Effects of light and microsite conditions on tree size of 6-year-old Cryptomeria japonica planted in a group selection opening

Abstract We examined the extent to which direct and indirect measures of light and microsite conditions could explain variation in tree height and diameter at the base of 6-year-old Cryptomeria japonica trees planted in a group selection opening of about 0.32 ha on a steep slope at Shiiba, Miyazaki Prefecture, southern Japan. We first used the gap light index (GLI) and soil thickness (ST) as directly measured indices. For an indirect measure of light, we used a between-cohort competition index (BCI) estimated from the position and total height of residual trees. For indirect measures of microsite, we examined topographic indices (slope, plan and profile curvature, average slope gradient, and relative elevation) derived from digital elevation models (DEMs) with different resolutions ranging from 2 to 10 m. The multiple linear regression using GLI and ST explained about 45% of variation in tree size, while simple regression using only GLI explained about 35%. The contribution of ST was about half of GLI. The multiple regressions using BCI and the topographic indices did not explain any more variation than using BCI alone (R² of about 0.26). We conclude that microsite conditions with shallower soil and steeper slope have negative effects on tree growth in group selection openings, although the relative importance is smaller than light conditions. More comprehensive studies considering several openings with more heterogeneous topography including different species are needed to generalize our growth prediction using the indirect measures, which are useful for practical forest management.

Key words Competition index · Digital elevation model · Gap light index · Soil thickness · Topographic indices

Introduction

In many countries, there is an increasing trend to convert even-aged plantation forests into uneven-aged stands (e.g. Cameron et al. 2001). In Japan, about 40% of the forested area (ca. 10 million hectares) is covered with plantation forests, mainly even-aged conifer stands (Fujimori 2001), and forest management policy for these simple conifer plantations has shifted away from large-scale clear-cutting toward uneven-aged methods (Nyland 1996).

Recently, the group selection system has received considerable attention as an alternative for uneven-aged stand management, as a compromise between the environmental effects of clear-cuts and the productivity penalties associated with single-tree selection (York et al. 2004). However, there are few examples of where the group selection system has been used in conifer plantations in Japan (Fujimoto 1984; Yamashita et al. 2006). Therefore there is a lack of basic information on the growth of planted trees in group selection openings, and the factors affecting the growth of regenerated trees have not been well documented.

In group selection openings, the existence of residual trees surrounding the openings causes gradients in resource availability for the regenerated trees. York et al. (2003) examined the effects of light and water availability on the height of 3-year-old trees planted in group openings ranging in size from 0.1 to 1 ha. Of three species examined, sensitivity to light and water availability was highest for giant sequoia (Sequoiadendron giganteum) and lowest for Douglas fir (Pseudotsuga menziesii var. menziesii), and only light was a significant predictor of ponderosa pine (Pinus ponderosa) performance. Their study suggests that light is a critical...
resource affecting tree growth planted in group selection openings.

In Japan, most conifer plantations have been established on steep slopes with complicated topography, resulting in heterogeneous microsite conditions for regenerated trees. Geomorphic factors such as slope aspect and slope steepness can substantially modify the local environment of plants by altering microclimate conditions and soil development (Oberhuber and Kofler 2000). Therefore, it is important to clarify the relative importance of microsite conditions in comparison with light resources to explain tree growth within group openings on steep slopes.

The objective of this study was to examine the effects of light and microsite conditions on tree size of 6-year-old *Cryptomeria japonica* planted in a group selection opening on a steep slope. This study adopted two approaches separately to assess light and microsite conditions. First, we examined two directly measured indices, gap light index (GLI, Canham 1988) and soil thickness. Second, we examined the effects of indirect measures of light and microsite conditions calculated from residual tree data (position and height) and a digital elevation model (DEM). This is because the intensive field surveys needed to get data such as GLI and soil thickness would be too time consuming and impractical in practical forest management, yet there is a need to improve growth prediction with such information; less intensively collected indices are needed. Recent progress in technology of the geographic information system (GIS) enables forest managers to handle digitized spatial data efficiently. Finally we discuss practical implications of growth predictions obtained from indirect measures for managers of forests.

**Material and methods**

Study site and field surveys

The study site is located on a steep slope with an average inclination of 38° at about 460–640m asl at Shiiba in Miyazaki Prefecture in southern Japan (32°27′N, 131°13′E). The site is owned by Sumitomo Forestry. The mean annual temperature and annual rainfall are about 14°C and 3000mm, respectively. In 1998 at this site, nine group selection openings with an average size of about 0.4 ha (about 80 × 50 m) were created within about 12 ha of a 45-year-old even-aged stand of *Cryptomeria japonica*. After removing the cut trees, slash was disposed of in windrows (Fujimori 2001). Then in 1999, the seedlings of *C. japonica* variety obisugi, with average size of about 35 cm, were planted in the openings with about 1.8-m intervals between trees, except for the windrows. Weeding was carried out every year between 1999 and 2003. The planted seedlings had been propagated by cuttings and grown for 1 year in the nursery, resulting in low variation in the initial size at planting. We can thus assume that the effects of the initial size of the planted seedling on our results of sixth-year size are much smaller than the effects of light and microsite conditions.

Within the nine openings we selected a typical one with a size of about 0.32 ha (about 70 × 45 m; Fig. 1) for this study due to good accessibility from the road. In 2003 when the residual and planted trees were 50 and 5 years old, respectively, we measured the height, diameter at breast height (DBH), and three-dimensional position of the residual trees that were within about 10 m of the edge of the opening. This 10-m range was adopted based on the study by Yamashita et al. (2006), who found that the residual trees, being far from the opening edge by more than about half of average residual-tree height, were unlikely to affect growth of the planted trees in the group openings. We also measured three-dimensional position of an additional 308 points on the ground selected arbitrarily in the area with distance of less than about 20 m from the edge of the opening. This measurement was performed to generate DEMs with lowest resolution of 10 m, which were used to calculate indirect measures of microsite conditions. In 2004, we measured the height, diameter at ground level (base), and position of all 685 of the 6-year-old trees planted within the opening. The canopy of the young planted trees was not closed at the time of the field survey.

Direct measurement of light and microsite conditions

Of the 685 young planted trees, we selected a sample of 93 trees for measuring light and microsite conditions along two roughly south–north and east–west aligned transects as shown in Fig. 1. To measure light conditions, GLI was determined from color hemispherical photographs taken at