

Chapter 11

Seedling Production



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Abstract Under the Stand-based Silvicultural Management System, conifer seedlings are planted in natural forests to assist natural regeneration. For this purpose, seedlings of *Abies sachalinensis*, *Picea jezoensis*, and *Picea glehnii*, which are major species of natural forest, are raised in a nursery at the University of Tokyo Hokkaido Forest (UTHF). Clonal seed orchards have been established as seed sources for *A. sachalinensis* and *P. jezoensis*, while seed stands are designated in natural forests for *P. glehnii*. To minimize genetic disturbance and maintain genetic diversity, ortets of seed trees that constitute the seed orchards were selected from natural forests within the UTHF. The seedlings are outplanted after a raising period of 6–7 years. Most of the raised seedlings are bare-rooted, while containerized seedlings are currently under trial. During the raising period, some diseases, such as *Racodium* snow blight and damping-off, threaten seedling production. These diseases are managed through cultural and chemical control methods. Care should also be taken to mitigate damage caused by extreme climatic events such as late frost, heat waves, and drought under ongoing climate change.

Keywords Nursery · Seed orchard · Genetic disturbance · Genetic diversity · Disease control · Bare-rooted seedling · Containerized seedling

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11.1 Introduction

At the University of Tokyo Hokkaido Forest (UTHF), seedlings are planted to assist the natural regeneration of native conifers under the Stand-based Silvicultural Management System (refer to Chap. 10). Exceptions are made for larch plantations in the plantation working group, where purchased seedlings of introduced tree species are planted as monocultures. Therefore, the target species for seedling production are limited to the native species, including *Abies sachalinensis* (Sakhalin fir, abbreviated as *As* hereafter), *Picea jezoensis* (Yezo spruce, abbreviated as *Pj*), and *Picea glehnii* (Sakhalin spruce, abbreviated as *Pg*). These species are not only dominant in the natural forests of the UTHF but also key species that characterize the hemiboreal conifer-broadleaf mixed forest in this region (refer to Chap. 5).

Seeds for raising these seedlings are collected within the UTHF to minimize disturbances to species and/or the genetic composition of the natural forests. This principle was established in 1996, although seedlings from outside the UTHF were purchased to compensate for shortages during the restoration following the typhoon damage in 1981. Additionally, seedlings of exotic species were planted during restoration after the forest fires in the 1910s and the typhoon damage in 1954 (refer to Chap. 13).

Seedlings have been produced in the nursery of the UTHF since its establishment in 1906 (Fig. 11.1). This nursery covers an area of 3.82 ha and is located on a river terrace of the Sorachi River, with lowland soil derived from river sediments. A total



Fig. 11.1 Nursery of the University of Tokyo Hokkaido Forest. (Photo by Daisuke Sakaue, October 18, 2016)

of 18,000 seedlings (7400 for *As*, 7900 for *Pj*, and 2800 for *Pg*, on average) are produced annually for outplanting, with 17,000 being bare-rooted and 1000 containerized seedlings (The University of Tokyo Hokkaido Forest 2022). This chapter describes the characteristics and the outline of seedling production at the UTHF.

11.2 Seed Sources and Seed Preparation

When collecting seeds, minimizing genetic disturbance and maintaining genetic diversity are emphasized. Therefore, it is crucial to use proper seed sources for each species. Cones with open-pollinated seeds of *As* are collected from a clonal seed orchard (Fig. 11.2) established in the 72A subcompartment of the UTHF in 1960. This seed orchard covers an area of 1.0 ha and consists of 16 clones. The ortets of these clones were plus trees selected from natural forests in the UTHF (refer to Chap. 10) that were significantly superior to surrounding trees in height, diameter, straightness, and branch height. Ramets of these plus trees were propagated by grafting during the period 1956–1958. A total of 958 ramets, with 33–70 ramets per clone, were planted at 3-m intervals in a systematic square arrangement. No pruning has been conducted. The seed orchard is surrounded by farmlands and is approximately 1 km away from the forest, minimizing pollen contamination. Abundant



Fig. 11.2 Clonal seed orchard of *Abies sachalinensis*. (Photo by Susumu Goto, March 4, 2024)

seeds were first obtained in 1974. Cones with open-pollinated seeds have been collected by felling seed trees in mass-fruiting years since 1985, and thinning seed trees has been conducted simultaneously. Recently, abundant fruiting has not been observed, which is speculated to be due to disturbed pollen flow caused by the high density of seed trees (Sakaue et al. 2019). Therefore, the stem density was reduced to 205 stems/ha by thinning in 2022. Further investigations into pollen flow within seed orchards and from external sources are necessary to evaluate the productivity and quality of seeds. Additionally, understanding the differences in progeny characteristics among maternal clones and the adaptivity of progenies at planted sites is needed to improve the seed orchard.

Cones with open-pollinated seeds of *Pj* are collected from naturally growing healthy trees that are felled in areas where logging operations are conducted during years of abundant fruiting. This method, adopted since the 2000s, is labor-intensive, because the felled trees from which cones are collected are scattered throughout natural forests, and the collection sites are far from the nursery. Moreover, the genetic characteristics of seed trees vary among harvesting years, and excellent seed trees are lost once seeds are collected. There is also concern about the decreasing number of suitable seed trees due to the recent decrease in *Pj* in natural forests. In the past, a seed stand was designated and cones were collected by climbing seed trees. However, the seed stand was abolished after severe damage by the typhoon in 1981. Consequently, a seed orchard was newly established in 2017 (Sakaue et al. 2018, Fig. 11.3). This clonal seed orchard covers a total area of 0.73 ha, with 201 ramets from 60 clones planted at 5-m intervals (400 trees/ha). The ortets of these



Fig. 11.3 Clonal seed orchard of *Picea jezoensis*. (Photo by Daisuke Sakaue, August 25, 2022)

clones were selected from naturally growing trees throughout the major area of *Pj* distribution in the UTHF based on their superior characteristics, such as diameter, straightness, taper, and branch height compared to surrounding trees. The plus trees selected in the 1950s and 1960s were not used for ortets, because their branch height was too high to collect scions for grafting. Ramets were propagated by grafting during the period 2010–2014 in cooperation with the Hokkaido Regional Breeding Office, Forest Tree Breeding Center, Forest Research and Management Organization, Japan. The planting design was primarily based on a random arrangement, but adjustments were made to ensure that individuals of the same clone were not adjacent to each other and that no single individual was adjacent to multiple individuals of the same clone. To increase the number of clones as much as possible, the number of ramets of each clone was limited to a maximum of four. There are few *Pj* trees around the seed orchard, minimizing pollen contamination. Flowering has already been observed in several ramets since 2017, and seed harvesting is expected in the near future. This is the first establishment of a seed orchard for *Pj* in Japan.

Cones of *Pg* were previously collected from a designated seed stand in natural forests in the subcompartment 8A by climbing seed trees after open pollination (Fig. 11.4). In addition to this stand, cones of *Pg* were sometimes collected from *Pg* stands in the subcompartments 9B and 13B. Recently, the designated seed stand has declined and the designation has been canceled. New seed stands were designated in the subcompartments 10B and 27B in 2020. Seed stands require abundance of mature trees, but *Pg* grows sparsely in most natural forests, and *Pg*-dominant forests

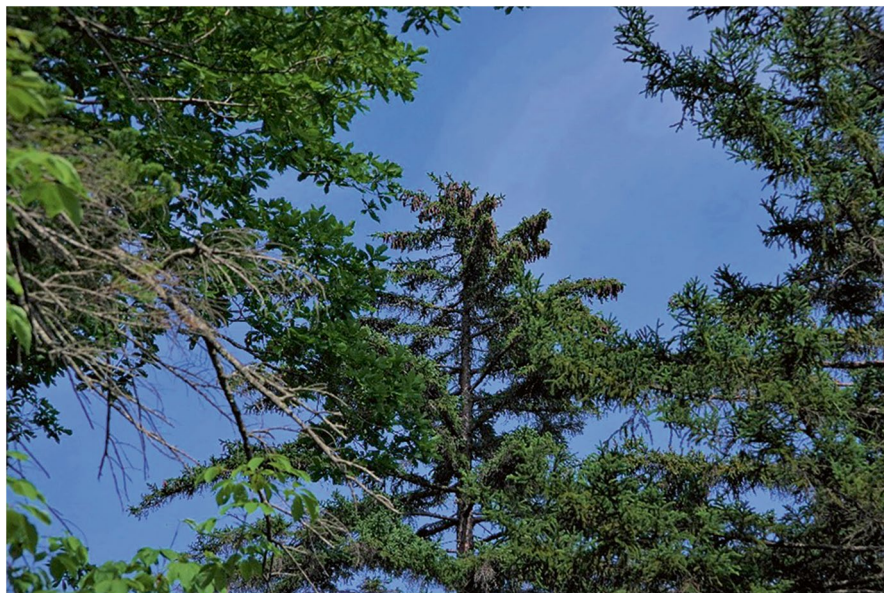


Fig. 11.4 Seed stand of *Picea glehnii*. (Photo by the UTHF, July 16, 2021, licensed under CC BY-NC-ND 4.0)

are limited to specific sites such as moors, rocky areas, lapilli, serpentine, and higher elevations. Because populations established in these habitats are isolated, the population size sufficient for random mating and the genetic diversity of the population should be examined when selecting seed stands (Goto et al. 2009, 2011).

For each species, cones are collected from late August to mid-September in years of mass fruiting. The collected cones are sun-dried, and winglets are mechanically removed from the obtained seeds. After the contaminants are carefully removed, the seeds are stored at -5°C . Seeds can be stored for more than 8 years (*Pj* and *Pg*) or 11 years (*As*) without losing their germination ability.

11.3 Nursery Practices for Bare-Root Seedling Production

In Hokkaido, the production of *As* and *Pg* seedlings has been widely conducted at the commercial level. In contrast, seedling production of *Pj* has been inactive, because it has been avoided in commercial plantations. The reasons include nursery diseases (refer to Sect. 11.5 for details), damage to young plantations, such as late frost injuries and bud galls caused by aphids (*Adelges japonicus*), and the fundamentally slow growth of *Pj* (Koshika and Seino 1966). In the UTHF, seedlings of *Pj* are raised stably using the following method, in addition to *As* and *Pg*.

The seedlings of the three species are raised using the same method, with bare-root seedling production taking six years. After sowing, germinated seedlings are kept for 2 years on seedbeds (Fig. 11.5) and then they are transplanted to new beds (seedling beds) and grown for 4 or 5 years (Fig. 11.6). As a result, 6- or 7-year-old seedlings are outplanted. The growth period of *As* and *Pg* in the UTHF nursery is longer than other forest nurseries in Hokkaido, where the process typically takes 4–6 years (2 years in seedbeds and 2–4 years in seedling beds).

Seeds are sown in seedbeds in late autumn (mid-October) to avoid labor concentration in spring, although they can also be sown in early spring. The number of seeds sown depends on the maturation rate of the seed lot. The expected density after germination in seedbeds is several thousand seedlings per square meter, which are then thinned to approximately 1000 seedlings/m² in the second spring. Seedlings are later transplanted at a density of 36 seedlings/m² to the seedling beds. During the third and fourth years, and if necessary, the second year as well, both lateral and longitudinal roots are pruned by a root-cutting plow attached with a tractor at seedling beds. Root pruning prevents excessive elongation of seedlings and encourages the emergence of fine roots. As a result, raised 6- or 7-year-old seedlings are outplanted from September to December during the final year of the raising period (fourth or fifth year in the seedling beds). Further details of these practices are described in Ogasawara (2001).

Fig. 11.5 Seed bed of *Picea jezoensis* maintained for two growing seasons. (Photo by Daisuke Sakaue, October 18, 2016)



11.4 Production of Containerized Seedlings

Recently, containerized seedling production has become common in Japan, including Hokkaido (Forestry Agency 2023). Containerized seedlings are grown in air-pruning cells without root looping, resulting in steady root balls. This characteristic enhances survival rates compared with those of bare-rooted seedlings by preventing root injury during outplanting and extends the suitable period for outplanting. Moreover, containerized seedlings require smaller planting holes and eliminate the need to backfill roots. Additionally, since containerized seedlings are portable, the timing of their bud flushing can be managed by storing them at cold temperatures, such as in a large refrigerator. This allows outplanted seedlings to avoid frost damage at planting sites, which are usually cooler than nurseries. Compared with bare-root seedling production, the production of containerized seedlings can save labor for weeding because few weed seeds are contained in the culture media.

The UTHF started to raise containerized seedlings of three native conifers, *As*, *Pg*, and *Pj*, in 2009 (Fig. 11.7). The production of containerized seedlings had already started at that time in Hokkaido, but no standardized systems were available for these three conifer species. The UTHF subsequently developed methods by collaborating with the Forestry and Forest Products Research Institute, Japan, and the

Fig. 11.6 Seedling bed of *Picea jezoensis* just before outplanting. (Photo by Daisuke Sakaue, October 18, 2016)



Forestry Research Institute of the Hokkaido Research Organization. As a result, the collaborating group created a manual for containerized seedling production for native conifers (“Short-term and healthy *Picea jezoensis* seedling production” Research Group 2014).

For all three species, seedlings grown in seedbeds for two years are transplanted to container cells with the capacity of 150 mL or 300 mL. In countries such as Sweden, which are advanced in the use of containerized seedlings, direct seeding into containers is common because of the high germination rate (Okada et al. 2012). In contrast, the accuracy of discriminating viable and nonfilled seeds is low in Japanese tree species for plantations. Therefore, seeds are sown in seedbeds to avoid containers containing many blank cells. After two years of growth in containers in a greenhouse, the seedlings can be used for outplanting (“Short-term and healthy *Picea jezoensis* seedling production” Research Group 2014). The cultivation conditions of the containers, such as fertilization, irrigation, and day length, were examined (Ogawa et al. 2013).

However, the growth of 3- or 4-year-old containerized seedlings (1 or 2 years in containers after transplanting) fell short of that of 7-year-old bare-root seedlings in early trials of outplanting due to their shorter initial heights (Owari et al. 2013; Goto et al. 2015; Kimura et al. 2023), although the survival rate of 4-year-old

Fig. 11.7 (a) Production of containerized *Picea jezoensis* seedlings (Photo by Susumu Goto, October 12, 2011). (b) Containerized *P. jezoensis* seedlings (300 mL) for outplanting (Photo by Susumu Goto, October 2, 2010)



containerized seedlings was comparable to that of 7-year-old bare-root seedlings. Consequently, 6-year-old containerized seedlings (4 years after transplanting to the container) are raised in the UTHF. Containerized seedlings were initially expected to have the potential to shorten the raising period via an intensive culture system. Since a longer raising period increases the risk of disease, pest, and climatic damage, further research is desirable to shorten the raising period.

One advantage of using containerized seedlings is their ability to be planted throughout the year, offering a solution for optimizing nursery operations. To facilitate this, Goto et al. (2013) attempted to store containerized seedlings in a refrigerator. In their study, they compared the survival rates between storage boxes made of standard and those made of Controlled Temperature Method (CTM) cardboard. CTM cardboard boxes have been shown to be effective for refrigerator storage (Fig. 11.8).

In the early 2000s, when the UTHF examined culture methods, the use of containers without side slits was common in Japan. However, in countries such as

Fig. 11.8 Survival of containerized *Picea jezoensis* seedlings after storage in a refrigerator. The survival rate was significantly greater for seedlings stored in a CTM cardboard box (left) than for those stored in a standard cardboard box (right). (Photo by Susumu Goto, October 2, 2010)



Sweden, containers with side slits were commonly used, because they improved rooting systems. At the UTHF, the use of side-slit containers has proven to be more effective than the use of nonslit containers in enhancing the survival rate of *As* seedlings during the 3-year raising period (Fukuoka et al. 2022), potentially due to the reduced moisture level in the containers. Diseases such as gray mold are frequently observed in *As* seedlings grown in nonslit containers. Conversely, the survival rates of *Pj* and *Pg* seedlings were slightly higher in nonslit containers than in those with side slits. Although the exact reason for this phenomenon remains unclear, the relatively high moisture content within nonslit containers may be advantageous for *Picea* species.

11.5 Nursery Diseases and Their Control

The major diseases in the nursery are *Racodium* snow blight¹ and damping-off (Figs. 11.9 and 11.10, respectively). Additionally, gray mold sometimes occurs severely (Fig. 11.11). For containerized seedlings, there are no conspicuous diseases thus far. Care should be taken against gray mold, because containerized seedlings tend to be overcrowded, resulting in a humid environment in which the disease easily occurs.

Pj and *Pg* seedlings are often severely damaged by *Racodium* snow blight, not only on forest floors but also in nurseries, whereas *As* seedlings are less affected than *Pj* and *Pg* seedlings. Small seedlings in seedbeds can be killed, because they bend down under snow cover, causing their bodies to be pushed against the ground surface where pathogenic fungi are present. In contrast, damage to larger seedlings older than 5 years is limited to the death of lower branches, because they don't bend down, except for their lower branches. Therefore, it is important to raise seedlings

¹The outline of *Racodium* snow blight and the taxonomical situation of its pathogen are described in Chap. 14.

Fig. 11.9 *Racodium* snow blight on 2-year-old *Picea jezoensis* seedlings at the seedbed. (Photo by Daisuke Sakaue, April 10, 2009)



Fig. 11.10 Damping-off of current-year-old *Picea jezoensis* seedlings at the seedbed. (Photo by Daisuke Sakaue, May 20, 2011)



Fig. 11.11 Gray mold on 6-year-old *Abies sachalinensis* (left) and *Picea jezoensis* (right) seedlings. (Photo by Daisuke Sakaue, July 14, 2014)

Fig. 11.12 Snow sheds installed over seedbeds.
(Photo by Daisuke Sakaue,
March 5, 2009)



with larger diameters that are less likely to bend down. The density of seedlings in the seedbeds is also important, because sparsely growing seedlings are more likely to bend under snow pressure. To reduce snow pressure and prevent seedlings from bending, snow sheds are installed over seedbeds during winter to minimize snow accumulation (Fig. 11.12). Additionally, the fungicide oxine-copper (copper 8-hydroxyquinoline, 8-quinolinol) is sprayed before the seedlings are covered with snow in autumn. After germination, the surface of the seedbeds is covered by lapilli, an inorganic volcanic product, to prevent seedlings from being covered with soil displaced by raindrops (Fig. 11.13). This approach also helps prevent seedlings from coming into contact with pathogenic fungi in the soil. In late March, snowmelt agents are scattered to shorten the favorable period for the pathogen. These counter-measures have enabled the successful production of *Pj* seedlings by mitigating the fatal impact of *Racodium* snow blight.

Damping-off is caused by several soil-borne pathogens, including *Fusarium* spp., for example, *F. oxysporum*, and *Rhizoctonia solani*. In addition to the above pathogens, *Calonectria morganii* (= *Cylindrocladium scoparium*) also affects *As* seedlings, while *Globisporangium debaryanum* ($\equiv$ *Pythium debaryanum*) can impact *Pj* and *Pg* seedlings (The Phytopathological Society of Japan 2024). The occurrence of damping-off is limited to current-year seedlings that have just germinated and are un lignified; however, root rot caused by *Fusarium* spp. can affect older *As*, *Pj*, and *Pg* seedlings. The symptoms of damping-off typically manifest as rot near the ground level, but sometimes include top rot. Damage caused by *Rhizoctonia* occurs in wet conditions when snowmelt water is still present; thereafter, damage caused by *Fusarium* spp. occurs when the seedbeds dry. Compared with *As* seedlings, *Pj* and *Pg* seedlings experience more severe damage. Inoculation tests with *Rhizoctonia solani* demonstrated that *Pj* seedlings are highly susceptible, *Pg* seedlings are moderately susceptible, and *As* seedlings are relatively resistant, with tolerance increasing with age in weeks. The anastomosis group of *Rhizoctonia solani* isolated from *Pj* and *Pg* seedlings in the UTHF nursery was identified as

Fig. 11.13 Lapilli scattered on seedbeds.
(Photo by Daisuke Sakaue,
October 1, 2009)



Fig. 11.14 Seeds of *Abies sachalinensis* coated with thiuram (looks blue in the photo), just before being covered with soil after sowing. (Photo by Daisuke Sakaue, October 23, 2008)



AG-5 (Sakaue, unpublished data). To control damping-off, seeds are coated with the thiuram fungicide before sowing (Fig. 11.14). Fungicides, such as hydroxyisoxazole (hymexazole), tolclofos-methyl, or flutolanil, are sprayed at the onset of disease occurrence. In the past, bed soils were burned for sterilization against soil-borne pathogenic fungi and to kill weed seeds; however, their effectiveness was unclear, because only the surface of the beds could be burned.

Gray mold is caused by *Botrytis cinerea*, and its symptom is bud or shoot blight. It occurs on old-growth seedlings of *As* and *Pj*, especially on *As*. Since the humid environment created by overcrowded seedlings enhances the occurrence of gray mold, making it important to maintain a lower seedling density, particularly in the second year in seedbeds.

In forest nurseries in Hokkaido, additional seedling diseases have been reported, including seed rot of *As* caused by *Sclerotium* sp., black root rot of *As* caused by *Macrophomina phaseolina*, web-blight of *As* caused by *Rhizoctonia solani* (=

Thanatephorus cucumeris), Rosellinia needle blight of *As* and *Pj* caused by *Rosellinia herpotrichioides*, and root lesions of *As*, *Pj* and *Pg* caused by *Pratylenchus penetrans* (The Phytopathological Society of Japan 2024). However, these diseases currently seldom occur in the nursery of UTHF.

11.6 Weather and Climate-Related Damages

Seedling losses caused by weather and climatic conditions are also a significant concern in nurseries. Late frost injury and winter desiccation can threaten seedlings (Fig. 11.15). Severe late frost damage was observed in *Pj* and *As* in 2008 (Ogawa et al. 2010). With climate change, the timing of bud flush has gradually advanced,

Fig. 11.15 (a) Late frost injury of *Abies sachalinensis* seedlings (photo by the UTHF, May, 2008, licensed under CC BY-NC-ND 4.0) and (b) winter desiccation of 2-year-old *Picea glehnii* seedlings at the seedbed (Photo by Daisuke Sakaue, April 10, 2009)



increasing the risk of damage from late frosts due to early bud flush, even though it prolongs the growing period. Additionally, frost heaving, which uproots juvenile seedlings in late autumn, often leads to seedlings mortality in the following spring. Proper drainage of beds is crucial for mitigating frost heaving. Notably, *Pj* is particularly vulnerable to late frost injury and frost heaving.

Heatwaves and droughts have also become increasingly problematic due to climate change. The mortality of 1-year-old seedlings, particularly *Pj* and *Pg*, from seedbeds has occurred several times in the spring over the past 15 years (Sakaue 2017). The cause of this mortality remains unknown, but it is possible that the damage is related to heat canker caused by excessively high soil surface temperatures. During the summer of 2021, when precipitation in July totaled only 16.0 mm—far below the July average of 140 mm—approximately half of the seedlings that had just been transplanted to the seedling beds in the spring died (Tanaka et al. 2023). With predictions of increased severity and frequency of such extreme climatic events due to ongoing climate change, these issues must be addressed as significant concerns in the near future (Figs. 11.16 and 11.17).

Fig. 11.16 (a) Mortality of 1-year-old *Picea jezoensis* seedlings at the seedbed and (b) the lesion suspected to be heat canker. (Photo by Daisuke Sakaue, May 17, 2017)

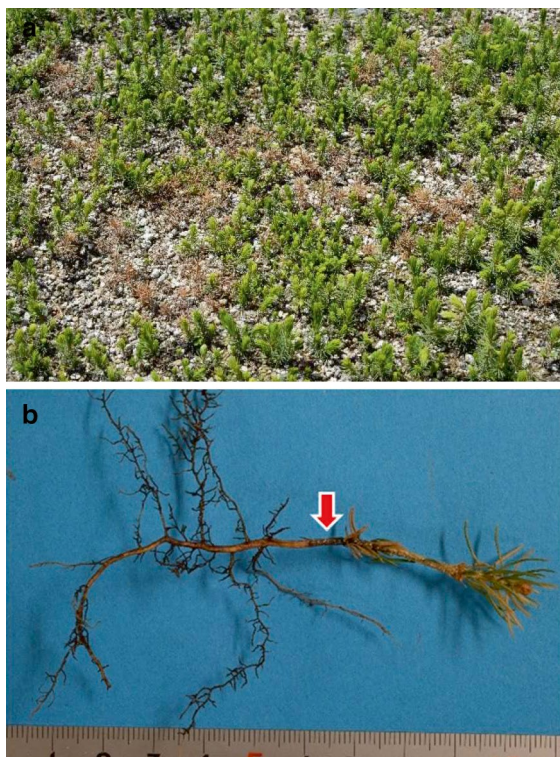




Fig. 11.17 Severe damage to transplanted seedlings (3-year-old) in seedling beds during drought years. (Photo by Satoshi Fukuoka, August 14, 2021, used with permission from the UTHF, licensed under CC BY-NC-ND 4.0)

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