Chapter 6
Infilling of Swamplands Behind Coastal Sand Dunes to Mitigate Coastal Disasters

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Abstract Japanese black pines in the coastal forests of Kujukuri and Futtsu-Misaki in the Chiba Prefecture have often withered under water-logged conditions due to impediment of gas exchange through tree roots. Such damp subsoil conditions could influence root development of planted seedlings. To successfully accomplish the reforestation of coastal forests, ensuring high disaster prevention, addition of soil to the lowlands is strongly recommended before planting seedlings. Taking into consideration the settlement of filled land, it is necessary to ensure that a minimum 180 cm-thick layer of fill materials is added. Common fill materials are composed of sandy soils excavated from adjacent hills, dredged soils from river mouths, and surplus soils generated from construction. In soil foundations constructed in this way, the root systems of planted trees are restricted to the shallow top layers. Few roots of 10-year-old trees are seen to extend more than 50 cm deep, likely due to the compactness of fill soils. Soil formation processes will also change with time. Thus, it is important to collect pedogenesis information in these coastal forests built on landfill for optimum success in reforestation efforts. Most of the soils in the land fill area of the Matsugaya coastal forest have high bulk density with low porosity and low water permeability. Sandy soil texture is uniformly distributed through the entire profile. Filamentous mottling occurs in all mineral soil horizons except for the top horizon, due to high humidity conditions in mineral soils. These soils are classified as Linic Spolic Technosol, mainly due to both the existence of the quite low permeability horizons and the high content of artefacts. Another research site,

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M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_6

Shirako town, located along the Kujukuri forest having stand ages of 21–22 years, has been infilled using sandy soils containing buried rice straws at fixed depth and constant intervals. At the 21-year old forest stand site, deep tillage was carried out at constant intervals before planting. Soils are classified as Spolic Technosol. Relatively high permeability was achieved at both sites despite of their high bulk densities, and many roots were found to spread both horizontally and vertically.

Keywords Land fill · Soil compaction · Tillage · Water permeability · Sandy soil materials

6.1 Introduction

Japanese black pines in the coastal forests of Kujukuri and Futtsu-Misaki in Chiba Prefecture often wither in low lying areas (less than 5 m above sea level, or ASL) behind coastal sand dunes. This is caused by impediment to gas exchange in tree roots by the continual water-logged conditions of the soils. Even willows (*Salix spp*.) and alders (*Alnus* sp.), species resistant to soil saturation, have withered and died (Oda 2001). Such damp subsoil conditions could influence root development of planted seedlings. To successfully achieve the reforestation of coastal forests to ensure high disaster prevention, the Forestry Research Institute in the Chiba Prefectural Agriculture and Forestry Research Center strongly recommended that the planting base for coastal forests be constructed by infilling the damp lowlands before planting seedlings. It also proposed a new method of reforestation using these methods (Oda 2001). This might be a crucial proposal because “the right tree for the right land” is a fundamental principle for traditional forestation methods in Japan (Morisada 1993). Since then, planting foundations for black pine forests have been developed by infilling the damp lowlands along the Kujukuri coastline (Nohara and Takahashi 2007). At this reforestation site, thick soil fill is used to ensure deep-rooted tree growth, which can help realize the disaster prevention capacity of the forest, as the stand age goal in reforested sites is 50 years. It is necessary to ensure a soil thickness of 120 cm for 50-year-old coastal forests (Oda 2000). Taking into consideration the settlement of filled land, it is necessary to utilize a 180 cm-thick layer of fill materials (Nohara and Takahashi 2007). Sandy soil cut from adjacent hills, soils dredged from river mouths, and surplus soils generated from construction are used as landfill materials. In soil foundations constructed using these materials, the root system of planted trees is primarily distributed in the shallow top layers. Even with development of shallow root systems, reforestation in areas infilled with the components noted above generally show high survival rates and satisfactory growth rates for aboveground plant structures for the first decade after planting. Few roots of 10-year-old trees are seen to extend more than 50 cm deep, which may inhibit aboveground growth thereafter. It is considered that one of the reasons why roots do not develop may be the compactness of fill soils (Nohara and Takahashi 2007). The saturated lowland areas of coastal forest with high levels of groundwater cover 235 ha of the 1400 ha coastal forest in the Chiba Prefecture. Of these, 81 ha of the area was treeless land (Chiba Prefecture 1997). Therefore, infilled coastal forests have historically grown in Chiba. Moreover, even under these conditions, soil formation processes will also change with time. Thus, it is important to collect pedogenesis information in these coastal forests built on infilled areas. Here, the physico-chemical properties of the soils are introduced from observations in three infilled coastal forests along the Kujukuri shoreline in Chiba Prefecture.

6.2 Matsugaya Coastal Forest

6.2.1 Construction of the Growth Foundation

One of the coastal disaster prevention forests introduced here is located 300 m inland from the shoreline in Sanmu City, Chiba Prefecture (Figs. 6.1 and 6.2). The growth foundation of this coastal forest was constructed by infilling the swamp areas between sand dunes using soils dredged from the mouth of the Sakuta River, and surplus soils generated by construction of road and housing lots in 2008. The initial thickness of the infill was ca. 1.3 m. In the filled area, black pine and some shrub species, e.g., *Myrica rubra*, *Quercus phillyraeoides*, *Pittosporum tobira*, and *Euonymus japonicas*, were planted as bare-root seedlings. Stand age and density was 7 years old and ca. 4000 trees per hectare, respectively, when the soil survey was carried out in 2015. Tree heights ranged from 1.2 to 3.1 m (average: 2.1 m) and the diameters of the tree bases ranged from 2.5 to 13.3 cm (average: 6.6 cm) in April 2015.

6.2.2 Soil Description and Soil Classification Using Soil Physico-chemical Properties

6.2.2.1 Site Description

Berm material: Soils dredged from the Sakuta River in Kujukuri Town, and surplus soils generated by construction of a road in Chiba Prefecture (part of the Metropolitan Inter-City Expressway in Chiba Prefecture and the Chousei Green-Line road; Forestry Research Institute, Chiba Prefectural Agriculture and Forestry Research Center, personal communication), which were used for building all C horizons as man-made planting foundations for the coastal forest,

Location: Matsugaya, Sanmu City, Chiba Pref. (35°33′52″ N, 140°28′49″ E),

Elevation: 2.5 m above sea level (ASL)

Topography: Top of the planting foundation of infilled swamplands behind the coastal sand dunes at ca. 300 m from shoreline,

Soil classification: Immature Soil (Forest Soil Division 1976), Linic Spolic Technosol (IUSS Working Group WRB 2015)

Fig. 6.1 Location of the survey point (red circle) in Matsugaya coastal forest, Sanmu City, Chiba Prefecture. The terrain map and the aerial photograph (photographed in May, 2015) was obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

Vegetation: 7-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*)

6.2.2.2 Description of Soil Profile 1 (Survey Date: February 17, 2015): Fig. 6.3

L: +2 to +4 cm thickness of fresh foliage litter of black pine, some hardwoods and weeds

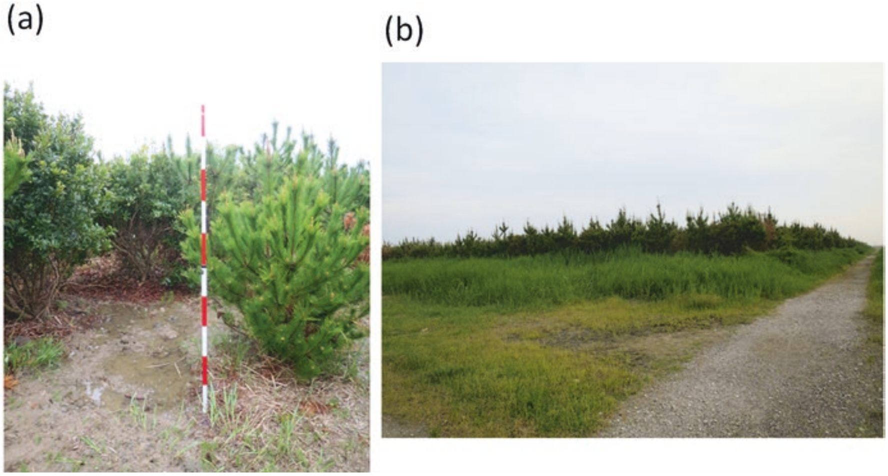

Fig. 6.2 Overview of the Matsugaya coastal forest in Sanmu City, Chiba Prefecture. Photographs were taken in (**a**) April 2015, facing the interior of the berm, and (**b**) May 2015, external appearance of the berm

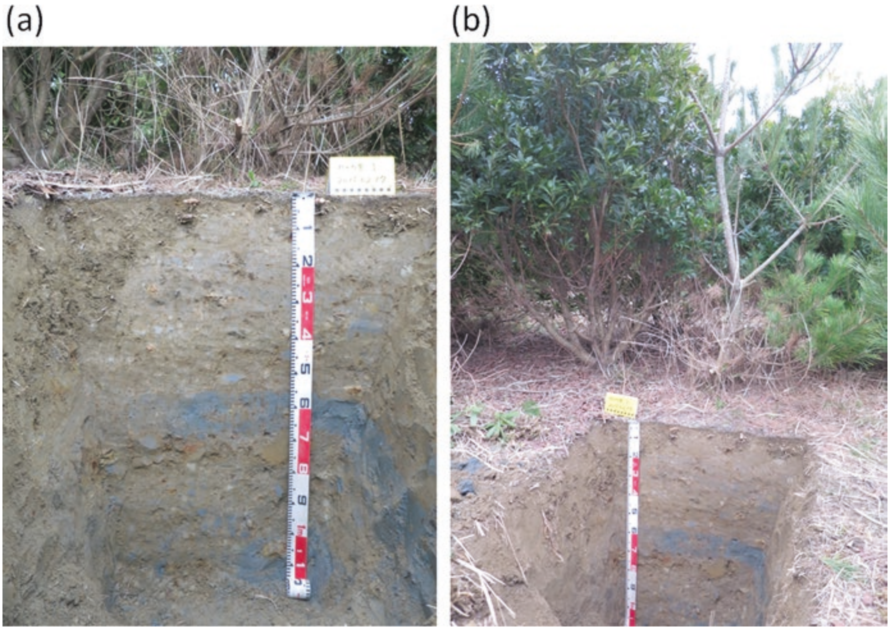

Fig. 6.3 Photos (**a**), (**b**) of soil profile 1, consisting of newly constructed infilled swamp areas as planting foundations for coastal forests. Black pine and some shrub seedlings were planted in 2009

F-H horizon: 0.5 cm thickness of decomposed foliage litter

AC: 0 to 2 cm, grayish yellow brown (10YR 4/2), silty loam, moist, none gravel, no structure, very friable, compactness of 9.2*, none voids, few fine living roots, many fine charcoal particles ($\phi < 1.0$ mm), abrupt smooth boundary,

C1: 2 to 25 cm, dark grayish yellow # (2.5Y 5/2), silty loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 29.8*, none voids, few very fine and fine living roots and very few medium and coarse living roots, many fine charcoal particles ($\phi < 1.0$ mm), gradual irregular boundary,

C2: 25 to 40 cm, yellowish brown (2.5Y 5/3), silty clay loam, very few fine prominent and sharp filamentous brown (7.5YR 4/6) mottling, moist, few sub-rounded strongly weathered stones and few medium fresh angular gravel, no structure, friable, compactness of 28.0*, none voids, very few very fine living roots, many fine charcoal particles ($\phi <1.0$ mm), clear smooth boundary,

C3: 40 to 55 cm, grayish yellow (2.5Y 6/2), silty loam, few fine distinct and sharp filamentous dark reddish brown (5YR 3/6) mottling, moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 25.2*, none voids, very few very fine living roots, many fine charcoal particles ($\phi < 1.0$ mm), clear irregular-smooth boundary,

C4: 55 to 65 cm, dark olive gray (2.5GY 4/1), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, none gravel, no structure, friable, compactness of 26.2*, no voids, very few fine living roots, clear irregular-smooth boundary,

C5: 65 to 90 (−100) cm, dark grayish yellow (2.5Y 4/2), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, wet-moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 22.2*, none voids, very few very fine living roots, few buried dead woody timbers, roots or stumps damaged by huge tsunamis, diffuse irregular boundary,

C6: 90 (−100) to 120+ cm, dark grayish yellow (2.5Y 5/2), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, few sub-rounded strongly weathered stones, no structure, firm-friable, compactness of 25.6*, few dead roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.2.2.3 Soil Physico-chemical Properties

General physical properties of soil profile 1 of the Matsugaya coastal forest are shown in Table 6.1. Soil in the planting foundations here is tightly packed. Bulk densities of all soils except for the C1 horizon are generally high, more than 1.25 g cm^{-3}. Volume percentages of the solid phase are relatively high, ranging from 40 to 55 vol%, throughout the soil profile, thus soil porosities are low, at less than 60 vol%. Especially in the C1 and C4 horizons, coarse pores in the soils are scarce,

Table 6.1 Physical characteristics of the soils of the planting base in Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba Prefecture

Sample ID	Depth (cm)	Permeability[a] (ml/min) 5 min	15 min	Average	Hydraulic conductivity (mm/h)	Bulk density (Mg/m[c])	Soil pore composition[b] Total (vol%)	Fine (vol%)	Coarse (vol%)	Three phase distribution Solid (vol%)	Liquid (vol%)	Gas (vol%)	Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
Profile 1														
AC	0–2	7.6	6.8	7.2	34.5	1.05	59.6	30.0	29.6	40.4	35.0	24.5	56.3	3.3
C1	2–25	0.2	0.1	0.2	0.9	1.46	45.4	44.0	1.4	54.6	44.1	1.3	48.8	−3.5
C2	25–40	4.6	4.8	4.7	22.6	1.35	49.2	n.d.[d]	n.d.[d]	50.8	42.7	6.5	49.0	0.2
C3	40–55	1.6	1.3	1.4	6.9	1.25	53.1	39.3	13.8	46.9	44.4	8.7	51.0	2.1
C4	55–65	3.7	3.2	3.5	16.7	1.41	47.3	46.5	0.8	52.7	44.4	2.9	49.9	−2.6
C5	65–90(−100)	25.6	19.9	22.8	109.3	1.25	53.4	44.2	9.2	46.6	46.1	7.3	54.8	−1.4

[a]Data of permeability show the respective measured values after 5 and 15 min from the beginning of the experiment and the average values of them
[b]Data of porosity shows the measured values according to the porous plate method (Kawada and Kojima 1976)
[c]Minus value of minimum air capacity is caused by swelling of soil volume with water saturation treatment
[d]Not determined

Table 6.2 Particle size distribution of the soils of the planting foundation in the Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba Prefecture

Horizon	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Profile 1					
AC	0–2	1.4	69.4	17.1	12.1
C1	2–25	1.8	65.7	19.7	12.8
C2	25–40	1.1	65.5	21.3	12.1
C3	40–55	0.8	66.2	20.0	13.0
C4	55–65	1.7	64.7	18.8	14.8
C5	65–90(−100)	2.5	66.5	18.4	12.6
C6	90(100)–120+	0.5	66.3	19.5	13.6

at approximately 1 vol%. The coefficient of permeability ranges from 1 to 110 mm h^{-1}. Filamentous mottling occurs in all mineral soil horizons except for the AC horizons, perhaps as a result of constant saturated conditions in the mineral soils. No structure throughout the profile showed progress of pedogenesis. This soil is classified as an Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also, they can be classified as Linic Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to both the existence of the quite low permeability horizons, especially C1–C4 horizons, and the high content of artefacts (i.e., usage of various sources of man-made soil materials for infilling, including soils dredged from the Sakuta River in Kujukuri Town, and surplus soils generated by construction of road in Chiba Prefecture). Major particle components in this soil are fine sand, generally over 60%, followed by silt, clay, and coarse sand (Table 6.2). Throughout the profile, soil particle distributions are quite similar and have relatively homogeneous properties. General chemical properties in soil profile are shown in Table 6.3. Soil pH (H_2O) generally shows (weak) acidic values, ranging from 4.1 to 6.8. Electric conductivity (EC) of mineral soil horizons is relatively high, contrary to expectations, except for the AC topsoil and horizon 2C. EC values in the C2 and C3 are noticeably higher, at approximately 80 mS m^{-1}. Total carbon content in soils is also low throughout the profile. Capacities of exchangeable cation in soils are ca. 20 $cmol_c$ kg^{-1}. The largest content for this soil was of exchangeable calcium in the exchangeable cations (7.0–10.9 $cmol_c$ kg^{-1}, with a considerably lower value of 0.2 for horizon 2C), followed by magnesium (4.3–11.5 $cmol_c$ kg^{-1}, horizon 2C much lower at 0.51), sodium (0.4–5.1 $cmol_c$ kg^{-1}), and potassium (0.2–1.2 $cmol_c$ kg^{-1}). It is not clear how the original quality of infilling materials for the planting foundation might affect the physico-chemical properties of the soils. Therefore, it is essential to gather more information on the characteristics of soils profiles built by infilling and use of heavy machinery.

Table 6.3 Chemical characteristics of the soils of the planting foundation in Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba prefecture

Sample ID	Depth (cm)	EC (mS m^{-1})	pH (H_2O)	TC (g/kg)	TN (g/kg)	C/N	CEC ($cmol_c$ kg^{-1})	Exchangeable cation ($cmol_c$ kg^{-1})				Water-soluble cation ($cmol_c$ kg^{-1})			
								Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
Profile 1															
AC	0–2	3.84	6.54	15.14	1.05	14.4	19.0	7.05	4.34	0.40	1.16	0.06	0.06	0.13	0.06
C1	2–25	23.20	4.91	3.58	0.33	10.7	20.7	8.44	4.94	0.56	0.93	0.37	0.41	0.22	0.06
C2	25–40	80.80	4.38	3.36	0.32	10.4	20.7	10.85	7.35	0.64	1.06	2.66	2.46	0.36	0.14
C3	40–55	74.90	4.14	3.17	0.32	9.9	20.2	10.24	5.39	0.58	1.03	3.27	2.24	0.44	0.19
C4	55–65	34.30	6.59	4.18	0.40	10.4	21.1	9.28	5.99	0.63	0.97	0.59	0.77	0.27	0.07
C5	65–90(−100)	24.10	5.21	2.89	0.27	10.6	21.1		11.48	4.99	0.59	0.98	0.83	0.60	0.27
C6	90(100)-120+	15.27	4.62	2.58	0.28	9.2	22.3		6.15	5.08	0.57	1.02	0.23	0.37	0.21
2C	100–120+	1.95	6.88	1.22	0.10	12.0	6.3	0.23	0.51	0.43	0.24	0.000	0.000	0.064	0.005

6.3 Ushigome Coastal Forest

6.3.1 Construction of the Growth Foundation with and without Tillage

Coastal disaster prevention forests of the Ushigome coastal forest introduced here are located ca. 150 m inland from the shoreline in Shirako Town, Chiba Prefecture (Figs. 6.4 and 6.5). The growth foundation of the coastal forest was constructed by infilling the swamp areas behind the sand dunes in 1994 and 1995 (Nohara and

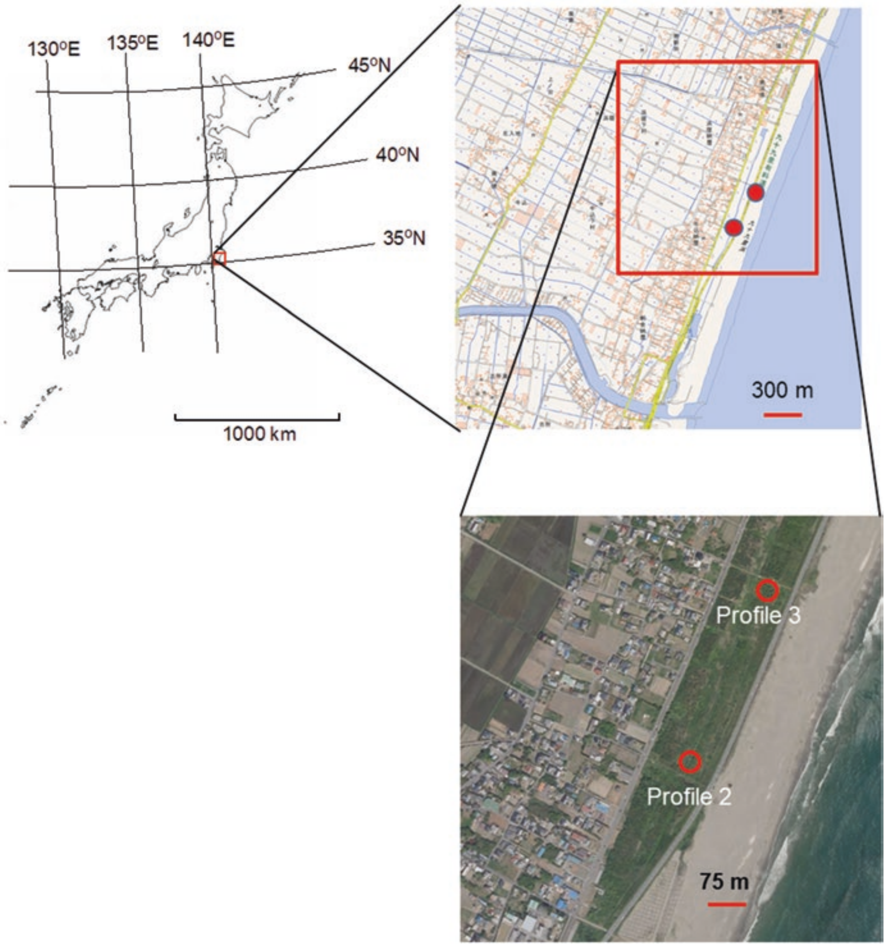

Fig. 6.4 Location of the survey points (Red circles) in Ushigome coastal forest, Shirako Town, Chiba Prefecture. The terrain map and the aerial photograph (photographed at May 2015) were obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

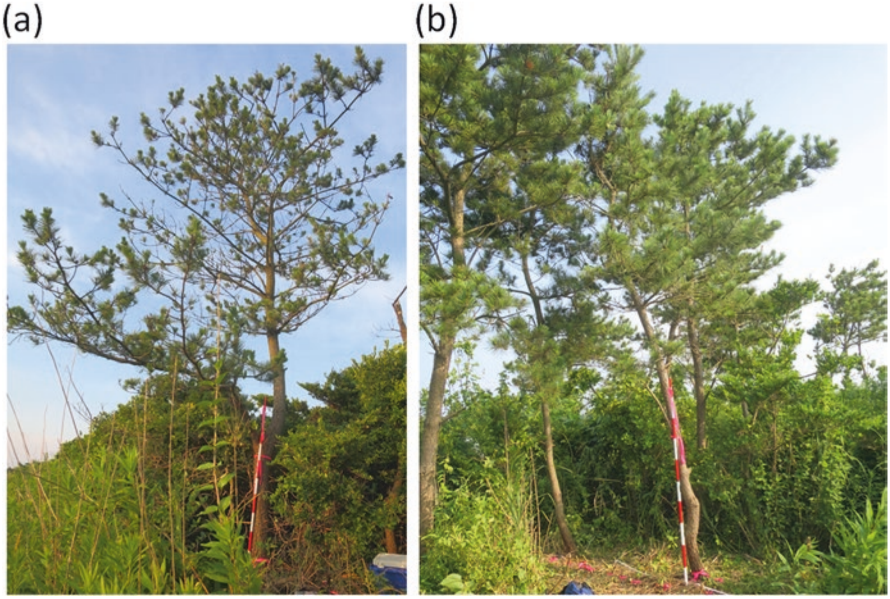

Fig. 6.5 Overview of the Ushigome coastal forest in Shirako Town, Chiba Prefecture, photographed in July 2016. Photos show the representative types of the black pine trees (**b**) the forest constructed in 1994, (**a**) the forest constructed in 1995

Takahashi 2007). During construction in 1994, soil at lower depths was compacted at each 30 cm-thickness horizon, followed by infilling using sandy soils purchased from a source pit in the adjacent hills for upper layers (which were 1.5–1.8 m in thickness). Afterwards, rice straw was buried at 30 cm in depth in the topsoil of the foundation at intervals of 1 m. The foundation constructed in 1995 utilized soils (originating from mudstones) generated by construction of road and housing lots for the bottom layers (0.8 m in thickness), compacted at 30 cm intervals, and was also infilled with the above-mentioned sandy soils for upper layers (1.1 m in thickness). Before planting, deep tillage (60 cm in width, 1 m in depth) was carried out at intervals of two meters, and rice straw was buried at both 30 and 100 cm depth in the topsoil of the foundation at intervals of one meter. In each foundation, black pine (*Pinus thunbergii*) and some types of shrub species, e.g., *Myrica rubra*, *Quercus phillyraeoides*, *Pittosporum tobira*, and *Euonymus japonicas*, were planted using bare-root seedlings in holes 30 cm in diameter, and 30 cm deep. The summary of the constructed foundation is shown in Fig. 6.6. Stand ages in the respective forests were 22 years and 21 years when the soil survey was carried out in 2016. Tree heights and diameters at breast height (1.3 m height) of trees grown near the pit of the July 2016 soil survey were 6.6 m and 20.3 cm at the 1994 site and 5.9 m and 9.9 cm at the 1995 site, respectively. Unfortunately, both sites are affected by pine wilt disease, so few trees survived there.

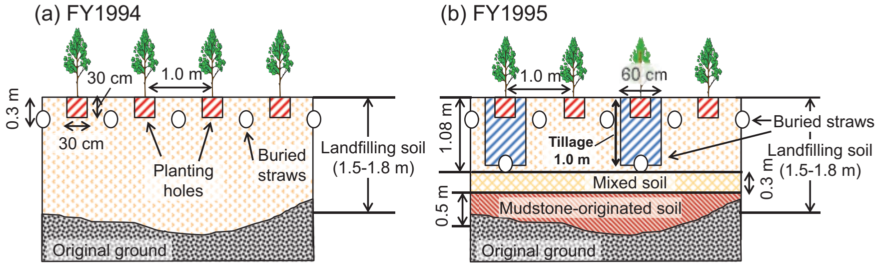

Fig. 6.6 Summary of the planting bases constructed in 1994 (**a**: Profile 2) and 1995 (**b**: Profile 3) at Ushigome coastal forest in Shirako Town, Chiba Prefecture This diagram is a modification of one in a previous report published by Nohara and Takahashi (2007)

6.3.2 Soil Description and Soil Classification Using Soil Physico-chemical Properties

6.3.2.1 Site Description for the Planting Base at the Site without Tillage (Fig. 6.6a)

Berm Material: Upper layer (1.08 m in thickness): Sandy soils purchased from borrow pit in the adjacent hills; Bottom layer (0.8 m in thickness): Surplus soils generated by construction of roads and housing lots (Nohara and Takahashi 2007), which were used for building all C horizons as a man-made planting foundation for the coastal forest

Location: Ushigome, Shirako Town, Chiba Prefecture (35°33′47″ N, 140°28′35″ E)

Elevation: T.P. 3 m ASL

Topography: Top of an embankment on the planting foundation on infilled swamplands behind the coastal sand dunes at ca. 150 m from shoreline

Soil classification: Immature Soil (Forest Soil Division 1976), Spolic Technosol (IUSS Working Group WRB 2015)

Vegetation: 22-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*)

6.3.2.2 Description of Soil Profile 2 (Survey Date: July 15, 2016): Fig. 6.7

L: +1 cm in thickness of fresh foliage litters of black pine, some hardwoods and weeds

A: 0 to 5 cm, black (10YR 2/1), clay loam, dry, none gravel, no structure, very friable, compactness of 8.9*, interstitial voids, common very fine and fine living roots, clear smooth boundary,

C1: 5 to 20 cm, brown (10YR 4/6), silty loam, dry, none gravel, massive structure, very friable, compactness of 12.2*, interstitial voids, very few very fine, fine, and medium living roots, diffuse smooth boundary,

Fig. 6.7 Photo of soil profile 2 in newly constructed foundation in swamp areas to reforest the coastal forest in 1994. We can see two large horizontal roots in the profile

C2: 20 to 40 cm, brown (10YR 4/6), silty loam, moist, very few coarse sub-rounded weathered gravel and boulders (similar to shales), massive structure, very friable, compactness of 13.8*, interstitial voids, very few very fine, fine, and medium living roots, diffuse smooth boundary,

C3: 40 to 70 cm, brown (10YR 4/4), silty loam, moist, very few coarse sub-rounded weathered gravel and boulders (similar to shales), massive structure, very friable, compactness of 19.6*, interstitial voids, very few very fine and fine living roots, diffuse irregular boundary,

C4: 70 to 100 cm, brown (10YR 4/4), silty loam, moist, very few coarse subrounded weathered gravel, massive structure, very friable, compactness of 17.6*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C5: 100+ cm, dull yellowish brown (10YR 4/3), silty loam, moist, none gravel, massive structure, very friable, compactness of 18.6*, interstitial voids, very few very fine and fine living roots.

* Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.3.2.3 Site Description for the Planting Base at the Site with Deep Tillage (Fig. 6.6b)

Berm Material: Fill soil (1.5–1.8 m in thickness): Sandy soils purchased from borrow pit in the adjacent hills (Nohara and Takahashi 2007), which were used for building all C horizons as a man-made planting foundation for the coastal forest

Location: Ushigome, Shirako Town, Chiba Prefecture (35°27′58″ N, 140°24′41″ E)

Elevation: T.P. 3 m ASL

Topography: Top of the planting foundation for infilled swamplands behind the coastal sand dunes at ca. 150 m from shoreline

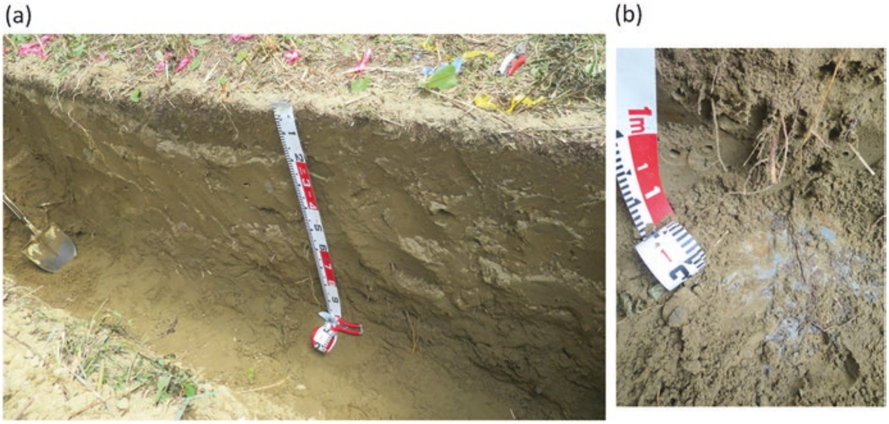

Fig. 6.8 Photos of soil profile 3 from (**a**) a newly constructed foundation made by infilling swamp areas to reforest the coastal forest in 1995, and (**b**) arrested vertical root development at the induration layer with grayish color on the bottom of the foundation

Soil classification: Immature Soils (Forest Soil Division 1976), Spolic Technosol (IUSS Working Group WRB 2015)

Vegetation: 22-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*).

6.3.2.4 Description of Soil Profile 3 (Survey Date: July 15, 2016): Fig. 6.8

L: +2 cm in thickness of fresh foliage litter of black pine, some hardwoods, and weeds

A: 0 to 2 cm, brownish black (2.5Y 3/2), silty loam, dry, none gravel, very weak fine granular structure, very friable, compactness of 8.5*, interstitial voids, common very fine and fine living roots, clear smooth boundary,

C1: 2 to 20 cm, dull yellowish brown (10YR 4/3), silty loam, dry, none gravel, massive structure, very friable, compactness of 9.9*, interstitial voids, few very fine and fine living roots, diffuse irregular boundary,

C2: 20 to 40 cm, dull yellowish brown (10YR 5/3), silty loam, dry, none gravel, massive structure, very friable, compactness of 13.8*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C3: 40 to 70 cm, dull yellowish brown (10YR 5/3), silty loam, moist, none gravel, massive structure, very friable, compactness of 13.4*, interstitial voids, very few very fine and fine living roots, clear smooth boundary,

C4: 70 to 100(−110) cm, brown (10YR 4/4), silty loam, moist, none gravel, massive structure, very friable, compactness of 16.3*, interstitial voids, very few very fine and fine living roots, clear smooth boundary, C5: 100(−110) to 120 cm, grayish yellow brown (10YR 5/2), silty loam, moist, none gravel, massive structure, very friable, compactness of 20.4*, interstitial voids, very few very fine and fine living roots, abrupt smooth boundary,

C6 120+ cm, gray (N 4/0), silty loam, induration, firm, compactness of 31.0*

* Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.3.2.5 Soil Physico-chemical Properties

General physical properties of soil profiles 2 and 3 of Ushigome coastal forest are shown in Table 6.4. Soils of Ushigome coastal forest are generally composed of silty loam, not as tightly packed in comparison with that of Matsugaya coastal forest. Bulk densities of all soils except for the top soils (A and C1 horizon) are relatively high, more than 1.3 g cm^{-3}. The volume percentages of the solid phase ranges from 31 to 57 vol% throughout both soil profiles. Soil porosities tend to decrease with depth, to less than 50 vol%. Hydraulic conductivities range from 27 to 483 mm h^{-1}, thus the permeability of these soils is better throughout both profiles, especially profile 3 in which tillage treatment occurred after constructing the planting foundation. Both soils are classified as Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also, they can be classified as Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to the high content of artifacts (i.e., usage of various sources of infill from man-made materials obtained from borrow pits in hilly areas together with the natural soils of the original coastal forest in swamp areas for constructing the planting bases) in profiles 2 and 3 without low permeable horizons. In both profiles, many roots have spread both horizontally and vertically (Figs. 6.9 and 6.10) over the past 20 years.

6.4 Conclusion

Soils beneath coastal forests constructed by infilling swamp areas have high bulk density and low water permeability due to compaction by heavy machinery, despite the incorporation of sandy soils. Fill materials including dredged sediment from the mouth of the Sakuta River, and materials obtained from construction of road and housing lots were compacted in the constructed berm, resulting in diminished soil conditions and prevention of vertical root extension. The soil is classified as Linic Spolic Technosol due to low permeability and the inclusion of artifacts. Tillage was shown to be an effective technic to improve the soil condition for reforestation efforts on berms. The tillage process results in a change of the soil name to Spolic Technosol because water permeability has been improved.

Table 6.4 Physical characteristics of the soils of the planting bases in Ushigome coastal forest along Kujukuri shoreline in Shirako Town, Chiba Prefecture

Sample ID	Depth (cm)	Permeability[a] 5 min (ml/min)	15 min (ml/min)	Average (ml/min)	Hydraulic conductivity (mm/h)	Bulk density (Mg/m^3)	Soil pore composition[b] Total (vol%)	Fine (vol%)	Coarse (vol%)	Three phase distribution Solid (vol%)	Liquid (vol%)	Gas (vol%)	Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
Profile 2														
A	0–5	100.3	94.4	97.3	467.1	1.01	61.2	31.1	30.1	38.8	29.9	31.3	59.7	1.5
C1	5–20	25.2	22.5	23.9	114.6	1.18	55.8	23.6	32.2	44.2	19.3	36.5	56.5	−0.7
C2	20–40	22.5	21.2	21.8	104.8	1.33	50.2	20.4	29.8	49.8	21.1	29.1	56.4	−6.2
C3	40–70	35.8	35.5	35.6	170.9	1.53	43.3	22.3	21.0	56.7	28.8	14.5	47.9	−4.5
C4	70–100	5.8	5.2	5.5	26.6	1.44	45.2	19.9	25.3	54.8	16.9	28.3	44.2	1.0
Profile 3														
A	0–2	102.5	98.6	100.6	482.6	0.83	68.7	23.0	45.6	31.3	12.6	56.0	65.5	3.1
C1	2–20	32.7	30.5	31.6	151.7	1.19	56.2	27.1	29.1	43.8	15.5	40.7	58.1	−1.9
C2	20–40	10.4	6.5	8.5	40.7	1.47	45.6	23.2	22.4	54.4	17.8	27.8	49.8	−4.3
C3	40–70	30.2	25.7	27.9	134.1	1.41	47.8	17.4	30.4	52.2	19.1	28.7	51.2	−3.4
C4	70–100	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.36	49.8	n.d.[d]	n.d.[d]	50.2	16.6	33.2	41.0	8.8
C5	100–120	50.5	46.3	48.4	232.3	1.44	46.8	37.5	9.3	53.2	40.1	6.7	50.2	−3.5
C6	120+	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.30	52.5	41.5	11.0	47.5	51.5	0.9	53.6	−1.2

[a]Permeability data shows the respective measured values 5 and 15 min from experiment start and the average values for both

[b]Porosity data shows the measured values according to the porous plate method (Kawada and Kojima 1976)

[c]not determine

[d]The Negative value of the minimum air capacity is caused by swelling of soil volume with water saturation treatment

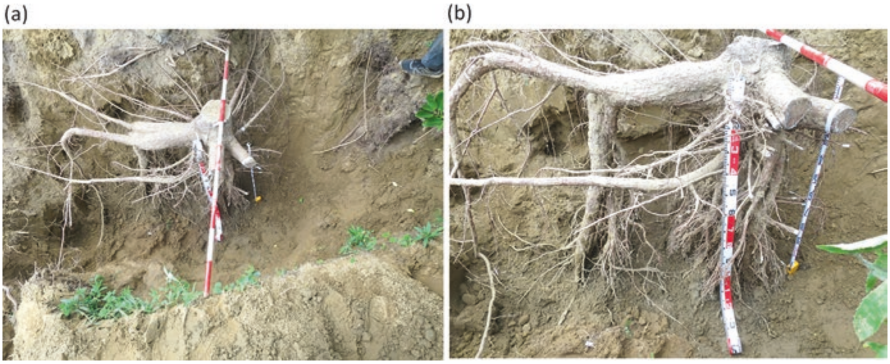

Fig. 6.9 Photos of the roots of a black pine planted in 1994, growing near Profile 2. In (**a**) horizontal root growth is observed, and in (**b**), the extent of vertical growth is seen

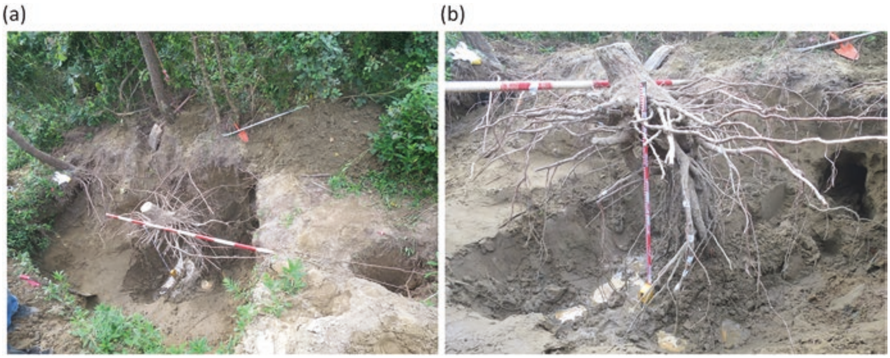

Fig. 6.10 Photos of the roots of a black pine planted in 1995, growing near Profile 3. The puddles in the pit were from rainfall on the day before the exploration. Photo (**a**) horizontal growth, (**b**) vertical growth

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