Reducing ecological risk from the impacts of introduced exotic species in forestry industry: Limiting the invasiveness through a management and biological practices in Acacias plantation in Indonesia

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Abstract. Balance benefit of ecological, economic, and social is a part of sustainable forest management. Industrial forest plantation is one of the ecological practices through increasing land cover to provide a good impact for economic and social. Introducing suitable species for industry from out of regions is commonly practiced in the plantation. In Indonesia, some Acacias species have been recognized as major plantation species to meet industrial requirements that are economically feasible, suited to major end-product, high productivity, and fast growth. However, some studies have classified the Acacias as exotic species which potentially show an invasive. Taking into account such invasiveness and anticipating ecological risk, this paper presents some considerations on plantation management and biological practices of the Acacias. Compromises among the reproductive system, growth, and rotation in the plantation management could limit the invasiveness. Besides high stand productivity, results from genetic and breeding could also provide a positive impact to diminish the reproductive process of trees that consequently reduce seeds in the Acacias plantation and limit its invasiveness. It concludes that some considerations and a good understanding of biological factors in plantation management practices could reduce ecological risk from the invasiveness of Acacias, and even it could be used for increasing plantation productivity.

1. Introduction
The global world population is projected to increase by nearly 2.5 billion, rising from 7.3 billion to an estimated 9.8 billion [1], which provides a consequence on ecological and global economic impacts. Forest is one of the potential natural resources that are susceptible to being destroyed along with the increased need for population and economic growth. Sustainable forest management is then being adopted to ensure economic growth while maintaining the sustainability of the environment. In the forestry sector, it could be implemented in the industrial forest plantation management through a linkage of the tree plantation into the industrial forestry program. Under this scheme, the economic impact from forest plantation throughout the downstream of relevant industries could be achieved under a sustainable environment. The government of Indonesia has allocated around 11.8 million hectares of forest area for industrial forest plantation in which pulp and paper are the biggest industries consuming the wood products [2].
Species selection for the plantation will be an essential factor to meet any industrial need in order economically feasible, suited to end-product, high productivity, short of rotation. However, such selected species are often exotic that are introduced from other regions. The invasiveness of the exotic species should be taken into account to anticipate appearing serious problems for ecological and local biodiversity. The invasive species could spread quickly and occupy the native species' habitat. Therefore, an understanding of the characters of the selected exotic species for industrial forest plantation is necessary to find out an effective way to limit the invasiveness impacts for reducing ecological risk while preserving the local biodiversity. The invasiveness of non-native species could be minimized by compromising the biological factors in managing plantations, such as reproductive system, growth characteristics, and age rotation.

Some Acacias species are among the dominant fast-growing tree species planted in an industrial forest plantation out of Java to supply raw material for the pulp and paper industry, such as Acacia mangium and A. crassicarpa [3]. Under a longer of rotation age, the Acacias species, including other species, such as A. auriculiformis are also commonly cultivated in the community-based forest in Java to supply logs for sawn-timber industry, either through planting or natural regeneration. Although there is no evident data concerning the references of negative impacts as mentioned in the preceding paragraph, these three Acacias species are cited as among the invasive species in Indonesia [4]. Regardless of this fact, a review of the Acacias species regarding their invasive potential is necessary to anticipate ecological risks towards sustainable forest management in an industrial forest plantation.

This paper presents a review on reducing ecological risk from the impacts of introduced exotic species in the forestry industry referencing Acacias plantation. The review is focused on the basis of understanding some biological and morphological characters related to the invasive behavior of the three dominant Acacias species for forestry industries in Indonesia: A. mangium, A. crassicarpa and A. auriculiformis. In the last part, it is also discussed the implication in compromising between the Acacias species characters and the planting management practices to minimize the invasiveness while maintaining the high economic value of the plantation.

2. Invasive species: an overview

2.1. Why the invasiveness occurs

2.1.1. Reproductive system. Invasive species is commonly defined as a non-native species that is introduced to the new ecosystem that causes environmental harm. High-spreading invasive species in the new ecosystem could cause ecological risks and diminish local biodiversity. The interaction between the invasion behavior of a species and its supportive grown environment will cause the invasiveness of the species. In terms of plants, invasive species come in various growth forms, shapes, and sizes and have been grouped into Aquatics, Grasses Climbers, Herbs, Shrubs, Succulents, and Trees [5].

There are many factors, including biotic or abiotic, that can stimulate a plant species to become invasive. Among the identified factors, the reproductive system behavior of species is the main factor triggering the strength of invasiveness. This is because the product from the reproduction process of a plant, either sexual or asexual, is the main agent in species regeneration and distribution. Sexual regeneration will be more common in many plant species rather than sexual. Seed is a product of the asexual reproduction process that could regenerate a plant to be more in population number and wider spreading of growth areas distribution. Barret [6] reported that the reproductive system is an especially important life-history trait for invasive species because the quantity and genetic quality of propagules influences dispersal and spread to novel environments with both demographic and biogeographical consequences.

Plant sexual reproductive system covers some simultaneous series of processes from juvenile and mature plant growth phase comes to reproductive phase including the sequential process of flowering, pollen receptivity, pollination, fertilization, fruit and seed set. In terms of plant regeneration, the ultimate
product of the reproductive process is the matured seed which is then germinated for producing seedling of the new progenies plant. This process is simply summarized as presented in Figure 1.

![Sexual-reproductive cycle of plants](image)

**Figure 1.** The sexual-reproductive cycle of plants.

Regardless of the internal factors in the reproductive development of the plant, the external factor of the environment will play an important role in each step of the sequential reproductive process to the success in producing viable seed as a major agent in plant regeneration. Edaphic, climate, temperature, sunlight and type of pollinators are among the external factors that affect the reproductive process of the plant either individually or concomitantly, particularly in flowering behavior. However, it is often found that plants under growth-stressed conditions could pronounce reproductive process in an earlier period than that under normal growth. On the other hand, vigorous plant in growth characters tends to pronounce diminishing its reproductive process.

During the process of pollination through transferring of pollen from anther to stigma, which is followed by the process of fertilization through releasing male gametes from pollen tube and fuses with the egg from female to form the embryo, there are two important factors attributable to the success of seed production. The first is the availability of pollinators as an agent of transferring pollen, either by wind or animal vectors. The second one is the population in which the female and male gametes will be mated. The success of pollinators in the pollination process will not always be followed by the success of the fertilization process. This is because there is a difference in compatibility and self-incompatibility systems among the genetic of an individual within the mated population. Inbreeding depression is commonly associated with one of the indicators in the low success of fertilization which could perform as aborted seed, un-germinated seed, low quality of seedling growth, and high mortality.

Concerning the potential of invasive behavior, the success of the reproductive process of a plant in producing large amounts of viable seed under supportive biotic and abiotic factors could attribute to the large spreading of the plant is out of range of its natural distribution. Moreover, prominent size and colors of the seed produced that attracts animal to consume and pass the indigestible seed could enhance the spread of the plant [7].

From some viewpoints described above, its reveal that the reproductive system behavior of plant is important aspects to better understand the potentially invasive species and their impacts. Following this understanding, effective management practices could be then taken place to control and minimize the invasiveness strength and to prevent further problems and negative impacts. For invasive plants suited
for industries, the appropriate management during the development could be used to control the invasiveness while maintaining their benefits and economic value.

2.1.2. Planting management and industrial need. In terms of biological processes, planting can potentially stimulate further regeneration and spreading of the invasive species. Planting is one of the management practices under the concept of re-vegetation in which the regeneration process of a plant is managed in an area to obtain the benefit towards specific purposes, such as for commercial, industrial need, environmental protection, and ornamental. In commercial and industries, plant density and spacing are arranged to stimulate the plant growth and productivity by considering the end-products target that could be harvested from the plant, such as vegetative (stem, bark, leaves, roots), flower, fruit, and seed. Therefore, management of planting will be different among the plant species and target of end-products.

Under commercial and industrial need purposes, planting of invasive species having high economic value is commonly practiced in a specific area. Planting of invasive species out of range of natural distribution can potentially stimulate further regeneration and spreading of the invasive to invade new site environment, well adapted and then alter the local biodiversity. In addition, the plantation is commonly established in a large area consisting of many plants which perform characters suited for industrial need, such as fast growth, early flowering and fruiting, adaptable to adverse environments. Some of the promising species for the plantation is often categorized as exotic or non-native. Stocks material transferred between the regions are then commonly taken place to adjust with the newly available site planting area.

Along with the maturity up to harvesting age, the plants will produce a large amount of seed that could be naturally regenerated understorey of plant canopy or transferred to other places by wind or animal vectors. Seed produced from the plant might drop in the ground but could keep the seed viability for a longer time and ready to germinate soon after the exposure to sun-light when plant harvesting is finished. Considering the large area and number of plants, a large quantity of seed production per unit area would be abundant and trigger the potential of a species to be invasive.

2.1.3. Impact of invasive species. Risk analysis and assessment are necessary when introducing exotic species into considerable site planting. In the case of the invasiveness, the severity of an invasion impact from the introduced species could vary depending on a species behavior and the susceptible environment of where the species are grown. The impact of invasion could harm biotic and abiotic environments, such as humans, local biodiversity, soil and water.

Among the ecological risks affected by the invasive species, the impact on local biodiversity is the main focus to be discussed in this paper. This is because biodiversity is a variety of life organisms that provides an essential contribution to the sustainability of the environment and human well-being services. The impact could also subsequently alter the ecosystem structure and function [8]. However, the impact of invasive is not always as a direct impact that is defined as species-to-species impact. Often the impact starts from the change of edaphic or climatic in which the exotic species could more adaptable than the native, quickly spread and then occupied the native species habitat. In this case, the change of environment, more adaptable of exotic species accompanied with susceptible native species could stimulate the aggressiveness of invasive species to displacing the local biodiversity. For example, it was reported that 80% of the threatened species in the Fynbos biome of South Africa are endangered due to invasions by exotic species [9].

As compared to abiotic factors such as soil and water, the impact on losing biodiversity is often less awareness due to the complexes of biodiversity assessment indicators. In terms of a commercial plant, over-exploitation of suited native plants for industrial need will aggravate the loss of local biodiversity instead of due to the invasive species impact. In certain cases, it is often difficult to determine what is the main cause of loss of local biodiversity between the two potential sources. In some cases, the aggressiveness of invasive species would become more intense and un-controlled if the site in which it's grown is under limited access for human intervention, such as in protected areas, national parks, and other areas subjected to conservation. For example, the infestations of Acacia nilotica, which are
displacing valuable pasture species for banteng in Baluran National Park has threatened the population of banteng [5]. It was further reported that more than 50% of protected areas in Indonesia are invaded by one or more invasive plant species.

2.1.4. Acacias species and its invasive issues. There are three known Acacias species that are commonly planted in Indonesia concerning the program of developing industrial forest plantation due to its fast growth, adaptability in an adverse environment, and the wood suited as raw material for industry. They are A. mangium, A. crassicarpa and A. auriculiformis in which the respective species is planted on different specific site area: A. mangium and A. auriculiformis for dry land, A. crassicarpa for peatland. The three Acacias species are originated from Eastern parts of Indonesia (Papua, Papua New Guinea) and Northern Queensland, Australia. In Indonesia, they are introduced as exotic species to the site plantation in Java, Sumatra, and Kalimantan for supplying raw materials for industries (Figure 2).

![Figure 2. Site planting distribution in introducing Acacias as exotic species for industrial plantation in Indonesia which is out of range from the natural habitat in Eastern Indonesia and Northern Queensland.](image)

It was reported that more than 1 million hectares of A. mangium and A. crassicarpa have been established in Indonesia [10], which are specifically located in critical and marginal land. While for A. auriculiformis, the area of plantation is not clearly recorded because it is planted mostly in the community-based forest with varies in age harvesting and planting area. However, in Vietnam, it was reported that around 90000 hectares of A. auriculiformis have been planted by small grower farmers [10]. In Indonesia, the Acacias plantation are mostly aimed to supply raw materials for pulp and paper industries, and thus, they are harvested in an earlier age of rotation (< 7 years) than that for sawn timber industries (> 10 years). The planting stand density (trees/ha) for pulp and paper is also denser than for sawn timber, and as a consequence, the higher stand density requires a narrower spacing.

Sexual reproduction is a major process in the regeneration of Acacias species. The reproductive system of the three Acacias is a somewhat similar pattern. The types of flowers, as shown in Figure 3, are hermaphrodite with many tiny flowers in an inflorescence [11], with various colors depending of the species that are from creamy-white to greenish-yellow [12]. The type of pollen is sticky polyad pollen [11], and therefore bee is the main pollinator in Acacias species to the success of open-pollination in natural crossing, as reported in the study for A. mangium by Sedgley et al. [13]. Griffin et al. [14] reported that A. mangium is predominantly outcrossing, and outcross pollination of some flowers within a spike is sufficient to reduce the proportion of selfed progeny. In another study, Butcher et al. [15]
reported that good and abundant flowering in the population of *A. mangium* will stimulate the open pollination to produce fully outcrossed seeds.

The flowering time among the three *Acacias* species (Figure 3) is generally similar, but they vary from the northern to the southern latitude of natural distribution and in the newly introduced sites of planting as well. Climate change might also stimulate the changing of flowering time of the *Acacias*. Some trees of the *Acacias* could start first flowering at 2-3 years of age, but the abundance of flowering in a population have commonly occurred after 4-5 years of age, and in general, their flowering behavior could occur in almost all sites of planting as long as suited for the trees to maturity growing up. Inflorescences of the *Acacias*, which consist of many flowers, are located at the distal portion of the crown [11]. Therefore, bearing branches and crown development will become important factors to produce abundant flowers in *Acacias* which could be stimulated through a larger spacing or planting distance between the trees.

![Figures 3. Flower morphology of (a) *Acacia mangium*, (b) *A. auriculiformis*, (c) *Acacia* hybrid (*A. mangium* x *A. auriculiformis*), (d) *A. crassicarpa* (photo sources: Nirsatmanto & Sunarti [3]).](image)

Following the flowering period, further biological process is fruit maturity, ripening and seed maturity. Mature fruits of the *Acacias* occur three to four months after starting the flowering, which is then followed by the fruits ripening phase as an indicator of seed maturity at the next one to two months. The seed morphological features of the three *Acacias* accompanied by other *Acacias* species are presented in Figure 4. Among the *Acacias* species, the distinction of seed morphologies could be recognized from the shape, size, and funicle patterns. Along with the differences, there are some similar patterns of the seed, including black and shiny color, relatively small in size and hard in the seed coat.

A variety of morphological patterns of the seed (Figure 4) attract some animals, such as ants and specific birds, in consuming the funicles and then pass the indigestible seed. The hard seed coat of the *Acacias* causes difficulty in of seed germination process and requires a specific pre-treatment for seed scarification, such as soaking in hot water or chemical. In natural regeneration, the germination process is stimulated through exposure to sunlight for warming the seed, which is commonly occurred under an open area after tree harvesting. This is because the dropped seed could not germinate directly under the crown-shaded area.
Witt (2007) [5] wrote a book of the Guide to the Naturalized and Invasive Plants of Southeast Asia and reported that there are some classes of the plant concerning invasive behavior, including an alien species, an alien invasive species and a naturalized plant. Although the three *Acacias* species are some of the major tree species for planting, either under industrial forest plantation or community-based forest programs, in this book *A. mangium* and *A. auriculiformis* are reported as invasive species in the group of growth form as large trees. This group is defined as woody plants that are larger than shrubs and which usually have only one erect perennial stem or trunk and a wide crown, but which (unlike small trees) may reach several meters in height [5]. It is also further reported that some evidence of the invasion impact from the two *Acacias* were identified in Florida USA, Singapore, and Brunei in which they have displaced some native vegetation, invaded some horticulture plants, and inhibited the germination of some agriculture crops. In Indonesia, Setyawati et al. [4] reported in the book of A Guide Book to Invasive Plant Species in Indonesia that *A. mangium* is one of the invasive species, but there is no report in detail of the impacts.

Considering the uses, biological characters, morphological features, and site of planting as described in preceding paragraphs, the invasiveness of *Acacias* species could potentially occur due to three considerable factors. First, the Acacias are introduced in a protected area that has limited access by human intervention, such as in Natural Park or other conservation plot areas. In this situation, the spreading of *Acacias* through natural regeneration will be aggressively stimulated through the dropped of seed from mature trees that are then germinated and fast grew after some disturbances of the tree population or opened area. Less-allowed human intervention in such kind of area and situation leads to difficulty in controlling the enlargement of invaded land. The second one is *Acacias* that are planted as an ornamental plant which is commonly grown such as in home-yards, roadsides, and coastal areas. For this purpose, the trees will be maintained in growing up to matured habitus accompanied with their routine reproductive phase over several years of growth. This long period of matured growth will stimulate the spreading of seed and naturally regenerated seedlings. Third, the *Acacias* are planted in a large area of plantation to fulfill raw materials for industries. Unlike the two previous factors described above, culling trees for harvesting is the main goal in the plantation to produce woods in supplying raw materials for industries. Therefore, the invasiveness of *Acacias* could be more controllable, particularly in the limitation of routine seed production due to earlier harvesting rotation, such as in *A. mangium* and *A. crassicarpa* plantation for pulp and paper in Indonesia that is economically feasible to be harvested in 4-5 years of age.
3. Implication in minimizing the invasiveness of *Acacias* toward economic value

3.1. Management of the plantation

Although in terms of biological process, the planting can potentially stimulate further regeneration and spreading of the invasive species, appropriate planting management by considering the reproductive behavior of the species could be used to control the invasiveness. Disturbing the reproductive and regeneration system of invasive species could be associated with the planting management, as long as the purposes of the product are not related to its reproductive organs such as flowers, fruit, or seed. For example, sun-light is a vital component in the reproductive and regeneration process. The lack of exposure to sun-light will inhibit the development of the flower of the plant and seed germination. It could be arranged by planting in narrow spacing to get dense growth and canopy closure of plant to limit the exposure to sun-light.

Regardless of the *Acacias* species grown in protected areas and ornamental purposes, discussion on the linkages of the invasiveness of *Acacias* to industrial forest plantation is the main focus in this paper. There are three considering reasons for this focusing. First is the concern in economic growth, followed by the second one is the planting for forestry industries while practicing re-vegetation under land rehabilitation program, and the third is a large size and widely distributed plantation area.

Although there is no clear evidence of the invasion impact from the *Acacias* plantation to local biodiversity, management practices for the plantation could be used to prevent the negative impact of invasiveness. As described in the preceding paragraphs, the sexual reproductive system through seed is the main agent of the invasiveness in *Acacias* species. Therefore, plantation management practices that have some indirect impacts to disturbance the reproductive process would be an effective way to control the natural regeneration in the plantation.

In the first rotation, *Acacias* plantation establishments are mostly located in a disturbed secondary forest or in grassland areas. Because of the exotics, the *Acacias* species are not found in the new planting site, and they are firstly introduced in such site. Therefore, land preparation during first planting is not disturbed by *Acacias*'s natural regeneration. High stand density is commonly adopted through narrow space of planting, such as ±1,600 trees/hectares in the spacing of 3×2 m. Due to its fast growth and no thinning practices, at three years of age, the crowns began to close towards closed-canopy up to the rotation age of five to six years. Such spacing management will pressure the crown and flowering development of the trees, and the blocking out sun-light will keep the dropped seed to be un-germinated in the ground.

In the second and subsequent rotations, abundant natural regeneration of *Acacias* seedling comes out in the site after logs harvesting. During the land preparation for the second rotation, mechanical in combining with the chemical was applied to remove the naturally regenerated seedlings together with other weeds. Fertilizer is applied periodically during the planting to stimulate the fast growth accompanied by further weeding to remove other new natural regenerated seedlings and weeds up to the canopy closure that began at around 3 years after planting.

Culling trees for harvesting is another important management practice in plantations to break the cycles of the reproductive system of the trees. *Acacias* plantation for pulp and paper industries could be harvested earlier than that for sawn timber. Owing to the faster growth of the trees, they could be harvested at an earlier age under the acceptable and suited quality of wood for the industry. This situation is preferred by industry because of low risks, and the return of the investment could be obtained faster. Some comprehensive management of planting is then adopted to get a more productive stand, such as combining in the uses of genetically improved stock under appropriate cultivation practices. Under these management practices, stand productivity of *Acacias* could be increased while minimizing the invasiveness of the trees through reducing seed production in the plantation.

3.2. Benefit from genetic and breeding program

A better understanding of the genetic factors of the plant will help in the comprehensive management of invasive species, particularly in relation to a breeding program; in case of the three *Acacias* species...
studied here, first genetic information concerns the distributed natural population, which represent the magnitude of genetic diversity. The breeding program for these species could be directed into at least two targets of improvement. The first is breeding to improve characters related to stand productivity, such as growth, wood quality, pest and disease tolerance, and adaptability [3]. The second one is breeding to overcome the problems related to the reproductive system, either to improve seed production or to diminish seed production.

In terms of Acacias wood-based industrial purpose, the first type of breeding program will attribute to the increasing of end-product that are economically feasible. While in terms of preventing the invasive impacts, breeding directed to diminish seed production is necessary. Genetic information and the product of the first type of breeding could also be used to control the invasiveness while maintaining high stand productivity. For example, planting stocks of closely related genetically could stimulate occurring inbreeding and arise from the expression of deleterious and recessive traits in the progenies. It could be practiced through the planting of the same genetically improved clones resulted from breeding in the same compartment block of planting to stimulate occurring mating among relatives in the plantation. As a result, inbreeding depression will increase to result in a decline in reproduction and survival (reproductive fitness) [16], such as producing aborted seed, un-germinated seed, lethal seedling. In addition, the planting of genetically improved stocks will stimulate superior growth of the trees that could be harvested earlier before the reproductive phase. Under this management, the invasiveness of Acacias species could be minimized, and thus the negative impacts to ecological and local biodiversity could be avoided.

4. Conclusion

Three Acacias species of *A. mangium*, *A. crassicarpa* and *A. auriculiformis* are suspected as invasive species either in Indonesia or in other regions. Biological behavior and morphological features of the Acacias, such as fast growth, highly adaptability, and abundant seed production, are among of the major agents in stimulating the invasiveness. However, along with the efforts in land rehabilitation, increasing land cover, and the concerns in economic growth as well, the Acacias species are selected as the major species in the re-vegetation practices through plantation due to a suited of the wood for industries. This study revealed that some planting management practices, including genetic and breeding, could be compromised with the biological factors in the diminishing of the reproductive process that consequently followed by the limitation of seed production in the Acacias plantation. It could be practiced, such as in increasing the canopy closure for blocking out sun-light through the narrow spacing between the trees, accelerating the growth for earlier harvesting before the reproductive phase through the application of fertilizer and the uses of genetically improved stocks. In addition, a stimulating of the mating among genetically closed relatives in the plantation could be practiced to increase inbreeding depression through the planting of the same genetic stock in the same compartment blocks. Planting the Acacias species in the appropriate management practices of the industrial plantation will improve the plantation productivity while preventing the negative impacts of the invasiveness to ecological and local biodiversity.

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