Conservation strategy for *Taxus sumatrana*, a species with limited geographical distribution yet limitless benefit and economic value

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Abstract. *Taxus sumatrana* is a pharmacologically essential tree species that have not yet adequately studied and commercially utilized in Indonesia yet recently was added in the List of Protected Plants and Animals by the government of Indonesia. This paper discussed the conservation strategy of the paradox situation. Protected species yet has not been utilized. *T. sumatrana* in Indonesia is distributed in a confined range of geographical areas and with particular environmental requirements. *T. sumatrana* allegedly occurs along unexplored Bukit Barisan Mountains. Biologically, the species is a slow-growing dioecious tree with prolonging seed dormancy period, lack of suitable regeneration site, leading to low generation capacity creating population dominated by tree stage with barely pole sapling and seedling. Genetically, the species own insignificant differences among the population. Strategy to conserve *T. sumatrana* should include an in-depth exploration of *T. sumatrana* in the natural habitat, improvement of regeneration capacity, revitalization and development of reserves based on genetic information, cultivation and development of plantation for sustainable utilization, campaign and promotion on sustainable utilization, stakeholder networking, and capacity building.

1. Introduction
Conservation has become one of the priority programs in many countries in the world. However, the United Nations warned that one million species are at risk to become extinct globally in a decade [1], denotes the severe loss of the world biodiversity. Many countries and various international organizations have taken measures through various conventions, regulations, and policies on the conservation of biodiversity. Indonesia, as one of the mega biodiversity countries, has a consideration of conservation of its biodiversity and ecosystem and since 1990 had ratified Law No. 5 the Year 1990 on Conservation of Living Natural Resources and Its Ecosystem and developed a Biodiversity Action Plan in 1993. Recently, the Government of Indonesia has updated the list of protected plants and animals in Indonesia through The Regulation of Minister of Environment and Forestry number
P.106/MenLHK/Setjen/Kum.1/12/2018 on The Protected Species of Plants and Animals. *T. sumatrana* is included for the first time in that updated-list that will define its utilization and conservation measures onward.

*T. sumatrana* or Sumatran Yew is a species in *Taxus* Genus with important medicinal properties. *Taxus* species is most valued for an active chemical called paclitaxel and its derivatives that are extracted mostly from the leaves and bark. Paclitaxel that commercially known as Taxol has an active ingredient that can inhibit the growth of cancer cells. However, a 200 years old *Taxus* tree of 40 feet tall has to be felled to obtain barely 0.5 g of Taxol [2], or 10 tons of yew leaves to produce 1 kg of 99.5% paclitaxel [3], which put concern on the sustainability of *Taxus* plant. The Taxol is sold at US$ 690 for each gram [3]. The taxane compounds that show active ingredient was found only 0.006% in *T. sumatrana* [4]. Secondary metabolite from *Taxus* species is not only used for anticancer but also for activities of anticonvulsant, antipyretic, analgesic, anti-inflammatory, anti-allergic, antibacterial, antifungal, antiplatelet, and vasorelaxant-effect [5]. Moreover, studies on the secondary metabolite of *Taxus* are further developed to treat also non-cancer, e.g., Alzheimer, Kaposi's sarcoma, and kidney sclerosis [6].

In many countries, *Taxus* species have been commercially exploited. It had caused to its almost extinction. Therefore, all of the *Taxus* species are listed in Appendix II CITES to protect the sustainability of the species. As the case with *T. sumatrana* in Indonesia, even though it has high medicinal value thus far, it had never been exploited commercially. However, a recent study found that this species environmentally has barriers to survive and to regenerate. Sumatran Yew is also slow-growing and has environmental requirements. Thus it has geographically limited distribution. The inclusion of *T. sumatrana* into the updated list of protected plants of Indonesia (P.106/MenLHK/Setjen/Kum.1/12/2018) was slightly due to its existing small population than immediate concern on its excessive exploitation.

The circumstances of *Taxus* in Indonesia that have not fully utilized and benefited Indonesian people, yet already listed as a protected plant is discussed in this paper. Recommendation on conservation strategy plan and action for this species are then developed and proposed based on the recently updated data on the *T. sumatrana* population.

### 2. Conservation strategy and action on *Taxus* species

However, *Taxus* species have been utilized and commercialized in many countries in the world due to its medicinal importance and high economic value. The excessive exploitation of *Taxus* species had led to their progressive extinction that causes all *Taxus* species to have then been listed in Appendix II CITES (as *Taxus* spp.) and categorized as endangered in the IUCN Red List [7]. Specific policies and immediate actions on the *Taxus* conservation plans and measures are required to be implemented in many areas.

Excessive extraction of Taxol derived from *Taxus* species is the main cause of their globally endangered status. In addition, pressure from rapid deforestation, illegal logging, conversion of forest for agricultural expansion, and habitat fragmentation also contribute to the decline of the natural *Taxus* population[8, 9]. Other than those anthropogenic factors, the *Taxus* species also have their natural limitations that lead to its endangered position. The species is slow-growing, low generation capacity thus old population [9], dioecious plant, and some species even have limited geographical distribution, which also means particular growing site requirements that would limit the development of the population. Furthermore, the species also has adverse natural regeneration because of prolonging the seed dormancy period and weak seedlings capacity to establish in natural conditions [8, 9]. The conservation measure for *Taxus* species at least should cover one of the aspects mentioned above.

In many cases, the most common conservation measures are developing nature reserved or establishing plot conservation of the targeted plant species, both in their natural distribution (in-situ) as well as in the other favorable area (ex-situ). Meanwhile, the propagation technique is also required to be developed to support the population expansion of the species, protection policy (regulation), and
stakeholder networking is also necessary measures for Taxus conservation. Nevertheless, the characteristics of the species and the population are essential to be studied to set the proper baselines for fruitful and beneficial conservation measures of the Taxus species.

3. *Taxus sumatrana* potential in Sumatra

3.1 Taxonomy and habitus

*Taxus sumatrana* (Miq.) De Laub is a species in the Family of Taxaceae, the subclass of Taxidae. *T. sumatrana* is a Gymnosperm without resin duct. Some authors synonymized *T. sumatrana* with *T. wallichiana* [10], although the species that grows in Sumatra Island is consistently named as *T. sumatrana* [8], thus the naming mostly due to geographical location [10]. Species identification in the same genus is rather difficult because many species in the same Taxus Genus exhibit similar features, it is even difficult at the genera level [11] and within the order Taxales [12].

This evergreen slow-growing long-living conifer is a dioecious plant, which means it has a separate individual of the male and female flower (not hermaphrodite) [13], which also contributes to its difficult regeneration. The habitus of this plant that locally known as tampinur batu (Karo, Malay) or kayu tadji (Mt. Dempo) is a big tree up to 14 m tall and 200 cm in diameter [10]. The needles of *T. sumatrana* are linear-lanceolate, green-yellowish, 1.2 – 2.7 cm long and 2.0 – 2.5 mm wide. The trunk bark is grayish-red and exfoliating in irregular flakes. Fresh-cut sapwood is pale yellow with inconspicuous wood rays [10]. The seeds are drupe-like 6 – 7 x 5 mm in size and covered with fruit flesh that would become reddish at maturity in November-December [10, 14]. The fruits reach maturity (ripe) in the same year, yet the germination would appear in the next year, which in turn also contributed to its challenging regeneration.

3.2 Natural distribution of *Taxus sumatrana*

Even though Taxus species can be found as far north as Russia to as far south as Sumatra Island, they mostly distributed in the northern hemisphere [15]. The geographical distribution of Taxus species are in North America (*T. Canadensis, T. floridina, T. brevifolia, and T. globusa*), Euro-Mediterranean (*T. baccata*), the Sino-Japanese (*T. cuspidata*) and tropical Southeast Asia (*T. sumatrana* that sometimes synonymized as *T. chinensis* or *T. wallichiana*) [15, 17]. The distribution of *T. sumatrana* is detached from the other Asian species; it is the only species of Taxus genera found in the full tropical habitats [10].

Geographically, *T. sumatrana* distributed in Indonesia (Sumatra and Celebes Island), Vietnam, and the Philippine [10]. The plant can be found at 1,400 – 2,800 m asl in a moist subtropical forest, or tropical highland forest. *T. sumatrana* mostly grows at a moist hilly area of highland, high steep ridges, (>45°) and mountain summit in a mossy forest [7, 16, 17]. This highland plant prefers a moist environment to grow. In Indonesia, *T. sumatrana* is naturally distributed in Sumatra and Celebes and it is usually found at a high elevation of the montane forest [10, 7].

In Sumatra Island, *T. sumatrana* allegedly occurs along the Bukit Barisan Mountains. However, studies recorded the occurrence only in Sibuatan Protected Forest (North Sumatra), at several mountains within the Kerinci Seblat National Park (KSNP) and Mount Dempo (South Sumatra) [20],[21]. At those locations, *T. sumatrana*, based on its canopy stratum, is classified as a sub-dominant tree. The potential population of the Taxus in Mount Kerinci, Mount Tujuh, and Mount Sibuatan were recorded 31 trees/ha, 17 trees/ha, and 15 trees/ha, respectively [19]. Although photograph specimen dated in 1933 collected in Mount Bonthain recorded the occurrence of *T. sumatrana* in Celebes Island [22], there is little to no record about the population of this species in Celebes to this day.
The distribution of *T. sumatrana* in Mount Kerinci and Mount Tujuh of KSNP is a cluster with the Morisita index of 2.19 and 1.21, respectively [20][23] yet widely scattered between population. The growing sites of *T. sumatrana* had air temperature and humidity of 16 - 23 °C and 70 - 91%, respectively [20, 23, 24], fertile soil with acidic pH, and wide range of light intensity from around 37-639 Lux [20, 23]. This species is neither as a dominant nor an emergent tree in the KSNP. *T. sumatrana* appears as sub-canopy in the forests dominated by *Cinnamomum iners, Lithocarpus cyclophorus, Canarium littorale, Ficus grossularioides*, and *Argostemma angustifolia* [25, 8].

The population structure of the species in Mount Kerinci of KSNP was dominated by tree stage with barely pole sapling and seedling (Table 1) [19]. This condition implies the occurrence of the mature population of *T. sumatrana* and adverse natural regeneration. Although without the threat of exploitation, a mature population with low regeneration and limited distribution will extinct in the future.

| Stages        | Density (Individual/ha) | Morisita index | Population | Distribution pattern |
|---------------|-------------------------|----------------|------------|---------------------|
| Tree          | 19.10                   | 2.19           | 87         | Clustered           |
| Pole          | 0.45                    | 2              | 2          | Random              |
| Sapling       | -                       | -              | -          | -                   |
| Seedling      | 2.5                     | 11             | 11         | Clustered           |

Table 1. The tree structure of *T. sumatrana* in Mount Kerinci of KSNP [20].
3.3. Genetic analysis of *T. sumatrana*

Genetic analysis that was performed on two populations (Mount Kerinci and Mount Tujuh of KSNP) showed a genetic diversity of 0.254 and 0.256, respectively, for each population. The values indicated an adequately fair genetic diversity of the population. Further, Genetic distance between the two populations was 0.0466, which showed that the difference in the genetic structure between the two populations was only 5% even though the geographical gap between the two mounts was considerably far. These results implied that most of the genetic diversity occurred within the population. It also suggested collecting as many as an individual tree as possible for the genetic conservation of this species [26]. Rahmat et al. [27] noted a similar result on insignificant differences of genetic structure between two populations of *T. sumatrana* in Mount Kerinci and Mount Dempo. This study also found low genetic diversity between individuals within a population.

4. Conservation strategy for *T. sumatrana* in Indonesia

4.1. Recent condition, threat, and challenges

The recent exploration of the potential of *T. sumatrana* in Kerinci Seblat National Park recorded that considerable numbers of *T. sumatrana* big trees were found in the area. However, further analysis revealed a not ideal stand structure that indicates the mature population of *T. sumatrana* with the adverse capacity to develop population due to poor regeneration in the KSNP. The dioecious nature of the species may also contribute to this adverse regeneration. It presumably due to imbalance composition between male and female trees in the habitat, which lead to limited regeneration capacity of the population. The lack of microsite availability for the seed to establish growth as well as a prolonged period of seed dormancy are also contributes to the lack of occurrence of the young generation (seedlings) of *T. sumatrana* [8]. [24] noted that seeds of *T. sumatrana* collected from Mount Kerinci were still not germinated even after over one year of sowing.

*T. sumatrana* in Indonesia is distributed in a limited range of geographical areas and with particular environmental requirements. The current natural habitat of *T. sumatrana* is within a national park or protected forest at a high latitude of the montane forest. It demands a high latitude environment with cold air temperature and high humidity. These environmental factors should be considered in the conservation strategy of this species. Furthermore, the status of the Taxus' natural habitat, which is in the national park or protected forest, does not guarantee that the plant will not be threatened by deforestation, encroachment, or forest conversion for agricultural expansion.

In Indonesia, *T. sumatrana* has not fully utilized and exploited. However, awareness of its medicinal importance and the tremendous economic value involved is increasing within the communities, especially those who live in the surrounding Taxus natural habitat. People near the national park started to utilize the plant to alleviate various health problems [8]. This development of awareness rising on an economic benefit is another threat and challenge on the sustainability of this plant.

The medical and economic importance of the Taxus species is already well recognized in the world to the point of development of Taxus plantation and paclitaxel production at the industrial basis in several countries. However, this progression has not yet reached and occurs in Indonesia. The people of Indonesia have not yet fully benefitted from this rare plant.

Lately, *T. sumatrana* was listed as a protected plant in the updated List of Protected Plants and Animals of Indonesia by The Regulation of Minister of Environment and Forestry No. 106 the Year 2018 on The Protected Species of Plants and Animals. The New protected status of *T. sumatrana* determines the utilization and conservation measured onward

4.2. Proposed conservation strategy for *T. sumatrana* in Indonesia

4.2.1. An in-depth exploration of *T. sumatrana* in the natural habitat. Mt. Kerinci, Mt. Tujuh, Mt. Dempo, Mt. Sibuatan (located in Sumatra) and Gowa (in Sulawesi) are recorded as *T. sumatrana*'s habitat. However, comprehensive surveys, so far, had only been conducted in Mt. Kerinci and Mt. Tujuh. There is no reliable updated data of the *T. sumatrana* population in the other locations. Thus,
in-depth surveys to assess the actual population, as well as study ecological aspects of \textit{T. sumatrana} in the other locations, are necessary to be conducted as it becomes a scientific basis for developing appropriate approaches to conserve this valuable tree species.

4.2.2. \textbf{Improvement of regeneration capacity.} Based on the recent finding, the \textit{T. sumatrana} population is composed of mature trees due to the lack of natural regeneration capability. This condition implies the urgent need for plant regeneration improvement. Propagation techniques must be studied and developed by any means such as cuttings, tissue culture, transplantation, air layering \cite{9}, seeds treatment, and developing seeds garden.

Advanced propagation techniques will ensure the expansion of \textit{T. sumatrana} and may improve its population status, which is expected to reach ideal plant-stage composition. Moreover, multi-locations planting tests of the selected tree populations will also assist \textit{T. sumatrana} to disperse beyond its current geographical barrier.

4.2.3. \textbf{Revitalization and development of reserves based on genetic information.} In-situ conservation is the first thing that needs to be concerned to conserve the genetic structure of \textit{T. sumatrana}. All the natural habitats of this plant are strongly recommended to be determined as a nature reserve by the government regulation to strengthen its juridical status. Based on this legal affirmation, commercial utilization and exploitation of Taxus species in those areas should be prohibited entirely. However, this legal effort solely will not directly affect the improvement of the \textit{T. sumatrana} population. The revitalization of the natural habitats and silvicultural intervention, such as pruning the adjacent tree species, seedling maintenance, etc. \cite{8}, are encouraged to be applied simultaneously with other conservation efforts of \textit{T. sumatrana}.

Also, the ex-situ conservation area, which considers the genetic information of \textit{T. sumatrana}, is supposed to be established as well. The ex-situ conservation plots must consist of as many individuals as possible with the plant materials come from a diverse population. The \textit{T. sumatrana} population in Mt. Kerinci, Mt. Tujuh, and Mt. Dempo were chosen because they have considerable genetic diversity within populations and relatively small genetic distance between populations.

4.2.4. \textbf{Cultivation and development of plantation for sustainable utilization.} There is a dilemmatic situation for utilizing \textit{T. sumatrana} in Indonesia. On one side, this species can produce secondary metabolites that valuable for pharmaceutical industries, but on the other side, due to its limitation on natural regeneration that has led the status as a protected plant species. It means it is prohibited to use the natural tree stands for further exploitation. Dealing with this situation, the development of \textit{T. sumatrana} plantation, which applying sustainable silvicultural practices such as using twigs and branches as resources for taxol extraction, should be encouraged. A chemical study found that almost all parts of this plant, except the trunk, containing antioxidant ingredients \cite{28}. It means taxol production does not require to cut down the whole trees.

However, the idea to develop plantations of \textit{T. sumatrana} would not be easily implemented shortly. Government regulation on the company privatization supposes to be depth-considered to support sustainable utilization through the establishment of protected natural habitat as well as the development of cultivation techniques to address plant regeneration constrains.

4.2.5. \textbf{Campaign and promotion on sustainable utilization.} Campaign on the benefits of \textit{T. sumatrana} as well as spreading the idea for developing \textit{T. sumatrana} plantations among stakeholders is required. While at the same time, silvicultural techniques to induce \textit{T. sumatrana} in their natural habitat, is also be implemented. Thus, the sustainable utilization of \textit{T. sumatrana} is also promoted.

4.2.6. \textbf{Stakeholder networking and capacity building.} Stakeholders play an essential role in saving \textit{T. sumatrana}. Such participation can be carried out under the function and authority inherent in each institution. These institutions are the Ministry of Environment and Forestry, in particular, the
Directorate General of Conservation of Natural Resources and Ecosystem, the Ministry of Agriculture, the Provincial and District Governments responsible for forestry and the environment, research institutions, universities, NGO, and the local communities around the habitat of *T. sumatrana*.

Ministry of Environment and Forestry is a representative of the central government in managing forest resources, including various protection and conservation efforts of natural resources. Moreover, the Ministry organizationally appoints the Directorate General of Conservation of Natural Resources and Ecosystems to implement various activities related to protection, saving, and regulating the use of natural resources at the national level. For this reason, the Directorate General of Conservation of Natural Resources and Ecosystems is implementing these basic principles and functions to develop guidelines for the protection of biodiversity throughout Indonesia. In its implementation, the Conservation of Natural Resources and Ecosystems established institutions that were placed in provincial areas throughout Indonesia as a delegation of authority; namely, the Natural Resource Conservation Institute works at the provincial level and the National Park Office at the site level. Both have their duties and functions to conduct data collection, monitoring, and patrols regarding the security of Conservation Areas and National Parks. National Park inhabited by *T. sumatrana* is Kerici Seblat National Park, which should conduct patrols and monitoring, including collect data on *T. sumatrana* populations.

Local government plays a crucial role in the protection and conservation of natural resources because of the direct authority to regulate the region and its territory, including the people in the area. Local governments have the authority to manage protected forests. The two protected forests inhabited by *T. sumatrana* are the Mount Dempo protected forest in South Sumatra, and the Sibuaton protected forest in West Sumatra. Local governments have the responsibility to secure endangered species, such as *T. sumatrana*, in its jurisdiction.

Various botanical and biological information of *T. sumatrana* is very much needed so that the goals and conservation efforts can be achieved. Research institutions and universities have reliable human resources to be able to play a role in exploring various information. Therefore, research needs to be carried out both individually and jointly between institutions.

Workshop to raise awareness on the importance of this species, its conservation, and the sustainable utilization should be implemented among related stakeholders, such as nature reserve management, park ranger, researchers, local government, and local communities.

5. Conclusion
Strategy to conserve *T. sumatrana* should include an in-depth exploration of *T. sumatrana* in the natural habitat, improvement of regeneration capacity, revitalization and development of reserves based on genetic information, cultivation and development of plantation for sustainable utilization, campaign and promotion on sustainable utilization, stakeholder networking and capacity building.

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