 2013). The unit measured cost of living, health care, pollution, education, infrastructure, and green spaces to obtain the scores. In general, green environments, and specifically trees, offer an array of benefits that can be categorized broadly into: ecological benefits, architectural functions, climate moderation, and monetary benefits, as well as recreational and social values (TEEB 2011; Bolund and Hunhammar 1999).

18.2 Challenges in Achieving Sustainable Green Urban Environments

The challenges to sustainable green environments in urban areas are many and require a proactive approach and the cooperation of all citizenry. Apart from an effective regulatory system, an informed citizenry will keep the environment in better condition than those who have to be policed to adhere to standards. Some of the problems facing urban areas in Kenya are severe and common to many cities in the developing world, although they may vary in magnitude. Management of urban environments in the developed world is more effective, and hence the environments are cleaner and greener but may have experienced pollution challenges in the past, e.g., Yokohama in Japan had major pollution problems in the 1960s. Some of the major environmental challenges facing urban environments in Kenya are:

18.2.1 Waste Management

Waste management is the biggest environmental problem in most urban areas and can lead to environmental pollution in many ways and affect drainage systems (Figs. 18.1, 18.2, and 18.3). The amount of solid waste generated per individual, homestead, or industry is usually high and requires a very comprehensive collection and disposal mechanism, ideally with facilities for sorting at source. In such cases organic waste is converted to manure or used to produce energy while most other types of waste are recycled. When it comes to liquid waste and effluents from industries, proper mechanisms are required to treat the waste to levels where no harm can result from discharging back to the environment.
Fig. 18.1 An unregulated roadside garbage dump site in Nairobi where informal sorting of polythene is also undertaken

Fig. 18.2 Industrial effluent discharge from a blocked sewer line showing waste treatment may be inadequate
Air pollution comes from different sources in urban environments. The first major source is combustion of fossil fuels from vehicles and industries (Fig. 18.4). As the middle class continues to expand in developing countries, so do the number of vehicles on the roads. The maintenance of vehicles is usually a major contributor to how efficient their combustion process is and those that are badly maintained will emit exhaust gases that are not well combusted. This, combined with bad fuel quality, exacerbates the problem. Bad fuel quality may be due to use of outdated crude oil refining technology or due to illegal adulteration of fuel by mixing different types, e.g., diesel with kerosene.

Other sources of air pollution include burning of waste and, perhaps worst of all, rubber (e.g., burning old tires to remove the steel ply inside) and plastic waste, especially in unmanaged dumpsites. Rubber and plastics release substantial amounts of toxic gases into the air which not only contributes to global warming but also to health problems among those inhaling the air. Open tire fire emissions include pollutants, such as particulates, carbon monoxide (CO), sulfur oxides (SO₂), oxides of nitrogen (NOₓ), and volatile organic compounds (VOCs). They also include hazardous air pollutants (HAPs), such as polynuclear aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs), and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium (Lemieuxa et al. 2004).
Lack of grass cover or properly paved roads and walkways leaves the soil exposed and constant traction by vehicles and human traffic results in dusty conditions that lead to respiratory diseases, as well as dusty buildings and installations. Urban dust is more likely to carry harmful substances including microbes, because often drainage systems block due to runoff soil and organic waste flooding the roads, and the micro-organisms can then be spread via dust. Therefore, if well-managed green areas and paved surfaces exist, these problems would be minimized.

18.2.3 Infrastructure

Infrastructure development is a key measure of urban growth. All developments should ideally be well planned with the necessary regulatory approvals including minimizing environmental impacts by undergoing an impact evaluation. Measures to mitigate environmental impact should be put in place during project implementation and maintained after commissioning. In Kenya for example, the National Environmental Management Authority (NEMA) or Environmental and Social Impact Assessment (ESIA) - (depending on scope) has to approve all projects after an Environmental Impact Assessment (EIA) has been conducted. Despite the regulations being followed, however, compliance challenges exist, especially in
ensuring that what is approved on paper is actually implemented during and after inception of the project. The capacity of such institutions may be limited such that each project is not monitored and assessed as it ideally should be.

An example of an urban environmental problem affecting green due to infrastructure development is the information technology industry. In the last 5 years or so, Kenya and the region as a whole have invested heavily in fiber optic connectivity with up to three international cable landings connecting Kenya and the rest of the world. Most if not all major towns now have a connection using the fiber optic network. Companies that have invested in the cable are now racing to connect as many buildings as possible and the negative effect of this is that there is no common cabling approach. This means that different companies dig up the same routes at different times and the result is repeated disturbance, while environmental restoration is not always to the previous standard or better.

Another example of challenges to green urban areas is the billboard advertising industry. While strategic positioning is important in brand visibility, urban greening programs could affect visibility over time as the trees mature. Observations around Nairobi show that this is countered by trimming trees, which is not ideal for coexistence between outdoor advertising industry and sound ecologically friendly urban environmental management (Fig. 18.5). This is a severe problem that needs to be addressed by the city management authorities and the advertising companies in conjunction with the NEMA.
18.3 Opportunities for Sustainable Green Urban Areas

Trees offer opportunities to create multi-strata natural areas and absorb 25–30 times more CO$_2$ than mono-strata grass surface areas, and therefore a scientifically guided restoration or reconstruction of green environments such as vegetation ecology or ecotechnology is desirable (Miyawaki 1998). Ecotechnology is a technological means of ecosystem management based on deep ecological understanding, to minimize costs of management measures and their harm to the environment (Straskraba 1993). Ecotechnology uses a vegetation ecology approach to build multi-strata greenery (e.g., canopy, understory, shrub, and herb layers) to fulfill the ecological potential of the area. Forests have different ecological functions and urban greening programs should not rely on the functions of green vegetation in general, but should address the suitability of different plants in light of the complexities of urban design and management. Such complexities may include: (1) open spaces such as parks, (2) areas along roads and walkways, (3) tracts of land along riverine areas and in wetlands, (4) mixed-use areas such as those around and within residential districts and other built-up areas, and (5) office and industrial zones.

Trees are the most memorable aspect of a roadside planting design. They have an appropriate scale for a road corridor, are clearly noticed when travelling and are the best means for ameliorating the hard built elements of the road corridor. Subject to their safe use, they should be the primary element of a landscape design. Trees should, however, be used selectively in a corridor. For example they should not obscure expansive views and they should be located carefully and deliberately, outside clear zones and away from utilities (Chang and Collins 2008).

Each urban district occurs in a distinct ecological area with unique naturally occurring plant species. These are species that have long adapted in these ecosystems and established their own niches in the communities that they occur in. In selecting tree species to plant in urban areas, this should be a key consideration to maintain natural environments. In many upcoming cities in the developing world, and in Kenya in particular, there seem to be no scientifically informed criteria for urban greening programs, and most of the time exotic species are planted. This may mainly be due to their visual appeal, availability, and growth under a wide breadth of ecological conditions (e.g., *Grevilia robusta*). Indigenous species are usually overlooked and this could be mainly because of insufficient understanding of their local suitability, optimum combinations, and interaction with other species, as well as impact on the infrastructure, among other considerations. Nonetheless, some other countries have made significant progress in urban green environments based on theories of vegetation ecology (Miyawaki 1998; Muller and Fujiwara 1998).

Some key benefits of green urban environments include carbon assimilation, disaster prevention and reduction, beautification and nutrition.
18.3.1 Carbon Assimilation

Urban environments are major sources of carbon dioxide (CO\textsubscript{2}) and other greenhouse gases (methane, nitrous oxide, and fluorinated gases) that contribute to global warming, a major contributor to climate change today. CO\textsubscript{2} is the primary greenhouse gas emitted through human activities. The majority of GHGs emanate from burning fossil fuels, mainly from motor vehicles and industry (International Energy Agency 2012). These emissions have risen steeply over the last century with some cities now being covered in smog that not only reduces visibility, but also reduces air quality, generating air pollution which in turn can cause major respiratory issues and associated health complications. Smog generally can affect plant development and human health, as well as cause damage to materials such as rubber, textiles, and paint (Marcella et al. 1957; Rani et al. 2011). Three major outdoor air pollution problems are industrial smog from burning coal, photochemical smog from motor vehicle and industrial emissions, and acid deposition from coal burning and motor vehicle exhaust (Rani et al. 2011). A wide range of experts have advocated decreasing individual carbon footprints and investing billions to reduce the risks of a major change in the earth’s environment (Stern 2008). Green environments can help absorb the CO\textsubscript{2} in the air which can be converted into stored carbon through the process of photosynthesis. Different plant species vary in the amount of CO\textsubscript{2} they can absorb and this variation is determined by various morphological and physiological characteristics of the plants as well as land use (Houghton 1989). Some characteristics that can help determine which plants would have high carbon assimilation rates include growth rate, leaf area, wood density, and seasonal vegetation changes, including whether they are deciduous or not.

18.3.2 Disaster Prevention and Reduction

Disaster prevention and reduction is a key contribution of green areas in urban environments when carefully planned. Experience from Japan has shown that areas with trees along elevated highways and railways have proved very important as a disaster prevention and reduction method because the trees form important barriers to fires and offer support from total collapse due to earthquakes or tsunamis (Miyawaki 1998). In Kenya, congestion of highways in urban areas such as Nairobi is forcing planners to consider elevated highways as a way of increasing capacity to handle vehicle traffic efficiently. Therefore, an integrated transport management strategy should incorporate planting the right species that can mitigate such incidents if they were ever to occur.

Headlight glare from opposing traffic can cause potential safety problems and plants can serve to reduce the glare during night time driving. The most favored design of highways today is to have dual carriageways that can handle several lanes of traffic going each way. Even when the carriageways are separated by ample
distance between them you will find that headlamp glare from motor vehicles will always affect other motorists around corners or bends. Glare can be reduced by the use of wide medians, separate alignments, earth mounds, plants, concrete barriers, and glare screens (WSDOT Design Manual 2013). Long-term maintenance should be considered when selecting the treatment for glare but some solutions can be expensive (e.g., glare screens). Plants can be used to create natural light barriers between the highways and consequently block light from headlamps, making night time driving safer and more pleasant. However, such greening programs need to be based on informed decisions regarding what species to plant where, and at what distances from the roads and road junctions. For example, if wrongly planted or mixed, trees can block the driver’s view at junctions and clear zones, thereby increasing risk of accidents, or of impact if the driver loses control of the motor vehicle. It is essential to understand the branching system and/or strength to ensure selected species do not break off easily, which is important in withstanding high winds, and consequently enhancing the safety of pedestrians, motorists, and utility lines. Some tree species, e.g., many species of Eucalyptus will snap during the rainy season when they cannot support the large volume of water they take up during this time combined with the effects of higher wind speeds or wind gushes.

The other importance of having vegetation in between dual carriageways or along highways is that it can act as a barrier when accidents occur. While tree removal may be beneficial to reduce the impacts of driving errors (e.g., angle crashes), appropriate vegetation may help to reduce speed and magnitude of impact in case of an accident. This can be achieved through frangible planting—planting which breaks under the impact of a motor vehicle (and hence helps to stop the vehicle). Generally trees and shrubs with a mature trunk diameter of less than 100 mm at around 500 mm above ground level are considered frangible. Vegetation can act as softer barriers than concrete or metal and therefore reduce impacts during an accident and increase the chance that injuries or loss of life are minimized.

18.3.3 Beautification

Since time immemorial, man has used different types of plants for beautification ranging from herbs and shrubs to trees. Plants of different species produce a wide variety of flowers with pleasant odors and colors. Flowers, being the evolutionary adaptation to help plants in pollination therefore have different shapes, colors, scents, and rewards such as pollen or nectar to attract specialized animal pollinators. Man has proceeded to breed and domesticate other flowers whose only purpose is beauty, usually deriving from the flower and/or leaf color. These plants are used both indoors and outdoors, and grown in a variety of ways including in pots, on walls and rooftops, in lawns and hedges, and in home gardens, as well as in parks and urban forests. Local vegetation that is well understood (e.g., in terms of flowering pattern and cycle, scents and vegetative growth) can be selected and incorporated in urban greening programs and serve the additional benefit of beautification.
18.3.4 Nutrition (Fruits)

Urban vegetation planning can include local and exotic fruit species. This can be in home gardens, public parks, and within compounds of institutions and office complexes. In Sweden for example, it is not uncommon to find fruit trees such as apples in public parks and people are free to pluck and consume as they relax or pass through these areas. In Kenya, fruits such as mangoes, avocados, plums, and coconuts can be incorporated in urban greening programs. At present, it is popular to grow fruit trees in urban home gardens but not common in public places.

18.4 Case Study: Opportunities in Urban Environments

18.4.1 Restoration of an Urban Green Environment Using Potential Natural Vegetation at the University of Nairobi, Kenya

The College of Biological and Physical Sciences of the University of Nairobi sits between Kirichwa Kubwa and Kangemi Rivers, and can be described as the zone where altitudinal cline starts accompanied by obvious remnants of upland dry forest vegetation to the west, south west, and north west, and separates the savannah landscape to the east and south east. This includes the riverine tree species such as Syzygium and Albizia. It is a unique and picturesque location that Ewart Scott Grogan (1874–1967), one of the pioneer colonial settlers, chose to build a home. Remnants of original vegetation show that the upland dry forest was continuous and spread from Karura upwards towards Ngong forests. However, only a few of the original species remain since the colonial settlers planted exotic species such as Eucalyptus (to drain the wetlands next to the two rivers), pine, and other species such as Jacaranda for beautification purposes. In addition, substantial infrastructure developments have taken place with the former residence converted into a campus of the University of Nairobi. The college is one of the few remaining areas of Nairobi with a natural feel and enjoys a clean and fresh environment compared to the city center barely 2 km away.

It therefore offers an opportunity not only to preserve the environment but also to restore it with original natural vegetation that has evolved in place for millions of years, while still offering a pristine educational environment for present and future generations.

To restore an environment with potential natural vegetation, one needs to understand the kind of vegetation that existed before human disturbance. Since 2007, our team led by Professor Kazue Fujiwara has conducted some intensive studies in Karura and Ngong forests with the aim of understanding vegetation composition and the social relationships among species. From these studies, we were able to identify common species that form all levels of vegetation in a forest from the canopy (T1) and understory (T2) canopies down to shrub and herb layers, and use
this mix to create a natural forest by planting seedlings using the Miyawaki method (Miyawaki 1998). The selected species were *Shrebera alata*, *Rawsonia lucida*, *Cassipourea malosana*, *Vepris simplicifolia*, *Drypetes gerrardii*, *Elaeodendron buchananii*, *Croton megalocarpus*, *Brachylaena huillensis*, *Calodendrum capense*, *Ficus thonningii*, *Warburgia ugandensis*, *Olea europaea ssp. Africana*, *Olea capsensis ssp. Hochestetteri*, *Ehretia cymosa*, *Markhamea lutea* and *Cordia africana*. The evenness of the above species was matched to ratios close to their natural distributions as we had found them in the natural forest studies such that, for example, there were more *W. ugandensis*, *C. capense*, *C. megalocarpus*, *B. huillensis*, and *C. africana* in the mix than *S. alata*, *E. cymosa*, *F. thonningii*, and *R. lucida*.

In designing an urban forest, understanding the species to plant is critical but also other important considerations come into play. Urban areas have zones such as recreational areas, roads, buildings, rivers, etc., each with their own characteristics, and therefore specific considerations and informed decisions should be applied in each case. For example, planning of tree planting in recreational areas such as parks needs to take into consideration spatial arrangements to enhance movements of people, as well as placement of benches. Therefore the pattern and intensity of planting must be well planned. In addition, the species selected should not break off easily or be uprooted by strong winds because of the potential dangers of them falling on people. In the case of Chiromo campus, we considered that the area chosen was also used for recreational purposes and so we could not plant a continuous forest. We decided to take advantage of the less utilized part of the area which formed step-like contours along the gradient of the slope (Fig. 18.6). Trees also do better on a slope than on a flat area, mainly because slopes have better drainage.

The site was prepared by clearing grass and bushes, and then holes of at least 0.3 m wide by 0.6 m deep were dug at a density of 3 holes/m². Seedlings were sourced from the local community groups as well as the Kenya Forestry Services nurseries. The 16 species were then mixed randomly and placed in each hole, with over 2,000 seedlings planted. The planting was undertaken by the university community, including members of staff and students, along with Japanese researchers and volunteers (Professor Miyawaki and Professor Fujiwara, as well as other scientists and volunteers). The student participation was very important because they were able to learn firsthand, as well as being able to take the experience out of the University when they finished their degrees. On conclusion of the planting, mulching from cut grass was placed around each seedling to prevent water loss and soil erosion. Management (weeding and replacement of any dead seedlings) has been ongoing since then and is expected to continue for a total of 3 years, at which point the seedlings are expected to be big enough.

### 18.4.2 Seedling Performance

The height of the seedlings was measured in September 2013 after 16 months of growth and the performance had been very good (Fig. 18.7). Some of the species had grown very fast with *S. alata* attaining the best mean growth of 211 cm (followed
Fig. 18.6 Newly planted site at the University of Nairobi with seedlings about 43 cm in height after 2 months (Photo dated: 28.06.2012)

Fig. 18.7 Same site after 16 months with some seedlings exceeding 2 m in height (Inset: Measuring height of *Cordia africana*-almost twice as tall as the person holding the measuring ruler)
closely by *E. cymosa* (210 cm), *M. lutea* (182 cm) and *C. Africana* (181 cm)) (Fig. 18.8). The slowest mean growth was that of *C. malousana* (32.5 cm) and *E. buchananii* (45.7 cm). The rest of the species had median growths varying between 71 and 132 cm. Compared to the traditional planting method with a spacing of 1 m² between the seedlings, the Miyawaki method showed better performance in the few species that could be compared (Fig. 18.8).

18.5 Conclusion

Scientifically informed decisions can help restore urban green vegetation by helping in identification of the right species and their combinations. The method of rehabilitation is also important as it is evident here that the Miyawaki method favors faster establishment of vegetation and therefore it is possible to regenerate a quasi natural forest over much shorter temporal scales. Involving communities, the public, or students is important in long term success since they learn and take the experiences to different parts of a country as well as taking ownership and practicing sustainable environmental practices on their own initiative.

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View Project
Toward Harmonious Green Urban Environments in Japan and Other Countries

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Synopsis

Natural vegetation and green environments have disappeared rapidly from cities since World War II, replaced by concrete deserts with only sparse, unnatural vegetation. Japanese cities traditionally did not destroy the surrounding vegetation except as needed for city growth, but now even in Japan there is a great need for both the ecological and socializing functions of productive, traditional green environments in the otherwise largely abiotic urban areas. True green environments are more than decorative greenery, protecting the soil, providing habitats for animals, buffering disturbances, and lending harmony to the landscape. Since the early 1970's, small, green "environmental protection forests", composed of native potential dominant species, have been retrofitted into urban and industrial areas throughout the evergreen broad-leaved forest regions of Japan, where most of the population lives. These greenbelts and other green patches combine techniques of modern vegetation science with the traditional Japanese methods of creating 'chimju-no-mori' (shrine and temple forests) and other forest areas in the built landscape. Comfortable urban environments, however, also require conservation of large green areas (e.g. patches of rural landscape) and the linking of greenbelts and other green nuclei to form interconnected green networks within the urban environment. Traditional native landscapes are the best basis for planning successful urban landscapes. "Environmental forests", based on aspects of traditional landscapes, are probably the fastest and cheapest way to create stable green environments in densely built-up cities.

Introduction

Most cities of significant size are biological semi-deserts, at least in their centers and industrial areas. The natural (spontaneous) vegetation which does occur in such areas is often dominated by weedy species plus other plants which are tolerant to disturbance and pollution. A few tolerant tree and shrub species may remain from the natural vegetation, but these often occur in cities in combinations which are unnatural elsewhere. Even where deliberately revegetated, the total urban landscape usually has a coverage by tree canopies and other taller vegetation of less than 30% (except in some parks). Introduced vegetation involves even more unusual combinations of local and foreign (exotic) species, especially when the exotic species survive better under intensive disturbance in the city than native species do. This results in chaotic, largely abiotic urban landscapes with only small remnants of natural vegetation and with patches of exotic vegetation which are often forced into the landscape in very inharmonious ways.

* This paper is a synthesis of separate presentations by the three co-authors at the international symposium "Planning for Greener in 21st Century Cities" held 5–6 June 1987 in Handa City (Aichi Prefecture), Japan (Box 1987, Fujiwara 1987, Miyawaki 1987).
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In many cases, the loss of vegetation in urban and other built areas has resulted from what has come to be known as the “tragedy of the commons”, by which a common-pool resource is degraded due to lack of sufficient managing control by any one authority (Hardin 1968, Hardin & Baden 1977). Users of limited resources are forced into unwanted competition for the resource, but this competition in turn may force even more resource use than would occur otherwise, yielding a runaway feedback dynamic which results inevitably in degradation or exhaustion of the common-pool resource. In cities, land is the most valuable common-pool resource. Land is taken over for buildings, transportation, utilities, etc. – each time based upon economically rational but single-purpose, non-holistic development decisions, without regard for other effects (which may be quite unpredictable). Planning for more pleasant, functional urban environments, without unwanted side-effects, can succeed only if planning is done more holistically, based on the carrying capacity and other attributes of the natural environment and on the full range of ecosystem functions and human needs.

Today, people demand a comfortable, affluent lifestyle filled with modern conveniences. They want to live in functional cities which provide the somewhat exotic way of life found in some new American and European towns. Although such conveniences may be necessary components of our working environment, we need to appreciate all the factors that contribute to the enrichment of human life, culturally, spiritually, and ecologically. It may be necessary to tolerate particular inconveniences in order to maintain our high standards of living. In urban areas it is especially important that we adopt harmonious lifestyles incorporating both modern-day comforts and at least partly self-managing, functional ecosystems. There is now an urgent need to preserve our green environments which have been kept as part of our traditional cultural landscape and to combine them with functional urban systems to create new harmonious city units.

Due to the rapid industrialization and urbanization after World War II, both the natural forest and other “greenery” within cities, which co-existed with human inhabitants, have disappeared at a drastic rate (e.g. Miyawaki et al. 1977, Numata 1977). As a result of the deterioration of the natural environment and disappearance of vegetation in urban areas, citizens have become more keenly aware of the need for nature conservation and preservation of green environments. Citizens are concerned about vanishing green surroundings and now are compelled to make special trips out of town to enjoy what is left of nature. It seems inadequate and superficial to regard these phenomena simply as a sign of sentimentalism or a product of affluence and leisurely life-styles. Although it is true that people’s expectations of and reactions to nature vary, it is more accurate to view these phenomena as consequences of people’s impulsive reactions, based on an instinctive sense of crisis over the decimation of their familiar cultural environment.

Japanese Cities in Geographic Perspective

We can put Japanese cities in perspective by comparing them with the rest of the world. As a small land with few resources but many people, Japan is characterized by intensive, space-efficient land use. This is symbolized by Tokyo, Yokohama, Nagoya, Osaka, and other cities in Japan. New Zealand, another small country but with fewer people and a shorter history of development, is similar but not so intensively developed.

For large countries one can see three main situations resulting from different factors of climate, geography, history, population size, etc. Some areas are already badly disturbed, such as China, India, and the Mediterranean region. This was due to large populations, long histories, and some poor land uses such as complete deforestation and overgrazing. These areas have not recovered. A similar case involving less severe but continuing current disturbance is that of Southeast Asia, disturbed by shifting cultivation, export of timber, etc.

A second situation in large countries involves areas which were disturbed but which have now largely recovered, such as northern and central Europe. This area was disturbed in the past by overuse and by warfare, but its climate permitted better recovery. People now have reclaimed and re-created productive, pleasant landscapes. In Japan, we have learned mainly from the successes of central Europe and from the pleasant landscapes of other countries.
A third situation involves areas such as North America, the Soviet Union, and Australia. These are large areas with many resources. These are now becoming greatly disturbed, at least in some areas, and are just now developing rapidly over large areas.

In planning for green environments in cities one must begin with the natural climatic-vegetation zones in which these cities occur. Japan has three main bioclimatic zones of potential natural vegetation: warm-temperate to subtropical evergreen broad-leaved forests in the south, deciduous broad-leaved forests in the typical-temperate (middle) latitudes, and mixed conifer-deciduous forests in the cool-temperate north (e.g. Kira 1977; Miyawaki 1979a, 1984, 1980–1987). In eastern North America and in China the vegetation zones are quite similar to those of Japan (Figure 1; see also

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Fig. 1 Relative Geographic Positions of East Asia and Ecologically Comparable East and West-Side Continental Regions of the Northern Hemisphere.

Fig. 2 Natural Evergreen Broad-Leaved Forest at (Mt.) Nachi-san on the Kii Peninsula (Mie Prefecture).
Box, in press). In addition, north-Pacific North America and much of northern Europe have oceanic climates and conifer-deciduous forest mosaics similar to those of Hokkaido, while the Caribbean area has subtropical forested limestone islands similar to southern Okinawa. Most similar climatically to Nagoya, Shizuoka, Yokohama, Handa City and much of Pacific central Honshu might be cities such as Norfolk, Raleigh, or Charleston near the east coast of the USA. Temperate-zone forest regions involve relatively productive and resilient natural landscapes, and geographic comparisons are both

Fig. 3 Protected Shrine Forest around the Gokoku (Shinto) Shrine at Shizuoka City.

Fig. 4 Protected Temple Forest around the Hachimangu (Shinto Shrine) at Kamakura.
interesting and instructive. Each of these characteristic natural regions also has its own traditional cultural landscapes related to the natural conditions and the human economic and other cultural activity.

We have learned from the history of other civilizations that although cities were often built on land previously covered with forest, this land was virtually reduced to a desert landscape and the cities disappeared. This has been seen over several thousand years of human history beginning with the Mesopotamian, Egyptian and Greek civilizations. In Japan there was a time when most of the land was covered by forests, including the areas currently occupied by all the major cities. The land below 800m in altitude was occupied by the evergreen laurel forest, except in northern Japan (Figure 2).

The forest was largely regarded as an obstacle to human activities as far back as the Jomon and Yayoi periods. Ever since rice cultivation started about 2000 years ago, our ancestors destroyed forests to build villages and towns. But without exception, the Japanese did not destroy all of the natural vegetation. They preserved, protected and re-created the native forest, consisting of trees native to each location (furusato-no:mori, cf. Schwabe 1977), as shrine and temple forests and forests around old houses. These can still be found today in Yokohama and many other cities throughout Japan (Figures 3 and 4).

**Functions of Green Environments**

In recent years ecologists have begun to look more and more at problems involving human uses of natural environments, especially at the landscape scale and including problems of urban ecology. Landscape ecology (e.g. Forman & Godron 1986) focuses especially on functional aspects of landscapes and how the functional integrity of these landscape ecosystems (energy flow, nutrient cycles, response to disturbance, etc.) is affected by land-use activities and changes. For example, in cities, how would different urban vegetation structures/configurations control unnatural flows of energy/materials/pollutants resulting from man's activities, and which configurations might be most effective? Or, how are pollination, seed dispersal, and animal populations affected by the fragmentation of forest areas into ever smaller and less natural patches, farther from each other? Restoration ecologists have begun to try to rebuild some types of natural ecosystems and distinguish between landscape revegetation, rehabilitation, and restoration. Of course restoration of completely natural ecosystems is not possible in urban areas, but restoration of functional integrity and natural, self-maintaining processes is a necessary component of any attempts to create stable, productive human environments.

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Fig. 5 Three-year old, planted "Environmental Protection Forest" on a man-made island near the Pacific coast at Gobo City (Kii Peninsula, Wakayama Prefecture, cf. Figs. 8, 9 and 10).
Fig. 6 Outside (above) and interior (below) of a 13-year old Environmental Protection Forest at the Nippon Steel Corporation Kimitsu Works (Chiba Prefecture) (Phot. by Kanto regional construction bureau, Ministry of construction).
In considering the need for green environments in cities it is important to distinguish between "greenery" (usually understood in English as decoration) and truly functional green environments. The Japanese word 'midori' (green) conveniently covers both of these meanings, but sometimes without emphasizing the need for green areas which perform necessary biological, ecological, and even psychological and economic functions in addition to their cosmetic value. Such natural functions may include water storage and management, soil protection, provision of habitats for other beneficial organisms, and buffering the effects of pollutants and other disturbances.

In urban and industrial areas of the evergreen broad-leaved forest region of Japan, small forest areas (greenbelts or green screens) have been created as "environmental protection forests" (EPF) in order to perform necessary functions in urban settings, including provision of some relief against otherwise starkly abiotic environments (Figure 5). Such small green areas are not always true forests. A true forest must have an interior which is not significantly reached by many effects from the surrounding outside environment (Figure 6). If one stands in the middle of a patch of trees and can feel that he is in a forest, then perhaps it is a true forest.

In urban areas, there is not always room to reconstruct true forests, even though these may be badly needed. The EPF is perhaps the next best thing. Wherever created, such "forests" are based on species of the potential natural vegetation, as determined from intensive vegetation surveys and analysis (e.g. Miyawaki et al. 1974, 1980-87, 1983). Such 'environmental forests' represent living filters against noise, airborne substances, and visual blight; very effective biological indicators of environmental changes (perhaps not easily measured otherwise); soothing green scenery for improved morale and productivity; and useful green buffers between living environments and less healthy parts of the urban-industrial landscape.

One practical function of the designed landscape, especially in cities, should be to provide harmony, physical and mental comfort, and a feeling of being "at home", just as in more natural environments. Such positive results seem best provided by traditional landscapes which combine characteristic regional features with traditional houses, big native trees, rural areas, patches of remaining forests, and so on. The traditional Japanese landscape was a harmonious patchwork of land uses which also preserved the surrounding native forest, especially around shrines, temples, farm houses, etc. We seek to restore this traditional wooded character, including creation of man-made native forests in urban and industrial areas and integration of old and modern aspects of Japanese culture into new, multi-use human environments (e.g. Miyawaki 1982, Fujiwara 1986a).

**Constructing Green Areas in Japanese Cities**

The methods for the actual construction of greenbelts and other green areas in Japanese cities, using native species, have been described before (e.g. Miyawaki 1975, 1981b, 1982; Fujiwara 1986b). These techniques have been especially applicable in the evergreen broad-leaved forest region of Japan, the potential vegetation of which has been summarized by Fujiwara (1981-1986) and by Miyawaki (1979b, 1981a). These construction methods will only be summarized briefly here.

The working plan for creation of new green areas, from vegetation sampling to the final environmental protection forest, is shown in Figure 7. The planting schedule and actual plant species used for environmental forests are determined from the results of phytosociological fieldwork. At the construction site, a linear mound is created, on which the forest is to be planted. This mound is covered with a 20-30 cm layer of topsoil. Then, tall-growing, site-suitable evergreen broad-leaved young trees (0.5 to 1 m, 2-3 years old, grown in pots for development of strong root systems) are planted at a density of 1.5 to 3 trees per square meter (Figure 8). Rice straw is then scattered on the soil (4 kg/m²) to protect both the soil and the young trees. Even ideal plantations appear weak and vulnerable at first. They can grow, however, at a rate of up to 1 m per year for up to 10 years, and thereafter grow taller and more luxuriously (Figures 9 and 10) (Fujiwara 1983). After initial weeding, the plantations require no maintenance after about three years. The final result is a mature "native forest", composed of native climax forest species, but achieved within 20-30 years by planting climax species (on a well prepared site) at the beginning. Experience has shown that understorey and edge species will come in naturally.
Fig. 7 Flow chart of operations for Creation and/or Restoration of evergreen broad-leaved forests as Environmental Protection Forests and Native Forests in Japan.
Fig. 8 Newly planted environmental forest at the Gobo Electric Power Station (Gobo City), showing seedlings, prepared mounding, and protection by rice-straw matting after planting (cf. Figs. 5 and 10).

Fig. 9 An environmental protection forest on a 5 km-long, linear embankment along the Kashiwara highway by-pass through the suburbs around Nara City. This environmental forest was planted in February 1983 by 1200 school children and has grown five meters in five years.

Fig. 10 Three years' growth of an environmental forest planted on a man-made island as a green screen around the Gobo Electric Power Station (Gobo City).
Of course, before destruction of the pre-existing vegetation of an area, a map of the actual vegetation should be drawn up. This map can be used for basic diagnosis of the environment and for identifying ecologically valuable vegetation and ecosystems as well as necessary protective measures for them (Miyawaki and Fujiwara 1975). A map of the potential natural vegetation should also be made, not only for purely scientific purposes but also as a guide to species selection for the creation and restoration of green areas.

In the 1970's, not only the preservation of nature but also the re-creation of rich green environments with biological diversity were proposed, in urban areas, industrial zones, and along transportation facilities. The re-creation of relatively natural environments can be realized by integrating up-to-date research on the potential natural vegetation and the traditionally Japanese method of creating 'Chinju-no-mori' (shrine and temple forests). Slowly but steadily, a campaign to bring native forests into largely abiotic environments has taken root in various places throughout Japan, such as:

1) Steel mills, factories and power stations on reclaimed coastal land.
2) Schools, parks, sewage disposal plants, and public facilities within urban and industrial zones.
3) Around transport facilities such as airports and harbors, and along streets.
4) Bordering mountain roads and highways.

Such plantings also perform educational functions for Japanese society (Figure 11). Through trial and error, our ancestors managed to find ways to create native forests with native trees in their towns and villages. By combining this traditional method with modern phytosociological and ecological diagnosis (i.e. maps of actual vegetation, study of site conditions) and prescription (i.e. maps of potential natural vegetation and habitats), new native forests with evergreen broad-leaved trees have already been created in more than 120 locations throughout Japan (e.g. Miyawaki 1987; Miyawaki et al., in press; see Figure 13), including some surprisingly steep slopes (Figure 12).

Preservation of nature and restoration of green environments have by now become inseparable aspects of conservation and planning efforts. The efforts to restore native woody green environments, adapting the indigenous vegetation of each location, have borne fruit after periods of only 3 to 12 years. Although still insufficient, the identification of the indigenous potential natural vegetation is

![Fig. 11 Planting an environmental protection forest (mainly seedlings of Castanopsis, Persea, and evergreen Quercus) at Ebina City in Kanagawa Prefecture. The children are from Imaizumi Middle School.](image-url)
Successful planting of native trees (EPF) on steep slopes around the Kanagawa Prefectural Kurihama High School, built on re-graded terrain at Yokosuka City.

expected to contribute to the formation and betterment of the human environment, a better foundation for our unique inheritance and conservation of the native landscape in each place.

With the introduction of environmental forests in cities, land with limited use can be utilized more effectively. Future maintenance costs may be reduced, and the substantial mass of threedimensional greenery will create a landscape that is permanently attractive and indigenous to the region. In Handa also, a vegetation and ecological study has been conducted throughout the city (Miyawaki et al., 1982). As a result, a map of the potential natural vegetation has been completed and has been used to develop native forests at the Itayama Primary School and other locations in Handa.

How to Plan Green City Environments

City environments should be convenient for human life. We can now use the most up-to-date scientific techniques and we know that the most harmonious landscape is the traditional native landscape (Figure 14). We can therefore combine these two factors to create a totally balanced city environment.

1) Conservation of rural areas within the city

Rural areas, especially rice fields, have produced the culture and the very nature of the Japanese people. They should therefore be preserved as important production as well as cultural areas within the urban environment.

2) Re-creation of green environments in urban areas

(a) Creating green nuclei: if native forests can be re-created at several sites within the city, such as parks or other open spaces, they can act as reservoirs and protection areas for wildlife. In more affluent cities, dense forests and other green areas can be created through “landscaping” (usually involving exotic species). This is expensive, though, and requires considerable maintenance. In cities with less money for landscaping, the method outlined above can be used, i.e. dense planting of pot-grown native tree seedlings on well prepared, mounded sites.
Environmental protection forests are needed in/around residential areas, industrial areas, public buildings, along riversides and coastlines, etc. They can range from hedges to greenbelts from several to a hundred meters wide. Linear greenbelts can be built along highways, smaller roads, and railways, as well as rivers or coastlines. Alleé trees can also be planted in dense miniature patches, with tree, subtre, and shrub layers.

Thick green walls guard the environment from pollution, landscape disturbances and other possible calamities. The green patches contain rich ecosystems, particularly along their boundaries (Forman and Godron 1986).
Traditional landscapes should be, and to some extent are, the basis for successful urban and land-use planning in other parts of the world as well. In American cities near the east coast, the blend of natural and traditional landscape elements is retained in cities especially in the form of large, stately, native trees along streets and around old traditional homes. Local historical societies seek to preserve these traditional elements of urban landscapes. Other areas of many cities, however, are dominated by concrete, by impoverished areas, and by other impersonal, “hard” surfaces and structures. Although it is difficult to re-vegetate the most extreme urban deserts, introduction of green areas has proven to be a useful step in the reclamation and redevelopment of urban slums.

Beginning in the late 1960’s, certain far-sighted government offices, prefectures, cities and industries in Japan began to cooperate in the conduct of large-scale vegetation surveys before land development or expansion of existing sites and facilities. This effort was expanded in the 1970’s to real attempts to create new green environments where badly needed.

Of course, people's tastes in green surroundings vary considerably. In some parts of the world exotic species are much preferred by developers over native species. Interests, fashion, life-styles and experience all yield diversity. The beneficial effects of greenery on people have always been a favorite topic of conversation. All types of greenery are soothing, refreshing and necessary for our mental and physical health. However, in view of the current impoverished conditions of shrine and temple forests in Japan, what is most needed in urban areas (where 75 percent of the population is concentrated) is forest consisting of trees native to the location. It is hoped that this kind of basic urban greenery framework can be established. Considering the speed with which properly prepared seedlings can grow and the self-maintaining nature of these plantations, “environmental forests” of native species are clearly both the fastest and the cheapest way to create stable, long-term green
environments in densely built-up landscapes.

Conclusion

Green areas are one of the main dynamic components affecting the general urban landscape and should be in balance with other important factors such as city area, population size, economic structure, education systems, and the constructive activities of government officials and/or members of the public. Historically, harmonious “environmental” towns were developed by people sensitive to their surroundings. Such areas only persist today, though, if their traditional character is regarded as a major economic resource (e.g. ancient towns, tourist towns, rich resorts, areas of rural landscape).

Relationships between population increase and decrease of green environments can be amply demonstrated if necessary. We should not wait for scientific “proof”, however, before acting to improve our living environments. Looking toward the 21st century, we must base our planning for green urban environments on total harmony of human activities and a sustained richness in plant and animal life.

The following objectives seem most important in the planning for balanced urban environments:
1) Programs of environmental education and citizen awareness, putting situations in perspective in terms of human history and the biosphere as a whole.
2) Re-examination of city environmental and land-use planning, establishing which green areas should be protected and how and where new ones should be created.
3) Creation or re-creation of green environmental networks in cities, i.e. creating green nuclei of native forest linked with interconnecting green-belts acting as environmental corridors for plant and animal movements. In general, natural vegetation maintains itself and maintains other necessary functions of the landscape (water management, buffering, etc.), making it much cheaper and more stable than artificial “landscaping”. In addition, native species provide more natural, harmonious landscapes (and usually require less maintenance than exotic species).

Urban areas and growth in the heavily industrialized or at least heavily populated modern world must be planned, for economic and social reasons as well as for “environmental” reasons or conservation objectives. Such planning must be done holistically and must be based on the ability of the natural and enhanced landscape to support the city’s requirements over long periods of time. Perhaps especially in urban areas, one must distinguish between “greenery” which is merely decoration and greener which represents truly functional, pleasing green environments. Planning based on green urban environments, involving traditional landscape elements as well as functional stability and self-maintenance, represents the best basis for successful cities.

It is important that administrative bodies, business enterprises and other organizations adopt a system that would make an essential contribution to the recovery of green environments, especially in urban areas. It is crucial to preserve, or create where lost, an environment in which human beings can live and co-exist comfortably, now and in the 21st Century. Such a “survival environment” is symbolised by the presence of healthy green areas. The responsibility lies with this generation to re-create green areas in cities and restore damaged and derelict land to a more salutary condition.

Green urban environments, as well as ecosystem restoration, represent an important area of current interdisciplinary research throughout the world (e.g. the International Symposium on Ecosystem Redevelopment, Budapest, April 1987, sponsored by IIASA, UNESCO and other organizations). It is our wish that the efforts in Handa toward the creation of “a city in a forest” will spread not only among Japanese cities but also to other countries.

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Sustainable Solution for Urban Environment: Miyawaki Forest

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Some of the authors of this publication are also working on these related projects:

- Low cost water treatment View project
- Effect of stubble burning on air quality of Delhi-NCR View project
Sustainable solution for urban environment: Miyawaki Forest

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Abstract—Rapid urbanization, population growth and rural-to-urban migration, especially in fast-developing economies (such as India and China) have resulted in a fast decline in forest cover and green space in a large number of urban centers around the world. Recent reports suggest that Delhi, India’s capital, has a green cover of only 20.6\% and has a declining trend of dense and very-dense forests. In fact, India ranks one of the highest among the large countries in terms of reduction in tree cover extent. This is an alarming situation and does not bode well for human health and ecosystem, in general. Immediate and long-lasting steps are needed to check the diminishing green cover in most of the metropolitan cities of the world.

Among a number of ideas suggested for checking the rapid decline in the green cover; the concept of Miyawaki forest offers a unique solution. Developed by the famous Japanese botanist, Akira Miyawaki, the Miyawaki forest is an affordable, low-tech, maintenance-free and rapid method of growing native vegetation on degraded lands (Fig. 1). Such forests can be grown by anybody using simple methods and a lush-green forest consisting of native vegetation in about an year’s time is expected. A number of industries and cities have successfully grown Miyawaki forests for enhancing the tree cover and a better environment.

Figure 1. Changes in landscape due to the growth of Miyawaki forest, pre and post-growth scenario

Miyawaki forests have also been successfully tried in India and several start-ups offer help to individuals and organizations in growing Miyawaki forest on their land. However, large-scale deployment of this technology for improving the declining air quality is yet to be attempted. The current work discusses the concept of Miyawaki forest, its advantages and possibilities of its utilization at large-scale in India. Potential issues in its deployment and solutions thereof are also presented. A competing technology, vertical gardens, is also briefly discussed for comparison. It is expected that Miyawaki forests will be able to reverse the declining tree cover, provide a better environment and improve our air quality.

Keywords—Miyawaki Forest, Sustainable, Urban Environment, Air quality, Health
INTRODUCTION

Rapid degradation of urban environment is a common scenario in rapidly developing economies, leaving the residents gasping for a breath of clean air. Delhi, India is a prime example of this and experiences only a handful of days each year that can be termed to have good air quality. The exploitation of vegetated fields for urbanization has caused a steep decline in the green cover of not only Delhi, but most of the other major Indian cities as well. The resulting health issues and environmental degradation requires rapid solutions, without compromising the economic growth and infrastructural development.

Unfortunately, the growth of trees and forests is a relatively slow process; while the need of the hour is relatively rapid solutions. Conventional forests may take decades to centuries to grow, that too assisted by numerous factors (including, but not limited to, environmental conditions, little or no human interferences, etc.). However, the cities are running out of time to provide cleaner air to their residents. The restoration of degraded lands is an urgent necessity in urban settings. An innovative and (relatively) rapid method of land restoration is Miyawaki forests [1], named after Dr. Akira Miyawaki (a Japanese botanist). This method has been used to restore forests and green cover at hundreds of locations throughout Japan. In addition, it has shown promising results in other parts of Asia, including Thailand, Malaysia and India.

This approach is based on identifying and growing native species in a given region. Non-native plant species, generally introduced for providing green cover and other purposes, have more stringent nutrient and environmental requirements. And, hence such species require more care, resources, and have a slower growth rate. Native species are already accustomed to the local soil and environmental conditions and hence stand a better chance of growth and that too a rapid one. The Miyawaki method makes use of this key advantage of native vegetation. It is important to provide conservation planner for the conservation of biology [2].

The technique supports the growth of a dense, mixed, native forest and results in a native forest ecosystem, complete with small animals, rodents, birds, etc. The natural selection, resulting from the competition between different types of native species, creates a diversified natural forest. The method supports the growth of primarily canopy trees. In order to match a natural forest system, random plantation of different types of native seedlings (with extensive root system) are randomly planted. Growth rates of a meter per year or higher are generally observed, ultimately resulting in a complete, mixed, native forest ecosystem in a span of few years, instead of decades (to centuries) needed by other systems of planting. There is another study also which is based on the relationship of the major forest types to the forests of the adjacent Korean Peninsula, Northern China and Russia Far East [3].

The ability of plants to consume carbon dioxide and produce oxygen, during the process of photosynthesis, is generally considered the best deterrent to global warming. And Miyawaki forests have the potential to act as carbon-sinks in our cities and minimize the global warming [4].

Despite its obvious advantages, the method has its share of disadvantages and is yet to be upscaled to really large-scale land restoration projects. The method has been shown to work well in Indian settings, however, vertical gardens (a competing approach) has received more traction in Delhi. This technique has been described briefly as well. The current work is aimed at providing a brief review of the Miyawaki forests technique, its advantages, disadvantages and possible ways to overcome them.

1. Air Pollution Issues and Health Effects in Urban Settings

According to the study of World Health Organization, the World is becoming hotter, as it gets more crowded. Engines continue to pump out dirty emissions and half of the World has no access to clean fuels or technologies. Air is growing dangerously polluted that we breathe in. Out of ten, nine people now breathe polluted air. Air pollution has a number of different emissions sources, but the major contributors are motor vehicles and industrial processes [5]. Ambient air pollution can have adverse effects on the health of exposed population [6]. Exposures to pollutants such as airborne participate matter and ozone has been associated with increases in hospitals admission also. Effects are found in short-term studies [7]. It is estimated that particles pollutants cause more than 500,000 deaths annually [8]. Mortality and morbidity were estimated the impact of outdoor and traffic-related air pollution on public health in Austria, France and Switzerland [9]. Combustion of fossil fuels is responsible for the progressive change in the atmospheric composition [10].

Many health effects also arise from air pollution like death from stroke, lung cancer and heart diseases. It is difficult to escape air pollution from the environment, no matter if you are living in the posh area. According to the study, it has been shown that exposure to the natural environment has an independent effect on health and healthy related behaviour [11].
Microscopic pollutants can penetrate deep into our respiratory and circulatory system. It damages our lungs, heart and brain. In atmospheric science, the new focus is on the impact of global air pollution on climate and the environment [12]. Few countries have some of the highest particulate matter level in the world. China is one of them. Objective of the study was to examine the association of particulate matter with an aerodynamics diameter of less than 10µm (PM$_{10}$) [13].

The lack of visibility clearly indicates that air is not healthy. Across the world, toxic pollutants are seen in the air and it exceeds average annual values recommended by WHO air quality guidelines. There are two types of air pollution-ambient air pollution or outdoor pollution and household or indoor pollution. According to the study, household air pollution kills 4 million people in a year and tends to affect countries in Africa and Asia, where polluting fuels and technologies are used every day particularly at home for cooking, heating and lighting. Women and children who tend to spend more time indoors, are affected the most. It also causes long term environmental damage and it is a major threat to health and well-being.

Placing trees is a cost-effective way to tackle urban air pollution, which is growing problems for many cities. According to the study of UN based, The Nature Conservancy (TNC) reported the average reduction of particulate matter near trees was between 7% and 24% while the cooling effect is 2 degree Celsius. Lead author Rob McDonald said that trees were already providing a lot of benefits to people living in urban areas. According the WHO Health Statistics 2016, air pollution is caused by inefficient energy production, distribution, and use especially in the industrial, transportation and building sectors and by poor waste management system.

Dr. McDonald observed, there is no other replacement of trees, only trees can help in order to clean the air [14].

One of the pillars of the Miyawaki forest technique is the identification of native vegetation species. For this purpose, a detailed field survey is needed to determine the type of vegetation. The field survey is coupled with the phytosociological survey and environmental description. It is important to investigate basic soil characteristics, light condition, effect of environmental factors on the survival of seedlings grown in three degraded vegetation [15]. The vegetation units in the surrounding region is studied and classified as either native or substitute vegetation (PNV) [16]. This data is then compared with the actual vegetation at the site of interest and potential natural vegetation are identified for restoration purposes. The potential natural vegetation consists of each unit of species combinations. Such detailed studies provide the knowledge of potential major tree species of the native plant communities of that region [17].

Once the potential natural vegetation is identified, their seeds are collected and germinated. These are allowed to grow in pots till their root systems are fully developed. This overcomes the difficulties associated with transplantation of bare seedlings of natural vegetation. The potted seedlings are then mixed with similar seedlings of other natural vegetation species and these are planted in a dense, yet random manner. This is done to ensure a true natural vegetation. The degraded land may have to be prepared by mulching with rice straw and similar organic materials (of agricultural origins) to minimize the soil dryness. The other advantages include prevention of soil erosion (especially on steep slopes and under extreme precipitation events), protection against cold and fertilization potential of the organic materials used. In the initial growth phase, weeding may be needed once or twice in first couple of years. The weeded grass is an additional source of mulch. Over time, natural selection takes over and a dense, mixed, native forest is resulted [18].

2. Outcomes and Indian Scenario

The first successful implementation of the Miyawaki technique took place in Nippon Steel Corporation, Oita, Japan in the 1970’s. Since then over 1300 sites in Japan have benefitted from this approach. Apart from the Asian countries (including, Malaysia and Thailand), Italy and Chile have also had success with this method. The outcomes include dense native forests, complete with native fauna including, birds, insects, squirrels, etc. Growth rates of about one meter per year have been reported in a number of sites [19].

In India, the technique has been used at few sites and is gaining popularity. A number of startups are working to promote this method and make it affordable to the interested individuals and/or organizations. These include, Digital Green, Waste Ventures, Banyan Nation, Saytrees, etc.

Another way of doing planation is vertical gardening. Greater Chennai Corporation planning to set up a vertical garden on flyovers, skyways, causeways and bridges. Generally, those species are mostly found in vertical gardening which can absorb heat and dust. Treated water from sewage treatment plant will use to maintain these gardens [20]. Inspiration is being drawn from China and Italy’s vertical forests. Noida also has started setting up vertical gardens to raise the aesthetics of the city and to reduce the pollution [21]. North and South Delhi Municipal Corporations are planning vertical gardens at Delhi’s school, markets and historical structures.
These will help in neutralizing the pollution which is caused by dust and vehicular emissions [22]. A competing technique, vertical gardens, has gained a lot of attention in Delhi. This is a relatively flexible and highly productive system (Fig. 2). In this system, gardening is done on a vertical surface than on a horizontal surface [23]. It has various advantages like it takes less space, is easier to harvest and maintain. In this method, the plants are easier to reach for fertilizing, watering and harvesting in a convenient manner. It provides improved air circulation by putting plants in a vertical configuration. It saves plants from damage due to pets or wild animals by keeping them out of their reach. Such gardens can be easily developed in congested areas and traffic intersections. Additional advantages of vertical gardens include, temperature regulation, shade, improvement in air quality by absorption of pollutants (including volatile organic compounds, etc.) [24]. Delhi government has recently planted lakhs of plants in vertical gardens situated on pillars of metro lines and elevated roads. Such system is being used to beautify the city as well as provide some much-needed greenery at busy areas.

![Fig. 2 Vertical Garden](image)

3. Advantages and Disadvantages of Miyawaki Forests

The advantages of Miyawaki forests include, rapid restoration of land, development of an entire ecosystem (instead of just plants), much faster development of greenery as compared to conventional forests, minimal maintenance and care, low-cost, etc. The disadvantages include, the necessity to carry out detailed field surveys (in case, potential native vegetation is not known), requirement of a tract of land (unlike vertical gardens), high cost in the initial phase (for land preparation, survey, planting, etc.) and a rather monotonous appearance due to trees being of relatively same age.

I. CONCLUSION

Forests are a human necessity for their ability to supply oxygen, act as carbon-sink, provision of shade, food, wood, among others. Yet, human greed has resulted in a steep loss of forest cover in many cities around the country. This has not only led to loss of trees, but soil erosion and land degradation as well. The cities are in a dire need of forests and greenery to ensure adequate air quality. Miyawaki forests, a technique that supports the growth of native vegetation, with low maintenance needs, is a promising solution. The method has shown tremendous success in Japan and some other parts of Asia as well. However, it is yet to find major traction in India. Governmental support, increased awareness and participation of NGOs and other organizations is needed to ensure the revival of our degraded lands and lost forests. It is expected that Miyawaki forests will help increase the forest cover in our country and provide a greener and better environment to our current and future generations.

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Two Year Study On The Comparision Of Miyawaki Method To The Traditional Method of Afforestation

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TWO YEAR STUDY ON THE COMPARISON OF MIYAWAKI METHOD TO THE TRADITIONAL METHOD OF AFFORESTATION

AIM
The Miyawaki method of afforestation advocates the rapid growth of dense forest in a small area. This study compares the effectiveness of the Miyawaki method of afforestation to traditional methods.

MATERIALS AND METHODS
In order to carry out the Miyawaki Method, native plant species were selected, the soil was prepared with manure, and the saplings were planed in a way that encouraged sociological connections and competition. In plot A the Miyawaki technique was used and in Plot B traditional methods was used.

RESULTS
In January 2020, the circumference (1 meter above the ground) of plants from both plots were compared. Difference in circumference between the trees in both plots varied from a 17% decrease to a 186% increase (See Table 1, Chart 1). The height could not be calculated as the Miyawaki forest is already over 20 feet high.

CONCLUSION
It can be concluded that the Miyawaki method is an innovative solution to combat deforestation. The utility of fruit-bearing trees in Miyawaki method is questionable. This method can be carried out in cities due to the small area (300 trees can be planted in 1000 square feet). It results in rapid afforestation rates compared to traditional methods, making it an efficacious and productive tool in the fight against deforestation and climate change.
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The Prediction and Mapping of Potential Natural Vegetation Based on Environmental Factors

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Yoshinobu KUSUMOTO, Fumito KOIKE, Kazue FUJIWARA

摘要

研究目的

本研究では、神奈川県の潜在自然植生マッピングを行うことを目的として、植生タイプの推定モデルを構築し、このモデルをGISを用いて推定を行った。これにより、神奈川県の潜在自然植生マッピングが可能となった。このモデルを用いて、自然植生の保全や回復の基礎的な情報を提供することを期待する。

1. はじめに

自然植生は現在国土の19.8%まで減少し、関東では6.8%まで減少している。自然植生を保全し、よりよい環境を構築していくには、自然植生がどのような環境に成立しているかという基礎的な知識を把握すること、そして関東植生がこれについてどのような条件を満たすかを知ることが重要であると考えている。これまでに、地形成像の成立要因の抽出を行い、潜在自然植生の推定を行う研究はいくつかの試みがある。潜在自然植生はTUXENにより、現在自然植生が停止した際にその地理が変えることができる理般的リスクを考察されるためであると定義された。その後、この概念は日本の幾つかの地域で説明され、地域全体で実施されることが求められている。

一般的に、地形学的な知識で潜在自然植生の推定は、1）残存する植生、2）対応する代償植生、3）土地利用形態、4）地形および土壌断面、5）気候などの情報を総合的に用いることにより正確な判断が可能である。しかし、実際には、飽和した状態で、また全ての情報を得ることは困難であり、客観的な推定が行われる場合もある。そのため、地形学的な知識を用いた統計的な手法を用いた植生タイプの推定が行われている。TUXENが提案したオーダーレベルでは流域、武内により数値情報分析を行い、自然植生と地形の対応関係を多項目ネットワークにモデル化し、日本列島の潜在自然植生の推定に成功している。種レベルでは、特黒・波田は地域フローラデータと10メッシュ気候類を用い、樹木種の推定に成功している。

2. 研究対象地

神奈川県全域とした（図1）。関東平野の南西部に位置し、東側は相模湾から多摩川を経て東京湾に接する。南側は、三浦半島と真駒内半島を有し相模湾に面している。西側から北は丹沢山地、小倉山地で山梨県と接し、北東部は東京都と接している。地形は大きくわけ、西部は山地、中央は平野と台地、東部は低地となっている。
部は丘陵と沿岸部の三つに関わる。南北の長さは約60km、東西の長さは約80kmで面積は2,415km²であり、海拔は5mから1672mまで幅を持ち、全面積の50％は100m以下の土地である。

3. 研究方法

研究の流れは、まず（1）統計的手段を用い植物群落の序列化を行う。2）植物群落と環境要因の関係を示すモデル化を行なう。3）モデル化を自然植生の潜在特性をシミュレーションし、4）作成されたシミュレーション図の検証を行なった（図2）。なお、研究を進めるにあたり環境データの調査および解釈によりGIS（Arc/info7.21、Arc/view3.1）を用いた。

（1）現地調査および植生データベースの構築

1972年から1983年の間に植物学的的な分類が目的で調査された神奈川県の753地点の自然植生の調査資料（ウオフナメ）のデータベース化を行った。データベースは全調査地点に出現したすべての植物の種名、被度、群度、調査地点IDをもとに、GISを用いて作成した調査ポイント図（図1）と調査地点IDによりリンクしている。さらに2000年に対象地全域に調査ポイントが存在するかを巡し、データの少ない地域について重点的に68地点の自然植生の現地調査を行いデータベースに加えた。

（2）自然植生の分類

合計821地点の植生データをTWINSERPによる解析を行なった。その際の分類はP の値を用いてP<01 レベルで有意が認められるところで分割を続けた。常緑広葉樹林の群集についてはTWINSERPによる解析で統計的に有意でなかったが、一般的には存在が認められているため、補助的に植物学的調査操作により行った。

（3）環境データの構築

気候データでは年平均気温、最低気温、最高気温、年平均降水量、温かさの指数（W1.1）、および寒さの指数（C1.1）のデータ精度は4次メッシュで構築した。地形データは標高、傾斜を表すブリアン、地形の複雑度を表す距離内高の標準偏差、傾斜面高でデータの空間精度は50mメッシュで構築した。現状環境データでは、土壌、地質、海からの距離の環境データを構築した（表1）。

（4）自然植生の成立する環境要因の抽出

自然植生データの調査地点と環境データをGIS を用いてオーバーレイを行い、環境データが植生調査の地点にクリッピングし、環境変数とした。

TWINSERPの分割に寄与した環境変数を算出するため、各変数のグループを有義変量（0と1を割り当てた）の従属変数として、（4）で集計した環境変数を説明変数として、ロジステック回帰分析を行った。なお、本研究では従属変数を確率として捉え、確率を扱うための可能なロジステック回帰分析を用いた。モデルの回帰式にモデル化が得られた予測値の0.5を基準にしてどちらかの植生タイプであるかの判別が可能である。分析にあたり多数の環境変数を扱うことによる多重共線性の問題を回避するため、相関係数の高い環境変数どうしをそのどちらかを落とすモデル構築を繰り返し、最終的により当てはまりのよい変数を選択することのできるステップワイズ法を用いた。

（5）自然植生の潜在域の推定

神奈川県内のヤブツバキクラス及びブナクラス域の一部の地域について、作成されたロジステック回帰モデルにに採用された環境変数をもとに50mメッシュを作成し、そのメッシュの潜在自然植生の推定を行い、それを地図化した。さらに本研究により作成された潜在自然植生図と、従来の植物学的調査手法により作成された図との比較を行った。

4. 結果および考察

（1）自然植生の分類

合計821地点の調査地点はTWINSERPによる分類で統計的に有意な10階級に分割された（図3）。Gr1 6はアオキ、キツツキ、シロダモ、ヒサカキ、ヤブツキ、サキツキカズラ、ダツノキを識別種とし、その中さらにGr1はコウボウムギの識別種とする海岸砂丘原、Gr2はハノキ、スギ、セリを識別種とする沼沢、Gr3はヒュオ、ベンゲリ、スダジイ、ヤブツキ、モチノキ、ヤブツキを識別種とする常緑広葉樹林、Gr4はモミを識別種とする常緑広葉樹林、Gr5はモミを持たない常緑広葉樹林、Gr6はキヨタキ、シナコンを識別種とする夏緑広葉樹林であった。Gr7 8はブナとマツザクラで識別された。
D1の分類では環境要因としてW.I.と年平均降水量が抽出された。これはブナクラス域とヤブナバナクラス域を分ける環境要因と考えられる。対応する種もGr.2からGr.6のアオキ、シプロレア、ヒサカキ、ヤブナバナ、ハバナバナ、ヤブナカクイを示し、一方Gr.9からGr.10ではブナ、マメナガがブナクラス域の種を示し、両クラスを代表する種で対応している。分布域は次式で予測される。

\[
\text{Gr.1からGr.6の確率} = 1 / (1 + 1 / e \cdot -0.024 (W.I.) + 0.006 (W.I.) + 1.315)
\]

\[
\text{Gr.7からGr.9の確率} = 1 - (W.I.のブナクラス域の確率)
\]

D2の分類では環境要因として海からの距離が53.5km以内で成立する確率が0.5を越える海岸砂丘植物のGr.1は識別種がコウポウムギであり環境要因とよく対応している。残りのグループは常緑広葉樹である。分布域は次式で予測される。

\[
\text{Gr.2からGr.6の確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

\[
\text{Gr.9である確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

D3の分類では環境要因として標高と安山岩質岩石が抽出された。安山岩質岩石を含まず、標高が136m以上に成立する確率が0.5を越えるブナクラス域の常緑広葉樹Gr.9と、一方で安山岩質岩石を含み、標高が136m以下に成立するブナクラス域の常緑広葉樹Gr.9、7、8であると考えられる。Gr.7からGr.8にヤマウトン、ススキ、Gr.9にニホンラテと識別種と対応の良いの。分布域は次式で予測される。

\[
\text{Gr.9である確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

\[
\text{Gr.7からGr.8の確率} = 1 - (Gr.9からGr.6の確率)
\]

D4の分類では環境要因として標高と安山岩質岩石が抽出された。安山岩質岩石を含まず、標高が136m以上に成立する確率が0.5を越えるブナクラス域の常緑広葉樹Gr.9と、一方で安山岩質岩石を含み、標高が136m以上に成立するブナクラス域の常緑広葉樹Gr.9であると対応する。一方Gr.9からGr.6は常緑広葉樹と考えられる。分布域は次式で予測される。

\[
\text{Gr.9である確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

\[
\text{Gr.7からGr.6の確率} = 1 - (Gr.9からGr.6の確率)
\]

D5の分類では環境要因として標高と安山岩質岩石が抽出された。安山岩質岩石を含まず、標高が983m以上に成立するブナクラス域の常緑広葉樹Gr.9であると対応する。一方Gr.9からGr.8の確率が0.5を越える。一方では安山岩質岩石を含み、標高が983m以上にイヌナブが識別種と常緑広葉樹Gr.7が対応する。分布域は次式で予測される。

\[
\text{Gr.8である確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

\[
\text{Gr.7である確率} = 1 - (Gr.8である確率)
\]

D6の分類では環境要因として標高と安山岩質岩石が抽出された。安山岩質岩石を含まず、標高が983m以上に成立するブナクラス域の常緑広葉樹Gr.9であると対応する。一方Gr.8からGr.6の確率が0.5を越える。一方では安山岩質岩石を含み、標高が983m以上にイヌナブが識別種と常緑広葉樹Gr.7が対応する。分布域は次式で予測される。

\[
\text{Gr.8である確率} = 1 / (1 + 1 / e^{0.38 (W.I-H.イノデ) - 1.17})
\]

\[
\text{Gr.7である確率} = 1 - (Gr.8である確率)
\]
である確率
\[ = \frac{1}{\left(1 + \frac{e}{1.0165(0.3509 - 0.0155) + 1.656} + 1.656\right)} \]

Gr. 4、Gr. 5 の確率
\[ = 1 - \text{Gr. 6 である確率} \]

D8 の割合を \( \theta \) と \( \phi \) の節点と仮定すると、Gr. 3 である確率
\[ = \frac{1}{\left(1 + \frac{e}{1.0165(0.3509 - 0.0155) + 1.656} + 1.656\right)} \]

Gr. 3 による適性
\[ = 1 - \text{Gr. 6 である確率} \]

D8 の割合を \( \theta \) と \( \phi \) の節点と仮定すると、Gr. 3 である確率
\[ = \frac{1}{\left(1 + \frac{e}{1.0165(0.3509 - 0.0155) + 1.656} + 1.656\right)} \]

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Gr. 3 による適性
\[ = 1 - \text{Gr. 6 である確率} \]

Gr. 3 の確率
\[ = \frac{1}{\left(1 + \frac{e}{1.0165(0.3509 - 0.0155) + 1.656} + 1.656\right)} \]

Gr. 3 の確率
\[ = 1 - \text{Gr. 6 である確率} \]

以上の割合を示した環境要因の解説を図-5, 6 に示す。

(3) 自然植生の潜在分布の推定
上記の判別式を用いて国立地理院発行地形図 1/25000 の大山（ブナ地区が大半を占める）の図解を座標、伊勢原、藤沢、平塚、江ノ島（いずれもブナ地区が大半を占める）の図解を用いて自然植生の推定を行い、モデルを用いてシミュレーション図（図-7）と従来の方法による潜在自然植生図（図-8）との比較を行った。
従来の手法による潜在自然植生図と、今回提案した方法による図の比較。表中の数字は(km)を示す。

(1) プナクラス域の結果は、オオモジガサーブナ群落、ヤマボウシープナ群落、タマアジサイフササクラ群落ではよい対応を示すが、シミュレーション図ではシキメモモ群落の分布域が従来の図とは違っている。従来の図ではシキシサーラジオガシ群落がヤマボウシープナ群落に隣接している。この原因はシキメモモ群落は丹沢山系の尾根部や、急斜面に成立している。本研究ではこれらの地形的要因をDEMに捉えきれずにモデルを構築したのが原因であろう。丹沢などの急斜面地形を把握するのは10メッシュのデータを構築する必要があると考えられる。

(2) ヤブツバキクラス域の結果を表-5を示す。ハンノキ群落の対応が弱く他の植生にぼらついている。同じようにシラカン群落も他の植生へのぼらつぎが存在し、ときにハンノキ群落へぼらつぎが生じている。
5. 結論と今後の課題

野外での変異調査データのデータベースを基礎に多変量解析（TWINSPAN）による自然植被の分類を行い、統計学的手法（ロジスティック回帰分析）を用いて変異植被の潜在分布を推定した結果は良好であった。ロジスティック回帰分析では正答率も高く（平均91%）、現存する変異植被とよく対応している。従来の手法で作られた潜在変異植生図の対応もよい。そして各群集の潜在的な分布域を推定するモデルが得られたため、容易に各群集の潜在的分布域を把握することが可能となり、自然保護や保全、または自然回復などの基礎的な情報になると考える。

今後の課題として、ハノキ群落およびカサカタカワリピースタングイ群落においては現存するサンプルが少ないためロジスティック回帰の路段を正確な推定が出来なかった。このような現存する群落が少ない場合の推定精度を確保する必要がある。全国の変異データを解析し、より多くのデータを用いることで精度向上することが可能となると考えられる。

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Summary：This study's aim is the prediction of potential natural vegetation (PNV). We built data base of the natural vegetation with remains from 862 stand descriptions that was investigated whole area of Kanagawa from 1971 to 2000, and We created environmental data of climate(warm index, cold index, mean temperature, min-temperature, mean precipitation), topography(elevation, slope, aspect of slope, unevenness index, distance from sea), soil, geology, by using GIS. All natural vegetation data was classified 14 types by using TWINSPAN and the mated of Phytosociology. The environment value of the field's sampling points was extracted by using GIS, environment factor of each vegetation types was grasped quantitatively by using logistic regression analysis. PNV of Investigation area were estimated by the warm index, cold index, mean precipitation, elevation, slope, aspect of slope, unevenness index, distance from sea, 2 soil types and 4 geology types. The proportion of right answers of the made model shows 98%. The result of the simulation of PNV by using the model correspond to potential natural vegetation maps based on phytosociology. The environment which each natural vegetation existed in became obvious by this research. The mapping of PNV by the objective method became possible.
Potential natural vegetation: reburying or reboring?

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Keywords
Conifer stands; Invasive plants; Natural vegetation; Nature conservation; Restoration targets; Succession

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Abstract
This paper deals with the recent debate on the potential natural vegetation (PNV) concept. After reviewing its limitations with respect to understanding of the processes involved in secondary succession, spatial and temporal scaling and data processing, we still consider it a useful tool for summarizing knowledge about a territory in a way that can guide good practice in nature conservation, and for hypothesis generation. Mapping PNV has a descriptive aim and offers the possibility of depicting not only a ‘natural’ scenario according to the extant vegetation types and current environmental factors, but also an ecological description of the territory. It is not a commitment to build any ideal stage of nature but it can contribute to better management by providing targets for restoration and improving naturalness, ecosystem conservation and biodiversity preservation. Constant development of the concept, through discussion, improvement of methods and incorporation of new knowledge, is necessary, but we are reluctant to accept the idea of abandoning it because a part of what has been achieved to date in nature conservancy management using PNV could be lost, as arguments supporting naturalness would be weakened.

Introduction
This article is concerned with the recent debate about the validity and usefulness of the potential natural vegetation (PNV) concept, which, after starting as a street brawl, has evolved to a true scientific level (Chiarucci et al. 2010). The opinions and ideas put forward here will not repeat those presented by Loidi et al. (2010), Farris et al. (2010) and Mucina (2010), rather we will attempt to complement these publications and will address the main questions raised in the critique of the validity and usefulness of PNV. We are aware that this debate involves two levels that are all too frequently confused: one concerns the specific procedures adopted by practitioners of PNV mapping, and the other relates to the unpredictability of ecological succession and hence the validity of any prediction about its trajectories and outcomes. To use arguments from the second level against the first level and at the same time defend other procedures for identifying something like potential vegetation seems to lack scientific rigour. Therefore, we will set out to introduce new perspectives, with the aim not only of crediting or discrediting the approach but also of clarifying conflicts derived from the dogmatism under which it has been applied and interpreted, to evaluate its strengths and weaknesses and to compare it with alternative approaches. We strongly desire to enlighten the issue sine ira et studio instead of obscuring it, in order that the scientific community as a whole and nature conservancy services in particular can benefit from the values of this concept and the documents it produces.

General issues: on the validity of the construction
In the cases in which PNV has been applied and used in areas where Braun-Blanquetian phytosociology has a certain tradition, criticisms appear to be targeted more against the Braun-Blanquet approach than the PNV itself. The debate about the validity of European phytosociology is very old and we have no intention of entering into it here, its current status being established by the papers published in volume 42 of Folia Geobotanica (2007) and some others (Ewald 2003; Willner 2006). Returning to PNV, we agree with the concerns expressed by Härdtle (1995) and Zerbe (1998) about the difficulties of constructing PNV from remnants of supposedly natural or near-natural vegetation and extending their potential area to places where natural conditions are similar; it is also true that PNV has been built by means of chronosequences (space-for-time
substitutions), which has the methodological flaws indicated by Chiarucci et al. (2010). Mapping PNV certainly cannot pretend to survey the processes and mechanisms of succession (Pickett 1989; Glenn-Lewin & van der Maarel 1992): its scale is coarser and its aim is descriptive; it provides a framework for the ecological description of a territory.

The idea that PNV is an exclusive product of Braun-Blanquetian phytosociology is false. Nevertheless, it is true that the description of floristically defined vegetation types, as in phytosociology, and the acceptance of succession as a phenomenon that involves different phases, leads to each community type being labelled with its position in the successional trend, and in former times it was assumed that such a trend was linear and deterministic. The result is that one of the recognized vegetation types is considered as the most ‘natural’ to be found in the area and attributed with being the living representation of the PNV. The more accurate the phytosociological surveys, the more precisely PNV units can be defined. So, naturally, in the phytosociological school PNV has been largely accepted and its cartography carried out.

An important point to consider is whether it is really feasible to identify a PNV. Research on succession has shown that processes in this field are much less deterministic than was previously thought, as stated in Chiarucci et al. (2010), but there are some examples that indicate that the idea of the existence of a mature and fairly stable vegetation in balance with environmental conditions (climate and soil) is not so far from reality. There are numerous examples of sacred sites in many areas of the world, particularly in Africa (Morocco, Burkina Faso, Togo, Tanzania, Ghana and Ethiopia) and Asia (India, Indonesia, China and Japan) around which human alterations have been severely restricted or are simply not allowed (Deil et al. 2009 and references therein). Outstanding, well studied examples are the North African Muslim shrines (marabouts) whose sacred groves (besides epitaphs) show excellent examples of natural or near-natural vegetation (Taı́qui et al. 2005). Similarly, forests surrounding the Japanese Shinto shrines (Chinju-no-mori) have been taken as the main reference for establishing the PNV in that archipelago (Miyawaki 1979; Itow 1991). Another factor to consider is the growing interest in old-growth forests among conservation biologists, not only in North America (Spies 2004) but also in Europe (Nilsson et al. 2002; Burrusciano et al. 2009). Such interest is based on the assumption that they represent the maximal naturalness in a given area. The idea of a sort of chaos reigning in succession everywhere implies perpetual uncertainty. Factors such as disturbances (human-induced or natural), biological invasions, changes in environmental conditions, etc., can co-exist perfectly with the idea of PNV.

Critical issues on methods
Scale and resolution

Chiarucci et al. (2010) point to (at least) three main methodological problems in dealing with definition of PNV. The first, derived from the subjectivity of phytosociological sampling, is at most relative, because PNV identification can also be based on other sampling approaches or descriptions of vegetation units (Farris et al. 2010 and references therein). Spatial scale issues are interesting because they involve intrinsic assumptions of the PNV concept. Characterization of PNV types from their extant remnants is ineluctably fine-grained, and hence lacks large-scale properties. But it has been stated that PNV mapping is feasible at small scales (large extent) but faces increasing uncertainty at more detailed scales (Chytry 1998; Zerbe 1998). This apparent contradiction stems from the process by which pieces of land are ascribed to a given PNV type among several competing or possible types. Ascription problems are expected to be minimal in the core area of a PNV type, but increase towards its boundaries with other types, as the information from indicators (remnants, discriminating species and communities, environmental factors) becomes more imprecise or scarce. Therefore, the ascription process implicitly excludes any large-scale property of the hypothesized PNV and must be interpreted in other terms. Passing from a map of current vegetation to a PNV map implies a strong smoothing of the vegetation mosaic, justified in theory by the homogenizing effects on environmental conditions attributed to PNV (Tüxen 1956; Zerbe 1998). Again, it is clear that some degree of spatial variation (and hence uncertainty) should be accepted within the territory ascribed to a PNV unit due to environmental variation or divergent successional trajectories induced by local conditions, uneven rhythms, random processes, etc., and that this variation is partially subsumed when mapping is carried out at a small scale (low spatial resolution). Hence, the pixel-by-pixel transfer of a complex landscape to PNV units can in theory be reformulated under a probabilistic (Bayesian) view as the expectation that the PNV unit would represent the dominant or the more probable outcome of successional trajectories in the territory ascribed to it. This view introduces corresponding measures of uncertainty and heterogeneity to PNV maps, which have too often been viewed as a prediction of continuous, monotone and even single-species forests covering immense landscapes. In practice, detailed PNV maps include information about such heterogeneity (permanent communities, metastable seral stages, invaders, stands that are difficult to replace, such as tree plantations) in the supplementary descriptions of the PNV units.
PNV mapping includes among its objectives a characterization of PNV units based on their remnants that must at least provide their differentiating elements with respect to neighbouring PNV types. Despite the aforementioned methodological constraints, extant remnants are the reference because they must provide the sources of propagules for the dominant and engineer species of the PNV unit, as well as for the other species associated with them. A parallel, loosely defined concept is that of the ‘reference’ or ‘target’ ecosystem used in restoration ecology (SER 2004; Clewell & Aronson 2007). The description of a reference ecosystem should include at least those structural, compositional and functional characteristics that allow a restoration project to be monitored to assess its degree of success (of course, a reference ecosystem does not need to belong to any PNV type). On the other hand, PNV mapping is conceived to provide complete territorial coverage, based on the analysis of spatial links between remnants, indicators and environmental conditions, besides additional rules to ensure the geographical coherence of results. The degree of consistency of such links, which is expected to be weaker in highly transformed landscapes, should provide additional uncertainty in the ascription of territories to PNV units.

Characterization of units and spatial resolution and coverage may be used to compare the performance with that of other approaches. The interpretation of natural vegetation based on paleobotanical records is obviously limited by sampling scarcity and the uneven compositional and spatial distribution of pollen records; macro-remains can give finer spatial resolution (e.g. Rubiales et al. 2007) but they are usually even scarcer. Interestingly, and for the same reasons, in restoration ecology it is advised that caution be exercised in the use of target ecosystems based on paleobotanical references (Millar & Brubaker 2006; Clewell & Aronson 2007).

Distribution modelling can potentially offer key contributions to explaining the relationships between environmental factors and PNV units (Tichý 1999; Zimmermann & Kienast 1999). Nevertheless, this type of modelling technique, after a burst of development, currently offers a huge variety of approaches (including differing model assumptions and initial parameters), and models often project considerably different distributions (Elith et al. 2006; Araújo & New 2007). Techniques for community modelling are less well developed (Ferrier & Guisan 2006; Baselga & Araújo 2010), although progress is expected in the short term and this kind of approach would have closer links with PNV interpretation. Species distribution modelling has been mainly applied at coarser scales than those used in PNV mapping, but finer analyses are also possible with data of higher resolution. In any case, distributional input data for modelling are essentially the same as those used for PNV mapping and hence they are subject to similar biases, in particular those derived from human modification of species distributions and assumptions about their degree of environmental adjustment.

Anatomy of a moment

The ‘instantaneous’ (schlagartig, Tüxen 1956) solution proposed for the determination of PNV is the most controversial and misinterpreted aspect of the approach. For some researchers (e.g. Andric & Willis 2003) PNV should refer to the vegetation existing before human transformation of the landscape (up to several millennia ago in Europe or several centuries in North America), while others demand a time reference in the future (at least 50–150 yr according to Stumpel & Kalkhoven 1978). As noted before, each of these approaches adds different kinds of uncertainty that are difficult to resolve based on current knowledge. Tüxen’s PNV concept simply eludes these uncertainties, focusing the interpretation on the real distribution of vegetation by assuming that remnants must act as sources for the coming successional trajectories and the links among remnants–seral vegetation–geophysical constraints must be based on their current distributions. The newly recognized uncertainties (identification and characterization of PNV units, heterogeneity within PNV, role of disturbances, invasions or pests, etc.) could be at least partially reduced by improving our knowledge of successional processes and making PNV schemes more flexible, but the starting point is focused on restricting the range of possible successional outcomes. The frame of co-occurrence relationships among plant communities and environmental factors is the basis of the mapping units, but one of the mature vegetation types is chosen as the reference to guarantee the relative homogeneity of the territory ascribed. Incidentally, we consider that the term ‘projection’ (Solomon et al. 2007) is more correct than ‘prediction’ for the PNV concept, precisely because of the forcing assumptions involved.

Data processing flaws

Surprisingly, the critique of Chiarucci et al. (2010) does not extend to the methods used to infer PNV units, which we consider a main drawback and an aspect that needs revision. Currently, the process of building a PNV map is too often a kind of black box from which only results emerge, in the form of PNV distribution maps and lists of their environmental conditions and indicator species or communities. Given this, the repeatability of procedures is not guaranteed and, in particular, heterogeneity and variation tend to be poorly reflected. Contributions to the literature reporting analysis of, for example, discordances
among remnants and indicators are scarce (Šamonil et al. 2009; Muñoz & Raya 2010). Curiously, an inductive way to establish and characterize PNV units similar to the phytosociological tabulation procedure was proposed at the outset (Tüxen 1973; Rivas-Martínez 1978) but it has rarely been put into practice since then, and hence has not been optimized. The causes of this methodological precariousness are unclear, but typology instability, inefficient application of diagnostic species (for which objective methods have only been proposed in recent times; Dengler et al. 2008) and the limited use of GIS techniques may have contributed.

A consequence of this weakness seems to be an inflation of terms. When many terms are used to indicate the same thing, or nearly the same thing, confusion encroaches on the core issue and risks discrediting it. An excess of nomenclature (Terradas 2001) has certainly occurred in the case of PNV and related concepts over time and has had negative impact on the degree to which they have been generally accepted by ecology researchers. Far from being intentional, this is the result of a long series of reflections and discussions, the more accurately it will be possible to understand of possible indicators, either selected species or communities. GIS thematic layers, now widely available, should be used both to stratify sampling and to properly ascribe territories to PNV units (Capelo et al. 2007). In addition, characterization (including structure and regeneration estimates of the main species) and distribution patterns of remnants should be better documented. The hypothesis framework also ought to be enhanced with current knowledge of past vegetation, trajectory analyses of vegetation changes, distribution modelling and the outcome of mechanistic models of succession.

Old ghosts and future troubles

In pursuit of conifers

Conifers have been historically favoured for economic reasons in many countries, and there are large areas currently covered by conifer plantations and spontaneously grown forests whose degree of naturalness is difficult to state in some places. This issue has implications for PNV interpretation in some regions like the Iberian Peninsula, where it has become an important topic in the debate (Blanco et al. 1997; Gil 2008; Génova et al. 2009). From the evolutionary point of view, conifers are an ancient group emerging in the late Paleozoic and had their optimal development during the Mesozoic era. Thereafter they were widely replaced by angiosperms (Bond 1989; Coomes et al. 2005) in most of the resource-rich habitats, as angiosperm newcomers were more efficient in exploiting soil nutrients (Berendse & Scheffer 2009). The result is that in modern times conifers mainly occupy habitats or regions that are stressed in terms of climatic (low temperatures) or edaphic (shallow rocky, permanently flooded or nutrient-poor soils) conditions in various territories (Urbietta et al. 2011). This is only a general statement because there are many examples of conifers dominating natural forests in mesophytic environments in different parts of the world, particularly in those areas that have experienced fewer extinctions in recent history (Pleistocene), as is the case of some North American redwood forests (Sequoia, Sequoiadendron). Europe is a continent that experienced the stress of several successive ice ages that caused massive extinctions of tree species, particularly in those taxa adapted to mesic conditions. The contrast between European dendroflora with that of North America or East Asia is overwhelming (Tallis 1991). Specifically, Europe hosts fewer gymnosperm trees than its two homologous regions and so it has fewer conifer species to compete with angiosperms in mesic habitats. However, in comparison with the Euro-Siberian region, the Mediterranean region (southern Europe, the Near East and North Africa) is relatively rich in tree species, including conifers, and they certainly have a role in the plant communities of the area. The more carefully we document their population dynamics in the past and the better data we gather about their current dynamics, the more accurately it will be possible to describe their communities, and changes in the consideration of some PNV units have and will be introduced. It is
widely accepted that spatial heterogeneity and disturbance regimes favour the co-existence of pines and oaks in Iberian landscapes (Zavala & Zea 2004), and this indicates the need for a further review of the PNV assumptions in many areas. Some researchers are reluctant to accept certain of the proposed PNV models because they are difficult to tally with the suggestions derived from the results of surveys of paleoremains (Carrió 2000). Certainly, historical records have to be carefully taken into account, as we stated unambiguously (Loidi et al. 2010), because the past conditions affect the present status of ecosystems, but the past cannot condition the future in terms such that the current and coming environmental conditions tailor terrestrial ecosystems independently of what happened in the past. The idea that pines have been disregarded in the current documents describing Iberian PNV types has been supported by palynological surveys, but, in relation to this, there are cases in which pollen diagrams show abundant pine pollen even in areas where pines are scarce in the landscape; pine pollen is sometimes overrepresented in sediments and has to be interpreted with caution (Roc et al. 2002). Pollen rain as a representation of extant vegetation is not always very reliable (Vázquez & Peinado 1993). If we examine Tüxen’s paper (1956), several pages are devoted to explaining the difference between primitive vegetation and current (heutige) PNV due to changes in environmental conditions caused by human influence or by natural processes since the original vegetation was altered or has disappeared. This means that the historical element is essential in the construction of the idea of PNV for two main reasons: first because of the human disturbances and second because paleoremains show us the biological material (species) existing in a particular area in the past. Such species may or may not survive local extinctions that are happening now or in the past. All these factors explain why existence in the past does not necessarily correspond to suitability in the present day. Although management and tree selection have played a role we should be careful not to exaggerate their contribution. In any case, modern global change means abandonment of large areas in many European countries, particularly in mountainous regions. This has triggered secondary succession in a substantial part of the territory, which has revealed that in a relatively short period of 40–50 yr (after the rural population fled), vegetation develops towards maturity at a faster pace than expected. Perhaps we will not need to wait too long to see good examples of ecosystems changing towards maturity in order to glimpse the final or mature stages of secondary succession in vegetation, and the real impact of natural or human-induced disturbance. The experiment, provided unintentionally by socio-economic changes and inscribed in what we could call ‘abandonment ecology’, is in motion.

Biological invasions

These have taken place in Europe since at least Neolithic times (Kornaš 1990), and a large number of plant species that migrated and established under human influence have, since then, come to be seen as native in their new territories after a certain amount of time has passed. They stabilize demographically and ecologically, becoming part of the native plant communities, i.e. they reach a sort of balance in the competitive dynamics with other native or alien plants involved in the same community. Eventually, they are effectively incorporated into the ecosystems and hence they have been duly incorporated in the current descriptions of flora and vegetation. The newcomers are those which have not yet reached such a degree of stabilization or steady state; many of them become extinct (ephemeral) while others are in an expansive phase (invasives). In any case, most of the alien flora of a territory is found in disturbed habitats (Kornaš 1990; Chytrý et al. 2005, 2008; Lambdon et al. 2008; Campos 2010; Pyšek et al. 2010) and they likely will withdraw as succession develops to more mature stages. Nevertheless, all new plants, in the past and nowadays, that come to seem native in any territory will participate in the development of its plant communities with all the associated consequences, such that they become part of various vegetation types (Hobbs et al. 2006; Vítková & Kolbek 2010).

Management and conservation of natural resources and PNV

The uses of PNV and related concepts have been demonstrated over many years, during which their cartography has been used in many countries for applied vegetation science. Basically, PNV provides guidelines for good practices for nature conservation in the frame of land-use planning (Pedrotti 2004; Miyawaki & Box 2006), taking into account that optimally it should be combined with real vegetation maps (Zerbe 1998); planning of infrastructure, land evaluation for agriculture, livestock and forestry, environmental impact assessment, ecological restoration and landscape architecture; together with reserve selection, design and management. It is not a commitment to restore, favour or build the PNV as the only possibility for conservation; rather it provides a framework of information on the territory (pool of communities, environmental factors) that can be applied for sustainable management. PNV is also a keystone of landscape analysis and fine delimitation of biogeographical units (Alcaraz 1996; Schwabe 1997).

One of the most typical and common products of PNV is maps, of which numerous have been produced, in a wide range of countries and at different scales. The map of
natural vegetation of Europe at the scale of 1:2 500 000 (Bohn et al. 2003) is an example of how maps based on natural vegetation have been produced in territories in which Braun-Blanquetian phytosociology had not been established, including the former USSR, Fennoscandia and the British Isles, among other countries (i.e. most of the mapped territory). Handbooks on vegetation mapping recognize and explain the natural vegetation concept and the mapping of its potential territory (Küchler & Zonneveld 1988; Pedrotti 2004). Such maps provide the spatial pattern of all the environmental features that can be used as indicators for vegetation (bedrock, climatic conditions, biogeographical scenarios) from which all the aforementioned useful information is derived, making PNV documents much more meaningful than a static description of existing units (Terradas 2001).

A collateral point of criticism in the debate concerns the EC Habitats Directive. This document establishes a guide for focusing conservation efforts on a couple of ‘habitat types’ (certainly the term is used here with a different meaning to that defined in ecology) that are loosely related to phytosociological units. Phytosociological typology relies on over 4.36 million relevés in Europe alone (Schaminée et al. 2009), is widespread and based on similar sampling protocols, and provides a practical tool for vegetation classification, evaluation and conservation (Géhu 2006b). Its value and potential applications have been recognized even by authors critical of phytosociological sampling procedures (Lepš & Šmilauer 2007; Lájer 2007; see also Jennings et al. 2009). A large proportion of the units designated as European conservation targets in Annex I of the Directive correspond to seral stages (scrub, heathlands, grasslands, open grazed forests such as dehesas or montados, etc.), whose conservation unavoidably requires maintenance of the corresponding disturbance regimes or management practices: fire, grazing, pruning, etc. In our opinion, it is wrong to accuse the Directive of having a bias to conservation of pristine or natural vegetation units. On the contrary, it is particularly sensitive to historically altered (cultural) ecosystems.

PNV mapping requires a high level of mastery of the flora and vegetation of the surveyed area, and such experience is essential in the definition and delimitation of each PNV unit; decisions often made in the field in sight of the reality of the extant vegetation. This knowledge is to a great extent integrated in the legends of PNV units, with the result that such documents constitute a valuable advisory guide for land-use planners and conservation policy-makers. Management involves day-to-day decision-making, and usually managers cannot wait for long and complicated research to yield solutions or for advice on what to do or not to do in a particular area.

Clarifying the concept: some last words, but not yet epitaphs

We have tried to explain that an operational definition of PNV must take into account two conceptual aspects. First, the repertoire of PNV types that can be recognized in a geographical space must be established according to the analysis of remnants of mature or near mature vegetation, as well as to knowledge on vegetation dynamics and history of vegetation and land uses. These PNV types correspond to the most natural and successively mature vegetation remnants. They do not represent the vegetation prior to the historical anthropogenic disturbance (primitive vegetation) or the unknown vegetation at the end of a sufficiently long and undisturbed succession. Such a succession is subsumed to an unavoidable uncertainty of spatial-temporal events and processes. PNV simply represents the more natural vegetation reflecting the current environmental conditions of a given territory. Second, the ascription of a location to one of the PNV types is evaluated through geographical, environmental (geophysical) and biotic (indicator species and communities) evidence of its closeness to the respective conditions associated with the accepted PNV types.

Most of the criticism against the PNV approach is addressed to the first aspect. We have stressed that characterization of PNV units is based on remnants. The minimum characterization required should consist in the differential elements with respect to other PNV units (structure, dominant species and differential species). There are many examples of PNV maps in which the characterization of PNV units is very general or merely physiognomic. PNV maps based on phytosociological units can furnish more detailed descriptions, and remnant samples can be compared among them according to criteria such as age structure, stand continuity, core area, indicators of land-use pressures, etc., in order to establish which of their structural or compositional traits are closer to the hypothesized maturity. But a detailed and reliable prediction about how the true mature state would appear is outside the capabilities of the PNV concept, particularly in territories heavily managed for centuries, where remnants may be a pale and biased image of the future mature vegetation. Even if the pool of vascular plant species proper of such remnants could be approached through a detailed analysis, the structural and compositional details of other species pools relevant for forest functioning (forest lichens, fungi, birds, mammals, insects …) would remain largely unknown. We argue that despite the relatively loose characterization of PNV units, the approach is still valid as an integrated analysis of the actual vegetation patterns. In fact, the validation procedures of the hypothesized PNV frame rely on this second aspect of the analysis.
In spite of all the difficulties and flaws, the PNV concept is a useful one in that it depicts not only a ‘natural’ scenario according to the extant vegetation types and current environmental factors, but also an ecological description of the territory in terms of extant plant communities. The challenge is to improve the maps through discussion and supported by new knowledge, not abandon the concept. It is easier to demolish than to build. If, however, we abandon what has been achieved to date using PNV, ceasing to work in that line of research and thereby provide government bodies with valuable documents for conservation management of the territory, we believe it would be a great victory for forces that are not particularly interested in nature and biodiversity conservation. Any changes can potentially be admitted if they are supported by evidence in the field and research findings; paleoremains, quantitative ecology, population ecology, alien plants, etc. will all influence the ever-shifting PNV constructions. It is an ethical duty to provide society with an accessible guide to what the science yields to serve as a source of advice for managers and decision-makers. Currently, PNV provides this.

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References


Rehabilitation of Tropical Rainforests Based on Potential Natural Vegetation Species for Degraded Areas in Sarawak, Malaysia

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ABSTRACT. A rehabilitation study of tropical rainforests in Sarawak was conducted in two phases, namely a phytosociological study and stand-establishment studies, the phases run consecutively. Two vegetation communities were recognized: a *Cyrtoctachys lakka* - *Whiteodendron mouliamum* community and a *Hopea kerangasensis* - *Allantospermum borneense* community. All the species for the planting trial were collected from the *Hopea kerangasensis* - *Allantospermum borneense* community, which has been recognized as the PNV at Bintulu (based on the phytosociological studies). The planted seedlings produced different vertical stratification in different stands. Faster growth was shown by light-demanding species, and their behavior supported their selection for trial planting. *Dryobalanops aromatica* recorded the largest growth increment at all trial planting sites, followed by *Pentaspodon motleyi*, *Shorea ovata*, and *S. leprosula*.

Key Words: Malaysia / rehabilitation / tropical rain forest / potential natural vegetation

Rehabilitation of rainforest is often undertaken for two primary reasons: to restore ecological stability for amenity and biological improvement of degraded sites or to restore productivity to degraded sites in order to gain economic returns via agriculture or forestry (Lamb & Olsen, 1992). Rehabilitation of forest would involve the re-establishment of a more intact canopy that is found in undisturbed forests. It is also important to define the objective of rehabilitation in order for the efforts to be evaluated subsequently. This can be the restoration of the degraded forest to its original pristine stage with the use of indigenous tree species. Even though the potential for using indigenous tree species for forest plantation in Malaysia has been known since 1921 (Appanah & Weinland, 1993), the species were never planted on a large scale. They were planted only as experimental research or reforestation projects. Species such as *Shorea macrophylla*, *S. pinanga*, *S. splendidica*, *S. palembanica* and *S. streoptera* were planted in Sarawak mainly due to their fast growth and illipe nuts (Joseph, 1992). Many rehabilitation efforts (by different techniques) have been carried out in Malaysia with varying degrees of success. One of the techniques that has proven to be successful in the warm-temperate zone is the dense planting technique, which has been described in detail by Miyawaki (1993), Miyawaki & Golley (1993), and Miyawaki, Fujiwara & Ozawa (1993). This technique was tried out, along with three other rehabilitation techniques, in Bintulu, Sarawak, to rehabilitate the degraded shifting-cultivation area using indigenous tree species. This paper will highlight results of these trials that were conducted over a period of five years.
MATERIALS AND METHODS

Description of the study area
The experimental research was conducted on a 47.5 hectares area in the campus of Universiti Putra Malaysia (UPM), Bintulu branch, Sarawak. It is located about 600 kilometers northeast of Kuching, at the latitude 3° 12' N, longitude 113° 05' E and altitude 50 meters above sea level (Figure 1). The site receives an annual rainfall of 2900 to 4430 mm and annual temperature of 26.7°C. The soil at the study site belongs to Nyalau and Bekenu series. The Nyalau series is characterized by coarse loam, light yellowish brown topsoil, while the Bekenu series is characterized by fine mixed loam, light yellowish brown topsoil. Both soils are well drained (Peli, et al., 1984).

Experimental Design
This rehabilitation study was conducted in two phases, namely phytosociological and stand-establishment studies with the phases run consecutively.

Phytosociological study in Bintulu, Sarawak.
Phytosociological studies in natural forests in the Bintulu and Kuching areas were carried out from February 28 to March 2, 1993 based on the phytosociological method described by Braun-Blanquet, (1951 & 1964), Ellenberg (1956) and Fujiwara (1987). These natural forests were surveyed for comparison of species composition in the rehabilitation project of degraded tropical forest areas (Fig. 1). These study are characterized by:
Rehabilitation of tropical rainforests for degraded areas in Sarawak, Malaysia

1. Selection of homogenous sites without gaps
2. Creation of a survey boundary around areas with homogenous species composition
3. Recording of every species in each layer; usually five vegetation layers are involved; super tree (ST), dominant tree layer (T1), tree understorey / co-dominant layer (T2), shrub layer (S) and herb layer (H).
4. Estimation of values for coverage and sociability
5. Tablework-based classification of communities
6. Comparison of species composition in the communities with the species planted for rehabilitation

Stand Establishment
The forest rehabilitation stand was established by the following steps:

a) Selection of species from the potential natural vegetation is of paramount importance. Due to the limited time available, the selection of species to be planted was done according to the availability of the seeds and seedlings surrounding in the Bintulu area.

b) Once the seedlings germinated and wildings were collected, the next important step was the development of seedlings with strong root and shoot systems in the nursery.

c) Preparation of the experimental plots in the field is another task towards achieving forest rehabilitation. Open abandoned and degraded shifting-cultivation areas, a man-made mound, Macaranga secondary forests and shrub areas were chosen for experimental plots, with different types of planting techniques. There is no relationship between planted species and planting sites in term of species selection for different methods of planting. For open, abandoned shifting-cultivation areas and the man-made mound, dense planting of three mixed seedlings per meter square was adopted, for plot size of 20m × 20m and 50m × 5m. For open areas, 512 seedlings were planted using 14 species and 656 seedlings with 16 species on the man-made mound. Meanwhile, for the experimental plot under Macaranga secondary forest, the seedlings were planted at a distance of 3 meters apart. The size of the plot was 36 m × 36 m, with 105 planted seedlings from four species. A line-planting technique, at a distance of 1 meter

<table>
<thead>
<tr>
<th>Species</th>
<th>Open area</th>
<th>Mound</th>
<th>Macaranga forest</th>
<th>Line planting</th>
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<tbody>
<tr>
<td>1 Cotylelobium burckii</td>
<td>17</td>
<td>107</td>
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<td>2 Dryobalanops aromatica</td>
<td>39</td>
<td>94</td>
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<td>3 Durio carinatus</td>
<td>56</td>
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<td>4 Eugenia sp.</td>
<td>52</td>
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<td>5 Eusideroxylon zwagerii</td>
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<td>6 Hopea beccariana</td>
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<td>51</td>
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<td>7 Hopea kerangasensis</td>
<td>34</td>
<td>60</td>
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<td>8 Parashorea parvifolia</td>
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<td>9 Pentaspodum motleyi</td>
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<td>10 Shorea gibbosa</td>
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<td>11 Shorea leprosula</td>
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<td>12 Shorea macrophylla</td>
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<td>14 Shorea majoris</td>
<td>32</td>
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<td>15 Shorea ovata</td>
<td>29</td>
<td>20</td>
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<tr>
<td>16 Vatica sp.</td>
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<tr>
<td>17 Whiteodendron moultanianum</td>
<td>16</td>
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between seedlings, was adopted in shrub areas. For this technique, 217 seedlings were used, from nine species. A list of the species planted is shown in Table 1. Mulching material (Imperata cylindrica and Ischaemum nagnum) was placed on the surface of the plot to reduce soil erosion, encourage retention of soil moisture and discourage incoming weeds.

d) Measurements of basal diameter and total height growth for all seedlings in the plot were taken from time to time.

RESULTS

Vegetation communities in tropical rainforests in Bintulu
From the phytosociological studies, two communities of vegetation have been recognized: a Cyrtostachys lakka - Whiteodendron moultianum community and a Hopea kerangasensis - Allantospermum borneense community.

Cyrtostachys lakka - Whiteodendron moultianum community (coastal heath forest)
The forest stratification of the Cyrtostachys lakka - Whiteodendron moultianum community (coastal heath forest) consists of four or five vertical layers: emergent tree (ST), canopy tree (T1), lower tree (T2), shrub (S) and herb (H). This forest occurs at low altitude ranging from 10 to 30 meters, on flat areas. Coastal heath forest occurs on soils developed from siliceous sand and coastal alluvium. This kind of soil is also known as podzolized soil, which is poorly buffered and highly acidic. The small stream located near the study plots was black or tea-colored. The small amount of clay in the soil washes down the profile to leave almost pure silica sand. Without vegetation cover or a surface humus layer, the white sand gets extremely hot in the sun. Emergent trees can reach 50 m in height (Table 2). This forest is a completely closed forest, in which the canopy crown cover is between 60 and 80%. The species-richness polygon for this community is shown in Fig. 2. The shrub layer had the largest number of species (47 to 71 species). This community had 37 families and 70 genera, comprising 70 to 95 species found in relevés of 750 m² and 1200 m². Coastal heath forest is differentiated from other communities by Whiteodendron moultianum, Cyrtostachys lakka, Eugenia attenuata, Shorea albida, Gnetum sp. and Euthemis minor.

The coastal heath forest has two subunits. The first subunit is differentiated by Cotylelobium burckii, Horsefieldia kerangasicola, Myristica malaccensis, Swintonia glauca etc. This subunit has the lowest species density (70 species) in coastal heath forest and occurs farther from the seashore. The soil was richer in humus than in the second subunit, and the litter layer was 0 to 2 cm. The second
### Table 2. Plant communities in tropical rain forests in Kuching and Bintulu divisions.

1-2: *Cyrtostachys lalcka - Whiteodendron moultainum* community.
3-7: *Hopea kerangasensis - Allantospermum borneense* community.

<table>
<thead>
<tr>
<th>Relevé reference number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original relevé number (in field)</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Relevé date</td>
<td>28/2/93</td>
<td>28/2/93</td>
<td>23/2/93</td>
<td>24/2/93</td>
<td>27/2/93</td>
<td>1/3/93</td>
<td>2/3/93</td>
</tr>
<tr>
<td>Relevé size (sq. m)</td>
<td>1200</td>
<td>750</td>
<td>750</td>
<td>400</td>
<td>2250</td>
<td>900</td>
<td>2000</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>287</td>
<td>50</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Slope</td>
<td>L</td>
<td>NW</td>
<td>L</td>
<td>L</td>
<td>W</td>
<td>NW</td>
<td>NW</td>
</tr>
<tr>
<td>Height of super tree layer ST (m)</td>
<td>50</td>
<td>.</td>
<td>.</td>
<td>60</td>
<td>55</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Cover of super tree layer ST (%)</td>
<td>60</td>
<td>.</td>
<td>.</td>
<td>30</td>
<td>25</td>
<td>.</td>
<td>.</td>
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<tr>
<td>Height of tree layer T1 (m)</td>
<td>24</td>
<td>40</td>
<td>33</td>
<td>32</td>
<td>30</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>Cover of tree layer T1 (%)</td>
<td>60</td>
<td>80</td>
<td>70</td>
<td>80</td>
<td>30</td>
<td>65</td>
<td>85</td>
</tr>
<tr>
<td>Height of tree layer T2 (m)</td>
<td>12</td>
<td>20</td>
<td>28</td>
<td>12</td>
<td>18</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Cover of tree layer T2 (%)</td>
<td>50</td>
<td>40</td>
<td>80</td>
<td>30</td>
<td>80</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Height of shrub layer S (m)</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Cover of shrub layer S (%)</td>
<td>50</td>
<td>70</td>
<td>60</td>
<td>70</td>
<td>40</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Height of herb layer H (m)</td>
<td>1.2</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Cover of herb layer H (%)</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>15</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Number of species</td>
<td>70</td>
<td>95</td>
<td>126</td>
<td>145</td>
<td>129</td>
<td>148</td>
<td>143</td>
</tr>
</tbody>
</table>

#### Differential species of community

| Whiteodendron moultainum | T1.T2.S.H | 3.3 | 2.2 | . | . | . | . |
| Cyrtostachys lalcka | T2.S.H | 2.2 | 2.2 | . | . | . | . |
| Eugenia attenuata | T2.S | 3.3 | + | . | . | . | . |
| Shorea albida | ST.T1 | 2.2 | + | . | . | . | . |
| Gnetum sp. 1 | T2.S | 1.1 | + | . | . | . | . |
| Euthemis minor | S | + | + | . | . | . | . |

#### Differential species of sub-units

| Cotelocalyx birckii | ST.T1.T2 | 3.3 | . | . | . | . | . |
| Horsefieldia kerangasicola | T1.S | 2.2 | . | . | . | . | . |
| Myristica malaccensis | S | 2.2 | . | . | . | . | . |
| Spondias glauca | ST.S | 2.2 | . | . | . | . | . |
| Tetramerista glabra | STS | 2.2 | . | . | . | . | . |
| Casuarina nobilis | T1.T2.S.H | 4.4 | . | . | . | . | . |
| Casuarina sp. | TI | 2.2 | . | . | . | . | . |
| Cotelocalyx sp. | T2.H | 2.2 | . | . | . | . | . |
| Trystania beccarii | TI | 2.2 | . | . | . | . | . |
| Dacryodes sp. | T1.T2.S | 2.2 | . | . | . | . | . |
| Ternstroemia arcuria | S | 2.2 | . | . | . | . | . |
| Palaquium ridleyi | T1.S | 2.2 | . | . | . | . | . |

#### Differential species of sub-units

| Allantospermum borneense | T1.T2.S | 2.2 | 1.2 | 2.2 | 2.2 | 3.3 | 1.1 |
| Hopea kerangasensis | T2.S.H | . | 3.3 | 2.2 | 1.2 | 1.1 | 1.1 |
| Anisoppliaca corneii | T1.T1.S.H | + | 1.1 | + | + | + | + |
| Scaphium marcopodum | T1.S.H | 2.2 | + | + | + | + | + |
| Memecylon sp. 1 | T1.T2.S.H | + | + | + | + | + | + |
| Sterculia sp. | T1.S | 1.1 | + | 1.1 | + | + | + |
| Dryobalanops aromatica | ST.T2.S.H | 3.3 | . | . | . | . | . |
| Shorea macroptera | T1.T2.S | 2.2 | 2.2 | 2.2 | + | + | + |
| Shorea scaberrina | T1.S.H | 1.1 | + | 1.1 | + | + | + |
| Shorea amplcraulis | T2.S | + | 3.3 | 2.2 | + | + | + |
| Euphobiaceae sp. | S | + | + | + | + | + | + |
| Maranthaceae sp. | H | + | + | + | + | + | + |
| Shorea maxswelliana | T1.S.H | + | 2.2 | + | + | + | + |
| Strombosis lucida | T1.T2.S.H | + | + | + | + | + | + |
| Heritiera auroa | S.H | + | + | + | + | + | + |
### Differential species of sub-unit

<table>
<thead>
<tr>
<th>Species</th>
<th>Sub-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Shorea beccariana</em></td>
<td>T1.S</td>
</tr>
<tr>
<td><em>Shorea ovalis</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Balbophyllum sp. epiphyte</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Tristania whiteiana</em></td>
<td>ST.T1</td>
</tr>
<tr>
<td><em>Sindora beccariana</em></td>
<td>T1.T2.S.H</td>
</tr>
<tr>
<td><em>Alangium ebenacum</em></td>
<td>T1.2</td>
</tr>
<tr>
<td><em>Beilschmiedia madang</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Annonaceae sp.</em></td>
<td>T2.H</td>
</tr>
<tr>
<td><em>Xanthophyllum macrophyllum</em></td>
<td>T2</td>
</tr>
</tbody>
</table>

### Differential species of sub-unit

<table>
<thead>
<tr>
<th>Species</th>
<th>Sub-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Santria tomentosa</em></td>
<td>T2.S.H</td>
</tr>
<tr>
<td><em>Vatica borneensis</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Baccaurea sumatrana</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Canarium caudatum</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Crudia sp.</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Dacryodes costata</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Lithocarpus leptogène</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Mesua garcinoides</em></td>
<td>T1.S</td>
</tr>
</tbody>
</table>

### Differential species of sub-groups

<table>
<thead>
<tr>
<th>Species</th>
<th>Sub-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Alseodaphne olivaceolata</em></td>
<td>T1</td>
</tr>
<tr>
<td><em>Endiandra clavigerata</em></td>
<td>T1.S</td>
</tr>
<tr>
<td><em>Anisophylea javanicum</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Diomonoecus sp. 2</em></td>
<td>H</td>
</tr>
<tr>
<td><em>Friesodielsia affinis</em></td>
<td>H</td>
</tr>
<tr>
<td><em>Pinandra coeruleus</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Lasianthus maingayi</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Cleistanthus griffithii</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Ashtonia excellua</em></td>
<td>T1</td>
</tr>
<tr>
<td><em>Hopea flubialis</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Hopea sp.</em></td>
<td>ST.T1.H</td>
</tr>
<tr>
<td><em>Kokoona reflexa</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Demophlocaulis denticulatus</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Vatica sp.</em></td>
<td>T1.T2.S</td>
</tr>
<tr>
<td><em>Pleiocarpia borneensis</em></td>
<td>S</td>
</tr>
</tbody>
</table>

### Differential species of sub-unit

<table>
<thead>
<tr>
<th>Species</th>
<th>Sub-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Palaquium stenophyllum</em></td>
<td>T1.S.H</td>
</tr>
<tr>
<td><em>Shorea pacinifera</em></td>
<td>ST.T1.T2.S.H</td>
</tr>
<tr>
<td><em>Canarium sp.1</em></td>
<td>T2.S.H</td>
</tr>
<tr>
<td><em>Vatica nitens</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Rubiaeaceae sp. 3</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Eugenia sp. 3</em></td>
<td>T1.T2.S</td>
</tr>
<tr>
<td><em>Acromycha sp.</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Urticaceae sp.</em></td>
<td>T2.S.H</td>
</tr>
</tbody>
</table>

### Differential species of sub-groups

<table>
<thead>
<tr>
<th>Species</th>
<th>Sub-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dacryodes incarvata</em></td>
<td>T2.S</td>
</tr>
<tr>
<td><em>Nepheleum mutabila</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Shorea materialis</em></td>
<td>T1.T2.S</td>
</tr>
<tr>
<td><em>Agaia cordata</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Blumeodendron kurzii</em></td>
<td>T1.T2.S.H</td>
</tr>
<tr>
<td><em>Agaia bicolor</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Mesua myrtifolia</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Shorea ferruginea</em></td>
<td>ST</td>
</tr>
<tr>
<td><em>Shorea isoptera</em></td>
<td>S</td>
</tr>
<tr>
<td><em>Acios heteropetala</em></td>
<td>T2</td>
</tr>
<tr>
<td><em>Artocarpus odoratissimus</em></td>
<td>T1</td>
</tr>
<tr>
<td><em>Mastixia euginiodes</em></td>
<td>T1</td>
</tr>
<tr>
<td><em>Knema latifolia</em></td>
<td>T1</td>
</tr>
</tbody>
</table>
Dehassia caesia  T1  .  .  .  .  .  .  .  1.1
Parkia maingayi  T1  .  .  .  .  .  .  .  1.1
Parkia singularis  T1  .  .  .  .  .  .  .  1.1
Dialium platysepalum  T1,T2  .  .  .  .  .  .  .  1.1
Diptocarpus rigidus  T1  .  .  .  .  .  .  .  1.1
Vatica vatangans  T2  .  .  .  .  .  .  .  1.1

Companion species

Eugenia sp. 1  ST,ST,ST,S.  +  .  .  2.2  +  +  +
Garcinia sp. 1  T1,ST,ST,S.  +  +  .  .  1.1  +  +
Diptocarpus sp. 1  T1,ST,ST,S.  1.1  +  .  .  2.2  1.2  +
Calamus sp. 1  T1,ST,S.  3.3  .  .  .  .  2.2  1.1  +
Gluta sp.  T1,ST,S.  +  +  .  .  2.2  1.1  +
Connerus sp. 1  T1,ST,S.  +  .  .  .  2.1  1.2  +
Stemonurus secundiflorus  T1,ST,S.  2.2  +  .  .  .  +  +  +
Ixora sp. 1  T1,ST,S.  +  +  .  .  1.1  +  +
Liquila spinosa  S,ST  2.2  +  +  .  .  +  +  +
Leguminosae sp.  T2,ST,S.  +  .  .  +  +  +  +
Pandanus sp. 1  T1,ST,ST,S.  +  2.2  1.1  1.1  .  2.2  .
Litsea sp. 1  ST,ST,ST,ST,S.  +  .  .  2.1  2.1  +
Alpinia sp. 1  S,ST  +  .  .  +  .  +  +
Tetramea sp. 1  T1,ST,S.  +  .  .  .  .  1.1  +
Eugenia kuchingensis  T1,ST,S.  1.1  2.2  2.1  .  .  1.2  +
Rubiacae sp. 2  S,ST  .  .  +  +  +  +  +
Antidesma sp. 1  S,ST  +  .  .  .  .  +  +  +
Korthalsia sp.  S,ST  +  +  .  .  1.1  +
Dillenia excelsa  T1,ST,S.  +  1.1  +  +  +
Blumeodendron calophyllum  T1,ST  2.2  +  .  .  +
Calophyllum sp. 1  T1,ST,S.  2.3  .  .  .  +  +  +
Calophyllum teamanum  T1,ST,S.  2.2  1.2  .  +
Malotus penangensis  T1,ST  1.1  1.1  .  .  +
Ganua kingiana  S,ST  1.2  .  .  +
Palaquium gutta  T1,ST,ST,S.  2.2  +  .  .  .  .  3.3
Xanthophylcum sp. 1  T1,ST,ST,S.  1.2  +  .  .  +
Peimeodendron griffithi  S,ST  +  .  .  .  .  +  +
Goniocalycium andersonii  S,ST  +  .  .  .  .  +  +
Kemena intermedia  T1,ST,S.  +  .  .  .  .  +  +
Calophyllum natesum  S,ST  +  .  .  .  .  +  +2
Artisca sp.  S,ST  +  .  .  .  .  +  +
Artocarpus sarawakensis  T1,ST  .  .  .  .  .  +  +  1.1
Caesalpinia sp.  T2,ST  +  .  .  .  +  +
Cephalandra sp.  S,ST  .  .  .  .  .  +  +  +
Diospyros mangii  T2,ST  1.1  .  .  +
Menispermaceae sp.  S,ST  .  .  .  .  .  +  +  +
eled


subunit is differentiated by Casuarina nobile, Casuarina sp., Cotylelobium sp., Crystania beccariana, Dacryodes sp. etc. This subunit occurs near the seashore, and the soil is very sandy. The stratification in this subunit involved four vertical layers, with the T1 layer reaching 40 m in height and more open.

Allantospermum borneense - Hopea kerangasensis community (Diptocarpacese forest).
The stratification of Dipterocarpaceae forests consists of four to five vertical layers. The crown cover is more open under disturbance. This community has more species (126 to 148 species) than Cyrtostachys lakka - Whiteodendron moultianum community. Dipterocarpaceae forest is differentiated
from other communities by the occurrence of *Allantospermum borneense*, *Hopea kerangasensis*, *Anisophyllea cornerii*, *Scaphium macropodium*, *Memecylon* sp., *Sterculia* sp., *Dryobalanops aromatica*, *Shorea scaberrima*, *Shorea macroptera*, *Shorea amplexicaulis* etc. This community occurs on slopes between 0 and 20°. The soil was deep and rich in humus. Species planted on the experimental research plot mostly came from this forest community.

The Dipterocarpaceae forest has three subunits. The first subunit is differentiated by *Sindora beccariana*, *Shorea ovalis*, *Balbophyllum* sp., *Tristania whiteana* *Sindora beccariana*, *Alangium ebenacium* etc. This subunit has the lowest species density (126 species) in Dipterocarpaceae forest and occurs on a slope of 25°. The second subunit is differentiated by *Santiria tomentosa*, *Vatica borneensis*, *Baccaurea sumatrana* *Canarium caudatum* etc. This subunit has four to five vertical layers and has a more open canopy. This subunit has two subgroups. The first subgroup is differentiated by *Alseodaphne oblanceolata*, *Endiandra clavigera*, *Anisophyllea javanica* etc. This subgroup occurred on flat areas at an altitude of 287 meters. The soil was mesic, deep and mixed with small gravel. The second subgroup is differentiated by *Hopea flubialis*, *Hopea* sp., *Kokosoa reflexa*, *Demophocalyx denticulatus* etc. The second subgroup occurred at lower altitude (50 m) than the first subgroup. The third subunit is differentiated by *Palaquium stenophyllum*, *Shorea pauciflora*, *Canarium sp.* *Vatica nitens*, *Rubiaceae*, *Eugenia* sp., etc (Table 2). This subunit occurs on slopes between 10 and 20°. The soil was mesic, deep and rich in humus. The litter layer was 2 to 5 cm in depth. This subunit has two subgroups. The first subgroup is differentiated by *Dacryodes incurvata*, *Nepheleium mutabilae*, *Shorea materialis*, *Aglaia cordata*, *Blumeodendron kurzii* etc. This subgroup has the highest species density, with 148 species. The second subgroup is differentiated by *Fagraea* sp., *Acios heteropetala*, *Artocarpus odoratissimus*, *Knema latiflora* etc. The species-richness polygon for this community is shown in Fig. 3. The species diversity was highest in the shrub layer, especially in Relevé 9.

**Experimental results**

Data on growth performance (basal diameter and total height) and survival rate of planted seedlings were collected since the seedlings were planted. For the open and under-*Macaranga* planting techniques, the data used in this study covered 72 months. The data for the mound-planting technique covered 66 months, and those for line planting covered 60 months.

**Survival**

A tally of seedling survival after planting showed a generally low survival for all species (Figs. 4,5,6 and 7). *Whiteodendron moutianum* had more than 50% survival rate at all planting areas. In the open area, *W*
Rehabilitation of tropical rainforests for degraded areas in Sarawak, Malaysia

Table 3. Growth performance and statistical values of planted species.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistical value</th>
<th>Open</th>
<th>Mound</th>
<th>Line</th>
<th>Shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>mean (SD)</td>
<td>342.57 (174.29)</td>
<td>411 (207.24)</td>
<td>357.81 (118.48)</td>
<td>462.93 (267.70)</td>
</tr>
<tr>
<td></td>
<td>Range (Min - Max)</td>
<td>(102 - 598)</td>
<td>(148 - 750)</td>
<td>(154 - 515)</td>
<td>(188-705)</td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>mean (SD)</td>
<td>5.31 (2.18)</td>
<td>6.84 (3.68)</td>
<td>4.47 (1.61)</td>
<td>3.46 (1.48)</td>
</tr>
<tr>
<td></td>
<td>Range (Min - Max)</td>
<td>(2.5 - 10)</td>
<td>(2.84 - 16.2)</td>
<td>(2.1 - 7)</td>
<td>(1.88 - 6)</td>
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<td>Correlation coefficient (r) between height and diameter</td>
<td>r</td>
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<td>0.77</td>
<td>0.89</td>
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Fig. 4. Survival rate and growth performance of seedlings planted in the open area.
Survival rate of seedlings planted

Mean total height growth of seedlings planted

Mean basal diameter growth of seedlings planted

Volume (diameter x diameter x height)

**Fig. 5. Survival rate and growth performance of seedlings planted in mound.**

*moultianum* had 51%, while *Parashorea parvifolia* had 10% survival rate. On the mound, the highest survival rate was 78% for *Pentaspodon motleyi* and the lowest was 10% for *Vatica* sp. The survival rates of all planted species under *Macaranga* secondary forest were higher than those of other planting areas. *Eusideroxylon zwagerii* had 96% survival rate, and the lowest was 69% for *Pentaspodon motleyi*. Two species had 0% survival rate when planted by the line-planting technique: *Hopea kerangasensis* and *Cotylelobiun burckii*. The highest survival rate under the line-planting technique was 73% for *Durio carinatus*. Based on the previous studies by Mohd Zaki et al. (1993), the inability of some seedlings to
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adapt to the site microclimate may have contributed to seedling mortality, especially during the first six months after planting. The rates of survival of planted seedlings remained constant after six months, even with the increasing competition between them for sunlight, water, nutrients and space. In general, taller trees have better chances to survive than do smaller trees.
Growth performance
Statistical analysis showed no significant difference in growth performance between species groups (p<0.05) for all study plots. However, there was a significant difference between the effects of different species on variations of mean height and basal diameter increments (p<0.05) (Table 3).
Rehabilitation of tropical rainforests for degraded areas in Sarawak, Malaysia

In general, the open-planted species had moderate growth in basal diameter and height growth, except that *Dryobalanops aromatica* and *Whiteodendron moultianum* showed good growth for basal diameter, total height and volume. Species which had less growth in basal diameter and total height, had less volume.

The biggest height growth for the open-planting technique was exhibited by *Dryobalanops*
aromatica, with 598 cm, followed closely by Whiteodendron moulitianum (594 cm) and Shorea ovata (588 cm). W. moulitianum recorded the highest diameter increment with 9.5 cm, while D. aromatica attained a diameter growth of 9.2 cm. D. aromatica, W. moulitianum and S. leprosula had good growth in total height, basal diameter and volume, except that S. leprosula showed only moderate growth in total height and volume. Others species under the open-planting technique showed less growth.

As for the mound and under-Macaranga planting techniques, Pentaspodon motleyi exhibited the largest height and basal diameter growth, while the biggest growth performance (both height and basal diameter) was recorded by Shorea leprosula. In mound planting, P. motleyi, S. leprosula, S. ovata and Whiteodendron moulitianum had good growth in total height, but only P. motleyi showed good growth in basal diameter.

Fig. 8 shows that height and diameter growth are strongly correlated, especially for the seedlings planted with the line-planting technique and under the Macaranga forest. These results contradict the popular beliefs that seedlings do not increase their height and diameter simultaneously.

Line graph showing the measured height and diameter at different periods are shown in Fig. 4, 5, 6 and 7. In general, the inability of small seedlings (less than 50 cm in height) to adapt well to site microclimate and to compete with taller planted seedlings has resulted in small growth increment as well as low survival rate.

**DISCUSSION**

The two plant communities surveyed in Bintulu consisted of several subunits. The subunits showed species combinations for each site condition. Tree species in these two plant communities showed potential for use in rehabilitation projects in the Bintulu area because they were from the potential natural vegetation for that area. All the planted species in the planting trial were collected from Allantospermum borneense - Hopea kerangasensis communities in Bintulu. Some species from these two communities also had wide distribution, such as Hopea kerangasensis, Dryobalanops aromatica, Shorea macroptera, S. scaberrima, S. maxwelliana, S. pauciflora, S. materialis, S. ovata, Vatica borneensis, Palaquium stenophyllum, and Palaquium gutta.

In the experimental research, the planted seedlings exhibited different vertical stratification. Faster growth of planted seedlings was shown by light-demand species. The behavior of these species, which have been recognized as PNV species for Bintulu (based on the phytosociological studies), supported their selection for trial planting. S. ovata, for example, which was classified as a light demander by Wood and Meijer (1964), performed well in the open, since it could utilize the full sunlight to increase its photosynthetic activities and hence its growth. S. ovata occurred in both communities and in four vertical stratification layers. S. leprosula had a self-pruning capacity and was, therefore, better suited for planting in less competitive conditions. Based on previous study by Azman (1990), S. macrophylla has very fast diameter growth but also has very fast early height growth before leveling off at the later stage (Appanah & Weinland 1993).

In the young stage, Dryobalanops aromatica is distinctly shade tolerant and can be planted densely under heavy shade. The species is very intolerant towards other species and should be grown in less mixed plantation. D. aromatica is a good species for planting, especially under some shade, since it recorded a relatively high survival rate of 45% when planted under the shade (that is, the line-planting technique). D. aromatica occurred in Allantospermum borneense - Hopea kerangasensis communities in all vertical layers, even as emergent tree. Barnard (1949), Walton (1938), Landon (1948) and FRIAR (1953) learned that D. aromatica had a survival rate ranging from 45-90% when
planted under the shade of shrubs. The species has rapid height growth, and its young form is a long conical crown with slender side branches. This phenomenon can be seen in the open plots and under line planting. Watson (1935) found that D. aromatica planted in Kepong, Selangor, reached an average height of 6 m and 11.3 cm in diameter, with maximum height and diameter of 11.3 m and 12.9 cm in six years, respectively. Meanwhile, Edwards & Mead (1930) estimated that it takes only 43 years for the species to reach 50 cm in diameter and 66 years to reach 70 cm. It is interesting to note that the 46-year-old trees that were planted within the compound of FRIM, Kepong, yield more than 50 cm dbh and a mean annual increment of 8 m³. Abdul Rahman et al. (1996) recommended D. aromatica as the most suitable species for forest management based on the growth increment, Lok et al. (1996) arranged the performance of four dipterocarps species in term of diameter, height and survival rate in the order S. leprosula > D. aromatica > S. parvifolia > S. curtisii. Interactions among the factors investigated showed no significant effect on the height and diameter of the dipterocarps, but interactions of terrain-shade and terrain-species did correlate with survival.

Amongst the non-dipterocarps, Pentaspondon motleyii recorded the largest growth increment when planted on the mound and under Macaranga forest. P. motleyii appears to have weak apical dominance and so needs strong lateral competition to maintain an upright position. Its self-pruning capacity is good but not its self-thinning ability. The crowns are feathery, and much light penetrates to the ground floor.

CONCLUSIONS

The following conclusions can be drawn from this study:
1. The planted species were categorized as:
   a. Light-demanding species
      Shorea ovata, S. mectistopteryx, S. leprosula, Dryobalanops aromatica, Pentaspondon motleyi and Whiteodendron moulitianum.
   b. Shade-tolerance species
      Shorea macrophylla, S. gibbosa, S. materiais, Parashorea parvifolia, Hopea beccariana, Cotylelobium burckii, Calophyllum ferrugenium, Durio carinatus and Eusideroxylon zwagerri.
   c. Late-growth species
      Hopea kerangasensis, Eugenia sp. and Vatica sp.
2. All the species recommended for planting in Bintulu can be planted in open areas and under secondary forest. These species have been determined as potential natural vegetation for Bintulu based on their growth and occurrence in forest communities near Bintulu.
3. Ecotechnological method could be used to a mean to elucidate the suitable species for rehabilitation of tropical forests.

ACKNOWLEDGEMENTS We are greatly indebted to the following people who helped us until this manuscript was done: Elgene O. Box (manuscript correction), Amir Hafids Mohd Taha and the other staff of this project (fieldwork).

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Mohamad Azani ALIAS, Mohd Zaki HAMZAH, 藤原一緒, 目黒伸一
マレーシア国サラワク州における荒廃地の潜在自然植生を基礎とした熱帯雨林の回復

熱帯雨林回復研究が植物社会学的研究およびスタンド設定研究により進められた。植物社会学的植生調査により、ピントツの熱帯雨林は海岸林の Cyrtostachys lakka-Whiteodendron moulitianum 群落と丘陵地林の Hopea kerangasensis-Allantospermum borneense 群落の 2 群落としてまとめられた。植栽実験地の植栽樹種のすべては、実験地の潜在自然植生と判定された Hopea kerangasensis - Allantospermum borneense 群落から採種、採苗された。植栽地に約 50 個所の永久方形区を設定して、各株、根元直径の成長測定を行い比較した。本報では、植栽後 6 年のブロットの中で、同年齢で異なる光環境の 4 永久方形区（オープン地帯の斜面およびマウンド上、Maananga 二次林内および Isochneumum magnum 草原内の植栽地）を選び、各種の成長比較を行った。植栽された幼苗は異なった生长速度をあらわす階層曲線を示した。早い成長を示す幼苗は、陽光を必要とする種群であり、示された階層曲線は、種により異なった生長速度を持つこと、森林回復を行う際には、混植によるそれぞれの樹種の階層成長が、森林形成の第一歩となり効果的な手段となることが明らかにされた。Dryobalanops aromatica が全植栽樹種の中で、最も成長率が高かった。Pentaspodon motleyii, Shorea ovata, S. leprosula などが後に続く。
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The impacts of non-native species on UK biodiversity and the effectiveness of control

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Summary

1. The introduction of non-native species continues to cause ecological concern globally, but there have been no published reviews of their effects in the UK. Impacts in the UK are therefore reviewed, along with current legislation and guidelines relating to the introduction and control of such species.

2. A large number of non-native species have been introduced to the UK, both deliberately and accidentally, but only a small number have established and caused detrimental ecological impacts. However, general declines in UK biodiversity, and the potential effects of future climate change, may increase the susceptibility of ecosystems to invasions.

3. Detrimental impacts of non-native species on native biota have occurred through competition, predation, herbivory, habitat alteration, disease and genetic effects (i.e. hybridization). There are potential effects on genetic biodiversity as well as species biodiversity.

4. Several high profile examples highlight the technical difficulties, and financial implications, of removing an introduced species once it is established. Few UK control or eradication programmes have been successful.

5. Control might be more feasible if ‘problem’ species could be identified at an earlier stage of establishment. However, the poor success of attempts to characterize invasive species and predict which will have negative impacts highlight the individual and unpredictable nature of invasions. The difficulties of making general predictions suggest that every proposed species introduction should be subject to rigorous ecological characterization and risk assessment prior to introduction.

6. The plethora of UK legislation and guidelines developed to reduce impacts of non-native species only go part of the way towards ameliorating impact. Many species already established in the wild might cause future problems. Illegal releases and escapes of non-native species may augment feral populations or establish new colonies. While regulation of imports and releases is important, further enforcement of existing legislation and action against unlicensed releases is necessary.

Key-words: introduction, invasion, non-indigenous, non-native, UK.


Introduction

For as long as humans have travelled over and between land masses, species have been transported, deliberately or inadvertently, from their native ranges to new, previously unoccupied, areas. Since the Neolithic, c. 6000 BP (Webb 1985), human migrations and trade are thought to have introduced new species to many parts of the world. However, most non-native species have been introduced into the UK since approximately AD 1500, when improved marine transportation massively increased human movements between continents (di Castri, Hansen & Debuissche 1990). In addition to augmentation of the numbers of species introduced, the
modes of introduction of new species became more diverse, for example as ornamental species, accidental ‘stowaways’ aboard ships, and food species. A few recent colonists of the UK have arrived spontaneously, such as the collared dove Streptopelia decaocto (Frivaldszky) (Eversham & Arnold 1992) and the fulmar Fulmarus glacialis (L.) (Williamson 1996), but most are thought to have been brought by humans.

For the purposes of this paper, terms relating to the status of a species are defined using the International Union for the Conservation of Nature (IUCN) (IUCN 1987) guidelines and the UK Committee for International Nature Conservation (UKINC) report (UKINC 1979; see also Bullock et al. 1997).

‘Native’ or ‘indigenous’ refers to a species or race that occurs naturally in an area (for this review, the UK), i.e. whose dispersal has occurred independently of deliberate human translocation. In general, a species or race thought to have occurred in an area since before the Neolithic can be considered to be native.

‘Non-native’, ‘non-indigenous’, ‘alien’ or ‘exotic’ refers to a species or race that does not occur naturally in an area, i.e. it has not previously occurred there, or its dispersal into the area has been mediated by humans (UKINC 1979; IUCN 1987; Holmes & Simons 1996). It is usually assumed that species that have colonized since the Neolithic, e.g. 6000 BP, are non-native (Webb 1985). In some cases, the distinction between native and non-native may not be straightforward, and often is the result of estimates of the length of time a species has been resident in the UK. For example, it is not clear whether the pool frog Rana lessonae Camerano is native to the UK or has been introduced (Arnold 1995). A related issue is the distinction between non-native species introduced directly through human agency, and species colonizing through natural range expansion such as the fulmar Fulmarus glacialis. Because such species have colonized ‘naturally’, they could be considered as desirable additions to UK biodiversity. However, in some cases apparently natural colonization may have been facilitated by changes in the environment brought about by human activity.

‘Introduction’ is the deliberate or accidental release by human agency of an organism(s) into the wild by humans in areas where the species or race is not native. The term applies to translocations within the UK or into the UK from other countries.

The ‘wild’ is defined as any conditions in which organisms can disperse to other sites or can breed with individuals from other populations (sensu NCC (Nature Conservancy Council) 1990).

‘Naturalised’ refers to a non-native species or race that, following escape or release, has become established in the wild in self-maintaining populations.

‘Feral’ is an organism (or its descendants) that has been kept in domestication, captivity (animals) or cultivation (plants) but which, following escape or release, now lives in the wild state. However, populations are not necessarily self-maintaining.

It is not certain exactly how many non-native species are present within the UK (Table 1), in part because estimates vary according to definitions used, and there is not complete agreement about which species are native.

One concern about non-native species relates to their potential to cause economic losses through damage to crops or forestry. However, introductions can also have marked effects on native biodiversity. This is a global problem, particularly acute in North America (Mooney & Drake 1984), southern Africa (MacDonald, Powrie & Siegfried 1986), Australasia (Lunney & Leary 1988; Arthington 1991) and oceanic islands such as the Galapagos (Schofield 1989) and Hawaii (Mooney & Drake 1984). Specific examples include the introduced brown tree snake Boiga irregularis Merrem, which has caused range reductions and extinctions among native forest birds on the island of Guam (Savidge 1987), and the kiore Rattus exulans F., which has caused population declines, and/or extinctions, of birds, bats, tuatara, geckos, skinks, landsnails and large flightless insects in New Zealand (Atkinson & Cameron 1993). In the UK, biodiversity has not been impacted so obviously, but there are concerns nevertheless.

This paper reviews the types of non-native species introduced to the UK, the hazards to UK biodiversity arising from the establishment of non-native species, and the effectiveness of guidelines or legislation in reducing these hazards. The work is based on a broader review of species translocations in the UK (Bullock et al. 1997). The translocation of native species within the UK is outside the scope of this paper and has been reviewed previously (Hodder & Bullock 1997). The paper focuses on the effects of non-native species within Britain and Ireland, but excludes UK Overseas Territories which are dealt with elsewhere (Oldfield & Sheppard 1997).

**Impacts of non-native species**

Species have been introduced to the UK deliberately and accidentally (Table 2). Deliberate introductions include species used for food and other products (crops, aquaculture, timber, fur), as game, for ornamental purposes (private collections and pets), as garden plants, or for biological control. Accidental introductions have arrived in cargoes or have been otherwise carried on ships, aeroplanes or other vessels.

Hodder & Bullock (1997) derived a set of definitions designed to describe all aspects of biodiversity and reflecting the Global Biodiversity Assessment (Hengeveld et al. 1995), and these form the basis of...
our assessment of impacts on biodiversity. The UK has been fortunate so far, in that the majority of recently introduced non-native species have not caused major adverse ecological impacts (Table 3; Brown & Williamson 1986; Kornberg & Williamson 1987). In fact, some charismatic non-native species, such as the little owl _Athene noctua_ Scopoli or the horse chestnut _Aesculus hippocastanum_ L., are now widely accepted as part of UK biodiversity. There is little evidence that introductions to the UK have led to species extinctions, as witnessed in other countries (Savidge 1987; Atkinson & Cameron 1993). On a global scale the most severe impacts of non-native species have occurred on remote islands, where the native flora and fauna is depauperate and isolated and susceptible to invasion (Drake & Mooney 1989). The biota of the UK is essentially continental in character (Pennington 1969) and native species are unlikely to be excluded throughout their whole range by non-native invaders.

However, certain species introduced to the UK have caused problems for biodiversity, some of which have a high profile. These include the ruddy duck _Oxyura jamaicensis_ Gmelin, Canada goose _Branta canadensis_ L., grey squirrel _Sciurus carolinensis_ Gmelin, coypu _Myocastor coypus_ Molina, North American signal crayfish _Pacifastacus leniusculus_ Dana, zander _Stizostedion lucioperca_ L., _Rhododendron ponticum_ L., Japanese knotweed _Fallopia japonica_ Hout Ronse Decraene, Australian swamp stonecrop _Crassula helmsii_ T. Kirk and the New Zealand flatworm _Artioposthia triangulata_ Dendy.

The impacts of introductions on biodiversity may be categorized according to whether the introduction has had negative, positive or no impact upon native biota. Despite the apparently widely held belief that non-native species are without exception detrimental to native ecosystems (Rose 1979; IUCN 1987; Ruesink et al. 1995), they can be beneficial, for example when used for land reclamation (Daehler & Gordon 1997). Negative impacts may be further categorized according to the mechanism by which species are affected. For example, competitive impacts arise when non-native invaders and native species compete for resources (Table 4). Herbivores may directly affect plant populations through grazing and trampling, and have indirect effects by altering habitat (see below) (Table 5). Non-native species may predate upon native species, or themselves be predated upon, for example where high densities of farmed fish attract predators and scavengers (Table 6). Introduced species may be parasites or pathogens (Table 7). Alteration of habitat form or function, such as alteration of water table, fire regime, soil properties or vegetation structure, can make habitats unsuitable for native species (Table 8).

Finally, genetic impacts may arise through hybridization of non-native species with related native species (Table 9). The change in genetic constitution and in phenotype can be considered a loss in biodi-

<table>
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<th>Species/status (region)</th>
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</tr>
</thead>
<tbody>
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<tr>
<td>Phytophagous insects (British Isles)</td>
<td>340 of 8893 species of insects and mite on the British Phytophagous Insects Data Base (Ward, Hackshaw &amp; Clarke 1995)</td>
<td>L. Ward (personal communication)</td>
</tr>
<tr>
<td>Type of organism</td>
<td>Purpose</td>
<td>Impacts on native biodiversity</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>----------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fish and shellfish</td>
<td>Angling</td>
<td>Competition; predation; habitat alteration; spread of disease</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Aquaculture</td>
<td>Few adverse effects</td>
</tr>
<tr>
<td>Wildfowl and game (e.g. mammals, birds, fish)</td>
<td>Biological control</td>
<td>Herbivory; habitat alteration/damage; predation; competition; genetic impacts</td>
</tr>
<tr>
<td>Birds, mammals, fish, amphibians, reptiles, plants, invertebrates, etc.</td>
<td>Amenity/ornamental planting; zoological/botanical/private collections</td>
<td>Herbivory; competition; hybridization</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mammals fish birds, etc.</td>
<td>Food; pets and domestic animals; pest control</td>
<td>Habitat damage; predation</td>
</tr>
<tr>
<td>Trees</td>
<td>Forestry</td>
<td>Soil/stream acidification; reduced native diversity</td>
</tr>
<tr>
<td>Plants</td>
<td>Utility plants; crop/pasture improvement</td>
<td>Hybridization</td>
</tr>
<tr>
<td>Mammals</td>
<td>Fur</td>
<td>Herbivory; predation; reduced floristic diversity</td>
</tr>
<tr>
<td>Mammals, invertebrates, algae, parasites, plants, crustaceans, disease organisms, etc.</td>
<td>None – accidental introductions</td>
<td>Competition; predation; herbivory; habitat alteration; transfer of disease</td>
</tr>
</tbody>
</table>
### Table 3. Benign or beneficial species

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rose-ringed parakeet <em>Psittacula krameri</em></td>
<td>Increasing since the 1960s, and is likely to become a serious crop pest, but there is little evidence that it will affect UK biodiversity (Feare 1996)</td>
</tr>
<tr>
<td>Slender speedwell <em>Veronica filiformis</em> Sm.</td>
<td>Widespread grassland plant introduced from the Caucasus, is not regarded as having any negative impact on native biodiversity (Akeroyd 1994)</td>
</tr>
<tr>
<td>Cynipid gall wasp <em>Andricus quercuscalicis</em></td>
<td>Will have little effect on populations of host, oak <em>Quercus robur</em> L., despite large effects on acorn production. Does not compete with native cynipids for acorns (Hails &amp; Crawley 1991)</td>
</tr>
<tr>
<td>Rabbit <em>Oryctolagus cuniculus</em></td>
<td>Grazing of chalk downland and breckland has positive effect on native biodiversity. Extinction of the British population of the large blue butterfly <em>Maculina arion</em> (L.), blamed partly on declines caused by myxomatosis in the 1950s (see above). The early successional grazed habitat was replaced with taller grassland which no longer supported the butterfly (Sheail 1991). The loss of an important prey species may have affected predators such as buzzards <em>Buteo buteo</em> L. (Moore 1957)</td>
</tr>
<tr>
<td>Mandarin duck <em>Aix galericulata</em> and Roman snail <em>Helix pomatia</em></td>
<td>Some non-native species subject to conservation measures in their native ranges. Ex-situ populations may represent important refugia meriting positive conservation action. In the past, speculated that the feral population of Mandarin duck in Britain may have outnumbered that within China (Lever 1977). More recently, estimated that the British population might number 7000 birds, three times greater than any previous estimate, and potentially at least one-third of the world population. If this were indeed the case, and the population continues to increase in Britain, conservation measures for this species should consider not only the population in its home range of the Far East, but that present within this country also (Davies 1988)</td>
</tr>
</tbody>
</table>

### Table 4. Negative impacts of non-native species on UK biodiversity: competition

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Ecosystem or species affected</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-clawed or Turkish crayfish <em>Astacus leptodactylus</em>, North American signal crayfish <em>Pacifastacus leniusculus</em></td>
<td>White-clawed/Atlantic stream crayfish <em>Austropotamobius pallipes</em> (Lereboullet)</td>
<td>Introduced species expanding its range, often into waters previously occupied by the native species (Holdich &amp; Reeve 1991) which is then often eliminated through competition (Hobbs, Jass &amp; Huner 1989)</td>
</tr>
<tr>
<td>North American grey squirrel <em>Sciurus carolinensis</em></td>
<td>Red squirrel <em>Sciurus vulgaris</em> L.</td>
<td>Red replaced by grey over much of former range (Usher, Crawford &amp; Banwell 1992; Lurz, Garson &amp; Rushton 1995). Grey have feeding advantage in deciduous woods (Gurnell 1983, 1989) possibly due to better ability to tolerate phytotoxins in acorns (Kenward &amp; Holm 1993)</td>
</tr>
<tr>
<td>Seaweed <em>Sargassum muticum</em></td>
<td>Native coastal species</td>
<td>Has spread quickly along south coast of England (Eno, Clarke &amp; Sanderson 1997). Likely to displace native species, as it is does on French Atlantic coast, e.g. <em>Laminaria saccharina</em> (L.) Lamour, <em>Zostera marina</em> L.</td>
</tr>
</tbody>
</table>
versity, while hybridization may affect the adaptedness of native species to the local environment. Genetic effects may be caused indirectly through fragmentation and reduction in the abundance of native populations, leading to a loss of genetic variation due to genetic bottlenecks. Examples of hybridization have been more frequently reported for species of birds, although fish, mammals and plants may also be affected.

Predicting invasiveness and invasibility

Of established non-native species in the UK, only 8.5% of vertebrates, 6.5% of insects and 13.6% of plants were described as having pest status by Brown (1986). Williamson’s (1992, 1993) ‘tens rule’ (see below) suggests that only about 10% of established non-natives are invasive and may become pest species. However, it is not clear what proportion of these species actually do cause nature conservation problems, as ‘pest’ status generally reflects potential to cause economic losses rather than impacts on biodiversity. Whatever the figures are, it is clear that most established non-native species have no significant effect on UK fauna and flora. This may be partly because many species are uncommon and have established over only small areas.

Williamson’s (1992, 1993) tens rule suggests that 10% of non-natives imported into a region appear in the wild, 10% of these establish, and 10% of the

<table>
<thead>
<tr>
<th>Table 5. Negative impacts of non-native species on UK biodiversity: herbivory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-native species</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Canada geese</td>
</tr>
<tr>
<td>Branta canadensis</td>
</tr>
<tr>
<td>Muskrat Ondatra zibethicus; coypu Myocastor coypus</td>
</tr>
<tr>
<td>Fallow deer Dama dama</td>
</tr>
<tr>
<td>Muntjac Muntiacus reevesi</td>
</tr>
<tr>
<td>Cynipid gall wasp Andricus quercuscalicis</td>
</tr>
</tbody>
</table>

Table 6. Negative impacts of non-native species on UK biodiversity: predator effects

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Ecosystem or species affected</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zander Sizostedion lucioperca</td>
<td>Native fish species, particularly in eastern England</td>
<td>Can cause substantial population reductions of native fish, particularly where there is a reduced diversity of prey species, i.e. all UK waters containing zander (Maitland &amp; Campbell 1992; Hickley 1986)</td>
</tr>
<tr>
<td>Feral mink Mustela vison</td>
<td>Water vole Arvicola terrestris (L.); native birds, mammals and fish along waterways</td>
<td>Impacts some waterbird species but magnitude of effects on many species unknown (Woodroffe, Lawton &amp; Davidson 1990; Ferreras &amp; Macdonald, 1999). Significant inverse correlation between mink, and water vole, activity. Probable that in the long run mink will depress water vole numbers</td>
</tr>
<tr>
<td>New Zealand flatworm Artioposthia triangulata; Australian flatworm Australoplana sanguinea var alba</td>
<td>Earthworms</td>
<td>May reduce earthworm populations to undetectable levels, thus impacting soil processes (Cannon et al. 1999)</td>
</tr>
<tr>
<td>Farmed non-native fish</td>
<td>Tern Sterna spp.</td>
<td>Tern breeding colonies in Scotland displaced from sea loch islands by gulls attracted to farmed fish (Beveridge, Ross &amp; Kelly 1994)</td>
</tr>
<tr>
<td>Farmed non-native fish</td>
<td>Wild fish stock</td>
<td>Shags Phalacrocorax aristotelis (L.) attracted to fish farms. Most fish eaten near the farms were wild native species that congregated around the fish cages (Carrs 1993)</td>
</tr>
</tbody>
</table>
Table 7. Negative impacts of non-native species on UK biodiversity: parasites and pathogens

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Ecosystem or species affected</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bee ectoparasite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varroa jacobsoni</td>
<td>Native bees</td>
<td>Causes large declines in commercial hives. May affect native bee species (Oldroyd 1999; Pearce 1998). Plant species may be indirectly affected by declines in pollinators (Allen-Wardell et al. 1998)</td>
</tr>
<tr>
<td>Pathogenic fungus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aphanomyces astaci (crayfish plague)</td>
<td>Atlantic stream crayfish</td>
<td>North American signal crayfish <em>Pacifastacus leniusculus</em> (plague vector) immune to effects of fungus, but European, Asiatic or Australasian crayfish susceptible (Holdich &amp; Reeve 1991). Outbreak of the disease in a population may quickly lead to complete mortality (Soderback 1995). Many indigenous British crayfish populations eliminated by plague and sites in Ireland have been affected (Holdich &amp; Roger 1997)</td>
</tr>
<tr>
<td>Myxoma virus</td>
<td>Rabbit <em>Oryctolagus cuniculus</em></td>
<td>First reported outbreak in 1953 caused nearly 100% mortality (Armour &amp; Thompson 1955). Effects now decreasing: virus strains currently in Britain less virulent than original strains; genetic resistance to virus detected in wild in 1970, and increasing (Trout et al. 1992)</td>
</tr>
<tr>
<td>Dutch elm disease</td>
<td>Elm trees <em>Ulmus</em> spp.</td>
<td>Spread by beetles of the genus <em>Scolytus</em>, or through roots of adjacent trees. Greatly reduced numbers of elm trees in much of England and Wales. Indirectly affected invertebrates dependant on elm, and many farmland birds (Osborne 1985)</td>
</tr>
</tbody>
</table>

Table 8. Negative impacts of non-native species on UK biodiversity: habitat alteration

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Ecosystem or species affected</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carp and goldfish</td>
<td>Native species</td>
<td>Bottom-feeding fish increase water turbidity by churning sediment while feeding (Richardson &amp; Whoriskey 1992)</td>
</tr>
<tr>
<td>Grass carp <em>Ctenopharyngodon idella</em>, red swamp crayfish</td>
<td>Macrophytes/reed beds and dependent species</td>
<td>Cause extensive damage to macrophytes. Completely remove submerged vegetation and reed beds in some places (Stott 1974; Crivelli 1995)</td>
</tr>
<tr>
<td>Procambarus clarkii</td>
<td>Aquatic freshwater biota</td>
<td>Planting on poorly buffered acid/acid-sensitive soils partly blamed for increased acidification of uplands. Subsequent felling generates more acidic stream water (Neal et al. 1992)</td>
</tr>
<tr>
<td>Non-native conifers/plantations</td>
<td>Aquatic and riparian fauna and flora</td>
<td>Caused extensive damage to watercourses and riverbanks by burrowing (Sheail 1988; Gosling &amp; Baker 1989)</td>
</tr>
<tr>
<td>Coypu <em>Myocastor coypus</em> and muskrat <em>Ondatra zibethicus</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Negative impacts of non-native species on UK biodiversity: genetic

<table>
<thead>
<tr>
<th>Non-native species</th>
<th>Ecosystem or species affected</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>White-headed duck (in Spain) <em>Oxyura leucocephala</em></td>
<td>Ruddy duck <em>Oxyura jamaicensis</em></td>
<td>Hybridization with western Europe’s most important breeding population of white-headed duck may lead to genetic introgression and extinction of white-headed (Hughes 1996)</td>
</tr>
<tr>
<td>Wild fish populations</td>
<td>Farmed fish</td>
<td>Hybridization may introduce maladaptive genes to wild populations, possibly leading to introgression of gene pools and subsequent inbreeding (Beveridge, Ross &amp; Kelly 1994; Ferguson, Danzmann &amp; Allendorf 1988; Leary et al. 1984)</td>
</tr>
<tr>
<td>Red deer <em>Cervus elaphus</em> L.</td>
<td>Japanese sika deer <em>Cervus nippon nippon</em></td>
<td>Genetic integrity of Scottish mainland red deer threatened by the continued range expansion, and continuing hybridization with, sika deer (Abernethy 1994)</td>
</tr>
</tbody>
</table>
establishing species, i.e. 0-1% of imported species, are invasive. This rule of thumb holds in Great Britain for angiosperms (Williamson 1993) and pines (Williamson & Fitter 1996a), and in other groups in other parts of the world (Lonsdale 1994; Williamson & Fitter 1996b). However, to achieve these fits, Williamson (1996) took 10% as being 5-20%, giving a 64-fold variation in the predicted proportion of introduced species that become invasive (0.0125-0.8%). In addition, there are a significant number of cases for which the former does not hold (Williamson & Fitter 1996b; Williamson 1996). Nevertheless, the rule reflects the fact that only a small proportion of introduced species establish in the wild.

**Characteristics of Successful Invaders**

There have been several attempts to determine the characteristics of a successful invader (Williamson 1996). Morphological, physiological and life-history traits might predict the probability of a non-native species becoming more or less invasive when introduced to a new region. Williamson & Fitter (1996a) found the only differences between native species and non-native invaders in the British flora were that the non-natives were larger (height, spread, leaf area index) and had an earlier age at first flowering. Crawley, Harvey & Purvis (1996) carried out a more sophisticated analysis, again comparing native and non-native British plants, but found only that the latter were taller, had larger seeds and more protracted seed dormancy. These analyses are of limited relevance because they compare native with successful non-native species. A better test might be to compare invasive and non-invasive non-native species. Rejmanek & Richardson (1996) carried out such an analysis by comparing invasive and non-invasive pines (in the genus *Pinus*) in the USA and found that the former had greater seed mass, faster growth and more frequent seeding.

Ehrlich (1986) reported that successful vertebrate invaders are likely to be vagile species, generalist in their feeding habits, with short generation times, high population genetic variation and the ability to function in a wide range of physical conditions. O’Connor (1987) found that successful bird invaders in Britain tended be species with a larger clutch size and lesser propensity for long-distance migration than unsuccessful invaders. For insects, Lawton & Brown (1986) reported that size was related to the probability of successful invasion, but the relationship was too weak to be of predictive value. Simberloff (1989) could make no generalizations about the invasive potential of insect species.

Given the lack of clearly identifiable characteristics associated with the property of invasiveness, could other predictors be used? It has been suggested that an invasion will only be successful where the climate of the region being invaded is similar to that of a species’ native region. However, both Williamson (1996) and Mack (1996) found as many exceptions to this rule as there are supporting cases. It is possible that genetic and breeding characters, such as inbreeding, asexuality, polyploidy or heterozygosity, are related to invasiveness. However, invaders of the British flora are not characterized by particular genetic characteristics (Gray 1986). Williamson (1996) concluded that genetic studies offered no generalities of predictive use. Species that are more abundant and have a larger range in their native region might be expected to be more invasive, because these parameters can be seen as a surrogate for wide ecological amplitude or good dispersal. Williamson (1996) reported some evidence to support this hypothesis, but concluded that it does not have good predictive potential.

Finally, certain families (e.g. the Poaceae and Asteraceae in plants) and genera (e.g. *Bromus*, *Cirsium*, *Poa*) contain a majority of the world’s problem species (Mack 1996). Because related species share traits, species from these taxa might be expected to be more invasive than species from other taxa. A similar idea is that if a species has been a successful invader of a region then its congeners might be invasive as well. Mack (1996) and Williamson (1996) reported that there are too many exceptions for these to be useful rules.

**Determinants of Community Invasibility**

Ecologists have been more successful characterizing communities in terms of their invasibility, i.e. their susceptibility to colonization by non-native plant species. It is widely accepted that disturbed habitats, such as urban wasteland, arable fields and river-banks, are generally more readily invaded (Smallwood 1994). Conversely, undisturbed natural and semi-natural communities tend to contain few, if any, recently introduced invasive non-native species. Thus plant communities may be ranked in terms of their invasibility, based upon the proportion of bare ground and on the frequency and intensity of soil disturbance (Crawley 1987). The length of time that has elapsed since the last major disturbance, i.e. the successional age of the site, will also influence the alien flora (Crawley 1987). Thus, disturbed urban sites tend to have a higher proportion of non-native species than unmanaged native woodland. Drawing upon the evidence of pine invasions, Richardson, Williams & Hobbs (1994) found that the most widespread invaders were those with attributes allowing populations to persist in habitats subjected to frequent disturbance.

All ecological communities are invasible to some extent and can be ranked accordingly (Crawley 1987; Usher et al. 1988). The rate at which plant
Communities are invaded will also be determined by biogeographic factors, such as the size of the available pool of non-native species and the rate of population immigration. This in turn will itself depend upon the isolation of the site and the size of the target community (Crawley 1987).

**Inability to Predict Invasions**

It is not possible to arrive at general conclusions about links between species’ attributes and invasive ability. While there is some information on the susceptibility of different habitat types to invasion, predictions of precisely which habitats will be invaded, by which species, and which of those habitats will be most affected by such invasions, cannot be made with any degree of certainty. This suggests that only a detailed ecological study of a species and its potential habitats can allow accurate prediction of the invasiveness of an introduced species (Crawley 1987; von Broembsen 1989; Simberloff 1989; Ruesink et al. 1995; Williamson & Fitter 1996b; Mack 1996; Williamson 1996). This was the general conclusion of the SCOPE (Scientific Committee on Problems of the Environment of the International Council of Scientific Unions) programme on biological invasions (Kornberg & Williamson 1987; Drake & Mooney 1989).

**Regulation of the release of non-native species**

A number of pieces of UK legislation directly concern the keeping, release and control of non-native species, reflecting European Community (EC) legislation and international agreements, notably the EC Habitats Directive, the Convention on Biological Diversity and the Bern Convention. However, contrary to many international statements, introductions are regulated rather than prohibited under UK law (Table 10). The most important piece of legislation is the Wildlife and Countryside Act 1981 [enforced in Northern Ireland under the Wildlife (Northern Ireland) Order 1985]. Under Section 14 of this Act, it an offence to release or to allow to escape into the wild any animal ‘of a kind’ that is not normally resident in or is not a regular visitor to Great Britain or Northern Ireland in a wild state (Department of the Environment 1997). However, the release of non-native plants in general is not prohibited. In addition, there are non-native plant and animal species that have become widely established in the UK (i.e. that are normally resident) that it is nevertheless illegal to release or to allow to escape in order to prevent increased numbers of these species in the wild. The species are listed in Schedule 9, which is revised regularly and at the moment comprises 12 mammals, 15 birds (excluding three native species; Hodder & Bullock 1997), three reptiles, seven amphibians, six fish and four invertebrates. Also on the Schedule are two non-native vascular plant species and eight non-native marine algae, which it is an offence to plant or cause to grow in the wild. Again, these are species that have established in the wild in the UK.

Licences can, however, be issued to permit release of a prohibited non-native species. Applications for releases of non-native species are assessed, appraising the risks associated with the release based on a simple risk assessment of the likelihood of certain harmful incidents occurring as a result of the release (negligible, low, moderate or high) and the potential amount of harm occurring as a consequence (negligible, low, medium or severe). Such assessment is based on information about the biology of the species involved and the circumstances of the release. Assessments examine such factors as the persistence of the species in the wild, competitive advantages over native species, effects on non-target prey or hosts, potential to invade other communities and ability to show rapid population increase.

Standard licences for release are issued with conditions, allowing the release of a single species or race into one or more named sites only for a specific named purpose. Other conditions usually include freedom from disease, need to notify the Secretary of State of spread outside of the release site, and use only of the donor sites named in the application. The licences are always for limited periods of time (usually several months), after which releases cannot continue without a further licence and, unless explicitly allowed in the licence (e.g. when a release is to establish a self-sustaining population), the released organism(s) must be removed. The most common reason for release is for use in biological control (Table 11).

**Problems with UK Legislation Concerning Introductions**

**Risk assessment**

The Wildlife and Countryside Act 1981 does not make provision for compulsory pre-introduction testing of potential environmental impacts of introduced species. This type of screening provides a great deal of relevant information, and may be essential to assess fully the risks of some proposed introductions (IUCN 1987). Current procedures make use of existing information only.

**Taxonomic constraints**

The EC Birds and Habitats Directives, the Bern Convention and the Convention on Biological Diversity all make statements concerning the introduction of non-native species, with no taxonomic restrictions. However, while the Wildlife and Countryside Act 1981 and the Wildlife (Northern Ireland)
Order 1985 prohibit the release of any animal not ordinarily resident in the UK, they make no general provision against the release of non-native plant species. The only specific provisions in UK law against the introduction of non-native plants are the short lists of named plant species in Schedule 9. There is no good conservation reason for this omission; non-native plants pose no less a threat than animals. There is a massive influx of non-native plant species to the UK, mostly from horticultural, forestry and agricultural imports. New cultivars and species of crop and forestry plants are being introduced with no controls with respect to conservation, whereas genetically modified crop plants are subject to strict controls by virtue of the molecular techniques used, rather than any greater potential for harm from such plants.

**Schedule 9 species**

Certain non-native animal species have established breeding populations in the wild but are not on Schedule 9. The barnacle goose *Branta leucopsis* (Bechstein), greylag goose *Anser anser* (L.), snow

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**Table 10. UK Legislation relevant to non-native species**

<table>
<thead>
<tr>
<th>Legislation</th>
<th>Function</th>
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</thead>
<tbody>
<tr>
<td><strong>Fish Health Regulations 1992</strong></td>
<td>To prohibit the import of live or dead fish or shellfish (Mollusca or Crustacea), their eggs or gametes, from zones within the EC not approved as free of certain diseases. Imports must be licensed and licensing conditions by MAFF (1999) lay down rules aimed at preventing the transfer of diseases of fish, molluscs and crustaceans in aquaculture</td>
</tr>
<tr>
<td><strong>Fish Health (Amendment) Regulations 1997</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Fish Health Regulations (Northern Ireland) 1993</strong></td>
<td></td>
</tr>
<tr>
<td><strong>The Shellfish and Specified Fish (Third Country Imports) Order 1992</strong></td>
<td>Covers releases of alien fungi, viruses, bacteria, protozoa and other microorganisms as biological control agents. MAFF (and its equivalents) license the releases of such organisms, and have arranged that applications for releases will be seen by ACRE (who advise on releases of alien animals and plants) prior to advising MAFF</td>
</tr>
<tr>
<td><strong>Control of Pesticide Regulations 1986</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Destructive Imported Animals Act 1932</strong> (Amended by the Destructive Imported Animals Act 1932 (Amendment) Regulations 1992) Further restricts the import (rather than release) and keeping of certain mammals, e.g. muskrats, coypus, grey squirrels, minks, Arctic foxes and ‘non-indigenous rabbits’. MAFF may license imports for research or exhibition</td>
<td></td>
</tr>
<tr>
<td><strong>Zoo Licensing Act 1981</strong></td>
<td>These both require precautions against the escape of captive non-native species considered to be dangerous to humans</td>
</tr>
<tr>
<td><strong>Dangerous Wild Animals Act 1976</strong></td>
<td>MAFF, or equivalent, can make orders to prevent introduction of disease through import of animals, carcasses, eggs or other animate or inanimate entity by which disease may be transmitted. Aimed at domesticated animals, but could be used to control imports of wild animals</td>
</tr>
<tr>
<td><strong>Animal Health Act 1981</strong></td>
<td></td>
</tr>
<tr>
<td><strong>The Import of Live Fish (Scotland) Act 1978</strong></td>
<td>Specific regulations for fish imports. The Secretary of State can make orders prohibiting, or requiring licences for the import, keeping or release of live fish or fish eggs of alien species which may harm the habitat, compete with or prey on freshwater fish, shellfish or salmon <em>Salmo salar</em> L. The statutory conservation agencies are consulted before such orders are made</td>
</tr>
<tr>
<td><strong>Import of Live Fish Act 1980</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Fisheries Act (Northern Ireland) 1966</strong></td>
<td>Empowers the Department of Agriculture of Northern Ireland to prohibit the introduction, unless under permit, into certain waters of fish species detrimental to that fishery</td>
</tr>
<tr>
<td><strong>Plant Health Act 1967</strong></td>
<td>These regulations are designed to control pests and diseases of agricultural, horticultural and forestry plants, but the legislation can cover wild plants also. MAFF, the Secretaries of State in Scotland and Wales and, for matters relating to forestry, the Forestry Commission are given powers to prevent or control plant pests (harmful insects, bacteria, fungi, plants, animals and all agents causative of transmissible disease). Powers include removal, treatment or destruction of infected plants or seeds, prohibition of keeping live pest individuals, prohibition of import of pests; powers of entry and inspection.</td>
</tr>
<tr>
<td><strong>Plant Health (Great Britain) Order 1995</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Control of Pesticides Regulations 1986</strong></td>
<td>Replaced by Plant Protection Products Regulations 1995</td>
</tr>
</tbody>
</table>

Acronyms: Ministry of Agriculture, Fisheries and Food (MAFF); European Commission (EC); Advisory Committee on Releases to the Environment (ACRE).
goose *A. coerulescens* (L.), pink-footed goose *A. brachyrynchus* Baillon and red-crested pochard *Netta rufina* Pallas are considered to be on the brink, or have started, forming feral populations in the UK and these might need to be scheduled (Holmes & Simon 1996).

**Enforcement of the Wildlife and Countryside Act 1981**

There are a large number of illegal releases or escapes from private collections of non-native species in the UK. This problem is especially well documented for birds (Holmes & Simons 1996). While imports or releases applied for under the Wildlife and Countryside Act 1981 are well regulated, enforcement of relevant legislation against unlicensed releases is poorly implemented. Holmes & Simons (1996) point out that there is great confusion over the interpretation of the Wildlife and Countryside Act 1981, and this contributes to a reluctance to enforce the Act.

**Control of non-native species**

The EC Habitats Directive and the Convention on Biological Diversity both require control of non-native populations. While it is an offence to release, or allow to escape, the species listed in Section 14 of the Wildlife and Countryside Act 1981, there is no explicit requirement for their control in the wild. In fact, other provisions of the Act (i.e. Section 1) mean that once a bird is viewed as ‘ordinarily resident’ in Great Britain it is protected, although this applies only to birds and not to other animals. Similar problems could apply to the control of resident non-native plants, as there is a general prohibition in the Wildlife and Countryside Act 1981 against uprooting any wild plant.

**Accidental introductions**

At this time accidental introductions are an unquantified, but probably major, source of non-native species and are also the most difficult to regulate. Eno, Clarke & Sanderson (1997) stated that most introductions of non-native marine algae and invertebrates into the UK have been unintentional. It is likely that the proportion is lower for other species, especially vertebrates, but it is probably still high for terrestrial plants and invertebrates. Problem non-native species that have come into the UK through accidental importation include the varroa mite *Varroa jacobsoni* (Oudemans), which probably arrived

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**Table 11. Outcomes of recent applications to the Department of the Environment for release of non-native organisms in the UK. Taken from the Newsletter of the Advisory Committee on Releases to the Environment (website http://www.environment.detr.gov.uk/acre/news.htm). In some cases the Latin name for the species was not given**

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Reason for release</th>
<th>Consent given? (reason if not)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fallopia japonica</em> (Japanese knotweed)</td>
<td>1995</td>
<td>Experiment</td>
<td>Yes</td>
</tr>
<tr>
<td>Predatory fly</td>
<td>1995</td>
<td>Insect control</td>
<td>No (insufficient information to assess risk)</td>
</tr>
<tr>
<td><em>Bombyx mori</em> L. (silkworm)</td>
<td>1996</td>
<td>Not given</td>
<td>Yes</td>
</tr>
<tr>
<td>Chinese praying mantis</td>
<td>1996</td>
<td>Not given</td>
<td>No (risk from establishment in the wild)</td>
</tr>
<tr>
<td><em>Glis glis</em> L. (fat dormouse)</td>
<td>1996</td>
<td>Experiment</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Danaus plexippus</em> L. (monarch butterfly)</td>
<td>1996</td>
<td>Filming</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Amblyseius degenerans</em> (Berlese) (predatory mite)</td>
<td>1996</td>
<td>Thrips control in greenhouses</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Macrolophus caliginosus</em> Wagner (predatory bug)</td>
<td>1996</td>
<td>Whitely control in greenhouses</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Amblyseius californicus</em> (McGregor) (predatory mite)</td>
<td>1997</td>
<td>Whitely control in greenhouses</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Delphastus catalinae</em> (Horn) (predatory beetle)</td>
<td>1997</td>
<td>Whitely control in greenhouses</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Rhizophagus grandis</em> Gyll (predatory beetle)</td>
<td>1997</td>
<td>Control of spruce bark beetle <em>Dendroctonus micans</em> Kug. in spruce woods</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Muntiacus reevesi</em> (muntjac)</td>
<td>1997</td>
<td>10 licences to release Hospitalized deer</td>
<td>Yes</td>
</tr>
<tr>
<td>10 cricket species</td>
<td>1997</td>
<td>Not given</td>
<td>No (not given)</td>
</tr>
<tr>
<td><em>Glossina palpalis</em> Robineau</td>
<td>1997</td>
<td>To test radar tracking (flies were disease free and mouthparts were removed)</td>
<td>Yes</td>
</tr>
<tr>
<td>Desvoidy (tsetse fly)</td>
<td>1997</td>
<td>Re-release of captured animals during study of impacts on native newts <em>Triturus cristatus</em> (Laur.)</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Triturus carniflex</em> (Laur.) (Italian crested newt)</td>
<td>1997</td>
<td>Re-release of captured animals during study of impacts on native newts <em>Triturus cristatus</em> (Laur.)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
on imported bees (Oldroyd 1999), New Zealand flatworm *Arioposthia triangulata*, which probably arrived in containerized plants (Cannon et al. 1999), Dutch elm disease *Ceratomeyes ulmi* Ellis & Halst., which was introduced in imported timber (Osborne 1985), and the alga *Sargassum muticum* (Yendo) Fensholt, which arrived in commercial introductions of oysters *Crassostrea gigas* (Thunberg) (Eno, Clarke & Sanderson 1997). Most accidental marine introductions are carried on the hulls or in the ballast of ships, or as contaminants of cargo (Eno, Clarke & Sanderson 1997).

IUCN (1987) guidelines expressed concern over accidental introductions, especially to islands and isolated habitats, and stated that many accidental introductions are avoidable. For instance, better seed cleaning has reduced the incidence of weed seeds in imported grain, and increased vigilance during packing and transport of cargo might lead to early removal of stowaways. The International Maritime Organisation (1993) ‘Guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships’ ballast water and sediment discharges’ deals specifically with the introduction of aquatic plants, animals, disease bacteria and viruses in ballast water. Possible procedures include ensuring that only clean ballast water and a minimal amount of sediment is taken on to a ship, and that contaminated ballast water is not released except into disposal or treatment facilities; ballast water is sampled before discharge into sensitive areas, and ships’ crews and other relevant persons are well-informed.

The guidelines were drafted to advise governments of the appropriate measures to take against such discharges, but the UK Government has not implemented these measures. Even for those taxa covered by the Wildlife and Countryside Act 1981, which also prohibits accidental release (i.e. ‘allow to escape’), enforcement is difficult with no specific protocols in place. de Klemm (1996), in a review of legislative in European countries, addressed accidental introductions in detail and proposed a wide range of legal measures to decrease the risk of such accidents.

**Guidelines for the release of non-native species**

In addition to legislation, some UK and international conservation organizations have developed position statements and guidelines relating to introductions (Appendix 2). However, these policies and guidelines are not currently implemented by law and represent, at best, agreed codes of conduct. Until recently the UK statutory conservation agencies (English Nature, Scottish Natural Heritage and the Countryside Council for Wales) have not had policy documents on introductions. The Joint Nature Conservation Committee (JNCC; the joint forum of the three statutory agencies) has been developing its own policy following review of the present situation (Bullock et al. 1997). The forerunner of the three statutory conservation agencies, the Nature Conservancy Council (NCC), conducted an internal ‘Review of NCC policy on species translocations in Great Britain’ (NCC 1990), but this was not adopted formally and has not been published. Discussion documents, e.g. Stubbs (1988) and UKINC (1979), suggesting what such a policy should contain, have been published. International guidelines have been adopted by IUCN and these are contained in the IUCN (1987) ‘Position statement on translocation of living organisms’. For licensing purposes the UK’s statutory agencies take the IUCN guidelines as a basis for policy.

The guidelines suggest that intentional introduction of non-native species should only be considered if clear benefits to humans or natural communities can be foreseen and if no native species is considered suitable for the purpose for which the introduction is being made. Introductions should not be carried out into habitats not already perceptibly altered by humans, for example islands, lakes, seas, oceans, centres of endemism or any semi-natural habitat, unless there are exceptional reasons for doing so. Introductions into habitat created by humans (for example arable land, ley grassland, forest plantations or other predominantly monocultural systems) are permissible following assessment of effects on surrounding semi-natural or natural habitats.

The IUCN (1987) guidelines state that planning of an introduction should involve assessment of the probability of an increase in numbers of the introduced species to a level that damages the environment, and the probability of invasion into other habitats. Plans should also consider how the introduction will proceed during all phases of the biological and climatic cycles of the area of release; the capacity of the non-native species to affect native species by breeding with them; whether the non-native is host to diseases or parasites that can spread to other species in the area of release; and the probability of a negative effect on the continued existence or stability of native populations through predation, competition or other means. The methods for control of the introduced species (if needed) should be investigated and subjected to risk analysis. No introduction should be made for which no acceptable control is possible. The environmental, aesthetic or economic benefits of the introduction should be compared to the possible disadvantages. A controlled experimental introduction should be made, in which the same stock should be used as that to be introduced extensively; the organisms should be free of diseases or parasites that could spread to other species; the performance of the introduced species and its effects on other species should be measured; and the suitability of the introduction should be
reassessed in the light of the results. Finally, the extensive introduction should be closely monitored and arrangements made to restrict, control, or eradicate the species if necessary.

The IUCN (1987) guidelines also state that where non-native species are already present, those of no apparent benefit to humans and with negative environmental effects should be eradicated. Priority areas for eradication of such species are islands with a high percentage of endemics, centres of endemism, areas with high species diversity or other ecological diversity, and areas in which a threatened endemic is negatively affected by the non-native species.

**Control of non-native species**

Although the evidence suggests that only a small proportion of non-native species cause adverse effects, the risk of damage in some cases makes a precautionary approach advisable. Of added concern are the possible future effects of non-native species. The general decline in UK biodiversity (declines in species number and abundance, disruption and loss of semi-natural communities, habitat loss and fragmentation, etc.) may render ecosystems more susceptible to adverse effects of introductions of non-native species in the future. Climate change may bring about more specific increases in the risks from non-native introductions, as conditions become better suited to introduced species that are not currently affecting biodiversity to a great degree (Hill et al. 1994). For example, predicted rises in temperature may permit many species to increase their ranges.

The biodiversity of the UK should not be the only concern. For example, the main threat from the ruddy duck *Oxyura jamaicensis* is that it hybridizes with the white-headed duck *Oxyura leucocephala* (Scopoli), which is not found in the UK but is a native species of conservation interest in continental Europe (Hughes 1996). However, the UK still has the largest ruddy duck population (an order of magnitude larger than that on continental Europe) and is the major source of colonists into Europe. Likewise, the New Zealand flatworm *Artioposthia triangulata* might spread from the UK to other European countries, where it could have great effects on native biodiversity (Cannon et al. 1999). It is therefore important to develop effective control strategies that can be used if necessary.

There have been relatively few successful control/eradication programmes against problem species (see below), and certainly not against species targeted solely because of their negative impacts on biodiversity. Control measures are generally not implemented until a species becomes a problem, by which stage they are very expensive and require extensive research into the ecological, economic and political aspects of the problem. More proactive approaches would be more effective.

Baker (1990) states that many problem species of naturalized mammals have been expensive to eradicate or control and, indeed, most attempts to remove such introduced species have failed. For example, the attempt to eradicate mink *Mustela vison* Schreber in the UK was abandoned in 1970 after only 5 years (Thompson 1971). Research into the control of rabbits *Oryctolagus cuniculus* L. found no successful or acceptable means of wide-scale control (Sheail 1991). Myxomatosis appeared to be a method for the complete extermination of the rabbit, but some individuals survived infection and, following an initial crash, population numbers have recovered. The coypu *Myocastor coypus* and muskrat *Ondatra zibethicus* L. were eradicated by control programmes following assessments of the effort required, the costs involved and the likely chances of success (Gosling & Baker 1989). Control was only possible because populations were confined to reasonably small areas of Britain with no immigration from elsewhere (unlike mink and rabbits). Moreover, the Ministry of Agriculture, Fisheries and Food (MAFF) provided sufficient funds for the eradication of coypu because of the agricultural damage being caused rather than to prevent ecological damage.

A variety of methods has been used in attempts to control the Canada goose *Branta canadensis* in the UK, but all present problems (Owen 1990). Egg collection is time consuming. Poisoning would be very effective but would be unpopular with the general public on a large scale. Increased shooting on wintering grounds could be used, but Canada geese are not popular targets for shooters. In addition, geese are often concentrated in protected areas. Wildfowling on such legally protected sites is seen as a potentially damaging operation. While existing levels of shooting activity are likely to be acceptable as they are in accordance with traditional practice, any increase would contravene the provisions of the Wildlife and Countryside Act 1981 (Owen 1990).

Control of the ruddy duck *Oxyura jamaicensis* is a more urgent priority, as it is still spreading and the threat to the white-headed duck *Oxyura leucocephala* is severe (Hughes 1996). National and international working groups have called for its control. However, while some organizations have proposed that shooting during the breeding season would be a viable method, others dispute this (Hughes 1996). A White-headed Duck Task Force, comprising UK government departments and conservation organizations, has recommended that a trial of methods to control ruddy duck, including shooting and trapping, should be initiated (http://www.wildlife-countryside.detr.gov.uk/whd/index.htm).

Control of plants is also problematical. *Rhododendron ponticum* control would require large-scale
 clearance, followed by spraying of regrowth. An estimate of the cost of a rhododendron control programme in the Snowdonia National Park by Gritten (1995) suggested that the initial clearance and follow-up spraying programmes would cost about £42 million (1992 prices). Dispersal of another non-native invasive plant, the giant hogweed Heracleum mantegazzianum Somm. Et Lev., is almost entirely by seed and so a control programme would need to prevent plants setting seed (Dodd et al. 1994). Due to extensive seed banks and possible long-term viability of seeds, any control programme would need to have follow-up monitoring and control for at least 7 years after the initial control measures using herbicide or cutting. The plant could be eradicated if a committed and co-ordinated control programme, using appropriate techniques, was implemented (Dodd et al. 1994; Collingham et al. 2000). Effective control of Japanese knotweed Fallopia japonica requires that rhizomes, as well as individual plants, are killed. There are very few examples of eradication of this plant, and successful control requires perseverance (Gritten 1988; de Waal 1995).

RISK ASSESSMENT

Every proposed introduction of non-native species to the UK should be assessed carefully, using a case-by-case approach to risk assessment. This is clearly necessary because of the existing risk of adverse ecological impacts of non-native species, the potential for increased risk due to future climate or other environmental change, the difficulty in naming the distinguishing characteristics of a potentially invasive species, and the problems of control.

This approach is characterized in the phrase ‘guilty until proved innocent’, which was applied by Ruesink et al. (1995) to non-native species. While some organizations oppose introductions outright, others provide guidelines on good practice. The conservation organization guidelines covering the introduction of non-native species are thorough, and suggested assessment procedures, such as those given by the International Council for the Exploration of the Sea (ICES) (1995) and IUCN (1987) (see Appendix 1), should be followed closely to ensure that harmful organisms are screened out before introduction. The information requirements for licences to release, market or keep in uncontained conditions (i.e. with the risk of escape to the wild) non-native species under the Wildlife and Countryside Act 1981 are similar to these (Department of the Environment 1997).

Assessment of the potential impact of an introduction on native biota requires a thorough understanding of the biology and ecology of each candidate for introduction, together with knowledge of the native species at the receptor site and in the UK. Risk assessments should consider the potential for escape of the non-native species from the receptor site; the potential for the non-native to establish and spread in the wild; assessments of likelihood and consequences of hybridization with native species; ecological consequences of establishment and spread in the wild; and potential for control and risk management.

Research requirements

The fact that it is hard to make general predictions about the characteristics of a successful invader indicates that future research should concentrate more on specific cases rather than the investigation of general theories. This approach was proposed by Gilpin (1990) in a review of the synthesis of the SCOPE programme on biological invasions (Drake & Mooney 1989). However, generic work, such as that by Williamson & Fitter (1996a,b) and Williamson (1996), should continue in order to pursue possibilities for a predictive approach. Research on specific cases should address the potential risk of proposed introductions according to guidelines for risk assessment from NCC (1990), IUCN (1987) and ICES (1995).

Research could use experimental introductions (as are used for genetically modified organisms), assessment of comparable case studies, and modelling. Techniques for modelling of invasion and spread are advanced (Williamson 1989, 1996). In addition, the development of geographic information systems to determine the distribution of appropriate habitat for a species and to model the expected rate and pattern of spread (Carey & Brown 1994; Rushton et al. 1997, 2000) will prove useful. Modelling of gene flow and thus possibilities of hybridization is also advanced (Gliddon 1994).

Additionally, research should focus on assessment of current changes in the status of non-native species resident in the wild and potential methods for control. The response to problem non-native species in the UK is generally reactive. However, models of invasions show that if action is taken while populations are small, few and restricted in distribution, it is more likely to be effective at restricting spread and persistence (Williamson 1989). A proactive approach would restrict damage to biodiversity and probably be cheaper than subsequent containment, control or eradication.

One approach would be to restrict or prevent the further release of any non-native species, but this is not always in the interests of all members of society. Another would be to aim to control or eradicate all non-native species established in the wild, but this could be over-cautious and expensive and might meet with widespread opposition. The optimum approach would combine a precautionary principle concerning approval of releases with a policy of no action until a problem is predicted or detected in its
early stages. To allow early detection, or even prediction, of problems of spread and/or negative effects on biodiversity, specific studies of the ecology of species and the mechanisms of their spread into new areas are needed, along with assessments of their effects on biodiversity. Population studies would also help the rapid development of control measures that can be implemented immediately problems are perceived, thus avoiding the loss of time in gathering ecological data after the species has become a problem.

Such detailed studies would be impossible for all non-native species in the UK, but such a review of the ecology and status of all such species (as carried out by Eno, Clarke & Sanderson 1997 on UK marine organisms) would allow identification of potential problem species that justified more detailed investigation. The distribution records held by the UK Biological Records Centre could be used to determine changes in the distributions of non-native species (Harding 1990).

Conclusions

Long-established and biogeographically stable non-native species that do not cause conservation problems should not necessarily be a cause for concern. However, a small number of non-native species do cause conservation problems for native flora and fauna. Given the difficulties associated with the control or eradication of these problem species, invasive non-native species should be prevented from establishing in the wild and increasing in numbers.

There are insufficient UK legislative provisions for the control of non-native species established in the wild. Current legislation needs enforcing, and rewriting where it is known to be ineffective. In addition, a case-by-case approach to risk assessment should be used for all proposed introductions of non-native species. Assessment procedures such as those suggested by ICES (1995) or IUCN (1987) would screen out harmful organisms prior to introduction. A proactive approach to assessing and managing future risks from non-native species (whether intentionally or unintentionally introduced) would limit damage to biodiversity and is likely to be more cost-effective than reactive control measures.

Research has shown that no generalizations can be made about the characteristics of invasive non-native species that hold for all cases. Thus future research needs to address specific cases. Identification of potential problem species will be possible only following reviews of the ecology of species, assessment of potential effects on biodiversity, and population studies to determine processes of dispersal and spread and to aid in the development of effective control measures before they are needed.

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Non-native species in the UK


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Non-native species in the UK


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Appendix 1

**INTERNATIONAL LEGISLATION AND CONVENTIONS CONCERNING INTRODUCTIONS OF NON-NATIVE SPECIES**

**European Community (EC) directives**
- Directive 79/409 on the Conservation of Wild Birds requires member states to ensure that any introduction of non-native bird species does not prejudice the local flora and fauna.
- Article 22b of the EC Habitats Directive requires measures to regulate the deliberate introduction of non-native species.
- The EC Fish Health Directive 91/67 prohibits import of fish material, live or dead, from zones within the EC not approved as free of certain diseases.
- EC Directive 77/93 (amended by 91/683 in response to the removal of frontiers in the European Union) concerns the passage of organisms harmful to plants and plant products, and calls for bans on introductions of certain organisms. This is primarily concerned with agroeconomic implications of pest introductions.

**International conventions**
- The Bern Convention on Conservation of European Wildlife and Natural Habitats requires that the introduction of non-native species be controlled.
- Recommendation R(84)14 of the Council of Europe Concerning the Introduction of Non-Native Species was based on the Bern Convention. It calls on member states to prohibit the introduction of non-native species into the natural environment, with possible exceptions only if an expert study of the consequences has been carried out. Accidental introductions should be prevented as far as possible.
- The Convention on Biological Diversity requires that the introduction of non-native species that threaten ecosystems, habitats or species should be prevented or that such species should be controlled or eradicated. The Bonn Convention on the Conservation of Migratory Species of Wild Animals encourages similar measures against non-native species that threaten endangered migratory species. The parties to the Bonn Convention have been negotiating an Agreement of African/Eurasian waterfowl (de Klemm 1996; Holmes & Simons 1996) that contains a provision that would require the parties to prohibit the deliberate introduction of exotic species, to take steps to prevent their accidental introduction and to prevent species already introduced from endangering native species.
- The 1982 United Nations Convention on the Law of the Sea, enforced in 1994, requires that the member states take all measures necessary to prevent and control the intentional or accidental introduction of alien species (and ‘new’ species, i.e. genetically modified organisms) that could cause harm to the marine environment.
- The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) developed a list of endangered species for which a permit system controls international trade. Trade is either prohibited (Appendix 1 species) or regulated (Appendices II and III). CITES was implemented in the EC in 1984 by Regulation 3626/82, and in the UK by the Endangered Species (Import and Export) Act 1976, the Control of Trade in Endangered Species Regulations (Enforcement) 1985, and the Control of Trade in Endangered Species Regulations (Designation of Ports of Entry) 1985.
**APPENDIX 2**

**ADDITIONAL GUIDELINES DRAWN UP BY BRITISH AND INTERNATIONAL ORGANIZATIONS**

**Stubbs (1988) Towards an introductions policy**
This was produced by Wildlife Link on behalf of 15 UK conservation organizations, and contained guidelines for assessing introductions, reintroductions and re-enforcements.

**UKINC (1979) Wildlife introductions to Great Britain (Linn report)**
An independent ‘Working group on introductions’ reviewed introduction, reintroduction and re-enforcement (restocking), and recommended the establishment of an ‘Introductions Authority’ to assess and monitor introductions and to develop guidelines.

**Conservation Committee of the British Herpetological Society (1983) Herpetofauna Translocations in Britain – a Policy**
These guidelines on the introduction of herpetofauna outlined acceptable translocations and reasons for introduction.

**NCC (1990) Review of NCC Policy on Species Translocations in Great Britain**
This was a discussion document that suggested extensive revisions of NCC policy. It was based on the belief that some alien species have posed problems as pests, carriers of disease or competitors with native species. However, it has not been formally adopted.

**ICES (1995) ICES code of practice on the introductions and transfers of marine organisms 1994**
These guidelines were developed for the translocation of fish, molluscs, crustaceans and plants for marine aquaculture. It recommends that a risk assessment be carried out prior to introduction, with subsequent monitoring.

**ICES (1988) Codes of practice and manual of procedures for consideration of introductions and transfers of marine and freshwater organisms**
This contains the most recent code of practice of the European Inland Fisheries Advisory Committee (EIFAC), the body that advises on introductions and translocations for aquaculture within European inland waters. It recommends that containment measures be used to ensure the introduced species remains within the watercourse/waterbody into which it was released.

**International Maritime Organization (1993) Guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships’ ballast water and sediment discharges**
The guidelines discuss procedures to prevent translocation of unwanted aquatic plants, animals, disease bacteria and viruses within ballast water, and advise on appropriate measures to take against discharges of ballast water from ships.

**North Atlantic Salmon Conservation Organization (1995) Introductions and transfers including the amendments proposed by the European Union**
Aimed at salmon *Salmo salar* restocking and translocation, but also recommends risk evaluation prior to introduction of non-indigenous fish into rivers containing Atlantic salmon, and that ICES and EIFAC codes of practice are followed if the introduction proceeds.