CHAPTER 19

SEEDING ON SLOPES IN JAPAN FOR NATURE RESTORATION

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Abstract. In the past few decades, improved seeding technologies have been developed in Japan. This paper discusses the restoration of degraded slopes by the application of seeding, which is known as "restoration of natural vegetation on slopes" in Japan. First, the technical aspects of revegetation work are described; second, historical changes in approaches to seeding are discussed; third, typical case studies of restoration of engineered slopes (road cuts) using the "thick-growth-media spraying method," a popular approach in Japan, are presented. The article concludes with a discussion of the basic principles of restoration of natural slopes based on previous Japanese studies and the author's experience.

1. INTRODUCTION

Afforestation work done to prevent flooding and erosion of sandy soil has been applied in Japan. This work has been necessary because much of the country is situated on steep slopes and in a region with abundant rainfall. However, afforestation alone cannot restore degraded vegetation on engineered slopes (road cuts), steep slopes, rocky ground with shallow soil, strongly acidic soils, or sandy soils.

Therefore, Japanese researchers have worked toward improved revegetation techniques that focus on restoration, correction, and management of vegetation. In Japan, revegetation technology that combines work on the underlying foundation as well as on the vegetation has been developed to promote successful restoration of the abovementioned difficult sites. The term "revegetation work" was first used by Kurata in 1953, who defined this as "planning, constructing, and management activities related to the restoration, creation, and protection of nature." This

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integrated science has become known as revegetation engineering technology (Japan Society of Revegetation Technology, 1990).

Revegetation work aims to restore various ecosystem functions that were lost when the original plant communities were destroyed. This technology has been based on the principle of creating a suitable environment for plant growth. Figure 1 shows an overview of the Japanese system of revegetation work, which is composed of three key stages: the creation of a foundation before introducing the new plants, seeding or planting of the species that will be used for revegetation, and monitoring and tending the introduced species. Recently, seeding has been studied as an alternative method to restore degraded slopes. This article describes revegetation based on slope seeding, a popular technique for slope protection.

The contents of this paper were first presented at the East Asian Federation of Ecological Societies (EAFES) International Congress (Yoshida and Morimoto, 2004), and the details of historical changes were published in the *Journal of the Japanese Society of Revegetation Technology* (Yoshida, 2005).

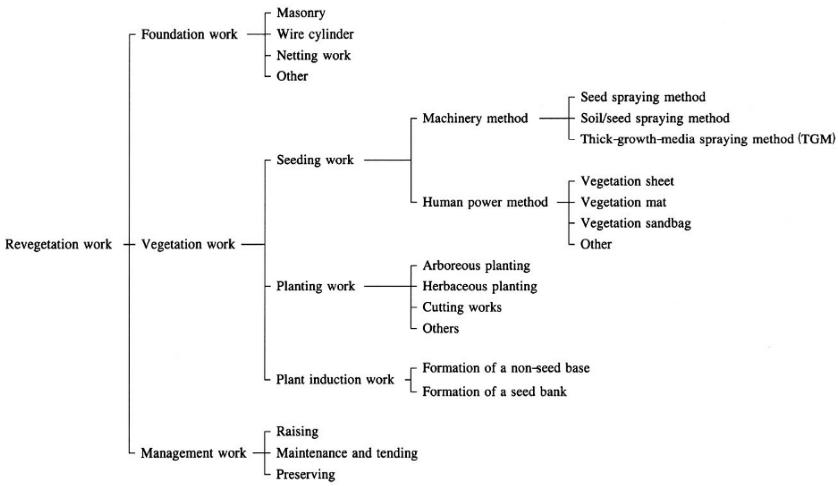


Figure 1. A technical overview of the Japanese system for revegetation work.

2. HISTORICAL CHANGES IN SEEDING TECHNOLOGY

Seeding technology has an 80-year history in Japan. However, the goal has changed little since the first use of this method. Seeding began with afforestation of slopes, particularly for erosion control. Recently, the main purpose of revegetation work has changed. Rather than revegetating solely for erosion control, this technique has been applied as a method for restoration of natural environments. Based on previous studies, I have classified the history of seeding work into five periods.

2.1 Birth of seeding work

The period between 1927 and 1948 began with the first seeding trial, done on the Korean peninsula, and extended to the development of a method called "mixed seeding on slopes" (MSS), and I have named this "period of early development of seeding" (the first period). The idea of "seeding work" at this time derived from afforestation. The initial technique was originally applied on the Korean peninsula in 1927 using *Alnus firma*, and shortly afterward, using *Robinia pseudoacacia* and *Alnus hirsuta* var. *sibirica* (Kurata, 1979). At the time, seeding work mostly took the form of linear revegetation techniques, with the seeds planted directly in shallow trenches.

The currently used MSS revegetation method was developed in 1939. This method emerged as an economical and rapid way to artificially recreate a forest (Sato and Ono, 1942). The goal was to restore bare mountainsides with herbaceous and woody plants. Trial and error revealed that on sites where various types of soil-improving trees such as *R. pseudoacacia*, *Lespedeza bicolor* var. *japonica*, *Amorpha fruticosa*, *A. hirsuta* var. *sibirica*, and *Acacia dealbata* had not been planted, growth of *Quercus acutissima*, *Quercus variabilis,* and *Aleurites cordata* decreased. These results clearly defined the necessity of using soil-improving trees for revegetation work. However, a simple method of covering bare mountainsides with seeded straw mats that was tested did not spread widely because rainfall and frost heaving caused much erosion during the winter (Kurata, 1979).

Kurata (1959, 1979) described the MSS method as a starting point for the development of modern revegetation technology. This method incorporated several improvements compared with previous revegetation strategies at afforestation sites: the formerly linear revegetation technique was changed into a planar approach that covered more of the site, mixed seeding provided both herbaceous (fast-growing groundcover) and woody vegetation (long-term stabilization), the use of several species rather than monocultures for revegetation became more common, and seeding became more widely used.

2.2 Spread of rapid revegetation techniques

After importing exotic grasses such as *Festuca elatior* var. *arundinacea* (Kentucky 31 fescue) and *Eragrostis curvula* (weeping love grass) from the United States, Kurata proposed a "rapid revegetation technique" that used the newly imported exotic species, organic matter, and soil-improving trees and grasses during the early stages of revegetation. This work was first done in 1951, and Kurata officially used the term "revegetation work" in 1953 (Nitta, 1995).

Seeding using hydroseeders attracted considerable attention as an efficient erosion-prevention method on the bare slopes created by large-scale exploitation forests (Nitta, 1959; Nitta and Kobashi, 1961). Furthermore, the newly imported exotic species adapted well to the damaged landscape in terms of their ability to grow easily and rapidly. Since this method proved to be reliable, it spread widely throughout Japan. A similar, technique developed in the 1970s called the "organic thick-growth-media spraying method" (TGM) allowed revegetation on rocky slopes that lacked soil (Kikuchi, 1980; Kurata, 1979; Oda, 1976); this approach applies a 3- to 10-cm-thick base on which plants can grow.

TGM is currently a popular seeding technique in Japan, as it provides high retention of water and nutrients and generally adapts well to steep slopes. This method uses a mix of a base material such as bark compost or peat moss, seeds, chemical fertilizer, and an erosion-control substance such as cement or vinyl acetate resin. This material is sprayed on the slope from a distance of 1 m using a spraying machine capable of handling the thick base.

Rapid revegetation using exotic grasses prevented erosion on many slopes and collapsed hillsides. This has contributed greatly toward preventing destruction of roadside environments during development and toward restoring the environment. Unfortunately, the popularity of revegetation using exotic grasses reduced attention on revegetation with woody plants. It is not surprising that many identified the concept of slope seeding as a restoration method for degraded environments that only used exotic species.

Because exotic grasses were mainly used for seeding work between 1949 and 1958, I have named this "the early modern period of revegetation work" (the second period). Between 1959 and 1985, seeding mainly used a spraying machine, thus I have named this period "the period of rapid revegetation using exotic grasses" (the third period).

2.3 Spread of rapid reforestation techniques

The landscape produced by the two rapid revegetation techniques could not prevent slope erosion and coincided with a period of growing recognition of the importance of landscape esthetics. It became ecologically important to achieve more lasting restoration results that would function similarly to natural forests (Yamadera, 1986, 1989). Thus, Yamadera described the significance of revegetation work as "lending a hand to allow nature to restore itself naturally" and recommended three characteristics of this approach to achieve the abovementioned goals: restoring ecologically suitable vegetation in the degraded landscape, valuing respecting and taking advantage of natural successional pathways, and restoring the environment's ecological functions as naturally as possible (Yamadera, 1995; Yamadera et al., 1993). He further recommended certain woody species for seeding on slopes: *Betula ermanii*, *Betula platyphylla* var. *japonica, Clerodendron trichotomum, Mallotus japonicus, Rhus javanica, Quercus mongolica* var. *grosseserrata, Ligustrum japonicum, Rhaphiolepis umbellata, Pittosporum tobira, Camellia sasanqua, Camellia japonica, Cyclobalanopsis* spp., and *Sorbus commixta* (Yamadera, 1986).

The guidelines published by the Ministry of the Environment's Conservation of Nature Bureau (1982) systematically arranged the woody species into groups for the purpose of revegetation by seeding. After the use of mixed seeding with leguminous shrubs and birch (*Betula*) species were introduced in the "Standard of road earthworks, Slope protection works" in 1986 (Japan Road Association, 1986), leguminous shrubs began to be widely used.

To successfully blend the seeds of exotic grasses and leguminous shrub species, researchers had to decrease the amount of exotic grass seeds. Whereas the original method (grasses only) was expected to grow 5000 to 10 000 plants per 1 m^2, the new method was expected to grow only 1–10% of this total. Since it was extremely difficult to form a mixed grass and woody plants using the rapid revegetation technique, many studies had to be done to provide some ratios of the numbers of seeds of grasses and other species that have been found to be successful.

Following the introduction of revegetation using leguminous shrubs, many guidebooks were published that presented specific design techniques; Road Management Technology Centre (1996), Japan Highway Landscape Association (1986), Ministry of Construction River Bureau Sand Control Department (1996), and Japan Association of Agricultural Engineering Enterprises (1990). As shown in Table 1, the main purpose of these research and development efforts focused on the formation of communities of leguminous shrubs on engineered slopes.

Because using mainly soil-improving trees enhanced the development of communities of woody plants, I have named the period after 1986 "the spread of rapid reforestation using mainly leguminous species" (the fourth period).

Table 1. Examples of seeding work during the fourth period.

Study	Introduced plant species or content
Egashira (1988)	*Lespedeza bicolo* var *japonica* community on the slopes of an expresswa
Nakaide et al. (1990)	*L. bicolo* var *japonica*, *A. fruticosa*, *A. hirusuta* var *sibirica*, and *A. firma* in an industrial par
Seino et al. (1995)	*B. platyphylla* var *japonica*, *A. hirusuta* var *sibirica*, *A. firma*, and *L. bicolor* var *japonica* in a cold zone with significant snowfall
Oyama et al. (1996)	*A. fruticosa* in the seaside sandy land beside the sea
Takeuchi and Nishizawa (1998)	Use of shrubs in family Leguminosae in a nature park
Tsuchimuro et al. (1998)	Use of shrubs in the Leguminosae on the slope of a woodland path

Table 2. Trial examples of seeding work on the nature restoration.

Study	Introduced plant species or content
Yoshida (1990)	Trial introduction of *Ligustrum lucidum*; results were sufficiently promising to perform additional trials (see below)
Yoshida (1991)	Trial introduction of *L. lucidum* and *Rhaphiolepis umbellata* on a soft rocky slope
Yoshida and Hosaka (1992)	Mixed seeding of *Betula* spp. and *L. lucidum*
Yoshida et al. (1995)	Trial introduction of *Acer palmatum* var *matsumurae* and *Sorbus commixta*
Yoshida (1998)	Proof of successful establishment of a multi-stratum community of woody plants by applying the TGM method to cut slopes; *L. lucidum*, *R. umbellata*, *Melia azedarach* var. *japonica*, *Rhus seccedanea*, *Rhus javanica*, *Indigofera pseudo-tinctoria*, *Alnus hirusuta* var. *sibirica*, *Alnus firma*, *Betula platyphylla* var. *japonica*, *Betula ermanii*, *S. commixta*, *Quercus mongolica* var. *grosseserrata*, and *Fagus crenata*

2.4 Development of nature restoration techniques

Yoshida and Yamadera (1989) introduced a method that applied TGM to vegetation in the mid- to late stages of ecological succession and in the climax stage. This approach built on older mixed-species approaches by specifically incorporating a mixture of seeds that included pioneer species (to provide rapid early coverage of the slope), mid-successional species (to provide cover for late-successional species), and climax species (to provide permanent stabilization and restore nature). Table 2 summarizes five studies of this method during the 1990s. This approach supports the production of a multiple-stratum community of woody plants by applying the TGM method on engineered slopes.

As seen in Table 3, many studies have been done since 1993 to revegetate engineered slopes using communities of woody plants. Slope seeding using mainly the endemic species listed in Table 3 has been recommended in various guidelines (Ehime Prefecture Engineering Works Part, 1999; Japan Road Association, 1999; Shikoku Construction Bureau of Japan Highway Public Corp, 1998; Shikoku Construction Bureau of Ministry of Land Infrastructure and Transport, 2002).

After 1996, the species chosen for revegetation have changed from soil-improving trees to endemic species such as evergreens. Accordingly, I have named this period "the period of development of nature restoration techniques using endemic woody species" (fifth period).

Table 3. Examples of seeding work in the fifth period.

Study	Introduced plant species or content
Yamamoto et al. (1993)	*Quercus glauca* and *Quercus phillyraeoides*
Hasegawa and Nishizawa (1998)	*Acer palmatum* var *matsumurae* and *Sorbus commixta* in a nature park
Saito et al. (1999)	*Quercus acutissima* and *Quercus serrata*
Shibata (2001)	*Q. phillyraeoides, Ligustrum japonicum, Rhaphiolepis umbellata*, *and Pittosporum tobira*
Akita et al. (2000)	*L. japonicum, R. umbellata, and Camellia japonica in a sedimentation area characterized by lapilli materials*
Ishida et al. (2000)	*C. japonica*, *Camellia sasanqua*, *L. japonicum*, and *R. umbellata*
Akita et al. (2001)	*R. umbellata*, *Q. phillyraeoides*, *Clerodendron trichotomum*, *Buddleja venenifera*, *Melia azedarach* var *japonica*, *Eurya emarginata*, and *Ardisia sieboldii* in the Yakushima World
Ishida et al. (2001)	*A. palmatum* var *matsumurae*, *S. commixta*, and *Rhus seccedanea* at a gabion-stabilized slope
Inoue and Yoshida (2002)	Formation of a mixed evergreen and deciduous broad-leaved tree community (See section 3.3); *L. japonicum*, *R. umbellata*, *Rhus seccedanea*, *Acer palmatum*, *Elaeagnus umbellata*, *Zizyphus jujuba* var. *inermis*, *Hibiscus syriacus*, and *Hibiscus mutabilis*
Kida et al. (2002)	*Myrica rubra*, *Prunus lannesiana* var *speciosa*, *A. palmatum* var *matsumurae*, *L. lucidum*, and *R. umbellata*
Sasaki et al. (2003)	*Q. glauca*, *R. seccedanea*, *Euptelea polyandra*, and *Q. phillyraeoides*
Furuta et al. (2004)	Revegetation examples using a double-layer spraying system; *C. japonica*, *L. japonicum*, *Mallotus japonicus*, *Rhus javanica*, *Elaeagnus umbellata*, *Lespedeza bicolor* var. *japonica* and *Indigofera pseudo-tinctoria*
Furuta and Yoshida (2004)	Formation of a *Q. serrata–Quercus mongolica* var. *grosseserrata* community
Yamanishi et al. (2004)	Formation of a *Pinus thunbergii* forest in a seaside area
Yoshida and Furuta (2004)	Endemic woody species introduced several years after work at 10 sites; *Acer japonicum*, *A. palmatum*, *A. palmatum* var. *matsumurae*, *A. palmatum* var. *amoenum*, *Alnus hirusuta* var. *sibirica*, *Alnus firma*, *C. japonica*, *C. sasanqua*, *E. umbellata*, *Kerria japonica*, *Melia azedarach* var. *japonica*, *Prunus jamasakura*, *Myrica rubra*, *Q. glauca*, *Quercus myrsinaefolia*, *Quercus variabilis*, *R. javanica*, *R. seccedanea*, *Thea sinensis*, and *Viburnum dilatatum*
Yoshida and Morimoto (2005)	Effects of mixed seeding of Chinese-grown *Indigofera* spp. and evergreen broadleaved trees; *C. japonica*, *C. sasanqua*, *R. umbellata*, and *Ligustrum obtusifolium*

3. FORMATION OF A COMMUNITY OF WOODY PLANTS ON ENGINEERED SLOPES

Three examples of nature restoration methods based on seeding using the organic TGM method on engineered slopes are discussed in this section. In these examples, no exotic woody or grass species were used.

3.1 Formation of an evergreen tree community (Case Study A)

In this example, researchers seeded evergreen trees on a rocky-engineered slope in Mie Prefecture. They sprayed a 6-cm-thick organic base to serve as a base for plant cultivation (Photo 1).

Germination of all plants was confirmed within 1 month. *Indigofera pseudotinctoria* had become the dominant species within 5 months and had attained a coverage class (C) of 3 based on the Braun-Blanquet method, an average height growth (H) of 0.3 m, and a density (D) of 35 plants/m^2. Hereafter, I will use these abbreviations and omit the units. After 2 years and 5 months, *I. pseudotinctoria* had reached C5, H1.3, and D5.0. *Melia azedarach* var. *japonica* (C5, H3.1, D1.5) became the dominant species in the upper layer and *Ligustrum lucidum* (C5, H1.7, D9.0) was dominant in the lower layer. After 3 years and 5 months, *I. pseudotinctoria* had declined to C2, H1.8, and D3.0. However, evergreen *M. azedarach* var. *japonica* (C3, H3.4, D1.3) became the overstory species, and *R. umbellata* (C4, H1.3, D11.8) and *L. lucidum* (C4, H2.3, D4.5) became the dominant understory species after 9 years and 7 months.

Currently, after 15 years and 1 month, *M. azedarach* var. *japonica* (C2, H4.7, D0.1) dominates the overstory, *L. lucidum* (C3, H3.1, D5.2) and *Rhus seccedanea* (C2, H3.1, D0.1) dominate the middle of the canopy, and *R. umbellata* (C4, H2.4, D12.8) had become the dominant understory species. The initial dominant species, *I. pseudotinctoria,* declined completely over time (Yoshida and Furuta, 2004).

3.2 Formation of a deciduous broadleaved tree community (Case Study B)

This example illustrates the restoration of a deciduous broadleaved tree community in a high-altitude (1220 m) cold area on a engineered slope. This study was done in Iwate Prefecture with a 3-cm-thick organic base sprayed to support plant cultivation (Photo 2).

Lespedeza bicolor var. *japonica* had become the dominant species (C2, H0.1, D79.5) after 10 months. Germination of *B. ermanii* and *S. commixta* were confirmed after 1 year and 10 months; their seeds have a long dormancy period. With woody *Betulaus* species growing well, *L. bicolor* var. *japonica* became dominant (C5, H1.5, D3.9). In addition, *A. hirsuta* var. *sibirica* (C3, H1.5, D0.5), *B. platyphylla* var. *japonica* (C3, H1.0, D2.4), and *B. ermanii* (C3, H0.6, D1.4) became dominant after 4 years.

The growth of these species was generally very slow, perhaps due to the fact that snow remained at the study site until June. However, by 8 years and 11 months, *B. platyphylla* var. *japonica* (C4, H2.2, D6.6) dominated the overstory and *B. ermanii* (C4, H1.8, D6.9) and *S. commixta* (C2, H0.8, D1.0) began dominating the understory. After 11 years and 11 months, *B. platyphylla* var. *japonica* (C4, H3.0, D5.3) and *B. ermanii* (C3, H2.5, D5.3) dominated the overstory, followed by *A. hirsuta* var. *sibirica* (C2, H4.0, D0.8) and *S. commixta* (C2, H2.5, D1.0), *Q. mongolica* var. *grosseserrata* (C1, H1.5, D0.2), *Fagus crenata* (C1, H1.5, D0.8), and *L. bicolor* var. *japonica* (C1, H1.5, D0.2).

After 13 years and 8 months, pressure from downhill creep of the snowpack had distorted the shape of the stem where it joined the roots. However, *B. ermanii* (C4, H3.3, D2.0) and *S. commixta* (C4, H3.2, D1.5) had become the overstory species, followed by *B. platyphylla* var. *japonica* (C3, H3.4, D2.0), *A. hirsuta* var. *sibirica* (C1, H3.1, D0.2), *Q. mongolica* var. *grosseserrata* (C1, H0.8, D0.2), *F. crenata* (C1, H2.2, D0.8), and *L. bicolor* var. *japonica* (C1, H0.7, D0.2) (Yoshida and Furuta, 2004).

3.3 Formation of a mixed evergreen and deciduous broadleaved tree community (Case Study C)

In this example, researchers revegetated road engineered slopes in industrial park in Nagasaki Prefecture using a 3-cm-thick organic base layer. A variety of revegetation species were used to create a park-like structure. These included trees chosen for their autumn coloration, as well as flowering and fruiting trees (Photo 3).

Germination of all plants was confirmed after 7 months. *Lespedeza bicolor* var. *japonica* (C4, H1.0, D9.0) and *I. pseudotinctoria* (C3, H1.5, D1.1) dominated the site, with *Zoysia japonica* also abundant (C5, H0.1, not counted D) by 1 year and 4 months. Four months later, *Z. japonica* had declined as a result of competition from woody species. After 3 years and 1 month, *Elaeagnus umbellata* (C3 to 4, H2.1, D8.0), *L. bicolor* var. *japonica* (C3 to 4, H1.6, D1.9), *I. pseudotinctoria* (C3 to 4, H2.3, D1.1), and *Acer palmatum* (C3 to 4, H0.7, D2.0) had become the dominant overstory species, and *R. umbellata* (C3 to 4, H0.5, D18.4) had become the dominant understory species.

After 6 years and 2 months, *R. seccedanea* (C2 to 4, H5.0, D0.6) had become the dominant overstory species, *A. palmatum* (C2 to 4, H2.0, D1.1) and *I. pseudotinctoria* (C2 to 3, H2.9, D0.6) were the dominant species below the canopy, and *E. umbellata* (C3 or less, H3.2, D0.1), *Hibiscus mutabilis* (C1 or less, H1.8, D0.3), *R. umbellata* (C4 to 5, H1.5, D11.7), and *L. japonicum* (C1 to 2, H1.5, D0.6) had become the dominant understory species.

Photo 1. An example of an evergreen tree community established using the TGM method (Case Study A). Left: before, Right: After 15 years.

Photo 2. An example of a deciduous broadleaved tree community established using the TGM method (Case Study B). Left: before, Right: After 12 years.

Photo 3. An example of formation of an evergreen and deciduous broadleaved tree community established using the TGM method (Case Study C). Left: After 4 months, Right: After 6 years.

As a result of this restoration work, a beautiful natural landscape could be observed from the spring green foliage to the colors of autumn leaves. In addition, several bird nests were confirmed in the plant community. The newly established plant community became a habitat for some wild animals (Inoue and Yoshida, 2002).

4. BASIC PRINCIPLES OF REVEGETATING SLOPES FOR NATURE RESTORATION

The main objective of slope revegetation in Japan has changed rapidly in recent years. In the past, revegetation was used primarily to prevent erosion. However, the goal has now become to restore nature. As demonstrated by the case studies in the previous section, seeding allows the creation of endemic communities of woody plants. In particular, TGM makes this possible by allowing rapid restoration of devegetated surfaces that would otherwise be difficult to revegetate.

In a natural community, landscape restoration through revegetation serves a variety of functions. It can improve slope stability, restore the ecosystem quickly, conserve biodiversity, and blend the revegetated site with the surrounding landscape.

As Yamadera et al. (1993) pointed out, it is very difficult to restore a community when restoration is impeded by human interference. To create or restore a natural community, it is necessary to develop a plant community in which the species can survive without human assistance. Humans, therefore, should support rather than control the survival of these species.

It is important to select a suitable slope revegetation method. For successful revegetation, a suitable goal must be chosen based on the slope's condition, and a variety of species should be used for revegetation rather than a monoculture; pioneer and mid-successional plants should be combined with climax species, and endemic plants should be used. Seeding should also be chosen so as to stabilize the slope and encourage natural succession of the forest that develops.

4.1 Setting a suitable revegetation goal for the actual slope conditions

Generally speaking, a engineered slope is not a suitable environment for plant growth, since this type of landscape is often characterized by rocky conditions and shallow or absent soil. Therefore, it is not surprising that engineered slopes are one of the most difficult landscapes to restore.

As a result, it is important to combine revegetation with the establishment of an appropriate foundation to make the growing environment less challenging for plants. If the goal is to reproduce a community of endemic woody plants, defining this goal during the early stages of the revegetation process is very important. Specifically, a suitable plant community such as the one shown in Table 4 should be chosen based on two conditions: first, the main species should eventually dominate the study site, and second, the outward form should resemble a natural vegetation community (Slope Revegetation Research Group, 2004).

Constructed solid structures covered with enough soil to permit planting will allow vegetation to recover on the slope. However, this method is very expensive and the vegetation community requires considerable maintenance. As a result, it is important to find a more cost-effective method, such as the various TGM approaches.

Table 4. First revegetation target of plant community (Slope Revegetation Research Group, 2004).

Main species	Outward form of community
Hearbaceous species and grasses	Grassy plain
Woody pioneer species	Bushes (shrubs) or forest
Mid- to late successional species	Bushes (shrubs) or forest

4.2 Seeding with mid- to late-successional and climax species in addition to pioneer plants

Revegetation must eventually establish a self-sustaining plant community. This means that it is necessary to seed with species that can rapidly cover and begin to improve damaged sites and also fertilize the soil (i.e., pioneer species), especially in areas where the site has lost its topsoil. As well, mid-successional species should be included to develop an increasingly complex plant community, and climax species should be included to help form the final community.

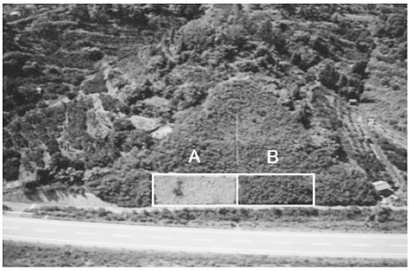


Photo 4. A photograph of revegetation after 6 years (1981).

Rapid revegetation using exotic grasses was applied on site A and rapid reforestation using mainly leguminous species was applied on site B.

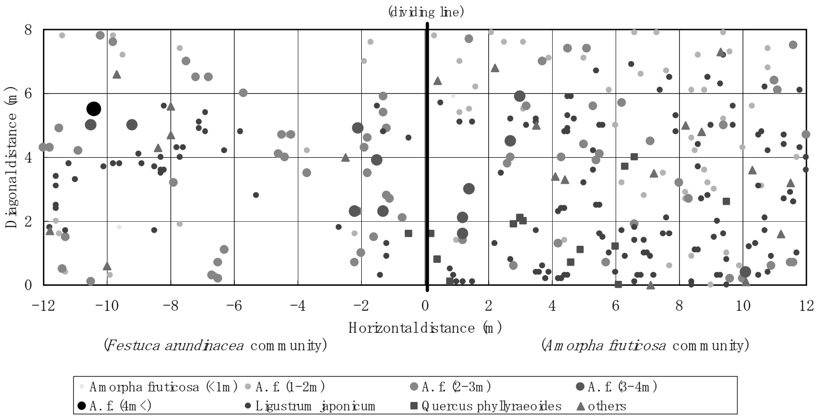


Figure 2. Comparison of two different plant communities after 24 years.

In the *Amorpha fruticosa* community (site A of Photo 4), plant succession occurs faster than in the *Festuca arundinacea* community (site B of Photo 4). The presence of a community of woody plants hastens natural invasion by evergreen trees by means of seed dispersal by birds and small animals that cache seeds.

When comparing plant succession in areas where grasses (*Festuca arundinacea*) and woody (e.g., *A. fruticosa*) plant communities have been established using the TGM method on rocky engineered slopes (Photo 4). After 24 years, the woody plant community became more successfully established (Figure 2). Studies have shown that the woody plant community acts as a habitat for birds and small animals, and that these species disperse seeds, allowing natural succession of the evergreens (Yoshida, 2000, 2003).

The speed of the recovery depends on when the seeding work is done. Figure 3 provides general guidelines for the vegetation sere at different time periods. When restoring engineered slopes near an expressway (Hoshiko, 1999), nature restoration techniques using endemic woody species should be used, with a combination of seeds from pioneer, mid- to late-successional, and climax species. This approach improves restoration of the slope. Compared to an approach in which only exotic grass species are selected, this approach produces not only higher slope stability but also restores the landscape more rapidly, with minimal subsequent tending required.

Current slope revegetation work introduces herbaceous plants or woody pioneer plants and leaves the resulting community to undergo natural succession. However, successful natural invasion that would blend the resulting community with the surrounding landscape is very difficult to achieve. Therefore, it is necessary to include seeds of species from later successional stages that are found in the surrounding natural environment.

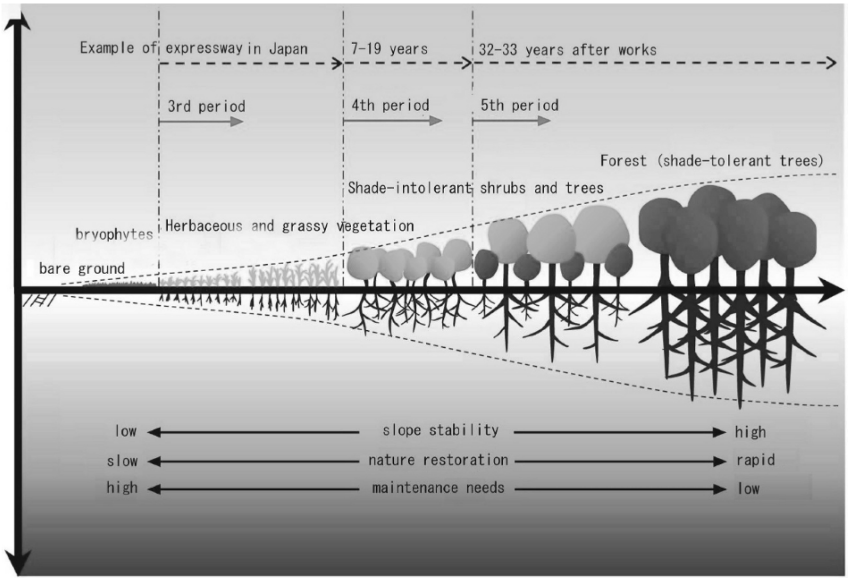


Figure 3. Illustration of the vegetation sere at different time periods after revegetation.

Nature restoration techniques using a mixture of endemic woody species can restore shade-intolerant mixed woodland 32 to 33 years earlier than revegetation using only grassy species and 7 to 19 years earlier than reforestation using mainly leguminous species.

4.3 Seeding work as an effective method for slope stabilization

Slope stability is one of the most important objectives of slope revegetation; this is true both because collapse of slopes can have serious negative environmental and engineering consequences and because unstable slopes will prevent successful revegetation. Past studies such as following photographs have demonstrated that seeded plants develop better than planted vegetation. After 7 years of revegetation work, Yamadera et al. (2002) found that trees that developed from seed formed stronger root systems than planted trees (Photo 5). In addition, Fukunaga (1996) suggest that seeded vegetation becomes established quickly (Photo 6). Furthermore, the main roots of seeded trees can often expand into gaps in the underlying rocks and lateral roots can expand more widely, possibly intertwining with the roots of other trees (Fukunaga et al., 1997).

The differences in the two types of root system are shown in Figure 4. When designing a restoration system for slopes, it is necessary to form plant communities that will develop strong root systems (i.e., to favor the use of seeds) rather than focusing on the aesthetics of the planting work.

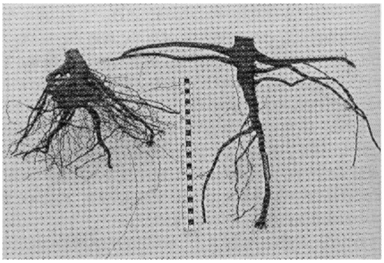
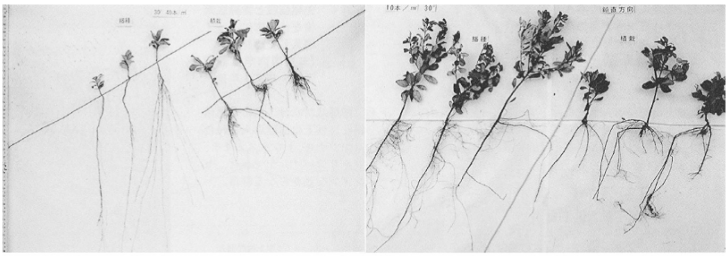


Photo 5. The root conditions of planted (left) and seeded (right) Quercus phillyraeoides tree after 7 years. (Yamadera et al., 2002).



Seeded Planted Seeded Planted

Photo 6. The root conditions of seeded and planted Rhaphiolepis umbellata trees (Fukunaga, 1996).

The left photograph shows the results 1 year after work and the right photograph displays the root condition after 2 years.

The planted trees (left) have less-abundant roots with less intertwining between trees, and often fail to penetrate deeply into the soil. In contrast, the roots of seeded trees (right) are more abundant, form a denser network, may become intertwined, and penetrate more deeply into the soil.

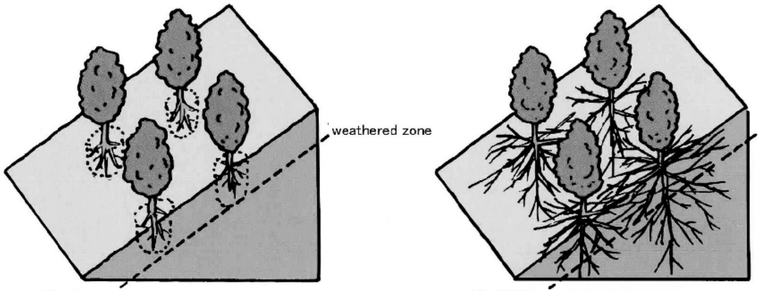


Figure 4. Conditions of the roots of planted and seeded trees.

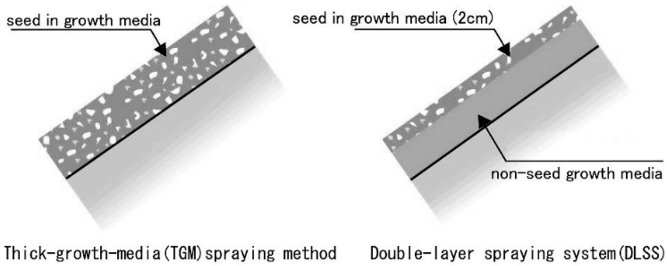


Figure 5. A comparison of the thick-growth-media (TGM) method and the double-layer spraying system (DLSS).

5. CONCLUSIONS

Seeding in Japan has a long history of the development of increasingly effective revegetation techniques. Further improvement of slope restoration technology has been reported, including mixed seeding using the TGM method (Yoshida, 2002) but supplemented by the development of a double-layer spraying system (DLSS) to improve the use of seeds of endemic woody plants and reduction of the amount of seeds required (Figure 5).

In the DLSS method, spraying occurs in two layers that are produced during the same pass with the spraying equipment: the first layer contains no seeds and serves primarily as the base for cultivation, and the second (top) layer contains the seeds. This offers the advantage of creating both layers using a single spraying process. In the past, the TGM method required workers to spray each layer separately if managers decided that a double layer was required. Because this was more difficult and expensive, double-layer spraying based on previous TGM methods has generally not been applied; that is, workers sprayed only a single layer containing both seeds and the base layer. Thus, the DLSS method makes more effective use of available seed and reduces the cost of the operation (Yoshida et al., 2004).

The technique of restoration of slopes is developing continuously. The Japan Society of Revegetation Technology (2002) suggested revegetation as a means to conserve biodiversity and proposed the basic principles of slope revegetation for nature restoration (Slope Revegetation Research Group, 2004). However, to expand this technology, the development of technology for the storage of seeds of woody plants, especially recalcitrant seeds (Akimoto et al., 2001, 2002, 2004), and technology for early detection of germinability of these seeds (Cho et al., 2004) are both necessary.

Most revegetation work has used seeds buried in the soil (i.e., in the soil seed bank). However, exotic species may also be present in this soil and can have a potentially devastating impact on Japanese ecosystems. Slopes consisting of naturalized and exotic plant species have limited usefulness in terms of slope restoration because they are less well adapted to the environment than endemic species. Therefore, seeding with a mixture of endemic species can be an effective and powerful tool for restoring slopes if seeding is combined with the development of artificial seed banks containing only the seeds of endemic species.

Japan's Invasive Alien Species Act was implemented in June 2005. Slope revegetation has emerged as a necessary technology to help combat invasive species by creating more vigorous ecosystems that can better exclude the invaders. I hope to contribute toward the technical development of slope restoration as a means to prevent both erosion and invasion by damaging foreign species.

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