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Promotion of Practical Learning about Plantation Management Planning and System Construction I –Forest Management Plan, Planning of Mensuration and Thinning Operations–

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To conduct the management practices of plantations and improve the capability of professional construction, about 30 ha of the 241.1 ha state–owned forest land situated at Alishan district 141 forest compartment provided by Chiayi Forest District Office in Taiwan was chosen as the planning scope of the forest management plan in this study. The contents covered mensuration, thinning, and ecological surveys. This study also took about 3 ha of the experimental forest area as the basis of the practical planning for "thinning, skidding, yarding and transportation". The forest management plan included the management objectives, status quo analysis, activity assessment, planning scheme, benefit assessment, and budget estimation. The measurement works included a survey on the thinning area via the double sampling method and forest stand volume estimation. The results indicated that the sampling percent of the planned thinning area in the photo sample area was 53%, and that of the ground sample area was 26%. There were totally 339 trees in 16 sample areas according to the survey of forest stand density in the sample area; the volume formula was based on the estimation formula of the crown area and volume shown in aerial photos established through the check formula. The Pearson product-moment correlation coefficient was 0.64–0.81. There was some correlation among the volume, coverage area of aerial crown, and crown projection area on the ground. The planning of thinning operations in forest management cover thinning and budget estimation. The volume of the three thinning modes, i.e., low thinning plan area, block clearing cut plan area, and intermediate thinning plan area, totaled 775.34 m^3, and the required budgets were NTD 3,394,185.

Key words: Plantation, Forest management plan, Mensuration Operation, Forest Stand Volume Survey, Planning of Thinning Operations

INTRODUCTION

Over time, the practical education of plantation management has led to a growing gap between the needs of industry professionals and traditional training courses. As a result, the basic practical skills that were once emphasized in traditional education have been weakened, making it difficult to grasp the future development trends of the forestry industry, leading to a serious mismatch between talent supply and demand (Williamson *et al*., 2009). Taiwan banned the harvesting of natural forests in 1990; since then, technical talents majoring in forest cutting, including forestry personnel, operators and academic groups, have gradually withered, as has the corresponding technical system (Taiwan Forest Bureau, 1995 and 2016). With the rapid development of information digitalization and the demand of practice-oriented learning in the new era, as well as the arrival of the first year of domestic timber utilization in 2017, the practical education on forestry has to cooperate with the professional system to construct practical learning and establish and improve information knowledge, so as to achieve the goal of strengthening plantation management education and the cultivation of professional talents.

To cultivate the practice of plantation management and strengthen the ability of professional construction, this study was conceived that the state–owned forest land provided by Chiayi Forest District Office in Taiwan was the experimental area of the plantation management plan. This study selected 30 ha within the area of 241.1 ha of Alishan district 141 forest compartment as the planning scope of the management plan, which belonged to the forest recreation area. The plan contents included forest stand volume, ecological investigation and thinning and transportation, and took a 3 ha forest land experimental area located in TWD97, X: 219368, Y: 2599486 of Alishan business area was as the basis of investigation. The scope covers forest management logging plans such as forest land survey, tally, volume calculation, ecological investigation, thinning operation, log scaling, release inspection, log transportation, etc. This study attempted to develop a reference suitable for practical courses related to plantation management through practice–oriented learning.

The purpose of this study was to scientifically provide practical learning via information through plantation management practice and the strengthening of professional construction practice operation, so as to innovate the teaching connotations and strengthen the foundation

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of the practical education of forest management. The Taiwanese Forestry Bureau vigorously promoted the use of domestic timber and ensured that wood materials came from well–managed forests; therefore, this study took into account the three goals of economic feasibility, environmental protection, and social fairness and justice advocated by the management and utilization of state-owned forests. Furthermore, the significance of substantially improving the self–sufficiency and utilization percent of wood was achieved. Moreover, the course model teaching was taken as the content of the learning course to achieve the goal of deepening and broadening the curriculum design. The forest management plan covered the management objectives, status quo analysis, activity assessments, planning schemes, benefit assessments, and budget estimations. Measurements of forests cover the survey on the thinning area via double sampling method and forest stand volume estimation. The planning plans of thinning in forest management covered thinning operations and budget estimation.

MATERIALS AND METHODS

Experimental materials

The experimental zone was Alishan district 141 forest compartment. Photo (Fig. 1 right side) of the forest land on the afforestation sites of *Cryptomeria japonica* planted in 1947, standing book: Jing No. 158: TWD97, X: 219368; Y:2599486, covering an area of 3 ha (Fig. 1–left: red box part).

The key technologies and skills of forestry management include: (1) measurements of forest areas, such as estimations from individual trees, forest stands, compartment levels, and forest volume; (2) aerial photogrammetry, using images taken by unmanned aerial vehicle (UAV) as the basis for high-resolution forest operation planning; (3) sampling from fixed areas and plotless sample area to estimate forest stand densities; (4) providing the database of forest stand management of plantation established for the ecological survey of the sample area associated with state-owned forest compartments; and (5) regarding the management plan of the plantation in the experimental area as the management basis of this area. The planning of thinning methods, as well as the techniques and methods of thinning, skidding, yarding and transporting the timber were as follows: (1) deduce continuous forest coverage and low-cost natural regeneration technology; (2) carry out thinning planning and operation control; (3) practice logging, yarding, and transportation; and (4) conduct volume estimation by means of National Standards of the Republic of China (CNS) and other scaling methods in combination.

Test methods

Forest management plan

The forest management plan covered the management objectives (management, environment, society), analysis of consecutive status quo: overview of forest land (natural environment, land ownership, forest resources, trees, plants, animals, etc.), and the assessment of the environmental and social impact of management activities, as well as the forest logging plan of management planning. On this basis, the assessment of the management benefits covered the assessment of the economic, environmental and social benefits. Definitely, there is also the part of budget estimation, including the cost of forest logging and monitoring plans (Bettinger *et al.*, 2009; Chen, 2019).

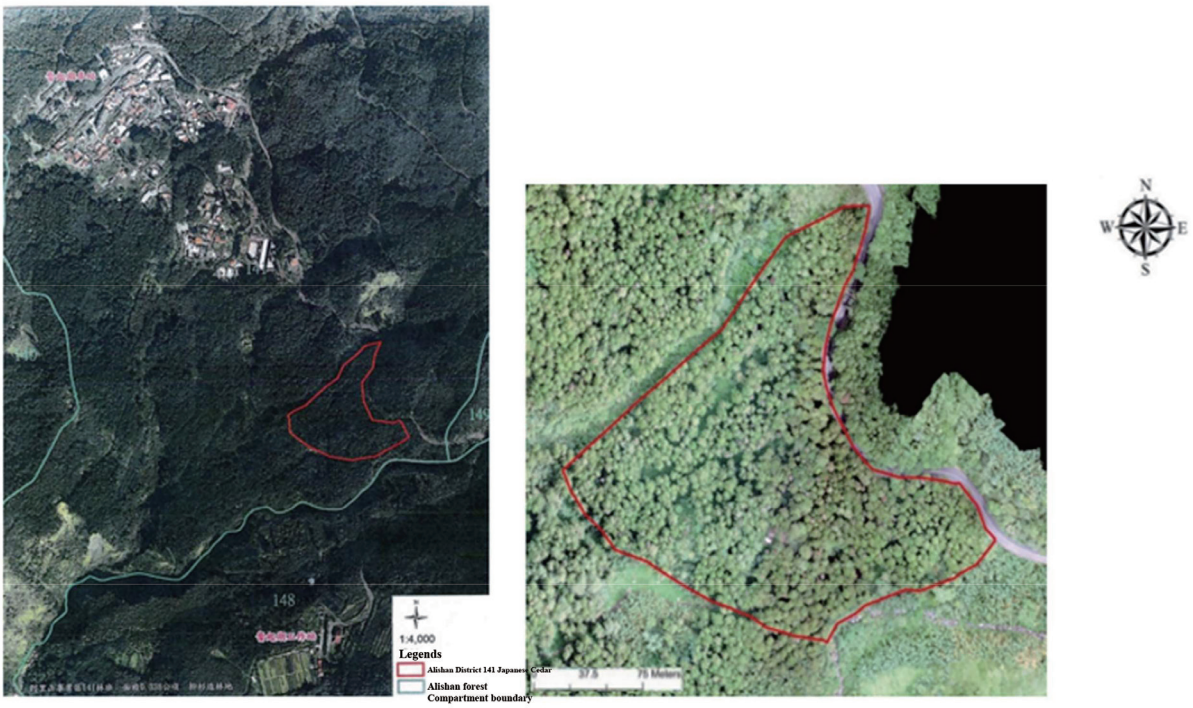

Fig. 1. Forestry bureau Chiayi forest district office Fenqihu workstation thinning area (left red) and thinning forest area (right red) of photogrammetry.

Mensuration operation

Taking trees and forest lands as the main survey objects, the accuracy of aerial orthophotographs available for the measurements of forests affects the reliability of the forest stand density estimation (Van Laar and Akça, 2007). This work was divided into two phases according to the double sampling method. In the first phase, this study measured the sample area (sampling thinning planning area) to calculate the coverage area of the aerial crown (acpa) via aerial photographs; in the second phase, this study measured the DBH, tree height (Th), and other forest stand characteristics and parameters from the ground sample area (Yang and Lin, 2008). The formula was as shown below:

$$\log V = -4.193148 + 0.933828 \log (DBH^2 \times Th) \quad (1)$$

where log$V$ is the logarithm of volume; DBH is the diameter at breast height, and Th is the tree height.

The forest stand density of the thinning ground sample areas was surveyed using the diameter distribution method (DDM). For the establishment of volume formula, the check formula was established by using the crown area of the ground sample area based on the coverage area of the crown in the sample area in the aerial photo and the projection area of the crown in the ground sample area, and the estimation formula of crown area in the aerial photo and volume was established. In addition, according to the Pearson correlation matrix, this study established the correlation among volume, coverage area of the aerial crown, and the crown projection area on the ground (Huseh *et al.*, 2002).

The basic map of the forest land survey featured rapidness, timeliness and high accuracy provided by UAV (SUPPORT FOR PHANTOM 4 PRO), and the 5 m curve of the orthoimages was nested in ArcGis software (Chianucci *et al.*, 2016). The ideal forest stand volume calculation for systematic sampling planning and design was acquired through the combined use of Google Earth and GIS, which served as a reference for compiling the forest management plan. The sequential steps were: (1) shoot orthoimages using UAVs, make a digital terrain numerical model (DTM, DSM), and produce a contour map; (2) integrate the orthoimages and digital terrain numerical model with compartment layer information; and (3) provide detailed geographic planning information for the planning of thinning areas by geographic information layer (Goodbody *et al.*, 2019).

Before planning the workflow of the images shot by the UAV, it was necessary to choose the take–off position around the sample area and the position of the aerial marks suitable for placing the ground control points (Dainelli *et al.*, 2021; Senthilnath *et al.*, 2017; Surový and Kuželka, 2019). Route planning was carried out after the take–off position and ground control points were well chosen; the ground control points were laid out according to the pre–planned position during shooting, and the ground control points were measured by Real Time Kinematic (RTK). The aerial shooting tasks of the UAV were performed upon completion of above procedures (Chianucci *et al.*, 2016). In addition, Google Earth served as an assistant for nesting the orthoimages shot by the UAV as the base map. Google Earth is free and open–source software that can be used to acquire spatial information related to the management of state-owned forests or urban forests (Gregoire and Valentine, 2007).

Planning of thinning operation

According to the distance from the road, the thinning plan adopted a variety of thinning methods such as the low thinning, block clearing cut, and intermediate thinning. The planning of the thinning operations was based on adjusting the forest stand row spacing by thinning the low layer of forests near the main external roads, while giving consideration to landscape-intended implementations, the spatial allocation of trees, and light perspectives (Kerr and Haufe, 2011). According to the forest management plan of Taiwan, shelter forests should be set up on both sides of streams to conserve water resources, and 12.5 m–wide protection belts on both sides of streams can also play a role in alleviating the possible impact on the ecological environment. Clear–cutting in patches is to cut down trees in the sample area, gradually build multi–layer forests, and create the heterogeneity of vertical and horizontal structure of forest stands. The purposes are creating biodiversity conservation, and providing examples of clearcutting in patches for forestry education. Improvement cutting is carried out in other areas for the purpose of teaching practice. Moreover, after thinning, the remaining trees have to be capable of natural seeding and updating (Ker, 2008). In the future, forest stands can be managed to provide sustainable forest coverage and gradually be updated into a native forest form in Taiwan that conformed to the ecological climate.

RESULTS AND DISCUSSION

Objectives of the forest management plan

Objectives of forest management

The objectives of forest management were built at three terms, short, medium, and long phase (Bettinger *et al.*, 2009). In terms of short–term forest management, it was to carry out thinning operation in the forest recreation area jointly through cleaning–cutting, intermediate thinning, and other work in combination. The operation mode mainly consisted of the low thinning to increase the diameter and crown width of the remaining trees, extend the forest stand with thick crown density, and increase the amount of light in the forest, resulting in a good perspective and a wider and more comfortable view. The overall landscape effect of the forest stand was positively evaluated. For the short–term environmental objective, it was to launch moderate forest thinning operations to cut down inferior trees with poor growth, alleviate the competition with the target trees, lower the density of the trees, reduce the probability of disease, guarantee the health of the forests, enlarge the stand spacing, and increase the diversity of ecological and wildlife habitats. Besides, the short–term social objective covered allowing tourists and local residents to

learn about the characteristics of thinning operations as well as the contribution of thinning to the forest and the environment through enhancing the educational function of the forest environment, building a forest recreation area, and boosting the development of local forest culture.

The medium–term forest management was planned on the basis of forest recreation principles. The forest recreation area was guided by the natural resources of the forests, and the thinning operation was carried out based on its landscape purpose. The operation mode was chosen according to local conditions, while taking into account the spatial distribution of trees, the light perspective, the growth of shrubs and ground cover plants, and the range of wildlife activities. For the medium–term environmental objective, it was to maintain the health of the forests and the sustainable growth of large–diameter trees, as well as facilitate the sustainable development of the forest recreation area. In addition, the medium–term social objective covered increasing the value of the forest recreation area around Fenqihu, attracting tourists to stroll about or have a rest, attracting business opportunities and new residents, increasing the aesthetic beauty of the forest space through thinning, offering recreational opportunities, reducing the psychological fatigue of tourists, and enhancing their mental health.

The long–term forest management plan was based on building the forest recreation area as a green rest space for local residents and satisfying their tourism needs. At first, the goals are to preserve the original distinctive trees, increase the forest landscape and build a variety of forest landscape features by thinning of this area year by year; on the other hand, the plan objectives to enlarge the hinterland for activities, rest and amusement in the forest recreation area of Fenqihu, raise the value of viewing and hiking, achieve space allocation and guarantee visual effects. For the long–term environment objective, based on upholding the principle of sustainable development, it was to rationally manage the forest land, alleviate unnecessary impacts on the environment due to the decrease of forest stands, and maintain the ecological diversity of the area. Moreover, the long-term social objective covered putting forest product education into practice, minimizing the loss of technical systems, letting relevant talents apply what they have learned to meet practical needs, and gathering relevant experience for the sake of the development of subsequent medium-term and long–term plans.

Analysis of the status quo of forests

The management planning area was situated at Alishan district 141 forest compartment, located in Chiayi County, Taiwan. As shown in Fig. 2, the light blue area covered a compartment area of 241.14 ha; the pink area was the predetermined scope of forest management area this time, with an area of 30 ha, and the orange area was the scope of the actual thinning planning area (3 ha). The forest land was situated at Alishan district 141 forest compartment, Chiayi County, which is subordinate to Zhonghe Village, Zhuqi Township, Chiayi County. The location had an altitude of about 1,400 m, a mean annual temperature of about 17.1°C, a monthly mean minimum temperature of 12.3°C, and a monthly mean maximum temperature of 20°C. The annual rainfall was 3,763.5 mm, and the rainy season lasted from June to October, with no obvious dry period. The area received an average of 71.1 sunny days per year, the relative humidity was 90.3%, and the annual mean wind speed was 4.2 m/s.

The forest land in the management planning area was around 1 230 – 1 390 m above sea level, with a height difference of around 160 m, which belongs to the mountainous terrain of middle altitude. Its slope was between 0.0 and 87.0%. The west–south direction of the slope covered the largest area, followed by the northwest direction and the west direction. The management planning area was situated in the upper reaches of the Bazhang River and included three wild streams that converged to the river within the experimental zone. A 30 ha area, spanning a total of 13 land numbers, was included in the management plan, with 10 land types for forestry and three land types for special purposes, all of which were state–owned.

The forest resources are situated at Alishan district 141 forest compartment. Forestland afforestation was dominated by *Cryptomeria japonica* and *Cunninghamia konishii*, followed by *Taiwania cryptomerioides*, and the artificial afforestation areas were 22.9 ha and 0.7 ha, respectively. In the management planning area, except for the plantation (the purple range), lower mountains–lowland herbaceous flora covered an area of 3.5 ha (the light yellow range), bamboo forest covered 3.1 ha (the purple range), construction site covered 1.1 ha (the blue range), natural exposed land covered 0.8 ha (the green range), and arable land covered 0.13 ha (the blue and green range), as demonstrated in Fig. 3.

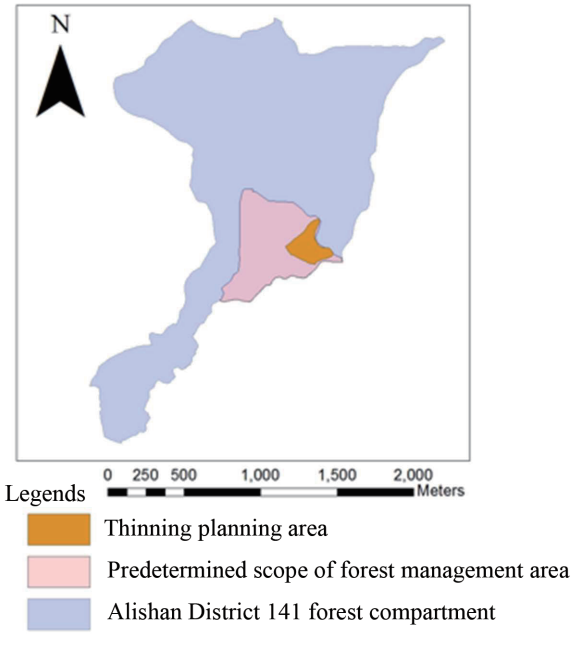

Fig. 2. Forest management planning area.

First of all, a 10 m x 10 m quadrat was set up for plant resources in the thinning area. The DBH of plants with a breast–height diameter of more than 1 cm was measured, and a stratified quadrat survey was carried out on the other plants using the Braun–Blanquet survey, which covered all higher plants in the quadrat and measured their dominance grades. The results of the preliminary sampling before thinning showed the existence of 82 species of vascular plants belonging to 41 families, among which *Elatostema lineolatum* var. majus was in the majority, and *Cryptomeria japonica* of Cupressaceae had the largest volume. Mammals, birds, reptiles, amphibians, and insects were surveyed in the sample area for a period of two years, and some *Herpestes urva* were found in the survey results.

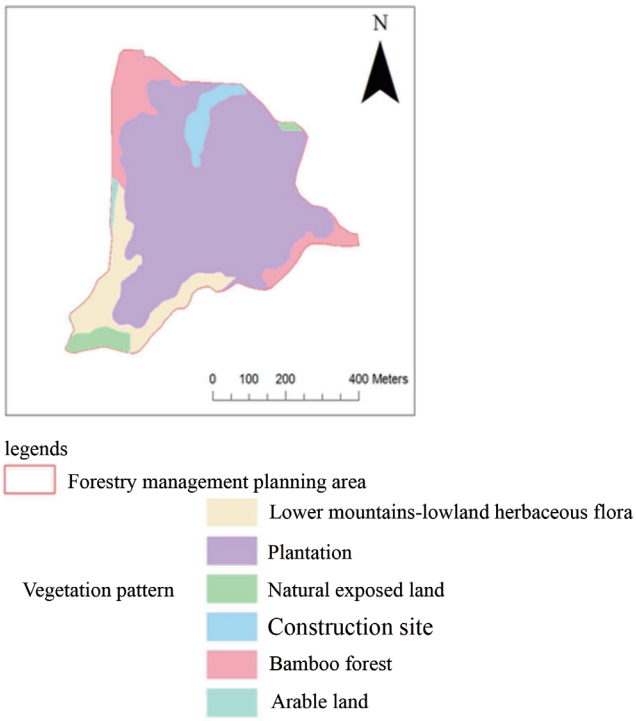

Fig. 3. Vegetation pattern of forestry management planning area.

In light of the environmental impact assessment of the management activities, the forest land was graded as a forest recreation area covering an area of 30 ha. The forest thinning planning area was 3 ha in the first year. Some areas were situated in geologically sensitive areas, including streams, operation roads, and other geologically sensitive areas. The impact on water and soil resources brought by management operations have to minimized in the course of logging. In view of the above, low thinning plan of logging mode was taken to increase the biodiversity of the area, maintain the ecological balance, and alleviate the impact of logging activities on the geological and ecological environment. The planned forest land was adjacent to the settlement of Fenqihu and situated in the traffic artery Alishan highway and branch lines, where the traffic is busy. Therefore, before and after logging, it was necessary to attach importance to traffic safety when transporting logging machinery and timbers, in a bid to minimize the traffic impact resulting from logging operation.

According to the topographical restrictions, contour distribution, and hydrological course, six thinning areas were set in the forest logging plan of the management planning scheme, covering an area of 30 ha, as demonstrated in Fig. 4. The forest thinning planning area also covered overground objects such as construction land, tea gardens, and natural grassland vegetation; the actual planning area of thinning was 27.35 ha; six thinning areas (A–1, A–2, A–3, A–4, A–5, A–6; left side of Fig. 4.) were scheduled for thinning operation. In accordance with the "Specification of the Forestry Bureau for Thinning Operation of State–Owned Plantation", the planned forest management area–forest thinning planning area was subordinate to the forest recreation area; the thinning operation; therefore, was launched for the purpose of landscape. In terms of the mode of the thinning operation, the spatial allocation of trees and the light perspective were taken into account, and inferior were removed by means of low thinning plan.

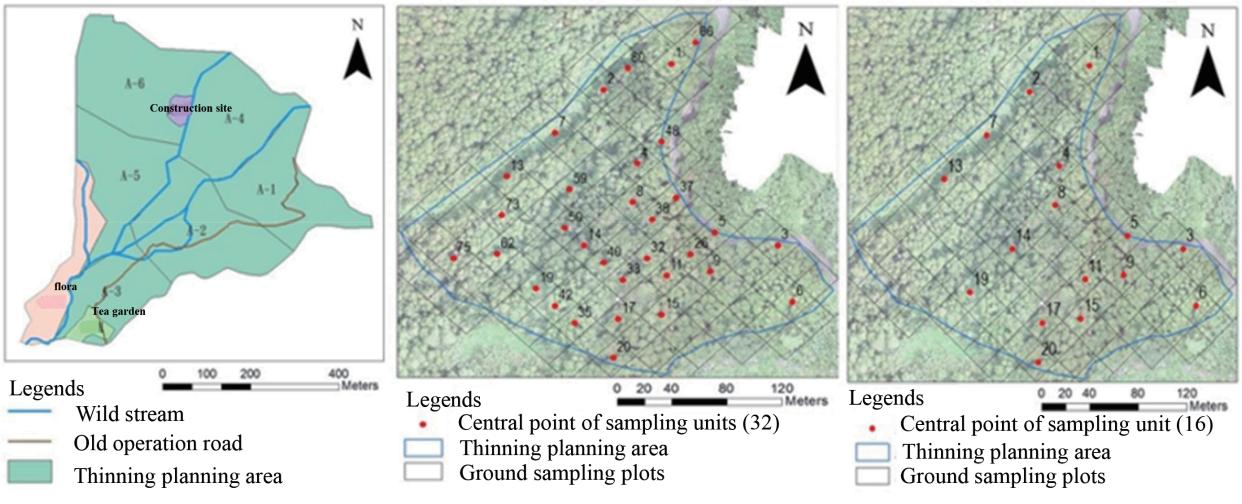

Fig. 4. Forest thinning planning area.

According to the assessment of the economic and management benefits, the forest form of the existing forest land need to improved by reforestation by stages and by districts, and *Cryptomeria japonica* harvested were taken as the source of economic income. After logging, native tree species such as *Taiwania cryptomerioides*, *Cunninghamia konishii*, and *Chamaecyparis formosensis* were planted to increase the productivity of the forest land and the self–sufficiency of domestic timber. According to the assessment of the environmental benefit, the poorly growing *Cryptomeria japonica* plantation had to gradually improved in form and updated as *Taiwania cryptomerioides*, *Cunninghamia konishii*, and *Chamaecyparis formosensis* (three of them are the native tree species of Taiwan at all). During the improvement of the forest form, the sensitive zones on both sides of the streams and relatively steep slopes was necessary to avoided to effectively protect and monitor the situation and changes of the surrounding environment during operation, and the forest land had to properly managed, thus achieving the effect of carbon sequestration and exerting positive functions and impacts on the global environment. According to the assessment of the social benefit, it was necessary to offer a safe working environment for workers, protect their rights and benefits, observe relevant government laws and regulations, communicate with local people to an appropriate extent, and respect the culture and customs of aborigines and local communities.

According to the budget estimate of the logging cost, logging area A–1 (Fig. 4 left; Fig. 2. orange area) covered 3 ha, and labor for the logging work was outsourced. The forest trees harvested were subject to the first and second logging intensities in the current planning scheme. The logging cost was calculated by volume, with 1 m^3 being around NTD 3,000 in Taiwan. Plan 1 estimated the logging volume as 612.23 m^3, with a total amount of NTD 1 836 690; Plan 2 estimated the total logging volume as 306.12 m^3, with a total amount of NTD 918 360, etc. The logged trees were used for educational purposes, so there was no actual benefit from harvesting wood sales. In addition, the logging trees were used for education, so there was no actual benefit from the sales of harvested wood.

Furthermore, the monitoring and planning cost involved investigating and monitoring the activities and growth status of the animals and plants before and after thinning in 30 ha, in which the cost to monitor the animals was estimated to be about NTD 300 000 and the cost to monitor the plants was estimated to be about NTD 200 000. These two items amounted to be totally NTD 500 000.

Mensuration Operation

Double sampling method for thinning area (Fig. 4 center and right sides): in the first phase, in the photo sample were the 3 ha thinning planning areas were divided into 60 plot and the area of each plot was 20×25 m, and thirty–two 20×25 m plots were selected as ground sample areas, with a sampling percent of 53% (Fig. 4 center). The coverage area of the aerial crown (acap) was calculated by measuring the aerial photo. In the ground sample plots, 16 ground sample areas with 20×25 m were selected, with a sampling percent of 26% (Fig. 4 right). The DBH, tree height, and other forest stand characteristics and parameters were surveyed in the ground sample plots. The density of the forest stands in the sixteen sample areas was surveyed by DDM, and 339 trees in total were located in the 16 sample plots.

The relationship between crown area and the volume formula of the ground sample area was established as per the coverage area of the crown (acpa) and crown the projection area (gcpa) of the ground sample area shown in the aerial photos. The estimation formula of the crown area and the volume of the aerial photos was established through the check formula, and the Pearson product–moment correlation coefficient was 0.64–0.81. A correlation was found among the volume, coverage area of the aerial crown, and the crown projection area on the ground (Table 1).

For the formula of ground volume, 16 ground sample plots were taken for tally, and the ground volume was established based on the crown area and ground volume in the ground survey materials, shown as Eq. (2):

Ground volume (V) = 12.916 + 0.0356 × crown projection area on the ground (gcpa) ..... (2)

For the formula of aerial volume, 16 plots in the air

Table 1. Building regression equation of aerial stand volume data table (sampling plot 20)

Sampling plot No	Volume (m^3)	Ground canopy projected area (m^2)	Aerial canopy coverage area (m^2)
1	41.14	601.47	448.03
2	25.46	422.78	384.00
3	24.46	430.84	357.00
4	37.69	745.68	443.08
5	15.30	292.86	200.00
6	40.80	641.51	387.48
7	37.99	529.74	352.20
8	26.57	619.15	359.10
9	21.49	487.19	394.00
11	28.03	653.59	403.74
13	41.69	678.30	431.63
14	32.04	388.34	335.09
15	25.94	202.79	150.20
17	33.44	334.87	387.72
19	14.53	279.21	160.00
20	37.93	492.31	397.78

n: Number of aerial sampling plots, n =32
m: Number of ground sampling plots, m =16
$\bar{Y}_m$: The mean estimated value of Y in the 16 sample areas on the Ground, $\bar{Y}_m$= 30.28 m^3
$\bar{X}_n$: Auxiliary variable X mean estimated value of 32 sample plots in the air, $\bar{X}_n$ =372.51 m^2
$\bar{X}_m$: The estimated value of the mean of X in the 16 plots on the ground, $\bar{X}_m$ =487.54 m^2

were sampled, and the crown area was surveyed by aerial photos to establish the formula for aerial volume, shown as Eq. (3):

Aerial volume (V) = 7.18572 + 0.06609 × area of aerial crown (acpa) ..... (3)

The intercept of the linear relationship between volume and the area of the aerial crown was not significant ($Pr > |t| = 0.28327$), so Eq. (2) was corrected by Ratio Estimator (Thompson, 2012) to conclude the final formula of aerial volume, as shown in Eq. (4):

$$\text{Ratio Estimator} = \frac{\sum_{i=1}^{m} \bar{X}_m}{\sum_{i=1}^{n} \bar{X}_n}$$

$$= \frac{\text{Estimated value of mean value of the area of ground crown}}{\text{Estimated value of mean value of the area of aerial crown}}$$

$$= \frac{487.5394}{349.4406} = 1.4$$

Volume (V) = (12.916 + 0.0356 × (1.4 × area of aerial crown (acpa)) …..…. (4)

Estimated value of the regression of the main variables in the confidence interval of the thinning area

$\bar{Y}_{reg} = \bar{Y}_m + b\ (\bar{X}_n - \bar{X}_m)$

$= 30.28 + 0.3562\ (372.51–487.54)$

$= 26.18$

$s_{\bar{Y}reg} = 2.69$

Estimated value of variance $s^2_{\bar{Y}reg}$

$$= 49.66 \left[\frac{1}{16} + \frac{(372.51–478.54)^2}{389351.72} \right] + \frac{79.28–49.66}{32}$$

$$- \frac{79.28}{60} = 7.25$$

Degree of freedom 16 – 2 = 14 and $\alpha = 0.05$, $t = 2.145$.

The 95% confidence interval of mean values of the volume in the sample area was 30.28±5.77 m^3.

The estimated value of the volume of the whole forest in the thinning area and the confidence interval was 1816.88±346.62 m^3

$$\text{Error percent of sampling } (E) = \frac{t \times S_{\bar{Y}_{reg}}}{\bar{Y}_{reg}} = \frac{5.78}{26.18} \times 100 = 22.07\%$$

Planning of the thinning operations

Thinning operation plan

In determining the species and methods of thinning the trees in thinning area A–1 (Fig. 4; Fig. 2. orange area), the tally in the sixteen ground sample areas in the thinning area A–1 in view of the characteristics of tree species shows that the planning of thinning area in A–1 area was surveyed in sixteen plots on the ground. The results showed that there were 308 *Cryptomeria japonica*, 23 *Cunninghamia konishii*, and one *Schefflera octophylla*, for a total of 339 trees. As most of them were coniferous trees, and due to their shade tolerance and narrow crown characteristics, the row spacings of the space retained for preserved trees could be smaller, about 1/5 to 1/4 Th of the tree height, i.e., 20–25% of the height. In determining the optimum number of trees, after measuring and calculating the data for thinning area A–1, the mean volume per unit grid in the thinning planning area was 30.28 m^3, the mean number of trees was 21, the mean row spacing was 4.8×4.8 m, the mean tree height was around 25 m, the mean volume was 1.4 m^3, the total number of trees per hectare was 424, and the total volume was 589.08 m^3/ha. The thinning intensity and the row spacing of the preserved wood were determined by the tree height. In accordance with the "Regulations of Thinning Operations for State–owned Plantation", the row spacings for the purpose of landscape or diversity need to be larger. The mean tree height of the forest stand of *Cryptomeria japonica* was 25 m and the optimal thinning number was 20–25% of the tree height, so the appropriate distance of the forest stands was 5.0–6.2 m.

Thinning method

The planning area (blue frame of Fig. 5) of the thinning operation for thinning area A–1 was divided into two areas, i.e., low thinning plan area, block clearing cut plan area, and intermediate thinning plan area (Fig. 5), because this area contained a forest recreation area, a wild stream (light blue area of Fig. 5) protection zone, and a geologically sensitive zone. The forest stand row spacing was adjusted by thinning the low thinning plan area (natural yellow area of Fig. 5) near the main external roads and the row spacing of forests was configured, while giving consideration to the implementation for the purpose of landscape, spatial allocation of trees and light perspective. According to the "Forest management plan of Taiwan", shelter forests were set up on both sides of the streams to conserve water sources.

The planning of the thinning operations resulted from clearly distinguishing different thinning intensities of the low thinning plan, i.e., setting up 5 m wide stream protection belts on the left and right sides of streams, so that the thinning planning of the low thinning cut would be less affected. The planning of the landscape from Alishan highway to Fenqihu was able to allow people to feel the spatial allocation of trees with different thinning intensities, which was of enormous significance for tourism development, forestry education, and ecological protection. Logging the low thinning plan was performed to extend the closed forest stand, offer space for the future growth of trees, enhance the health of the forest stand, and increase the biodiversity in the forest land, including dead and dying trees, top–broken trees, crushed trees, and trees with serious pests and diseases, and then thinning the intermediate trees in sequence and eliminating inferior trees in the middle and low layers of the forest stand.

The block clearing cut plan area (pink area of Fig. 5) was performed out–of–sight from the road. According to the relatively gentle terrain slope and hydrological distribution, 12.5 m wide stream protection belts were set on both sides of the streams, without influencing the planning of block clearing cut, which were able to be conducive to reduce the possible impact on the ecological environment as well. The block clearing cut involved removing trees in the sample area, gradually building multilayer forests, creating heterogeneity in the vertical and horizontal structures of the forest stands, targeting the

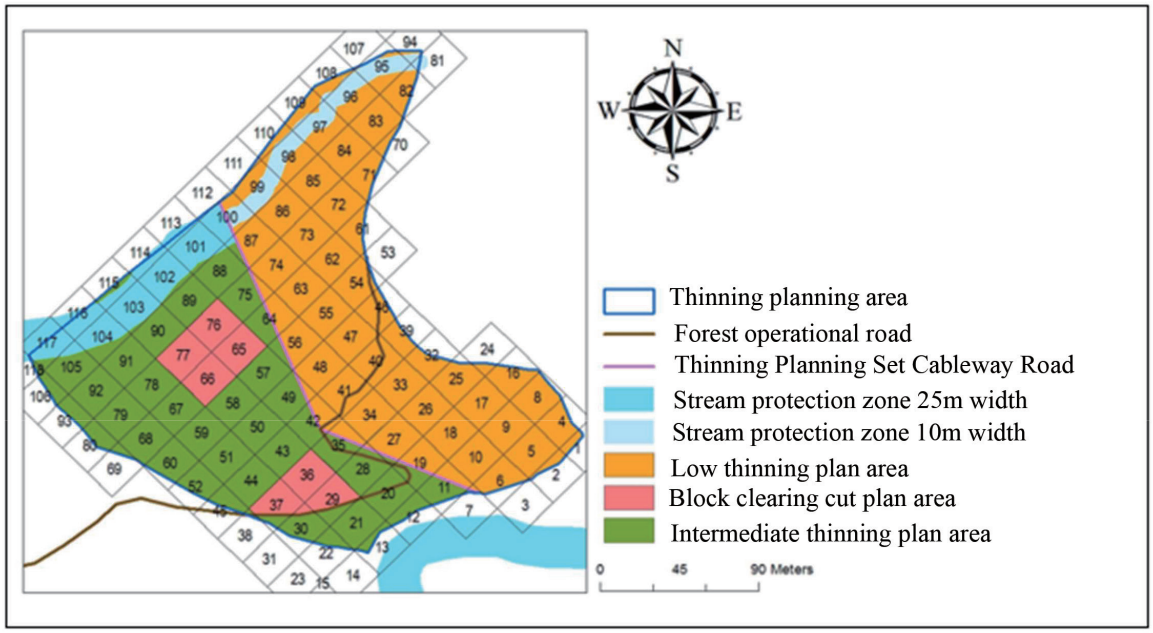

Fig. 5. Forest thinning type planning area.

conservation of biodiversity, and listing examples of block clearing cut for forestry education. Thus, in thinning planning, forest lands with relatively flat areas in the forest stand did not influence the soil and water conservation measures, and regional forest logging was launched at the ratio of tree height. When planning multi–zone logging, forest lands need to be separated by a certain distance to avoid influencing the growth of animals and plants as well as soil and water conservation in forest lands.

intermediate thinning (green area of Fig. 5) was performed to finish the forest land, remove short and dead trees, and facilitate the growth and maintain the health of the original forest stands, which were able to achieve the principal purposes of the planning of thinning operations, i.e., to set examples of thinning planning operation of forest products and carry out teaching practice.

CONCLUSION

In this study, state–owned forest land provided by the Chiayi Forest District Office in Taiwan was used for creating the forest management plan, and the experimental area of the forest land was used as the basis for the practical planning of thinning, skidding, yarding and transporting activities. The forest management plan included the management objectives, status quo analysis, activity assessments, planning schemes, benefit assessments, and budget estimations. The measurements included a survey on the thinning area via the double sampling method, and forest stand volume estimation, etc. The planning plans of thinning in forest management cover thinning operation and budget estimation, etc. The above related results and concept period were able to be used as a reference for the students in the cultivating plantation management practices and strengthening professional construction abilities.

AUTHOR CONTRIBUTION

Ming–Hsun Chan provided the equipment and performed the course/experimental data with the statistical analysis. Wan–Ting Xie carried out the experimental data. Noboru Fujimoto supervised the work. Han Chien Lin designed the study and wrote this paper. The authors assisted in editing of the manuscript and approved the final version.

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