

# The climate change influence on Indonesia medicinal plants: a review

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**Abstract.** Indonesia has high biodiversity and is well-known for its medicinal plant diversity, which is both singular and globally affluent. Due to their secondary metabolite efficacy for various ailments; medicinal plants are commercially and highly useful to human. Secondary metabolites assure the plant from abiotic and biotic stressors and aid pollination and fruit distribution. However, the changing climate, deforestation, population growth, overharvesting and the unsustainable manner of medicinal plant collection for trade, may drive many populations extinct. The study aimed to review some climate change effects on Indonesian medicinal plants as potential medicine sources for discovery and human being development. By reviewing with emphasis how each of the individual factors affects the growth, development and plant secondary metabolites production. This review illustrates a common figure of environmental factors such as temperature, drought, and CO<sub>2</sub> that affect Indonesia's medicinal plants. It is evident that climate change is having a detrimental influence on existing resources' life cycles, medicinal plant quality and production, habitat fragmentation, shifting distribution ranges, phenology pattern changes, etc. Compared to other commercial crops, medicinal plant research on climate change is infrequent and limited. The study suggests some different adaptive techniques be used to mitigate climatic challenges and preserve medicinal plants.

## 1 Introduction

The majority of the plant species found were largely left to flourish in their natural habitats in woods, villages, and rural families, contributing directly or indirectly to the rural people's economy by providing forest products, fruits, fodder, beauty goods, and fuel. It also provides raw materials for the pharmaceutical industry [1]. These herbs have numerous health benefits, especially in areas where Western medicine is scarce. Since the beginning of human civilization, medicinal plants have been the main source of curing, healing, and relieving the

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symptoms of different ailments. Medicinal plants have been identified as being essential to the local community because they contribute to the well-being of rural households through direct use, human nutrition, and income production.

In Indonesia both modern and traditional societies, medicinal plants have great economic and health values. The market value and the number of industries reliant on traditional medicine have grown recently. The cultivation, harvesting, processing, utilization, and selling of medicinal plants contribute significantly to the community's economic well-being [2]. For millions of underprivileged people worldwide, medicinal plants provide sources of medicine and pest control. However, because of the accelerating rate of deforestation and climate change, Indonesia's medicinal plants are at risk [3]. Furthermore, as environmental pressures increase, bioactive chemicals in medicinal plants may change, potentially affecting the quality of raw materials and products [4].

So far, climate change has influenced medicinal herbs. Changes in temperature and rainfall patterns, disturbance of commensal interactions, increases in pests and pathogens, and habitat fragmentation brought on by human activity hinder migration. The Earth's temperature is warming at an unprecedented rate, which is unmistakably attributable to climate change, whether caused by natural variability or human activity [5]. The global temperatures will likely raise by another 1.0-7.8°C in the twenty-first century. These extreme climate changes may jeopardize both medical plants and humans. Furthermore, medicinal species are frequently collected in an unsustainable manner, and this combination of stressors may drive many populations to extinction. Climate change may affect adversary medicinal plants and their consumers by reducing availability, most notably by causing species extinction. Climate change may influence not just the accessibility and productivity of medicinal plants, but also the phytochemical content of surviving populations, particularly of Indonesian species, potentially affecting their therapeutic characteristics.

Indonesia is threatened by climate change. Indonesia intends to experience air temperatures rise to 2°C on the main islands by 2100, with an abnormal monthly rainfall of more than 200 mm/month. This may result in more ambiguous and unpredictable effects on medicinal herbs in the future. Moreover, rising temperatures and changing precipitation patterns can have a considerable impact on the probable distribution of species range shifts, with some species' prospective habitats disappearing entirely. Due to severe alterations in climatic conditions, scientists agree that species are changing and declining in quality, quantity, variety, and range considerably faster than in the past [6].

Climate change is also having an impact on the distribution of medicinal plants in Indonesia. Evidence entails that local extinction and dispersal/migration are likely to cause changes in community composition as a result of individual species' shifting ranges. Indonesian medicinal plants are not an exception to the experts' warning that plant species that are native to geographic regions that are particularly vulnerable to climate change may face serious danger in the near future [7]. Species richness is anticipated to decline in more than half of the existing allocation area of medicinal plant species under both RCP scenarios in 2050 and 2080 [8]. As a result, Indonesia's traditional medicinal plants are susceptible and face extinction due to current and future climate change, especially if environmentally detrimental human activities.

To mitigate the consequences of climate change on biodiversity, we should take preventative actions, such as reducing emissions of gases in the long term and designing proper networks of protected areas (PAs) for immediate and effective preservation efforts in the short term [9]. It is critical to conserve and manage medicinal plant resources not just to preserve biodiversity, but also to promote the rural economy and welfare of local people who rely on these plants for income and survival [10].

The purpose of this review is to improve our understanding of the impact of climate change on medicinal plants. This can aid in the optimization of cultivation practices under

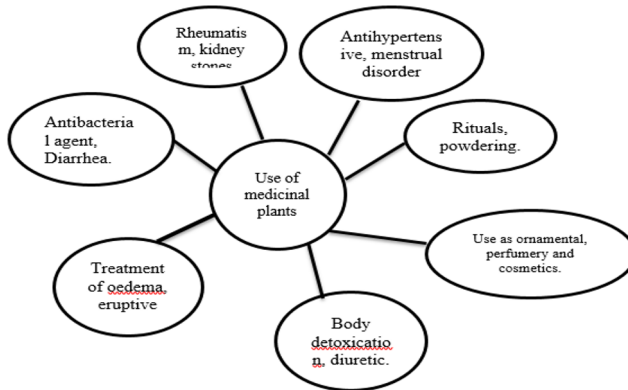
ambient environmental situations by boosting efficiently and sustainably the quality and quantity of the plant's secondary metabolites. Thus, in addition to actions to mitigate climate change, we recommend actions such as valuable plant preservation and local cultivation, sustainability training for harvesters and commercial material certification, traditional knowledge conservation, and programs to monitor raw material quality.

## 2 Methodology

To learn about the effect of environmental conditions on medicinal plants, a wide range of scientific databases were considered for relevant material and citations. This review is based on the current various books, international and national's research published, government websites, policy documents and traditional and scientific literature for data collection. The purpose of this study is to consolidate all of the literature on the individual environmental conditions impacts such as drought, temperature and carbon dioxide (CO<sub>2</sub>), on the growth and secondary metabolites production in medicinal plants. The analysis was conducted through the review to evaluate the environmental conditions' influence on Indonesian medicinal plants.

## 3 Why medical plants are important?

Since the beginning of human civilization, the relevance of numerous plant families has been recognized for their nutritional, therapeutic, preventive, and medical properties, as well as their capacity to provide sustenance. The secondary metabolites and pharmacological properties of medicinal plants, which are extensively used in the pharmaceutical, medical, cosmetic, and dietary industries, make them particularly important [11].



**Fig. 1.** Medicinal plant use mostly based on usual practice in Indonesia [12].

According to [13], reported there are about 21,000 different species and over 45,000 different plants that are used for medicinal purposes. The WHO estimates that for their primary healthcare needs, around 60% of the world's population and 80% of those in developing nations rely on traditional medicine, largely plant-based remedies. In terms of species counts, the use of plants as medicines is by far the most widespread use of biodiversity on the planet. Due to their accessibility, affordability, and ability to treat a variety of diseases, herbal medications are a common choice for people in developing countries but they are also utilized in wealthy nations [14]. Novel herbal items and pharmaceuticals are primarily derived from medicinal plants [15], they are consequently essential for maintaining human health, and the economy, especially in underdeveloped areas, cultures, and legacy. These traditional Indonesian remedies remain widely used today, in urban as well as rural areas and

among all social classes. The usage of medicinal herbs in Indonesia has always been a part of a culture passed down from generation to generation. Indonesians use a single plant or a combination of plants called *Jamu* in their herbal medicine.

Furthermore, the hereditary society believes that bioactive substances found in the leaves or other parts of medicinal plants, such as *Orthosiphon aristatus* (java tea), have antiallergic, antihypertensive, anti-inflammatory, antioxidant, and diuretic characteristics [16]. The plant is also grown for its distinctive flowers, which are white or purplish and have far-exserted filaments that resemble a cat's whiskers [13]. The essential oil is also utilized as a flavouring agent in tobacco and liquor preparations, as well as in perfumery and cosmetics [17]. Historically, Agarwood, sandalwood, and benzoin (*Styrax* spp.) are used in rituals, particularly those involving the world of spirits, by burning, powdering, or incense. Cajuput is used in aromatherapy. Agarwood has long been used as incense in religious rituals in other countries, such as Indonesia [18]. However, the more medical study is needed, as well as an endeavour to cultivate medicinal plant species. Medicinal plant cultivation, harvesting, processing, consumption, and selling contribute significantly to the community's economic well-being [19]. The economic worth of Indonesia's medicinal plants is estimated to be up to US\$14.6 billion per year. More than US\$3 billion was traded in medicinal plants globally in 2005, and by 2050, it is predicted that this trade will be worth US\$5 trillion [20]. Furthermore, due to their hardness, several medicinal plants may be grown successfully in barren/wastelands, degraded, eroded, and problematic (saline, alkaline, and acidic) soils, assisting in the reclamation of such neglected lands and providing greater remuneration to the farming community [21].

## 4 Climate Change Impacts on Indonesia Medicinal Plants

Climate change, according to researchers, has impacted plant phenology, growth habit, and range, placing species' output, product quality, and even survival in jeopardy [22]. On a timescale of decades to millennia, it is anticipated that rising greenhouse gas concentrations would significantly affect the global climate. A half of the world's biodiversity is already endangered. Climate change will very certainly increase the probability of plant mortality and extinction in many areas. On this basis, medicinal plants are expected to face serious consequences in the future decades [23]. There is growing evidence from lengthy monitoring studies that the recent climate is abnormal compared to past climatic changes and that recent climatic and atmospheric changes are already having an impact on species physiology, distribution, and vegetation patterns like phenology (the timing of lifecycle events in plants, especially concerning climate) [24].

Although changing phenologies and ranges may appear to be unimportant at first, they have the potential to pose significant threats to the survival of species. Climate change in Indonesia is also expected to result in more extreme weather, and medicinal plant species' tolerance to these weather events may play a role in their capacity to adapt and survive. Studies also revealed that plant species have started to adapt to current climate changes through changing species ranges, in addition to fluctuating phenology [25]. Additionally, a recent study revealed that Indonesia's warming rate would be slightly higher, between 0.2 and 0.3 degrees Celsius per decade. Earlier research has reported that climate change significantly affects biodiversity and ecosystem services through alters in plant species distribution, reproduction timings, and phenology [26].

Climate change affects adversely both the amount and quality of medicinal plants produced. Due to their limited geographic distribution and increased vulnerability to climate change, vulnerable plant species may be in danger of going extinct (Kunwar *et al.*, 2014). The sole purpose of ingesting medical plants or using them in other ways is to benefit from their bioactivities, even if changes in the chemical composition of food plants may be more

important to human health than is often recognized [27]. Furthermore, when plants are under stress, the production of secondary metabolites may increase because development is frequently more limited than photosynthesis and carbon fixed that is not assigned to growth is instead allocated to secondary metabolites [7]. Secondary metabolites have been found to rise in response to higher temperatures in certain studies [28], while they have been found to decrease in others [29]. Furthermore, light intensity and other environmental components such as temperature, water availability, CO<sub>2</sub>, drought, soil type and composition, and others have a significant impact on medicinal plant quality and productivity.

According to the results of the predictions, future climatic change in Indonesia may cause some medicinal plants to lose population and go extinct. By lowering the appropriate ranges and availabilities of their essential medicinal plants, this condition may have a significant impact on community livelihood, notably health care issues. Thus, due to their low climate change tolerance and slow migration rate, medicinal plants may be at a relatively high risk of going extinct due to projected trends in climate change [30]. Table 1 summarized some climate change and environmental factors effects on medicinal plants.

**Table 1.** The Environmental factors impacts on medicinal plants.

Environmental and Climatic factors	Climate change phenomenon	Effects
Temperature	High Air Temperature	<ul style="list-style-type: none"> <li>- Increase flavonoids, alkaloids a saponins in Robinia Pseudocacia</li> <li>- Enhance deciduous trees growth (height,diameter, leaf and stems biomass)</li> <li>- Decrease salicylates, flavonoids secondary metabolites in conifers</li> </ul>
	High minimum soil temperature	- Increase total java tea flavonoid concentration
	High maximum soil temperature	- Reduce phenol content
	High soil temperature based-Growing Degree Day (GDD)	- Increase total phenol and antioxidant concentration
Drought	Elevated drought	<ul style="list-style-type: none"> <li>- Increased monoterpenes in salvia officinalis</li> <li>- Increased flavonoids and phenolics in wallow leaves</li> <li>- Reduced saponins in chenopodium quinoa</li> <li>- Decreased shoot biomass and Increased the essential % in balm same as on the Bunium persicum's</li> </ul>
	Water stress	<ul style="list-style-type: none"> <li>- Caused Irregular growth, smaller leaf size, fresh weight and reduced root dry weight in java tea</li> <li>- Higher in main chemical compounds</li> </ul>
Carbon dioxide (CO <sub>2</sub> )	Elevated CO <sub>2</sub>	<ul style="list-style-type: none"> <li>- Increased phenolics Concentration and decreased height growth in conifers</li> <li>- Increased cardenolide glycoside in Digitalis lanata plants</li> <li>- Increased phenolics, alkaloids, tannins and flavonoids.</li> <li>- Increased Zingiber officinalis phenolics and flavonoids.</li> </ul>
Air temperature (related to elevation level)	30 - 42°C (elevation ≤ 500 m above sea level)	- Better growth, High biomass yield and sinensetin concentration in java tea medicinal plants.

	- >600m	- Increased styrax sumatrana growth and distribution
	- 600-1400m	- optimum high Styrax sumatrana distribution
	- 19 to 26°C	- Affected adversely styrax sumatrana distribution - Suitable temperature for styrax sumatrana medicinal plants distribution.

Source: [4].

#### 4.1 Shifting ranges

Along with altering plant phenology, climate change also affects species distribution, habitat loss, and species composition, and in recent years, much attention has been paid to comprehending these phenomena in climate change research. Plants are moving toward new ranges as a result of climate change. To reclaim acceptable growth zones, studies, and computer modelling techniques show that plant ranges have started to move towards the poles and/or higher elevations. Due to habitat loss and migratory difficulties brought on by climate change, a significant number of endemic species are in danger of going extinct worldwide [9].

Furthermore, under the RCP4.5 and RCP8.5 scenarios, overall medicinal plant distribution areas in Indonesia are anticipated to drop by 2050, but some species would change their allocation to other locations. On Papua, Java, and Sulawesi islands, species are predicted to lose enormous allocation areas. In addition, the sea level rise is expected to lead to a significant species allocation area loss on these islands [31].

**Table 2.** Observation of all studied medicinal plant species impacted by climate changes per future scenario [32].

Observation	RCP4.5 (2050)	RCP4.5 (2080)	RCP8.5 (2050)	RCP8.5 (2080)
Species gaining distribution area	17	18	18	17
Species losing distribution area	26	25	25	26
IUCN Redlist	7	13	12	14
Not IUCN Redlist	19	12	13	12

Due to the loss of 30-80% of their distribution area, more than half of the Indonesian medicinal plant species surveyed are predicted to experience a decline in population size. Furthermore, [32] propose that species with a potential distribution area loss of more than 50% be prioritized for the highest level of conservation, equivalent to the requirements for vulnerable and critically endangered species [33].

#### 4.2 Temperature influences medicinal plant

During the 20<sup>th</sup> century, the average global temperature has already increased by 0.74°C, approximately increasing 0.2°C per decade (IPCC, 2007). The rate of plant growth and development is significantly influenced by temperature, and each species has particular temperature requirements. Therefore, this climatic component remains the most important factor in determining the success or failure of plant establishment.

Elevated temperatures also extend the growing season by pushing bud bursts in the spring, as shown by *Populus grandidentata* Michx. [34], and *P. tremula* has been reported to delay bud set in the autumn [35]. Temperature increases have an impact on plant secondary

metabolites and growth because they change the metabolic pathways that control signaling, physiology, and defence systems [36].

For example, three different *Ribes nigrum* cultivars' phenolic component compositions showed positive associations with temperature [37], providing critical instructions for berry growing for commercial exploitation. Additional experiments in a greenhouse at various temperatures (10, 20, and 30°C) further demonstrated the relationship between temperature and alkaloid concentration [37]. Furthermore, [37] demonstrated that the elevated temperature enhanced plant height, diameter, leaf, and stem biomass, and additionally decreased phenolic concentrations such as salicylates, flavonoids, salireposide, and lignin in deciduous trees and total phenolic acids in conifers.

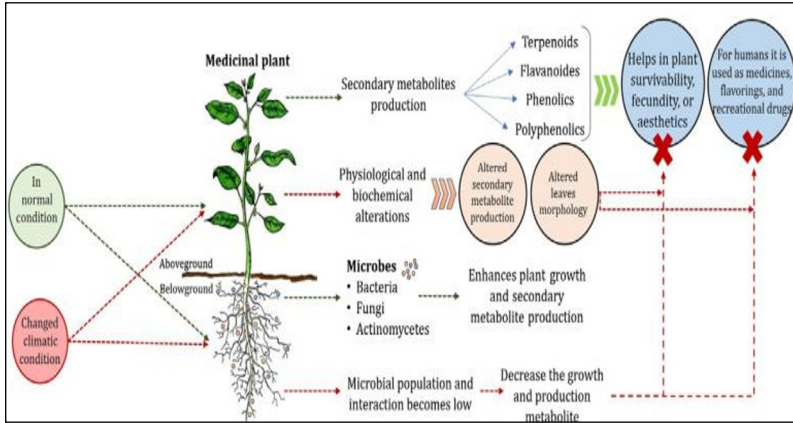
Furthermore, [38] found that greater maximum soil temperatures resulted in decreased phenol content, whereas higher minimum soil temperatures and a shorter harvest period increased total flavonoid in *Orthosiphon aristatus* plants (Java tea). Additionally; Kumis kucing (*Orthosiphon aristatus* (BL) Miq) is one of the thousands of medicinal plants in Indonesia and is often used for traditional medicine in the community. But the drying temperature (30, 50, and 70°C) negatively affected the secondary metabolites by reducing the total flavonoid content at 70°C in the ethanol extract of kumis kucing leaves.

### 4.3 Drought Stress on medicinal Plant secondary metabolites

Drought stress is caused by a shortage of water to critical levels, which is frequently accompanied by high temperatures and solar radiation [39]. Drought stress is a major abiotic factor that influences plant growth and development. Plant growth is decreased in water-stressed situations, in contrast to the content of secondary metabolites. A decrease in biomass production increases the concentration of secondary metabolites, but there is no change in the rate of metabolite synthesis. Therefore, dependent on fresh or dry weight, the overall concentration of metabolites rises [19]. Additionally, [16] revealed that the drought stress level affected the height, leaves, and roots of *Orthosiphon aristatus* (java tea).

### 4.4 Influence of CO<sub>2</sub> on Medicinal Plants Secondary Metabolites

An increase in CO<sub>2</sub> concentration has become a serious issue for both normal human life and plant physiology since the industrial age. Medicinal plants can adapt to changing environmental conditions. *Digitalis lanata* has medicinal characteristics and is used for heart failure treatment [40], but when treated with elevated CO<sub>2</sub>, a cardenolide glycoside rise was seen, while other glycosides concentrations, such as digitoxigenin, were substantially reduced. When determining the concentration of secondary metabolites in plants, the length of exposure, in addition to CO<sub>2</sub> concentration, is critical. *Ginkgo biloba* is a medicinal herb used to treat Alzheimer's disease, vascular dementia, and mixed dementia [40] but When exposed to high concentrations of CO<sub>2</sub> and O<sub>3</sub> combined, the terpenoid content changes and quercetin aglycon levels rise by 15%, and a 10%,15% failure in kaempferol aglycon, isorhamnetin, and bilobalide concentrations, and to a certain extent, respectively [41]. Moreover, *Catharanthus roseus* is well-known for its diuretic, antiviral, and anticancer effects around the world (Ezuruike and Prieto, 2014), consequently, as CO<sub>2</sub> levels rise, this plant's secondary metabolites, including phenols, alkaloids, tannins, and flavonoids, also rise [42]. Ghasemzadeh *et al.* (2010a, b) reported that with rising CO<sub>2</sub> levels, *Zingiber Officinale* phenolic and flavonoid content increased.



**Fig. 2.** Overview of medicinal plants in the context of climate change [43].

## 5 Vulnerability of Indonesia Medicinal Plants

The forecast of the medicinal plant's species vulnerability differs from the emission scenario according to the IUCN Red List assessment rang-loss criterion [27], the *Agathis borneensis*, *Anaxagorea javanica*, *Aquilaria malaccensis*, *Gentiana quadrifaria*, etc medicinal plant species are expected to be vulnerable to extinction in Indonesia in 2050 and 2080 as a result of climate change in pessimistic scenarios (Cahyaningsih *et al.*, 2021b). According to [44], extinction levels have been influenced by global range, habitat extent, and local abundance, and geographic range loss will increase them even if the local population is already thriving. The loss of distribution areas for many Indonesian medicinal plant species, however, highlights the higher threat level seen by the RCP8.5 scenario, which negatively impacts species more than RCP4.5. It reveals that significant medicinal plant species that grow in Indonesia might be at risk due to climate change, this is in line with [45] study, which found that climate change is causing a decline in germination rates in more than half of tropical species. The distribution of medicinal plant species is anticipated to diminish the most on the islands of Papua, Java, and Sulawesi. Furthermore, two-thirds of species will experience a loss rather than gain in suitable climate zones under future warming scenarios. Along with overharvesting for the medicinal trade, additional factors like climate change, land conversion, population growth, and deforestation that may increase the risk of plant extinction in Indonesia also contribute to the loss of medicinal plants [21].

## 6 Conservation Implications

In accordance with the United Nations' definition, protecting medicinal plants also means protecting ecosystems, natural habitats, and all other species that coexist with them and can be preserved in their natural habitat. Furthermore, there is a need to inventory, conserve, and document Indonesian medicinal plants and their ethnopharmacological and ethnomedicinal data to protect and support the growth of herbal medicinal plants and industries. Thus, it is difficult and expensive to conserve Indonesian species. Additionally, to overharvesting for the medicinal trade, factors such as human population expansion, land conversion, deforestation, and climate change all contribute to the loss of medicinal plants. The loss of local knowledge about medicinal plants and their uses is a worldwide concern. It is critical that active conservation programs are implemented due to the economic importance of medicinal plants in Indonesia, coupled with other dangers, and a lack of funding for their

preservation [21]. In the face of a changing environment, it is essential to take proactive actions for the conservation of medicinal plants to ensure their availability for future generations. First and foremost, it is essential to make the Indonesian community aware of climate change so they can prepare effective responses to it.

Additionally, it is vital to show the population how vulnerable the traditional medicinal plants used by the Indonesian people are to upcoming climatic changes in order to alert them to the extinction danger that exists and to promote awareness of the conservation planning for these plants. Second, the Indonesian community has to be encouraged to promote education on the sustainable usage of these therapeutic plants [46]. Additionally, one effective tactic to lessen the climate change effects on these medicinal plants is to cultivate species that are anticipated to be severely endangered or at high risk of extinction in fields, greenhouses, or microclimate conditions like home gardens. Furthermore, [32] revealed that a valuable contribution to the conservation of rare, endangered, or overexploited species is made by home gardens, which have also played a significant role in the domestication of plant species, particularly medicinal plants. Therefore, the government's role, agencies, and local communities should be recognized for their contributions to the conservation and use of medicinal plants.

## 7 Conclusion

Climate change has a profound effect on medicinal plants. Studies conducted in various parts of the world suggest that the life cycle of medicinal plants is being significantly impacted by climate change. A targeted study strategy is urgently required, particularly concerning the buildup of secondary metabolites that are important for human health and economic usefulness. Although the future impacts of climate change are unpredictable, they will have an impact on medicinal plants and could pose a far greater threat in the future. The disappearance of some medicinal plants may have an impact on the livelihoods of a significant number of people. The problem of rising temperatures and altered seasonal events is similarly difficult to comprehend, yet prompt efforts can almost likely avoid biodiversity loss. In comparison to other commercial crops, research on medicinal plants and climate change is quite sparse and negligible. As potential sources of biomolecules and nutraceuticals, it is time that this category of plants not be neglected. Additionally, more research on medicinal plants that are at risk of extinction in the face of climate change is necessary to develop conservation strategies. Thus, practising medicinal plant cultivation with the assistance of local populations and traditional indigenous knowledge might lessen the climate change effects.

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