Effects of Thinning and Pruning on Native Mangrove Plants Under Laguncularia Forest Postprint

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Abstract

To investigate the effects of a new approach in protected areas that, instead of implementing clear-cutting measures causing intensive habitat disturbance in exotic mangrove Laguncularia racemosa plantations, gradually phases out L. racemosa and replaces it with native mangrove forests through thinning and pruning treatments, this study took L. racemosa forests in Dongzhaigang National Nature Reserve, Hainan as the research area, and based on the reserve's thinning and pruning operations on L. racemosa forests, investigated the ecological effects of thinning and pruning regulation measures on restoring native mangrove communities. The results showed that: (1) The asexual reproduction through stump sprouting of L. racemosa after thinning and pruning weakened the treatment effects, but there was no significant difference in the sprouting effects between the two treatments of single intervention (50% intensity thinning and pruning) and double intervention (an additional pruning after 50% intensity thinning and pruning). (2) Thinning and pruning could enrich the species diversity of native mangroves in the understory shrub layer and promote their growth, with the double intervention showing more pronounced promotion effects than the single intervention, but had no significant effect on the natural regeneration of mangrove seedlings in the herbaceous layer. (3) When native mangrove seedlings were artificially planted in three types of sample plots (non-thinned, thinned and pruned, and forest edge), thinning and pruning had certain promotion effects on the survival rates of Rhizophora stylosa and Kandelia obovata seedlings; and the thinning and pruning treatment had effects on R. stylosa growth that approached forest edge conditions, but the effects were limited. It is recommended that, based on 50% intensity thinning and pruning, the thinning intensity or pruning frequency should be increased, native mangrove species should be appropriately planted in the understory, and sprouts from L. racemosa stumps should be simultaneously removed, which would be more

conducive to the transformation of L. racemosa forests into native mangrove forests.

Full Text

Preamble

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Effects of Thinning and Pruning on Native Mangrove Plants in the Understory of *Laguncularia racemosa* Forest

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Abstract: To explore a new pathway for gradually replacing exotic mangrove *Laguncularia racemosa* plantations with native mangrove forests through thinning and pruning—without implementing drastic clear-cutting measures that severely disturb habitats—this study investigated the ecological effects of such interventions on the restoration of native mangrove communities in Hainan Dongzhai Harbor National Nature Reserve. The results showed that: (1) Asexual reproduction through stump sprouting weakened the effectiveness of thinning and pruning, though no significant difference was observed between one-time intervention (50% intensity thinning and pruning) and two-time intervention (additional pruning after the initial 50% thinning). (2) Both interventions enriched native mangrove species in the understory shrub layer and promoted their growth, with the two-time intervention showing more pronounced effects than the one-time intervention, but neither significantly affected natural regeneration of mangrove seedlings in the herbaceous layer. (3) When native mangrove seedlings were planted in three plot types (non-thinned, thinned/pruned, and forest margin), thinning and pruning improved the survival rates of *Rhizophora stylosa* and *Kandelia obovata* to some extent; the growth of *R. stylosa* under thinning approached that in forest margin conditions, though the effect was limited. We recommend increasing thinning intensity or pruning frequency beyond the 50% level, conducting appropriate artificial planting of native mangrove species in the understory, and simultaneously removing sprouting branches from *L. racemosa* stumps to facilitate conversion of *L. racemosa* plantations to native mangrove forests.

Keywords: exotic mangrove, *Laguncularia racemosa*, thinning and pruning, native mangrove, ecological restoration

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Exotic plants typically exhibit rapid growth and strong adaptability, often forming monospecific stands in introduced areas that reduce biodiversity and constrain the growth of native understory and surrounding vegetation (Xiang et al., 2002). For instance, exotic species such as *Rhus typhina* (Wu et al., 2007), *Robinia pseudoacacia* (Luo, 2016), and *Eucalyptus robusta* (Wang et al., 1998) demonstrate strong invasiveness, outcompeting native tree species where they form extensive stands. In mangrove ecosystems, the introduction of *Sonneratia apetala* has hindered the development of *Aegiceras corniculatum* and *Avicennia marina* populations (Li et al., 2004). Another introduced species, *Laguncularia racemosa* (family Combretaceae, genus *Laguncularia*), a true mangrove species introduced from Mexico to Hainan Dongzhai Harbor National Nature Reserve in 1999 for mangrove wetland restoration (Zhong et al., 2011), has grown rapidly with a simple understory structure. Its strong reproductive capacity has enabled it to spread into native mangrove communities (Wang et al., 2020), posing potential invasion risks to native mangrove ecosystems (Liu et al., 2019).

To improve species diversity in exotic plant plantations, artificial intervention is necessary. Thinning is a crucial measure for regulating plantation structure and improving understory vegetation composition in exotic species stands. Studies have shown that thinning can increase shrub and herb layer diversity in *R. pseudoacacia* forests at moderate to low density levels (Fu et al., 2021). In mature, low-density Japanese larch (*Larix kaempferi*) forests that have undergone harvesting, understory shrub and herb coverage increased (Liu et al., 2020), with intensive thinning showing the best results (Tang et al., 2018). Huang et al. (2021) demonstrated that intensive thinning of eucalyptus plantations interplanted with native species was more effective in promoting stand growth, improving stand structure, and enhancing soil quality. Artificial thinning of introduced *S. apetala* in Shenzhen Futian Mangrove Reserve accelerated natural recovery of native mangrove species (Hu et al., 2016). In recent years, to control the invasion of *L. racemosa*, areas such as Sanya Tielu Harbor, Hainan Xinying Mangrove National Wetland Park, and Beihai Coastal National Wetland Park have been clearing *L. racemosa* and replanting with native mangrove species. Converting *L. racemosa* forests to native mangrove communities within protected areas represents both a practical challenge and a theoretical question in wetland restoration ecology regarding species substitution. To control *L. racemosa*, Hainan Dongzhai Harbor National Nature Reserve implemented two treatments: one-time intervention (50% intensity thinning and pruning) and two-time intervention (additional pruning after the initial 50% thinning).

This study examined the ecological effects of thinning and pruning on restoring native mangrove communities in introduced *L. racemosa* forests in Hainan Dongzhai Harbor National Nature Reserve. Using quadrat surveys, we compared native mangrove recovery in thinned/pruned versus non-thinned *L. racemosa* stands and evaluated stump sprouting to identify new pathways for orderly *L. racemosa* replacement without drastic clear-cutting. Specifically, we investigated: (1) whether the two interventions effectively controlled *L. racemosa*; (2) their effects on natural regeneration of native mangrove species and differences between interventions; and (3) the impact of thinning/pruning on artificial restoration of native mangroves, using non-thinned and forest margin plots as controls. These findings provide reference for effective management of exotic mangrove *L. racemosa*.

1.1 Study Area Overview

The study site is located in an exotic mangrove plantation area along the coast from Xinghui Village to Dongpai Village in Yanfeng Town, Dongzhai Harbor, Haikou City (110°35'05.22" E, 19°57'57.51" N), characterized by irregular semidiurnal tides (Liao et al., 2005). Originally bare intertidal flats, the area was afforested during 2011-2012, primarily with *L. racemosa* and a small number of *S. apetala* at a planting density of 2 m × 1 m (row spacing 2 m perpendicular to the coastline, plant spacing 1 m). By 2018, the stands had closed canopy. To convert exotic *L. racemosa* forests to native mangrove communities without drastic habitat disturbance from clear-cutting, the Hainan Dongzhai Harbor National Nature Reserve Management Bureau implemented two artificial interventions. The first intervention (thinning and pruning) occurred in February-March 2018, involving row-thinning perpendicular to the coastline at 50% intensity, resulting in a new spacing of 4 m × 1 m. Pruning retained a 1 m × 1.5 m crown on the main trunk while removing all side branches, except for a few large ones. The second intervention (pruning only) in November 2018 removed newly grown side branches from retained *L. racemosa*, leaving only the main trunk. Pre-intervention surveys in December 2017 showed average *L. racemosa* height of 5 m, DBH of 4.3 cm, crown width of 1.89 m, and canopy density of 0.92. Native mangrove species were mainly distributed on the landward side with low overall uniformity. The shrub layer was dominated by *Ceriops tagal*, *L. racemosa*, *Avicennia marina*, and *Kandelia obovata* (average height 0.98 m, basal diameter 1.8 cm). The herbaceous layer was mostly *L. racemosa*, with native species *Rhizophora stylosa*, *C. tagal*, and *Bruguiera sexangula* occurring sporadically.

1.2.1 Natural Recovery of Native Mangrove Species and Stump Sprouting After Thinning and Pruning

Three plot types were established: one-time intervention plots (thinned/pruned once), two-time intervention plots (additional pruning), and non-thinned plots (no intervention). In January 2022 (four years post-thinning), we surveyed *L. racemosa* forests in these plots. In the two intervention plots, we randomly selected six thinned rows to count stumps with sprouts (sprouting rate), sprouts per stump, and measured sprout height and basal diameter. In all three plot types, we established three 5 m × 5 m shrub quadrats to survey native mangrove species, individual counts, height, basal diameter, and crown width. Within each shrub quadrat, we set one 1 m × 1 m herb quadrat to survey native mangrove species, individual counts, and average height. Classification criteria: shrubs 50 cm < height < 3 m; herbs height < 30 cm (National Forest Resources Standardization Technical Committee, 2020; Wang et al., 2022).

1.2.2 Artificial Restoration of Native Mangrove Species After Thinning and Pruning

Three plot types were established: non-thinned plots, one-time intervention plots (referred to as thinned plots), and forest margin bare beach plots (forest margin plots). Two native mangrove species, *R. stylosa* and *K. obovata*, were planted as 1.5-year-old seedlings in these plots. For each species, three 5 m × 5 m replicate quadrats were established per plot type, totaling six quadrats. Sixteen seedlings (from Dongzhai Harbor nursery) were planted in each quadrat at approximately 1 m spacing in the inter-rows of *L. racemosa*. Growth indicators and environmental factors were monitored every three months from October 2018 to October 2019, with a final survey in June 2021 (three years post-thinning). Environmental factors measured included understory/canopy light ratio (Shen Dawei Sw-582 digital lux meter), soil pH (Zhengda ZD-18 intelligent digital pH meter), soil temperature, and soil salinity (Shunke Da TR-6D soil multi-function tester).

1.3 Data Processing

Stump sprouting rate = (number of sprouting stumps per thinned row / 19) × 100% (average 19 stumps per thinned row). Sprout number = (total sprouts per thinned row / number of sprouting stumps per thinned row). Survival rate = (survived individuals / 16) × 100%. All data were processed and analyzed using Excel and SPSS 25.0.

2 Results and Analysis

2.1 Effects of *L. racemosa* Stump Sprouting on Thinning and Pruning Effectiveness

Four years post-thinning, stump sprouting occurred in both one-time and two-time intervention plots, with sprouting rates of 12.93% and 5.26%, and average sprout numbers of 2.81 and 1.69 per stump, respectively. Both interventions failed to completely eradicate *L. racemosa*. Maximum sprout heights exceeded 300 cm and basal diameters reached over 4 cm in both intervention plots, indicating that *L. racemosa* can weaken thinning effects through asexual stump reproduction [Figure 1: see original paper]. No significant differences were found between the two interventions in sprouting rate, sprout number, maximum height, or basal diameter ($P > 0.05$).

2.2 Natural Regeneration of Native Mangrove Species After Thinning and Pruning

Before thinning, native mangrove species were sporadically distributed in the understory. Four years post-thinning, native mangroves were only found in intervention plots (Table 1). In the shrub layer, the one-time intervention plot had the most native species (*A. marina*, *C. tagal*, and *K. obovata*), while the two-time intervention plot only had *A. marina*, and the non-thinned plot had none. In the herb layer, *K. obovata* was only observed in the two-time intervention plot. No significant differences in native mangrove individual counts were found among the three plots for either shrub or herb layers. This indicates that non-thinned plots were unsuitable for native mangrove growth, while artificial intervention promoted natural regeneration, though the effect was not statistically significant four years post-thinning.

Growth metrics (height, basal diameter, and crown width) of native mangroves in the shrub layer were higher in the two-time intervention plot than in the one-time intervention plot [Figure 2: see original paper], with crown width being significantly greater ($P < 0.05$). Thus, increased thinning intensity promoted native mangrove growth. No native mangroves survived in non-thinned plots, so they were excluded from growth comparisons.

2.3.1 Dynamic Changes in Survival Rates of *R. stylosa* and *K. obovata* in Different Plot Types

Survival rates of both mangrove species declined over time in all plot types [Figure 3: see original paper]. By the end of the observation period, survival rates were zero in non-thinned plots for both species.

For *R. stylosa* seedlings, no significant differences in survival rates were found among non-thinned, thinned, and forest margin plots at any observation period. By June 2021, no *R. stylosa* survived in non-thinned plots, while survival rates were 20.83% in forest margin plots and 16.67% in thinned plots. This suggests that 50% intensity thinning and pruning created understory conditions approaching those at the forest margin for *R. stylosa*.

For *K. obovata* seedlings, survival rates were consistently lowest in non-thinned plots and highest in forest margin plots (except October 2019), with significantly higher rates in forest margin plots than in non-thinned plots in July 2019 ($P < 0.05$). Three years post-thinning (June 2021), survival rates were 18.75% in forest margin plots, 6.25% in thinned plots, and zero in non-thinned plots, though differences were not significant. This indicates that 50% intensity thinning promoted *K. obovata* seedling survival, but the effect was not significant and diminished over time.

2.3.2 Growth Increment Changes of *R. stylosa* and *K. obovata* in Different Plot Types

Height, basal diameter, and crown width increments of *R. stylosa* are shown in [Figure 4: see original paper]A, B, C. During the first year (October 2018–October 2019), height increment differed significantly among plots: forest margin plots exceeded thinned and non-thinned plots during April–July and July–October 2019, while thinned plots exceeded non-thinned plots during July–October 2019. However, during October 2019–June 2021, height increments did not differ significantly between forest margin and thinned plots, as all *R. stylosa* in non-thinned plots died.

Basal diameter increment was significantly higher in forest margin plots than in thinned and non-thinned plots during July–October 2019, but by the final period (October 2019–June 2021), thinned plots showed similar increments to forest margin plots. Crown width increments were negative in non-thinned and thinned plots during October 2018–January 2019 due to leaf shedding to reduce transpiration and maintain water balance. During April–July 2019, crown width increment was significantly greater in thinned plots than in non-thinned plots, and during July–October 2019, forest margin plots exceeded both other plot types. By the final period, thinned plots showed crown width increments similar to forest margin plots. These results indicate that *R. stylosa* grew fastest in forest margin plots, followed by thinned plots, and slowest in non-thinned plots (where all individuals eventually died). By three years post-thinning, growth conditions for *R. stylosa* in thinned plots approached those at the forest margin.

For *K. obovata* [Figure 4: see original paper]D, E, F, no significant differences in height, basal diameter, or crown width increments were found among plot types during any period ($P > 0.05$). By the final period, no *K. obovata* survived in non-thinned plots. Height and basal diameter increments in thinned plots were lower than in forest margin plots, while crown width increment was higher, but differences were not significant. This suggests that 50% intensity thinning had little effect on early *K. obovata* growth, but by three years post-thinning, growth in thinned plots was similar to that in forest margin plots.

Overall, 50% intensity thinning and pruning had some positive effects on *R. stylosa* seedling survival and growth, creating conditions approaching forest margin levels by three years post-thinning, while effects on *K. obovata* growth were only weakly positive at three years post-thinning.

2.3.3 Correlations Between Survival, Growth Increment, and Environmental Factors

Three years post-thinning, bivariate Pearson correlation analysis revealed no statistically significant correlations between *R. stylosa* survival rates or growth increments and environmental factors (Table 2). For *K. obovata*, survival rate was significantly positively correlated with understory/canopy light ratio and soil temperature, and significantly negatively correlated with soil pH, indicating that higher light ratios and temperatures increased survival, while high soil pH inhibited it. Height and basal diameter increments of *K. obovata* were significantly positively correlated with light ratio and soil temperature, and height increment was also significantly positively correlated with soil salinity.

3.1 Artificial Intervention to Regulate Exotic-Native Mangrove Relationships

Artificial intervention is a key component of biodiversity research (Ren et al., 2000). Thinning significantly increases understory vegetation diversity and coverage (Dong et al., 2019; Li et al., 2020; Wang et al., 2022). In this study, the 50% intensity thinning and pruning of exotic *L. racemosa* forests by the Hainan Dongzhai Harbor National Nature Reserve Management Bureau significantly reduced stand density, improved understory light conditions, and promoted native mangrove growth in the shrub layer, with two-time intervention being more effective than one-time intervention—consistent with Tang et al. (2018). This is because higher thinning intensity reduces resource competition, leading to more pronounced changes in woody plant composition (Deng et al., 2010). Unlike He (2017), who found that thinning significantly increased native mangrove numbers, our two interventions did not significantly affect natural regeneration in the herbaceous layer. This may be because four years post-thinning, rapid *L. racemosa* growth led to canopy closure, reducing understory light and failing to meet environmental requirements of herbaceous species, which are generally more sensitive to environmental changes (Gilliam, 2007; Xu et al., 2008).

Studying seedling survival and growth is crucial for predicting population dynamics, as growth metrics are key indicators of successful establishment (Wu et al., 2019). Our results on artificially planted native mangrove seedlings in different plot types showed that thinning and pruning improved *R. stylosa* survival rates, approaching forest margin levels by the end of the observation period, and significantly promoted height growth, creating conditions similar to forest margin plots by three years post-thinning. Thus, 50% intensity thinning had limited but positive effects on *R. stylosa* survival and growth. Effects on *K. obovata* were weaker because it is a light-demanding species whose survival and growth are significantly positively correlated with light intensity, requiring high light and temperature for optimal growth (Zheng, 2022). The 50% intensity thinning likely failed to create sufficiently favorable conditions, and as time since thinning increased, the survival rate decline in thinned plots exceeded that in forest margin plots, indicating that pruned branches regrew, reducing understory light. Therefore, we recommend increasing thinning intensity or pruning frequency.

3.2 Effectiveness of Thinning and Pruning

As previously discussed, thinning and pruning reduce *L. racemosa* density, improving ventilation and light penetration to provide more space and resources for understory plants (Wang and Yang, 2022). However, these spatial and temporal advantages diminish over time. Sprouting is a natural regeneration strategy and an important life history trait in woody plants (Bellingham & Sparrow, 2000). This study aimed to promote conversion of *L. racemosa* forests to native mangrove communities, so assessing stump sprouting provides a measure of intervention effectiveness. Four years post-thinning, both one-time and two-time interventions showed similar sprouting effects, failing to completely eradicate *L. racemosa*. Sprouts reached over 300 cm in height, occupying elevated positions less susceptible to shading (Bellingham et al., 1994) and accessing sufficient water and nutrients through the stump for robust growth (Chen et al., 2008). This demonstrates that *L. racemosa* can weaken thinning effects through stump sprouting, potentially impacting native mangrove growth. Therefore, controlling stump sprouting is essential to maximize the positive effects of thinning and pruning.

In summary, 50% intensity thinning and pruning of *L. racemosa* had limited positive effects on native mangrove restoration. To improve conversion effectiveness and prevent population recovery through stump sprouting, we recommend increasing thinning intensity or conducting annual pruning, supplemented by appropriate artificial planting of native mangrove species in the understory and removal of sprouting *L. racemosa* branches.

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Note: Figure translations are in progress. See original paper for figures.