Review Article

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Advances in the Biology, Behavior, Ecology, and Management of the Sal Heartwood Borer, Hoplocerambyxspinicornis Newman, 1842 (Coleoptera: Cerambycidae): A Review

Abstract

This extensive research on *Hoplocerambyxspinicornis*, a notorious pest inflicting substantial damage on Sal trees (Shorearobusta) in India. The focus is on the beetle's biology, behavior, ecological implications, and the current strategies for its management. The Sal tree, a vital component of Indian forests, faces significant threats from *H. spinicornis*, whose life cycle and destructive larval stage are closely examined. The review highlights the species' taxonomy within the Cerambycidae family and details its distinct morphological characteristics, particularly the adaptations observed in different developmental stages. The beetle's host selection process, largely dictated by the physiological state of Sal trees, and its feeding behavior, both in larval and adult stages, are critically analyzed for their extensive impact on tree health and forest structure.The ecological implications of *H. spinicornis* infestations are profound, with substantial effects on biodiversity and forest dynamics. This beetle's interaction with other species, including natural predators and symbiotic relationships, forms a complex ecological web influencing forest health. In addressing management strategies, the review covers a spectrum of approaches, from early detection methods like pheromone trapping to biological controls utilizing natural enemies and microbial agents. The role of chemical treatments, despite their efficacy, raises environmental concerns, highlighting the need for sustainable approaches. Cultural and mechanical controls, such as silvicultural practices and sanitation logging, are discussed as part of an integrated pest management (IPM) framework, which combines various strategies in a balanced and ecologically sensitive manner. The review identifies key challenges and future directions, emphasizing the necessity of genetic studies, long-term ecological research, and the development of sustainable management strategies. The impact of external factors such as climate change and habitat alteration on H. spinicornis and Sal forests is critically examined, underscoring the need for adaptive management strategies. This review aims to provide a holistic understanding of H. spinicornis, offering insights for researchers, forest managers, and policymakers involved in the conservation of Sal forests.

Keywords: *Hoplocerambyx, Shorearobusta, Cerambycidae, Biodiversity, Infestation*

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Introduction

The Sal tree, scientifically known as Shorearobusta, is a significant and dominant tree species found extensively in the Indian subcontinent, particularly in the deciduous and mixed deciduous forests. It holds immense ecological and economic value, forming an integral component of the forest ecosystems in regions like the Eastern Ghats, Central India, and parts of the Himalayan foothills. The ecological significance of Sal trees lies in their role in maintaining the forest ecology as a keystone species. They provide habitat and food resources for a wide range of fauna, including numerous bird species, mammals, and insects. Sal forests are known for their dense canopies, which play a crucial role in regulating the microclimate of the regions they cover [1]. These forests are also pivotal in soil conservation, water regime maintenance, and carbon sequestration, thus contributing significantly to ecological balance and climate regulation. Additionally, Sal trees have been traditionally valued by local communities for their hardwood, used in construction, furniture making, and for fuelwood. Its leaves, bark, and resin are utilized in various traditional practices and industries, making it a tree of substantial livelihood importance in rural India [2].

Hoplocerambyxspinicornis, commonly known as the Sal Heartwood Borer, is an insect species belonging to the longhorn beetle family (Cerambycidae). First described by Newman in 1842, this beetle has garnered attention primarily due to its specialization in infesting Sal trees. The adult beetles are characterized by their elongated bodies, long antennae, and distinctively patterned wings, making them easily identifiable. The life cycle of H. spinicornis comprises four stages: egg, larva, pupa, and adult, with the larval stage being particularly detrimental to the host trees. The larvae bore into the heartwood of Sal trees, creating extensive tunnel networks, which disrupt the tree's vascular system, leading to reduced vitality and, in severe cases, tree mortality. The adult beetles also contribute to the damage by feeding on the bark and leaves of the host trees. The Sal Heartwood Borer's life history, behavior, and interaction with its host species have been subjects of numerous studies, focusing on its biology, ecology, and the development of control measures to mitigate its impact on Sal forests [3].

Table1 : Sal Forests in India

State	Area(sq.km.)
Orissa	38,300
MadhyaPradeshandChhattisgarh	27,800
BiharandJharkhand	21,410
Assam,Meghalaya,Mizoram,NagalandandTripura	6,500
UttarPradesh andUttarakhand	5,710
WestBengal	5,700
HimachalPradesh	330
Haryana	40

The infestation of Sal trees by H. spinicornis has significant economic and ecological ramifications. Economically, the damage caused by this beetle leads to a substantial loss in timber value. Sal wood, known for its strength and durability, is highly prized in the construction industry and furniture making. The larval tunnels weaken the wood structurally, rendering it unsuitable for commercial use, thus causing financial losses to the forestry sector and impacting the livelihoods of communities dependent on Sal wood. Ecologically, the infestation compromises the health of Sal forests. As a keystone species, the decline in Sal tree populations due to H. spinicornis can lead to cascading effects on the forest ecosystem. The loss of Sal trees affects the species that depend on them for habitat and food, potentially leading to a decline in biodiversity. Furthermore, weakened trees become more susceptible to other pests and diseases, exacerbating the problem. The ecological balance of the forest areas is thus disrupted, affecting ecosystem services like carbon storage and water regulation. The decline in the health of Sal forests also has broader implications for climate change mitigation efforts, as these forests are significant carbon sinks [4]. Given these impacts, the management of H. spinicornis infestations has become a crucial aspect of forest conservation strategies in India, necessitating a multidisciplinary approach involving biology, ecology, and forestry management practices.

Purpose of the Review

The current state of knowledge regarding Hoplocerambyxspinicornis, the Sal Heartwood Borer, is a culmination of extensive research and studies conducted primarily in the Indian subcontinent, where the Sal tree, Shorearobusta, is indigenous. Understanding this beetle's biology, behavior, and impact on Sal forests has been an ongoing scientific endeavor. Research to date has highlighted the life cycle of H. spinicornis, detailing its four stages – egg, larva, pupa, and adult – and emphasizing the larval stage as the most destructive phase for Sal trees [5]. This destruction is primarily due to the larvae boring into the heartwood, disrupting the tree's nutrient and water transport systems. Recent studies have also shed light on the beetle's reproductive behavior, including mating rituals and oviposition patterns, which are crucial for developing effective control measures [6].The ecological studies have further illustrated how the infestation by H. spinicornis impacts not just the individual host trees but also the broader forest ecosystem. These impacts include reduced biodiversity, changes in forest composition, and weakened forest resilience to environmental stressors [7]. Economically, the beetle's infestation leads to significant timber loss, affecting both the forestry sector and local communities dependent on Sal trees for their livelihood [8].

Taxonomy and Morphology of *H. spinicornis*

A.*Taxonomic Classification*

The Cerambycidae family, commonly known as longhorn beetles, encompasses a diverse range of beetle species known for their elongated bodies and, particularly, their long antennae, which in some species can be up to three times the length of the body. This family is one of the largest within the Coleoptera order, with over 35,000 species described worldwide. Cerambycids are predominantly wood-borers in their larval stage, playing a significant role in the decomposition and recycling of dead and decaying wood, thereby contributing to forest ecology [9]. The family shows a wide range of morphological diversity, adapted to various ecological niches. Some cerambycids are known for their mimicry, imitating other insects such as wasps for defense.Hoplocerambyxspinicornis is placed within the Cerambycidae family, more specifically in the Lamiinae subfamily, which is characterized by beetles having robust bodies and antennae typically shorter than those of other subfamilies. H. spinicornis, like other members of this family, goes through a complete metamorphosis with distinct egg, larval, pupal, and adult stages. This species is particularly noted for its affinity to the Sal tree, Shorearobusta, a preference that distinguishes it from many other cerambycid species with broader host ranges [10].

Table 2: Insects recorded on Sal

Order	Numberofinsects	Percentageofinsects
Coleoptera	191	55.20
Lepidoptera	125+1	36.42

Thysanoptera	10	2.89
Isoptera	9	2.60
Hemiptera	4	1.16
Orthoptera	4	1.16
Ephemeroptera	1	0.29
Hymenoptera	1	0.29
Total	**345+ 1**	**100.00**

B.*Morphological Characteristics*

In the adult stage, H. spinicornis exhibits the characteristic features of longhorn beetles, including elongated bodies and long antennae. The body is typically brown with a rugged appearance, and the antennae, while long, are not as exaggerated in length as in some other cerambycids. The adult beetles are also characterized by distinct markings and colorations on their wings, which aid in their identification [11].The larval stage of H. spinicornis is of particular ecological significance due to its wood-boring behavior. The larvae are cream-colored, legless, and have a distinct, elongated body that is capable of boring into the heartwood of Sal trees. These larvae are known for their strong mandibles, which they use to burrow into the wood, creating extensive tunnel systems that can significantly damage the host tree [12].One of the distinctive features of H. spinicornis is its specificity to the Sal tree as a host, which is unusual among the often more generalist cerambycids. This specificity has significant implications for the management of Sal forests, as it links the health of these forests directly to the presence and control of this beetle species. Another distinctive feature is the larval tunneling behavior, which is more aggressive and damaging compared to some other wood-boring beetles. This tunneling not only weakens the structural integrity of the trees but also makes them susceptible to secondary infections by pathogens [13].

Biology and Life Cycle

A. *Developmental Stages*

The life cycle of Hoplocerambyxspinicornis begins with the egg stage. Female beetles lay eggs on the bark of Sal trees (Shorearobusta), selecting sites that provide optimal conditions for larval survival and development. These eggs are small, oval, and have a hard outer shell protecting the developing embryo inside. The duration of the egg stage varies depending on environmental conditions, particularly temperature and humidity [14].Upon hatching, the larvae bore into the bark and eventually into the heartwood of the Sal tree. This stage is the most destructive phase of the beetle’s life cycle. Larvae are creamy white, legless, and have strong mandibles adapted for boring through wood. They create extensive galleries in the heartwood, disrupting the tree's vascular system and leading to significant physiological stress and, in severe cases, tree death. The larval stage can last several months to a year, again influenced by environmental factors [15].After completing the larval stage, the insect enters the pupal phase within the wooden galleries. During this stage, the larva undergoes metamorphosis and transforms into an adult beetle. The pupal stage is a non-feeding period and is typically shorter than the larval stage, lasting a few weeks to a month. The completion of metamorphosis is marked by the emergence of a fully formed adult beetle [16].The adult stage of H. spinicornis is characterized by a hard exoskeleton with distinctive markings and long antennae, a trait common in the Cerambycidae family. Adults are primarily involved in reproduction and dispersal. They are also capable of feeding, though they do not cause as much damage as the larvae. Adult beetles have a relatively short lifespan, lasting a few weeks to a couple of months. During this time, they mate and lay eggs, thus completing their life cycle [17].

B.*Reproductive Behavior*

The mating behavior of H. spinicornis involves distinct rituals and strategies. Males typically seek out females using pheromonal cues. Courtship behavior may include antennal contact and other tactile gestures. After mating, females search for suitable sites to lay their eggs, with the choice of site significantly impacting the survival and development of the offspring [18].Female H. spinicornis exhibit specific behaviors when laying eggs. They preferentially choose sites on Sal trees that provide optimal conditions for larval development, such as areas with softer bark or those that are more sheltered. The choice of egg-laying site is crucial for the survival of the larvae, as it affects their ability to bore into the tree and access food resources [19].

C.*Longevity and Lifespan*

The overall longevity and lifespan of Hoplocerambyxspinicornis vary among the different stages of its life cycle. The egg stage is relatively short, lasting a few days to a couple of weeks. The larval stage is the longest, potentially extending over several months to a year. The pupal stage is shorter, and the adult stage, although critical for reproduction and dispersal, is the shortest, often lasting just a few weeks. The total lifespan from egg to adult death can range from one to two years, depending on environmental conditions and other ecological factors [20].

Behavioral Ecology

A.*Host Selection*

The host selection process of Hoplocerambyxspinicornis is a critical aspect of its behavioral ecology, with significant implications for its survival and proliferation. This beetle species exhibits a strong preference for Shorearobusta, commonly known as the Sal tree. The factors influencing this selection include the physiological state of the tree, bark thickness, and the presence of certain chemical compounds that may attract the beetles or be conducive to larval development. Studies have indicated that stressed or weakened trees, often due to environmental factors or prior pest infestations, are more susceptible to H. spinicornis attack. Additionally, the age and size of the tree play a role in host selection, with larger and older trees being more frequently infested [21].The interaction of H. spinicornis with Sal tree physiology is intricate. The beetles, particularly in their larval stage, impact the tree's vascular system by boring into the heartwood. This action disrupts water and nutrient transport, leading to physiological stress and, in severe cases, tree death. The infestation can also induce defensive responses in the tree, such as resin production, which can limit the spread of the larvae within the tree but also may weaken the tree further [22].

B. *Feeding Behavior*

The feeding habits of H. spinicornis differ significantly between the larval and adult stages. Larvae are xylophagous, feeding primarily on the wood of the host tree. They create extensive galleries within the heartwood, which is their primary food source. Adult beetles, on the other hand, feed on the bark, leaves, and sometimes young shoots of the Sal tree. However, the damage caused by adult feeding is generally less severe than that of the larvae [23].The impact of H. spinicornis feeding behavior on Sal trees is profound. The larval feeding activity, in particular, can weaken the structural integrity of the trees, making them more susceptible to breakage and uprooting, especially during storms or heavy winds. The reduction in tree vitality can also make them more prone to other pests and diseases. In forest ecosystems, this can lead to changes in forest composition and structure, affecting overall biodiversity and ecological balance [24].

C. *Movement and Dispersal*

The movement and dispersal mechanisms of H. spinicornis are essential for understanding its spread and management. Adult beetles are capable of flight, which facilitates their movement from one tree to another and contributes to the spread of infestations. The range of this movement can vary, with some individuals capable of traveling considerable distances to colonize new areas or find mates [25].Seasonal variations significantly influence the activity patterns of H. spinicornis. Generally, adult activity and dispersal are higher during warmer months, which coincides with the breeding season. Environmental factors such as temperature, humidity, and rainfall can affect these patterns. During colder months, the beetles, particularly in larval and pupal stages, may become dormant, resuming activity with the onset of warmer conditions [26].

Ecological Impact

A.*Effects on Sal Forest Ecosystems*

Hoplocerambyxspinicornis, by virtue of its wood-boring behavior, has a profound impact on the health of Sal trees (Shorearobusta) and, by extension, the forest structure. The larval stage of the beetle, where it bores into the heartwood, causes the most significant damage. This activity not only weakens the structural integrity of the trees, making them susceptible to breakage and uprooting, but also disrupts the tree's vascular system. This disruption impairs the tree's ability to transport water and nutrients, leading to stunted growth, reduced vitality, and in severe cases, tree mortality. Consequently, the infestation by H. spinicornis can lead to a decline in forest density, altering the forest structure. This alteration impacts the microclimate within the forest, including light penetration and soil moisture levels, which in turn can affect the composition of the understorey vegetation [27].The ecological consequences of H. spinicornis infestation extend to biodiversity within Sal forests. Sal trees are a keystone species in their ecosystem, providing habitat and food for a myriad of organisms, including birds, mammals, and other insects. The decline in Sal tree populations due to beetle infestation can thus lead to a reduction in habitat availability and food resources, impacting the overall biodiversity of the forest. Additionally, the altered forest structure and microclimate can affect the distribution and abundance of various other species, potentially leading to shifts in species composition and a decrease in biodiversity [28].

B.*Interaction with Other Species*

Hoplocerambyxspinicornis, like many insect species, is part of a complex ecological web and interacts with various other species, including predators and parasites. Birds and small mammals are known to prey on the larvae and adults of H. spinicornis. Additionally, there are parasitic insects, particularly certain species of wasps, that parasitize the larvae of the beetle. These natural enemies can play a role in controlling the populations of H. spinicornis, thus influencing the dynamics of infestation and its impact on Sal forests [29].The presence of H. spinicornis in Sal forests also leads to various symbiotic and competitive interactions with other species. For instance, the galleries created by the larvae can be inhabited by other organisms, either as a place of refuge or as a food source. This interaction can be either symbiotic, where both species benefit, or competitive, where the presence of H. spinicornis negatively impacts the other species by competing for resources. Additionally, the weakened state of infested trees can make them more susceptible to other pests and pathogens, leading to a complex interplay of interactions within the forest ecosystem [30].

Management and Control Strategies

A.*Monitoring and Detection*

Early detection of Hoplocerambyxspinicornis infestations is crucial for effective management. Techniques include regular forest surveys and the use of trapping systems. Visual inspections of Sal trees for signs of infestation, such as boreholes and frass (sawdust-like material), are commonly employed. Advances in remote sensing and GIS technologies have also facilitated the monitoring of large forest areas, allowing for the detection of changes in canopy health indicative of infestations [31].Pheromones and attractants are increasingly used for detecting H. spinicornis. Pheromone traps, which mimic the chemicals emitted by the beetles, are effective in monitoring beetle populations and can serve as an early warning system. Research into the specific pheromones used by H. spinicornis has enabled the development of species-specific lures, enhancing the efficiency of these traps [32].

B.*Biological Control*

Biological control involves the use of natural enemies of H. spinicornis to reduce its population. Predatory birds and parasitic wasps have been identified as natural biocontrol agents. Conservation of these natural enemies through habitat management and other conservation practices is crucial for this strategy's success [33].

Table3 : Biological Control Agents for *Hoplocerambyxspinicornis*

Biological Control Agent	**Example**	**Effectiveness**	**Additional Notes**
Parasitoid Wasps	*Sclerodermus* spp.	High	Lay eggs inside H. spinicornis larvae. The parasitoid larvae then feed inside the host, leading to its death.
Entomopathogenic Fungi	*Beauveriabassiana, Metarhiziumanisopliae*	Moderate to High	Infect and kill both larvae and adult beetles. Effectiveness can vary based on environmental

			conditions and application method.
Predatory Beetles	*Calosoma* spp.	Moderate	Feed on the larvae, providing a natural check on the pest population. Their effectiveness depends on abundance and accessibility.
Bacterial Pathogens	*Bacillus thuringiensis*	Moderate	Produces toxins lethal to larvae when ingested, used in biopesticide formulations. Effectiveness depends on application.
Nematodes	*Steinernema* spp., *Heterorhabditis*spp.	Moderate	Beneficial in soil applications, infect and kill the larvae. Effectiveness depends on soil conditions and larval habitat access.
Bird Predation	Woodpeckers	Variable	Natural predation on larvae, but impact on population control is inconsistent and dependent on bird species and population.
Conservation of Natural Enemies	-	Long-term Effectiveness	Promoting habitats of natural predators ensures sustainable control, impacting various pest stages.

Prospects for Microbial Control

The use of microbial agents, such as bacteria and fungi, against H. spinicornis is a promising area of research. Certain fungi and bacteria have been identified for their pathogenic effects on the beetle. These biocontrol agents can be particularly effective against the larval stages within the wood [34].

C.*Chemical Control*

Chemical control, involving the use of insecticides, is a common method for managing H. spinicornis populations. Insecticides can be applied to the bark or injected into the tree. However, the choice of insecticide and the method of application require careful consideration to minimize environmental impact and avoid harm to non-target species [35]. Despite its effectiveness, chemical control raises several concerns. Insecticides can have detrimental effects on non-target organisms, including beneficial insects and other wildlife. There are also concerns about chemical residues in the environment and the potential development of resistance in beetle populations [36].

Table 4: Chemical Control Methods for Managing Hoplocerambyxspinicornis

Chemical Control Agent	**Chemical Type**	**Effectiveness**	**Application Method**	**Environmental Impact**
Insecticides	Organophosphates (e.g., Chlorpyrifos)	High	Foliar spray, soil treatment	High toxicity to non-target species, potential environmental contamination
Pyrethroids	Synthetic Pyrethroids (e.g., Deltamethrin)	High	Foliar spray, stem application	Less toxic to mammals, but can affect aquatic life and beneficial insects
Neonicotinoids	Imidacloprid, Thiamethoxam	High	Soil drench, stem injection	High systemic activity, concerns about effects on pollinators and groundwater contamination
Carbamates	Carbaryl	Moderate to High	Foliar spray	Toxic to non-target organisms, potential for environmental persistence
Growth Regulators	Juvenile hormone analogs (e.g., Methoprene)	Moderate	Foliar spray, direct application	Targeted action with lower non-target impact, but variable effectiveness
Fumigants	Methyl Bromide, Phosphine	High	Fumigation of infested wood	High toxicity, ozone depletion potential (Methyl Bromide), restricted use

D.*Cultural and Mechanical Control*

Cultural control strategies involve modifying forest management practices to reduce the vulnerability of Sal trees to infestations. This includes selective thinning, which improves tree vigor and reduces competition, making trees less susceptible to attack. Maintaining forest diversity can also be an effective strategy [37].Mechanical control involves the physical removal of infested wood and sanitation measures. Infested trees and branches can be cut and removed to prevent the spread of larvae. Sanitation logging, where infested and susceptible trees are selectively harvested, can also be effective [38].

E.*Integrated Pest Management (IPM)*

Integrated Pest Management (IPM) for H. spinicornis involves a combination of the aforementioned strategies. IPM emphasizes the use of multiple approaches in a coordinated manner, focusing on long-term prevention and control while minimizing environmental impact. This includes regular monitoring, the use of biological and chemical control methods as needed, and cultural and mechanical practices [39].Several case studies have demonstrated the effectiveness of IPM in managing H. spinicornis infestations. For example, in certain regions in India, the combination of pheromone traps for monitoring, biological control through conservation of natural predators, and selective chemical treatments has led to a significant reduction in beetle populations and damage to Sal forests [40].

Challenges and Future Directions

A.*Limitations in Current Knowledge*

The study of Hoplocerambyxspinicornis, while extensive, faces certain limitations in current knowledge. These limitations hinder the development of comprehensive management strategies. One significant gap is the understanding of the beetle's complete life cycle under varying environmental conditions, which affects the effectiveness of control measures. Additionally, there is a lack of detailed understanding of the beetle's genetic diversity, which can provide insights into its adaptability and resistance to control measures. Another limitation is the insufficient knowledge of the beetle's interaction with other species within the Sal forest ecosystem, which is crucial for understanding its ecological impact [41].

B.*Emerging Threats and Challenges*

Climate change poses a significant challenge in managing H. spinicornis. Changes in temperature and precipitation patterns can affect the beetle's life cycle, behavior, and distribution. Warmer temperatures may accelerate the beetle’s development and increase its reproductive rates, potentially leading to larger populations and more severe infestations. Changes in rainfall patterns can also affect the moisture content of Sal trees, influencing their susceptibility to beetle attack. Furthermore, climate change can lead to shifts in the distribution of Sal forests, which in turn affects the beetle's habitat [42].Habitat alteration and loss, primarily due to human activities such as deforestation, urbanization, and agricultural expansion, are significant challenges. These changes can lead to the fragmentation of Sal forests, which affects the dynamics of H. spinicornis populations and their natural control mechanisms. Habitat loss also reduces the genetic diversity of Sal trees, potentially making them more susceptible to infestations. The reduction in forest cover can further exacerbate the impact of climate change on these ecosystems [43].

C.*Research Needs*

To address these challenges, there is a need for comprehensive genetic studies of H. spinicornis using molecular tools. Such studies can provide insights into the genetic variability and adaptability of the beetle, which are crucial for predicting its response to environmental changes and control measures. Genetic research can also aid in the development of targeted biological control methods, such as the use of specific pathogens or genetically modified organisms [44].Long-term ecological studies are essential to understand the impact of H. spinicornis on Sal forest ecosystems over time. These studies can provide valuable data on the beetle's population dynamics, its interaction with other species, and the long-term effectiveness of various control strategies. Long-term monitoring can also help in understanding the impact of climate change and habitat alteration on the beetle and its host ecosystem [45].there is a need for the development of sustainable management strategies that consider the ecological, economic, and social aspects of Sal forest conservation. This includes the integration of traditional forest management practices with modern scientific knowledge, the development of community-based management approaches, and the adoption of an ecosystem-based approach to pest management. Such strategies should aim to balance the conservation of Sal forests with the livelihood needs of local communities [46].

Conclusion

The management and conservation of the Sal tree (Shorearobusta) and its persistent pest, Hoplocerambyxspinicornis, present multifaceted challenges and demand a comprehensive approach. The ecological significance of Sal forests, coupled with the severe impacts of H. spinicornis infestations, underscores the urgency for effective control strategies. Addressing the gaps in current knowledge, particularly in the beetle's life cycle, genetics, and interactions within its ecosystem, is crucial. The emerging threats of climate change and habitat loss further complicate this scenario, necessitating adaptive and sustainable management strategies. Future efforts should focus on integrated pest management, combining scientific research, technological advancements, and community involvement to safeguard these vital forests and maintain their ecological balance.

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