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Breeding and genetic resource conservation of forest trees in Japan

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Abstract

Forests are valuable resources and essential for both ecosystem and human life. The breeding and genetic resource conservation of forest trees are two important means to secure the sustainability and profitability of forestry and forest management. In this presentation, the author presents the current status of the breeding and genetic resource conservation in Japan, emphasizing some unique approaches in Japan to realize conservation and use of the forest tree genetic resources.

Key words: *ex situ* conservation, forest tree breeding, genetic resource conservation, *in situ* conservation, National Forest

Introduction

The Forests and trees in the forests are valuable resources for both the ecosystem and human life. Two kinds of regeneration methods are common after harvesting from forests: natural regeneration and planting trees. In recent decades in Japan, plantation forestry has been the preferred means of securing the value of forests as resources. Forest owners require better seedling stocks for plantations on their land. Among various ways to obtain "better stocks," tree breeding is one of the most effective practices.

In Japan, the national government, in cooperation with prefectural (local) governments and other stakeholders, is responsible for forest tree breeding or the genetic improvement of forest trees. Forest Tree Breeding Center (FTBC) have been in charge of Japanese forest tree breeding. FTBC is a part of Forestry and Forest Product Research Institute (FFPRI), Forest Research and Management Organization (FRMO), which is a nationally owned institute (one of the National Research and Development Agencies). Another role of the FTBC is conserving Japanese forest trees' genetic resources, essential background for tree breeding.

This paper will review the breeding and genetic resource conservation of forest trees in Japan.

Overview of Japanese forests and forestry

Japan is a small country consisting of four main and many small islands and having only 378 thousand km^3 of land with 125 million people. However, the climate is highly variable within the country. Forests cover two-thirds of Japan, which is stretches over 3,000 km from north to south, from 45.5ºN to 20.4 ºN in latitude. The forest types in Japan include boreal, cool-temperate deciduous, warm temperate evergreen, and sub-tropical forests. Thanks to the high precipitation and relatively humid condition, Japan is rich in vegetation and is one of the biodiversity hotspots in the world (Conservation International 2021). The number of species in Japanese forest trees is estimated at approximately 1,500 (Forestry Agency 2012). Traditionally, Japanese people used many species from native forests in various ways. Recently, however, most of the timber production is from plantations. The annual harvest and planted area in 2018 were 22 mil m^3 and 29,500 ha, respectively (Forestry Agency 2020a, b). Conifers cover 90% and 93% of the timber production and planted area, respectively.

Forest tree breeding

As seen in the previous section, conifers are the main species for plantation forestry in Japan. Therefore, conifers are the main target species for forest tree breeding: sugi (Japanese cedar, *Cryptomeria japonica*), hinoki (Japanese cypress, *Chamaecyparis obtusa*), akamatsu (Japanese red pine, *Pinus densiflora*), kuromatsu (Japanese black pine, *Pinus thunbergii*), karamatsu (Japanese larch, *Larix kaempferi*), todomatsu (Sakhalin fir, *Abies sachalinensis*), and aka-ezomatsu (Sakhalin spruce, *Picea glehnii*). The first two are Cupressaceae and the others are Pinaceae, and all the species targeted in the forest tree breeding programme are native to Japan.

The national programme of forest tree breeding started in the 1950s. Among the seven targeted species, *C. japonica*, due to its importance, is the most advanced in the breeding programmes. Seed orchards with the second generation plus-trees have been established, and the third generation plus-trees have been selected. *C. japonica* is a very adaptive species and can grow in various conditions in almost all areas in Japan, excluding northern Hokkaido and southern Ryukyu and Bonin islands. Therefore, it is very suitable for Japanese forestry. As a result, *C. japonica* occupied 36% of all species in the annual planted area in 2018 (Forestry Agency 2020a, b). *C. obtusa* can grow in the southern half of Japan. This species grows slower than the other species but can produce better quality timber. *L. kaempferi* favours cooler climates and dryer conditions. Sixty-five percent of the annual planting was done in Hokkaido in 2018, although the species is not Hokkaido

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native but from central Honshu Island. In Hokkaido, a *L. kaempferi* and *L. gmelinii* var. *japonica* (its origins are the Kuril and Sakhalin islands) hybrid has been found to have superior resistance to a kind of vole and growth and wood properties. *A. sachalinensis* and *P. glehnii* are Hokkaido native and used only in Hokkaido. *P. densiflora* and *P. thunbergii* were originally targeted for timber and pulp production; however, those forests have been infected with pine wilt disease for more than 50 years in almost all areas in Japan, excluding Hokkaido. As a result, recent efforts in breeding have focused on improving the resistance to the disease.

The climate varies in temperature and snowfall, so to minimize the interaction between genetics and the environment, five breeding regions were established (Fig. 1) and each region is also divided into several breeding districts. The FTBC and four breeding offices look after five breeding regions, and additionally, five stations are working on area-specific issues.

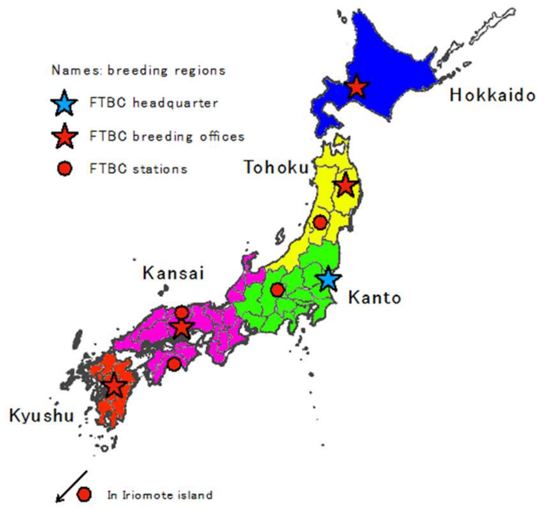

Figure 1. The map of Japan representing the five breeding regions. The lines indicate the borders between prefectures.

Table 1. Protected forests in the National Forest system used for *in situ* genetic resource conservation of the forest trees at the end of the 2019 fiscal year (FTBC 2020).

Type	Description	Number	Total area (ha)
Forest biosphere reserve	To protect native ecosystems. Very large area (>2000 ha). No specific target species.	43	700,987
Biotic community protection forest	To protect ecological communities of locally unique and important. Large area (>300 ha). No specific target species.	100	223,518
Rare population protection forest	To protect rare species or populations. Relatively small area. Each forest is designated with target species.	540	40,267

Genetic resource conservation of forest trees

Wood and paper products are now essential for human life. Timber production in the future will rely on resources planted today. Therefore, the role of forest tree breeding is enormous. To enhance the use of various species for forestry, conserving forest trees' genetic resources is an important task. Genetic resource conservation is also working to maintain biodiversity.

Genetic resource conservation of forest trees is managed in two ways, *in situ* and *ex situ*, the same as other plant species.

The National Forest of Japan has a scheme of "protected forests." This program is more than a hundred years old. Today, three kinds of forests are protected and maintained by the National Forest with the assistance of the FTBC (Table 1). The protected forests preserve habitat for wild plants and animals, maintain biodiversity, and conserve *in situ* genetic resources. National parks and other systems for protecting the natural environment and ecosystem also play a role in genetic resource conservation.

Table 2 shows the number of accessions in *ex situ* conservation organised and maintained by the FTBC. It includes clone banks for forest tree breeding. However, it excludes 2,500 ha progeny trials and 1,000 ha seed orchards, and scion gardens used to produce seedling/cutting stocks (trials and orchards are usually owned and managed by the National Forest or prefectures). Usually, *ex situ* conservation mainly consists of clone banks, seed orchards, provenance trials, and progeny trials in many countries. However, *ex situ* conservation by the FTBC includes many species and genotypes other than species targeted in the breeding programme. This is a unique feature of the genetic resource conservation of forest trees in Japan. The FTBC maintains living genetic resources in clone banks on the campus (a part of the accessions propagated from seeds). The FTBC also has facilities for low-temperature storage (–20ºC freezer or under liquid nitrogen) for seeds and pollen.

Table 2. The number of accessions in the *ex situ* genetic resource conservation by the FTBC at the end of the 2019 fiscal year (FTBC 2020).

Type	Number of Accessions
Living tree	29,356
Seed	11,298
Pollen	4,059
DNA	432

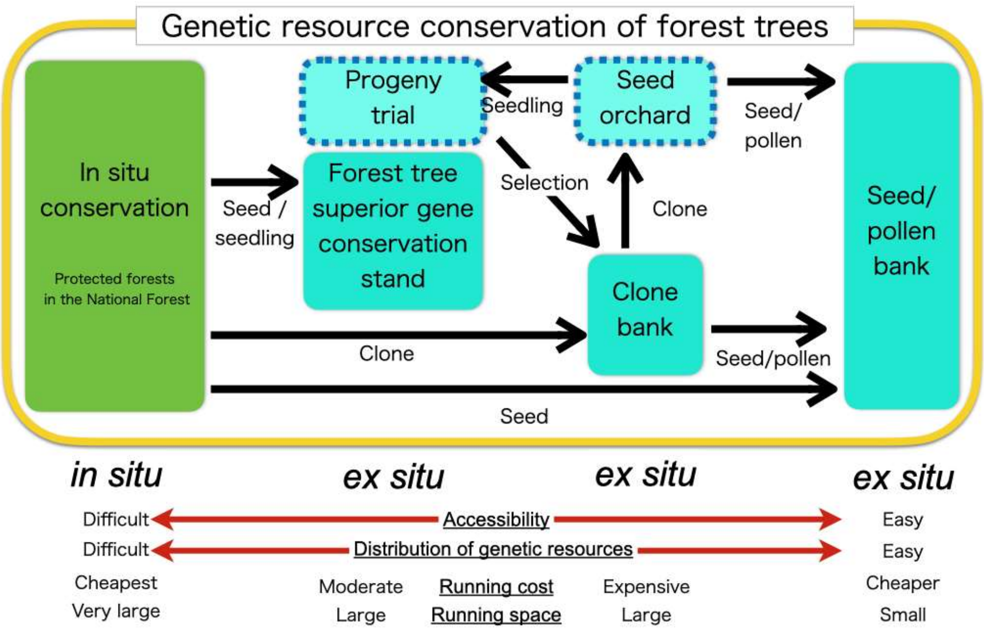

Figure 2. System of the genetic resource conservation of forest trees in Japan. Progeny trials and seed orchards are mainly for breeding rather than genetic resource conservation. Note that clones of superior trees in breeding programmes are not only come from *in situ* conservation but also from plantation forests and non-protected natural forests.

Researchers who want to investigate genetic resources can obtain accessions from the FTBC in the form of seeds, pollen, scions for grafting and cutting, and seedlings or rooted cuttings through a distribution programme.

Another unique feature of the Japanese *ex situ* genetic resource conservation is "forest tree superior gene conservation stand." These stands are plantations consisting of seedlings grown from seeds collected from superior stands before those superior stands were harvested. In the 1960s and 1970s, there was a strong demand for timber in Japan. During those days, many superior forests, natural and planted, were harvested to meet the demand. To preserve the genes of the superior forest stands, seeds expected to represent the superiority were collected from the stands and successor stands were established. The programme started in 1964, and at the end of the 2019 fiscal year, there were 234 stands, covering 931 ha in total.

Figure 2 summarises the system of genetic resource conservation of forest trees in Japan. We use several methods depending on the importance and rarity of each genetic resource. It also depends on the cost of conserving and accessing to the genetic resource. For example, think about a genetic resource in a protected forest 500 km away, one-day drive plus a ten-hour walk. When the clone of the genetic resource is growing on the campus at the FTBC, only 5-minute walk is necessary without any travel expenses. Therefore, we continue to collect genetic resources from all over Japan. However, clonal propagation and growing trees costs money, so it is not surprising the most clone banks consist of superior genotypes, such as plus trees, in the breeding programme. Some plus trees in the breeding programme were selected from protected forests for *in situ* genetic resource conservation as well as those from plantation forests and non-protected natural forests. FTBC also works on establishing clone banks and collecting seeds of species, which are not focused in the breeding programme, from various natural forests including *in situ* conservation forests. These efforts enhance the accessibility to those genetic resources.

Managing genetic resource conservation of forest tree

Figure 3 shows examples of clone bank in *ex situ* conservation. Establishing clone banks for forest trees is growing trees. We need to take care of trees. For example, at nursery and in the first several seasons after planting, we need to be careful with growth of root stock. It may happen that root stock grows better than grafted scion. Usually, row-plot design is taken for clone banks (Fig. 3). This design is better to maintain. We put a sign board at each row with the name and the other information of each clone. We make maps for the planting arrangement. We need to keep genetic resources in a long time, so that the managing cost becomes higher in clone banks.

Another way, *in situ* conservation requires usually lower cost. However, it is not "maintenance-free". Protected forests are protected from harvesting by human but may be suffered from succession in forest dynamics. Therefore, the conservation programme in Japan has "monitoring" scheme for the protected forest. The monitoring is managed as a part of protected forest project operated by the National Forest and is done usually once per five years.

Differed from the regular monitoring scheme run by the National Forest, many forest geneticists try to reveal the genetic diversities of various species at various locations. For such cases, the protected forests in the National Forest are used as materials along with the other stands, which are either protected by the different schemes or non-protected. Those studies focused on various objectives and on various species in the various conditions of conservation, for example, a main forestry species, Sugi (Kimura et al. 2014, Tsumura et al. 2020), a declining species by a pest, Akamatsu (Iwaizumi et al. 2019), and an endangered species, Togasawara (*Pseudotsuga menziesii*) (Tamaki et al. 2018). Those studies are not monitoring with regular intervals and usually funded by competitive grants. However, the knowledge from those studies may be useful to achieve efficient conservation.

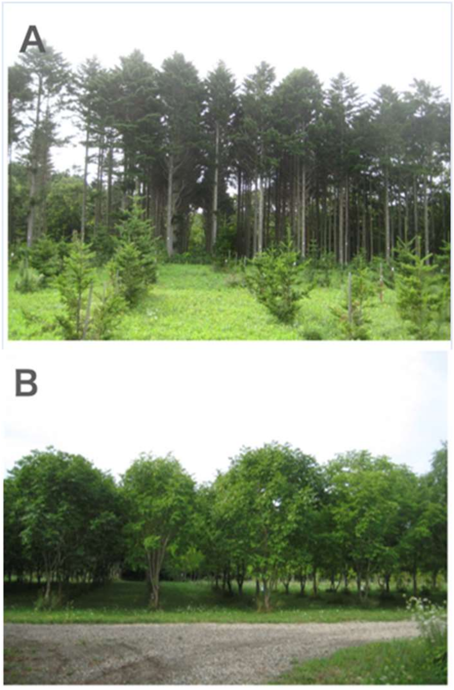

Figure 3. Clone banks of todomatsu (*Abies sachalinensis*) (A) and yachidamo (*Fraxinus mandshurica*) (B). Those were propagated by grafting. In A, a younger bank (7-year-old) is in front of an older bank (54-year-old).

Many problems need to be solved in genetic resource conservation. For example, there are many endangered species in Japan, but many of them are in the Ryukyu and Bonin islands. Growing such species is difficult in the main islands, where is too cold for *ex situ* conservation. Another example is that seeds of some species are very difficult to store and even germinate to confirm the storage efficiency. We continue to collect and preserve valuable genetic resources. Of course, funding is always insufficient. Therefore, conservation activities should balance the cost of conservation and the benefit accessibility.

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