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Review article

Sanidad o salud forestal en México: estudios comparativos en tres ecosistemas protegidos

Forest health or forest pest management: comparisons among three protected ecosystems

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Abstract

The concept of forest health is associated with an anthropocentric view of agronomic origin, focused on pest control. In contrast, the concept of ecosystem health is closely tied to ecological functionality, in which herbivorous insects play a crucial role in key processes such as organic matter recycling and natural succession. From this perspective, the use of the term "pest" is inappropriate for describing ecological dynamics in unmanaged ecosystems. The application of both approaches, forest health and sanitation, is analyzed through the review and comparison of three documented case studies in protected ecosystems in Mexico: (I) The phytosanitary contingency caused by ambrosial beetles in the mangroves of *Atasta*, *Campeche*; (II) The change of strategy against bark strippers in *Nevado de Colima* National Park, and (III) Mortality processes in *Abies religiosa* forests in the Central region of the country. These cases represent ecosystems with different compositions, dynamics, and phytosanitary management trajectories. The objective was to examine the implementation of both approaches in real scenarios and identify the management decisions taken and their consequences within their respective ecological and regulatory frameworks. This review provides a comparative basis for analyzing the practical and ecological implications of forest health and sanitation approaches, especially in areas where conservation and ecosystem functionality are priorities. It is a critical reflection on the contextualized use of both concepts, reinforcing their theoretical value and applicability in forest management.
Keywords: *Abies religiosa* (Kunth) Schltdl. & Cham., ecological functionality, herbivorous insects, mangroves, *Pinus* spp., forest management practices.

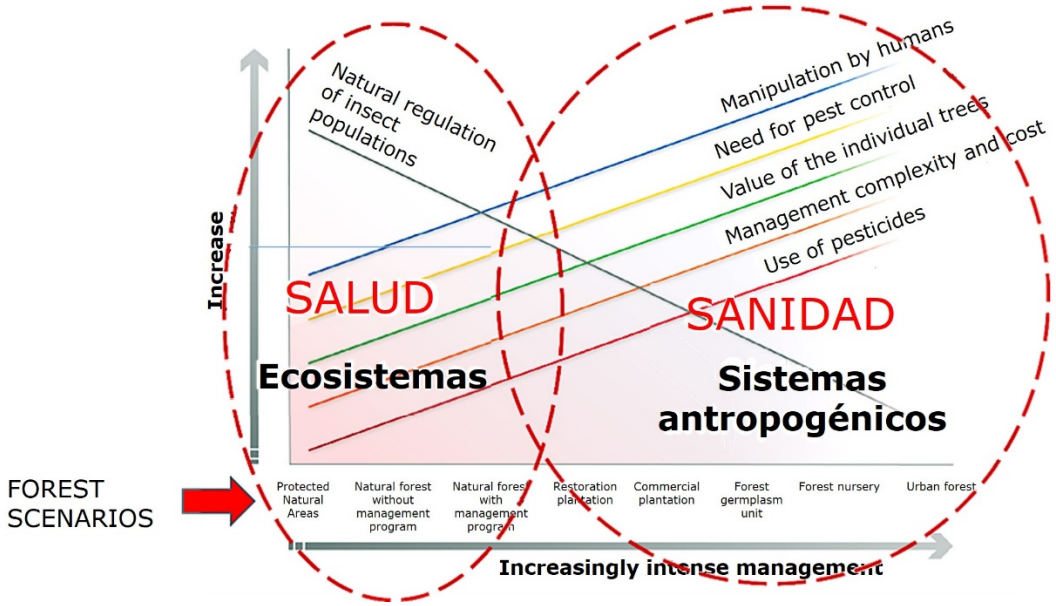
Resumen

El concepto de sanidad forestal se asocia a una visión antropocéntrica, de origen agronómico, centrada en el control de plagas. En contraste, el concepto de salud del ecosistema se vincula con la funcionalidad ecológica, en la que los insectos herbívoros participan en procesos clave como el reciclaje de materia orgánica y la sucesión natural. Desde esta perspectiva, el uso del término "plaga" resulta inapropiado para describir dinámicas ecológicas en ecosistemas no manejados. Se analiza la aplicación de ambos enfoques, sanidad y salud forestal, mediante la revisión y comparación de tres estudios de caso documentados en ecosistemas protegidos de México: (I) La contingencia

fitosanitaria por escarabajos ambrosiales en los manglares de Atasta, Campeche; (II) El cambio de estrategia ante descortezadores en el Parque Nacional Volcán Nevado de Colima; y (III) los procesos de mortalidad en bosques de *Abies religiosa* en la región central del país. Estos casos representan ecosistemas con distinta composición, dinámica y trayectoria de manejo fitosanitario. El objetivo fue examinar la implementación de ambos enfoques en escenarios reales, identificar las decisiones de manejo adoptadas y sus consecuencias dentro de sus respectivos marcos ecológicos y normativos. Esta revisión ofrece una base comparativa para analizar las implicaciones prácticas y ecológicas de los enfoques de sanidad y salud forestal, especialmente, en áreas donde la conservación y la funcionalidad ecosistémica son prioritarias. Es una reflexión crítica sobre el uso contextualizado de ambos conceptos, en el que se refuerza su valor teórico y su aplicabilidad en la gestión forestal.
Palabras claves: *Abies religiosa* (Kunth) Schltdl. & Cham., funcionalidad ecológica, insectos herbívoros, manglares, *Pinus* spp., prácticas de manejo forestal.

Introduction

In Mexico, forest health is based on the Integrated Forest Pest Management (IFPM) approach, which aims to control populations of pest organisms through coordinated strategies based on a cost-benefit analysis, without distinguishing between different types of forest scenarios (Cibrián Tovar & Macías Sámano, 2021). On the other hand, the concept of forest health applies to ecosystems where interactions between biotic and abiotic components develop naturally and continuously. These interactions have shaped the structure and functionality of forests over millions of years. In contrast, in settings such as plantations, nurseries, or urban tree plantations (Figure 1), these interactions are interrupted or altered by human interventions.



Salud = Health; *Ecosistemas* = Ecosystems; *Sanidad* = Sanitation; *Sistemas antropogénicos* = Anthropogenic systems. Modified from Cibrián Tovar (2021).

Figure 1. Forest scenarios and their relationship with the concepts of ecosystems, anthropogenic systems, health, and sanitation.

An ecosystem is considered healthy when its fundamental processes —such as the hydrological cycle, biogeochemical cycles, energy flow, and community dynamics— along with natural disturbances such as fire or herbivore outbreaks, operate within their historical ranges of variability, without compromising biodiversity or resilience (Folke et al., 2004; Kolb et al., 1995). Teale and Castello (2011) define a healthy forest ecosystem as one that maintains a balance between growth and mortality, thereby ensuring its structural sustainability. Tree mortality is an essential part of forest dynamics, and must be assessed at appropriate spatial and temporal scales, based on species biology (Harmon & Bell, 2020), in fact, the timescales and spatial scales governing these processes are often hundreds to thousands of years operating at a landscape level (Trumbore et al., 2015). In contrast, sanitary approaches respond

to annual events and are applied with a reactive logic, similar to that of agroecosystems.

Authors such as Raffa et al. (2009) have warned that human values are often imposed on ecological processes, generating distortions in the perception of what constitutes an ecological problem. Thus, the term "pest" becomes a construct linked to productive rather than ecological objectives. For example, native debarking insects are considered pests when they cause massive mortality in plantations or in managed forests, although in natural forests they play a key role in succession processes. In the absence of anthropogenic pressures, forests maintain dynamic balances between trees and bark strippers, generating successional mosaics as documented in Western Canada (Alfaro et al., 2015).

In the absence of scientific and technical tools tailored to the ecosystem, institutional responses often resort to the sanitary approach, which is more immediate but less compatible with natural processes (Lindenmayer et al., 2025).

The objective of this article is to analyze and discuss the scope of the concepts of forest health and sanitation, based on their concrete application in three case studies located in protected ecosystems in Mexico: (I) The phytosanitary contingency caused by ambrosia beetles in mangroves of *Atasta*, *Campeche*; (II) The impact of a natural outbreak of bark strippers in *Nevado de Colima* Volcano National Park, and (III) Phytosanitary processes applied in *Abies religiosa* (Kunth) Schltdl. & Cham. forests in the Center of the country. These cases represent protected ecosystems with different disturbance regimes, floristic composition and history of phytosanitary intervention. This diversity allows us to contrast how the concept of pest has been interpreted and applied under the sanitary approach in different contexts, as well as its implications on forest structure, functionality and management criteria.

Cibrián Tovar (2021) identifies eight forest scenarios, classified according to the degree of human intervention: (1) Protected Natural Areas, (2) Natural forests

without management program, (3) Natural forests with management programs, (4) Reforestation for ecological or economic purposes, (5) Commercial plantations, (6) Forest germplasm units, (7) Forest nurseries, and (8) Urban and suburban trees (Figure 1). The first two scenarios are ecosystems that function autonomously, with minimal or no human intervention. In contrast, the remaining six do require it for their management and permanence, since they are anthropogenic systems. In accordance with what was established in the introduction, this classification suggests that the concept of forest health is more applicable to natural ecosystems without management plans, since self-regulated ecological processes prevail. In contrast, the term forest sanitation is more relevant to anthropogenic systems, where the aim is to maintain desired conditions by controlling organisms (Arriola-Padilla et al., 2020; Manzo-Delgado et al., 2014; Secretaría de Medio Ambiente y Recursos Naturales [Semarnat], 2018).

Forest phytosanitary actions aim to control bark strippers and wood borers, which involve the removal and destruction of insects using physical, mechanical, or chemical methods. Actions include felling affected trees, debarking or cutting sections of the trunk, with the objective of exposing insects or removing the affected material from the ecosystem (Comisión Nacional Forestal [Conafor], 2015).

When this strategy is applied in natural ecosystems, it can have adverse effects on biodiversity, particularly on natural enemies and competitors of the target insects. It also affects soil health, as well as the structure and functionality of ecosystems (Lindenmayer et al., 2025). As a result, ecosystem services are compromised (Hagge et al., 2019; Lindenmayer et al., 2025; Pacheco-Aquino & Duran, 2023).

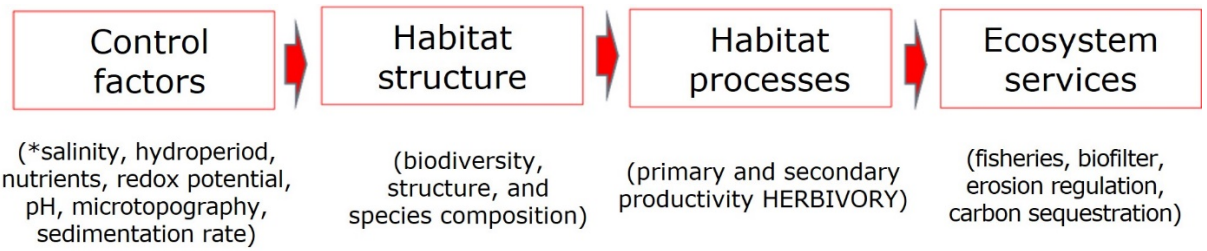
Case 1. Phytosanitary contingency in the mangrove ecosystem, *San Antonio Cárdenas*, *Carmen* municipality, *Campeche*

In the *Laguna de Términos* Flora and Fauna Protection Area, losses of 6 945 hectares were recorded during the period 1990-2010. In the last 10 years, the *Atasta* area has experienced changes in hydrology due to anthropogenic disturbances and meteorological phenomena, which have caused hypersalinity and anoxia conditions in the interstitial water of the mangroves and inland lagoons (Agraz Hernández et al., 2015).

In 2022, the National Forest Commission documented mangrove mortality Southwest of *Laguna de Términos* on more than 2 000 hectares. The damage was attributed to ambrosial beetles: *Euplatypus parallelus* Bright & Skidmore, 2002 and *Coptoborus pseudotenuis* (Schedl, 1936). As a result, the institution issued a phytosanitary alert in the states of *Tabasco*, *Campeche*, *Yucatan* and *Quintana Roo* (Conafor, 2022) and began sanitation work. According to testimonies of local inhabitants, the actions included the felling of trees, the bagging of residual material, and the application of direct injections to the trees (Agraz Hernández et al., 2016).

In view of these scenarios, Semabicce (Secretariat of Environment, Biodiversity, Climate Change and Energy of *Campeche*) with the support of the Institute of Ecology, Fisheries and Oceanography of the Gulf of Mexico (Epomex) of the Autonomous University of *Campeche* conducted an environmental diagnosis of the conditions of these mangroves (Agraz Hernández et al., 2016), with an ecosystem approach, in which the control

factors, habitat structure and composition were evaluated, and insect herbivory was also included as a component to be analyzed (Figure 2).



Source: Agraz-Hernández et al. (2022).

Figure 2. Conceptual model of mangrove habitat.

Habitat structure and control factors that give rise to various processes in the habitat, resulting in various ecosystem services.

The diagnostic results showed significant spatial variations with respect to the physicochemical conditions of the interstitial water (temperature, pH, redox potential, and salinity) in the mangrove forests (live and dead) located in 769 ha of degraded mangrove forest. In a similar way, hypertrophic conditions with high phosphate concentrations were identified, which potentially alter soil biogeochemical processes and affect nutrient uptake by plants. These sulfate concentrations indicated a limited influence of seawater, resulting in the release of sulfur and hydrogen sulfide.

The physiognomy of the mangroves was composed of 35.7 % of riparian type and 26.2 % of edge; physiognomies were considered as the original ones. In addition, four types of physiognomies were observed: (a) Edge with basin tendency, representing 9.5 %; (b) Basin scrubland, with 4.8 %; (c) Basin, with 14.3 %; and (d) Scrubland, with 14.3 %. The latter reflect the loss of the structure and function of the original vegetation, attributed to hydrological changes, alterations in the topographic

level, increased salinity and anoxia. The Normalized Difference Vegetation Index (*NDVI*) for 2021 and 2022 estimated as part of the diagnosis, indicated that the mass mortality event could have occurred in 2020, following a long stress process (Agraz Hernández et al., 2016).

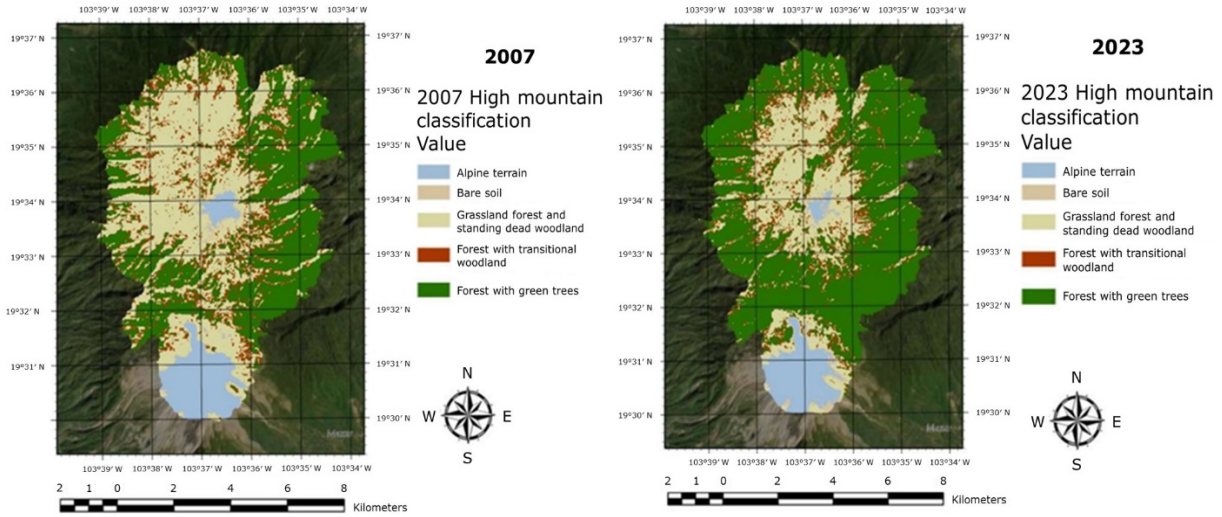
Herbivory was assessed in a total of 439 trees; of these, 47.4 % exhibited non-recent mortality, 49.4 % were recorded as healthy, and 3.2 % showed signs of decline, with death mainly occurring in a downward manner. *Avicennia germinans* (L.) L. had the highest number of declining individuals (11) and a total of 183 deaths (11); *Laguncularia racemosa* (L.) C. F. Gaertn had 32 deaths and none in decline (Agraz Hernández et al., 2016).

Signs and symptoms of the saproxylic borer beetles were common in the dead sections of *A. germinans*, and only three living individuals presented borings by ambrosial beetles in living tissue, which were always accompanied by resin extraction. However, their attacks were unsuccessful, and no remains or developmental stages of the insects were observed. This process of expelling borer insects using resin is a defense mechanism (Franceschi et al., 2005).

With the integration of the evaluated control parameters, forest structure and cover change, together with herbivory, the diagnosis confirmed that the mortality and ecological successions of vegetation are mainly caused by physicochemical disturbances and water hydrology. This has resulted in the recycling of organic materials; thus, the wood borer insects profit from the availability of dead material, which renders them ecological indicators of the vegetation’s conditions rather than their cause (Agraz Hernández et al., 2016).

Case 2. Pine bark beetles in the *Nevado de Colima* Volcano National Park (*PNVNC*)

At the *Nevado de Colima* Volcano National Park (*PNVNC*, for its Spanish acronym), the management of pests such as pine bark beetle insects follows regulations that establish specific measures for their prevention, control, and handling (Conafor, 2015). Between 1963 and 2003, the *Pinus hartwegii* Lindl. forests of the *PNVNC* underwent annual clear-cutting to combat pine bark beetle insects in accordance with current regulations. However, since 2004, those responsible for the park's management program (Comisión Nacional de Áreas Naturales Protegidas [Conanp], 2006) have questioned the effectiveness of these practices and pointed out the annual recurrence of the pest, as well as the associated damages, such as soil erosion, loss of forest mass, organic matter and bird species, and soil degradation (Jones et al., 2025; Sánchez-Ramos et al., 2022; Villalobos, 2021). In response, they suspended sanitation and adopted strategies such as reforestation, livestock eradication, fire management, park use limitations, and water resource management. These actions resulted in a 24.9 % increase in the forest area, according to satellite evaluations conducted between 1999 and 2023 (Villalobos Echevarría, 2023) (Figure 3).



Source: Villalobos Echevarría (2023).

Figure 3. Comparison of high-mountain vegetation cover in the *PNVNC* between 2007 and 2023 based on satellite images.

The increase in the vegetation area and the permanence of standing dead trees on the ground of the *PNVNC* have generated positive changes in the soil's nutrient content (Villalobos, 2021) and in biodiversity, particularly among resident and migratory birds (Sánchez-Ramos et al., 2022). Empirical knowledge and research conducted in the *PNVNC* have consolidated its management policy, supporting the elimination of sanitation activities.

Case 3. Sanitation in *Abies religiosa* forests in central Mexico

Hernández-Álvarez et al. (2021) compiled studies on the ecological and floristic aspects of *Abies religiosa* forests in the country's Volcanic Transverse Axis; the authors highlight the lack of basic information necessary to propose and establish management and conservation strategies in these forests.

The case of *Desierto de los Leones*, located in the *Cuajimalpa de Morelos* and *Álvaro Obregón* municipalities of Mexico City, sets an important guideline to understand the great complexity and dynamics of the historical decline and death of this type of forest in central Mexico (Ciesla & Macías-Sámano, 1987; González-Medina et al., 2010).

Initially, bark beetle insects and certain diseases were blamed as the primary mortality factors (Gómez-Pineda et al., 2022). Even as early as in the 1980s, continuous sanitation against these insects was already being carried out (Vázquez-Soto, 1988). The mortality that led to the almost total disappearance of *A. religiosa* in the park was triggered decades ago by the constant incidence of oxidizing gases from Mexico City, coupled with a series of biotic and abiotic factors (Ciesla & Macías-Sámano, 1987; González-Medina et al., 2010).

For several years, the overwintering area of the monarch butterfly has experienced a decline in the population of *A. religiosa*, which has been attributed to bark beetle insects. Consequently, sanitation efforts have long been carried out to control them (Garduño-Bernal, 2011). Ironically, however, losses of wooded area are associated with these reclamations (Manzo-Delgado et al., 2014). Similar tree mortality is occurring at the *El Chico* National Park, where bark beetle have been identified as the cause, and remediation efforts have been initiated to control them (Conafor, 2025).

In Mexico, similar attack behaviors to those occurring on pines have been attributed to bark beetles on *A. religiosa*; however, this is incorrect. On the one hand, the defenses against bark beetles in *Abies* spp. are very different from those found in pines (Macías-Sámano, 2001); likewise, the main species of bark beetles that colonize *Abies* spp. lack a pheromone aggregation system. Therefore, they do not produce infestation centers and are hardly directly responsible for the death of trees (Furniss & Johnson, 2002; Macías-Sámano et al., 1998a, 1998b; Macías-Sámano & Borden, 2000; Wright et al., 1984).

For the reasons described above, it should be stressed that the death of *A. religiosa* is a complex process in which many factors intervene, among them the biology and dynamics of the species (Hernández-Álvarez et al., 2021), the effects of climate change (Gómez-Pineda et al., 2022), and anthropic impacts (Hernández-Álvarez et al., 2021; Manzo-Delgado et al., 2014) which together stress and predispose trees to successful colonization by various organisms, including bark beetles, all of which leads to their death.

Conclusions

The comparison between the three cases enables the identification of patterns in the application of the health approach and its implications on ecosystem functionality. Although the ecological contexts are diverse, in all cases there is a homogeneous regulatory response based on direct insect control, with different levels of effectiveness and recognition of the ecological role of the organisms involved. Table 1 summarizes the

key characteristics of each case, allowing for a comparison between the ecosystem types, the affected species, the implemented actions, and the resulting outcomes.

Table 1. Comparison between three case studies in protected ecosystems in Mexico, based on ecosystem type, affected organism, phytosanitary intervention applied, dominant approach, and observed results.

Criterion	***Atasta mangroves (Campeche)***	***Nevado de Colima (Jalisco)***	***Abies religiosa (Kunth) Schltdl. & Cham. forests (Central México)***
Type of ecosystem	Tropical mangrove	High mountain forest	Temperate montane forest
Herbivore species	Ambrosial beetles	*Pinus hartwegii* Lindl. bark-stripping beetles	*Abies religiosa* (Kunth) Schltdl. & Cham. bark-stripping beetles
Type of intervention applied	Felling and burning of infested trees	Change of strategy: monitoring without direct intervention	Systematic sanitation
Dominant approach	Sanitary, without functional diagnosis	Transition to a health approach	Traditional sanitary
Evaluation of results	Limited effects; recurrence of symptoms	Structural recovery and increased coverage	Persistence of the problem; inconclusive results
Consideration of the ecological role of insects	Not considered	Considered and evaluated	Ignored in the regulations
Implications for forest management	Generalized intervention without ecological validation	Passive management is adopted with ecological basis	Application of the standard without ecological contextualization

The analysis of the three cases reveals that the phytosanitary actions applied in protected ecosystems have followed a sanitary approach that focuses on an immediate and corrective response aimed at eliminating insects considered pests without evaluating their ecological function or the collateral effects of such

interventions. This finding aligns with Lindenmayer et al. (2025), who suggest that the increase in disturbances, intensified by climate change, has promoted intensive management schemes with weak technical support.

The "sanitation" measures are limited in duration and spatial scope (Billings, 2011). Current regulations in Mexico (*e. g.*, NOM-019-SEMARNAT-2017) do not differentiate between forest scenarios, nor do they establish adapted preventive strategies. In contrast, such countries as the United States of America and Canada have adopted schemes based on forest structure and composition to reduce vulnerability to outbreaks (Guldin, 2011; Safranyik & Wilson, 2006).

Therefore, it is recommended that the phytosanitary regulatory framework be revised and updated to incorporate ecological criteria that recognize the functional role of herbivorous insects and establish differentiated strategies according to the ecosystem context and conservation objectives.

The comparative review indicates that sustainable forest management necessitates an understanding of the dynamics of disturbances within their ecological context, avoiding homogeneous interventions, and prioritizing the conservation of ecosystem functionality through approaches grounded in robust ecological science.

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Conflict of interest

The authors declare that there is no conflict of interest in sharing and publishing the information contained in this article.

Contribution by author

Jorge E. Macías Sámano: development, analysis, and revision of the manuscript; Claudia M. Agraz Hernández and José Villa Castillo: contribution with data and discussions that allowed for a clear and substantiated product.

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