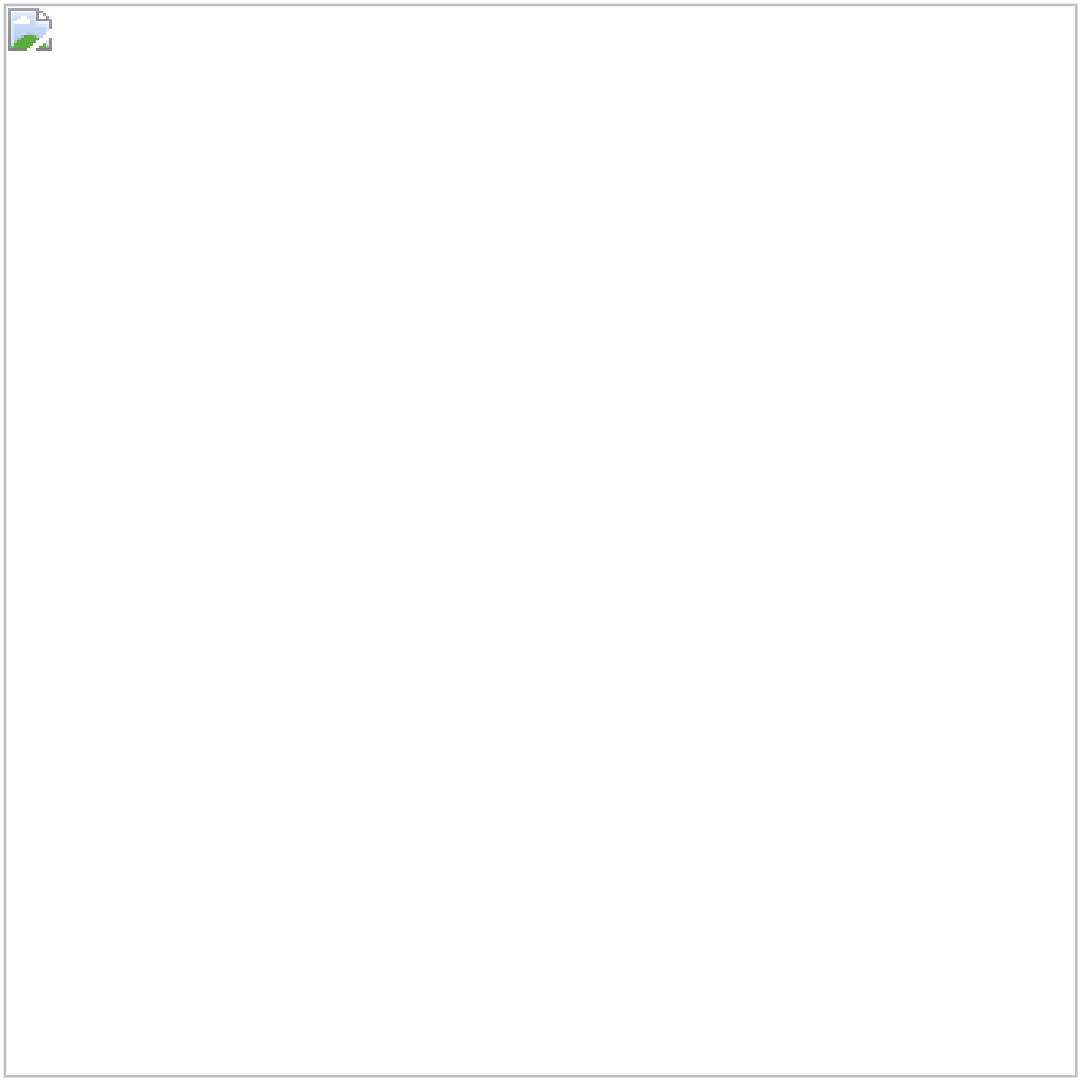

Spread of the invasive alien species Piper Aduncum via logging roads in Borneo

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Short communication

Spread of the invasive alien species Piper aduncum via logging roads in Borneo

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Abstract

We examine how spiked pepper (*Piper aduncum* L., Piperaceae), a shade intolerant, animal-dispersed Neotropical tree, is spreading in the interior of Borneo. Concerned that logging roads might be facilitating this spread, we made a series of observations, relating tree distribution, location and road history, in a concession in East Kalimantan. These roads will connect West Kutai and Malinau Districts and may allow alien plants to disperse from one to the other. We observed that *P. aduncum* was already well established on the oldest, southern portions of the logging road network, but was absent on the newest roads to the north. A few scattered individuals occur on the roadside as much as 150 km beyond the main areas dominated by *P. aduncum,* suggesting an occasional ability to achieve long-hop dispersal. Rivers of 30 m width are not a barrier to *P. aduncum*'s spread. Based on road age, we estimate a minimum rate of spread between five and seven km per year. We infer that logging roads are assisting *P. aduncum* to spread and the tree will become widely established in Malinau District. Prevention of this spread would require urgent, intensive and coordinated control over the length of the road network and, more generally, major restrictions on how such roads are located and managed.

Keywords: *P. aduncum*, spread, logging road, control, Borneo

Résumé

Nous examinons comment spiked pepper (*Piper aduncum* L., Piperaceae), un arbre néo-tropical heliophile et zoochore, se propage à l'intérieur de Bornéo. Craignant que les routes forestières puissent faciliter sa dispersion, nous avons fait une série d'observations, liant la distribution des arbres, leur location, et l'histoire des routes, dans une concession de Kalimantan Est. La construction de routes reliant les districts de Ouest Kutai et Malinau pourrait faciliter la dispersion de *P. aduncum* de l'un à l'autre. *P. aduncum* est déjà bien présente dans les parties les plus anciennes du réseau routier, mais est absente des routes les plus récentes dans le nord. Quelques individus isolés sont trouvés sur le bord de routes à 150 km de la zone principale dominée par *P. aduncum,* ce qui suppose une capacité occasionnelle à se propager par longs sauts. Des rivières de 30 m de large ne font pas barrière à la diffusion de *P. aduncum.* Nous basant sur l'âge des routes, nous estimons la vitesse de propagation entre cinq et sept km par an. Nous en déduisons que les routes forestières facilitent la propagation de *P. aduncum* et que l'arbre sera bientôt largement représenté dans le district de Malinau. Toute action préventive nécessite d'urgence un contrôle intensif et coordonné sur toute la longueur du réseau routier et, de manière plus générale, de limiter l'emplacement de ces routes et la façon dont elles sont gérées.

Mots clés : *P. aduncum,* dispersion, routes forestières, contrôle, Bornéo

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Introduction

Alien plants can cause various changes in tropical ecosystems and pose threats to forest biodiversity [1-3]. These threats and the underlying processes that lead to them are poorly studied in much of the species-rich tropics and require more attention from researchers and conservation managers [4]. The threats and challenges of invasive alien plants are recognized in the context of sustainable forest management. For example, in any Forest Stewardship Council (FSC) certified concession, the forest management is required to maintain the ecological functions and the integrity of the forest by conserving biological diversity and its associated values (Principle #6 of FSC International Standard). This principle requires monitoring and control of invasive alien species [5]. However, despite recognition of the problem, there is no guidance concerning what can or should be done.

Vast areas of the world's tropical forests have been harvested for timber, and many of these areas remain as forests. Around 300 million hectares of the world's tropical forests – an area almost four times larger than that designated for stricter conservation – are already managed primarily for timber [6]. These forests remain valuable in terms of biodiversity, carbon and other environmental values [7]. But timber extraction modifies the forest and leaves other legacies that can increase conservation threats, such as the road system, which has various effects on the forest's biota [8-10]. Roads cause habitat fragmentation and increase accessibility, with various negative implications for biodiversity conservation [11-12]. One problem that has been little documented, at least in the equatorial rain forests of South East Asia, is the role roads play in the spread of alien species.

Piper aduncum (Piperaceae), commonly known as spiked pepper, is a shade-intolerant Neotropical tree native to evergreen forests from Mexico to Bolivia. It is considered the most invasive species in the genus *Piper,* which comprises over 1,000 species [13-14]. It has been observed to flower more or less continuously through the year and to produce mature fruits about 70 – 80 days after flower emergence [15]. In its native range, and also in regions where it becomes newly established, it is believed that its seeds are primarily dispersed by bats and by birds [14]. *P. aduncum* is already widely distributed outside its native range, e.g. in Fiji, the Solomon Islands and the United States [16]. It is already naturalized in considerable areas of South East Asia and Melanesia and occurs from sea level up to 2,000 m a.s.l., but it seems unable to persist in the deep shade of closed natural forests and is thus restricted to disturbed or open locations, such as exploited forest and fallows, where it can receive enough light [1-2]. Indonesia, Malaysia and Papua New Guinea already have naturalized populations of *P. aduncum*. In these regions *P. aduncum* has become a significant

environmental concern by dominating regrowth vegetation over large areas, displacing native species [17], slowing forest recovery, and interfering with agriculture [1].

P. aduncum was first introduced to Indonesia, with plantings at the Kebun Raya Bogor (Bogor Botanical Garden), West Java, in 1860 [13]. It is already widely established throughout Java, Sumatra, Seram, Papua and many other islands (DS and MP pers. obs.). The spread in Borneo appears to have been slower or at least more localized. It was first collected in East Kalimantan (i.e. Indonesian Borneo) in 1952 [13], but by 2005, when our study began, it had still not yet established throughout all the districts, presumably because its spread has been slowed, or prevented, by the large areas of dense forest that still occur in the region.

On a visit to a logging concession in Long Bagun, West Kutai District in East Kalimantan, in 2005, one of us (DS) observed the dense cover of *P. aduncum* seedlings along the roadsides (leading from the Mahakam River), although such seedlings were absent from the nearby forest interior, even in areas that had been selectively harvested only a year or two before. In general only a few of the larger and more valuable trees are taken out of each hectare, so what remains is still forest. Understorey in these recovering areas grows rapidly and after only a few months is frequently denser than in neighbouring unlogged forest. We assumed that the absence of *P. aduncum* in these areas was due to the plants' intolerance of shade.

The access road to this concession goes northward from the Mahakam River, and there was a plan to extend this road to enter Malinau District (the next district to the north), where many of the concession area were as yet unexploited. From our 1999 to 2009 surveys, we knew that *P. aduncum* was absent from Malinau at that time. We were concerned that *P. aduncum* might use the new road to invade the rich and biodiverse forests of Malinau [18-20]. We undertook this study to examine this risk and determine whether the spread might be prevented.

We consider this assessment to be a case-study "snapshot" of one alien species at a particular time and place. Given the paucity of such studies, our observations may provide insight into a prevalent but neglected process throughout the wet-tropics: are logging roads increasing the spread of alien species, and if so, what can be done?

Based on our initial observations we hypothesized that logging roads were the principle means for *P. aduncum* to spread within the forest. We assume that locations where the tree has been longer established will have comparatively dense populations if conditions allow, while recently colonized areas will have sparser populations. Our study relates the history and layout of the logging-road network to the occurrence and density of *P. aduncum.* Our aim was to map the roadside distribution of this tree species and examine its potential to spread via these roads into new areas.

Methods

Study area

In 1979, two concession holders began extracting timber from the study area. They then merged in 1990 to become PT. Sumalindo Lestari Jaya II (hereafter referred to as 'the concession'), which lies between 100 and 1,100 m a.s.l. (00° 45' 00" – 01° 50' 00" N and 115° 05' 00" – 115° 45' 00" E) and is surrounded by protected and production forest under four other concession holders. The concession has FSC certification due to its basic good practices, including the implementation of

Reduced Impact Logging (RIL), which has minimized mechanical disturbances from timber extraction.

There are five villages inside the concession. These communities rely on the forest for small scale agriculture, hunting, and various forest resources (PT. Sumalindo Lestari Jaya II General Management Plan 2006, unpublished document).

The 269,660 ha concession is entered by the road from West Kutai District in the south, but about 80% of its area lies in Malinau District to the north. Both districts are divided by the Boh River at Km 122 of the logging road. The road had reached Km 200 in 2009, and based on the concession's general management plan, the road will be extended 20 km to the north by 2018. Logging roads inside the concession are maintained at least once a year by leveling with a grader, spreading gravel, and cutting road side vegetation.

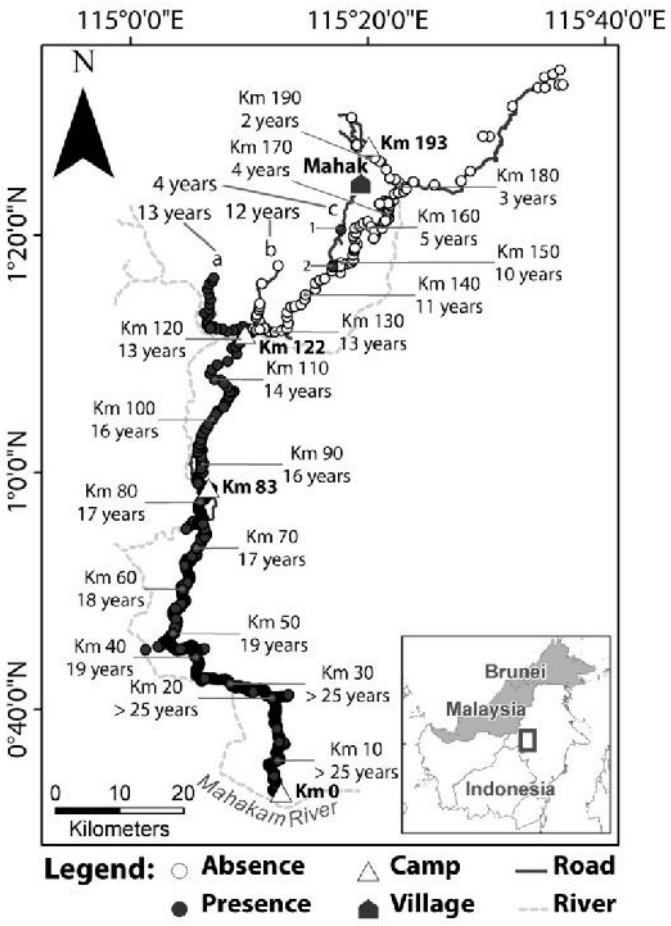

Fig. 1. *Piper aduncum* distribution based on road side observations along roads of different age

Data collection

We carried out a series of observations along logging roads inside the concession for two weeks in total. While driving at an average speed of 30 km/hour, we used a Global Positioning System (GPS) and mapped usable roads, i.e. main roads and branch roads that were being maintained for the next year's logging within the concession. The history of road construction was derived from concession records and discussion with the camp staffs.

P. aduncum was recorded using two rapid systematic approaches. We recorded whether *P. aduncum* was present or absent within five m on either side of each kilometer of road (a distance both easy to view and adequate to include the open forest edge areas). We also counted the number of *P. aduncum* stems in a 10 m x 10 m roadside plot every five km up to Km 130. Using ArcGIS 9, we developed a map of *P. aduncum* distribution in the concession area. In addition to our own observations, we interviewed five concession officers and nine local people (Dayak Kenyah and Dayak Bahau) – based on their availability –about their observations of the spread, impact and value of *P. aduncum*.

Results

Road history

The first concession camp was established in 1980 in Long Bagun, on the banks of the Mahakam River. Road construction began from this camp (known as "Km 0") in 1982, but stopped 45 km later at a rocky hill in 1985. It continued in 1986 – 1987, but to avoid the hill, the road branched out from Km 21 to the east for 15 km, then stopped at another hill. During the period of 1987 – 1990, the concession focused their work elsewhere, but returned to Long Bagun in mid-1990. Road construction then continued, branching from Km 35 and stopping at Km 52. Starting again in 1991, road construction followed the annual management plan, heading north-east at a more regular pace but with some revisions and branching. A map showing the roads that remain drivable, with their age at the time of our study, is provided in Fig. 1.

Distribution, abundance and density

P. aduncum was common along the road in the southern portion of the concession and was present up to Km 128, which is about six km into Malinau District. A high abundance of *P. aduncum* was observed from Km 0 to Km 65 along the main road (Fig. 2a, and Fig. 3).

The greatest plot level density occurred between Km 45 and 65, where 101 stems were recorded in five plots (equivalent to 2,020 stems ha^{-1}), while from Km 0 to Km 40, we found 102 stems in eight plots, equivalent to 1,275 stems ha^{-1}. There were only 27 stems of *P. aduncum* in eight plots between Km 70 and Km 105, which is equivalent to 338 stems ha^{-1}. There is an indication that stems density declines locally, reaching zero at both Km 85 and 100 before disappearing in all plots from 110 km onward (Figure 2b, and Figure 3). Considering *P. aduncum* has managed to reach between 128 and 199 km and accepting that the road is the primary route of this spread, the 27 years of spread indicates a minimum rate of advance between five and seven km per year.

Fig. 2a. The dense cover of *Piper aduncum* along the old road in southern part of the concession

Fig. 2b. *Piper aduncum* remains absent along the new road in northern part of the concession

Regarding branch roads, *P. aduncum* occurred along Road "a" (constructed in 1997) but was absent on road "b" (constructed in 1998) where maintenance activities (including the slashing of plants on the edge of road) were being undertaken in preparation for timber extraction. In addition, we recorded two localized occurrences of *P. aduncum* on road "c" (constructed in 2006) leading to Mahak Village. These occurrences are at a direct (linear) distance of 82 and 88 km (and 148 and 155 km measured along the road) from Long Bagun at "Km 0".

We observed that *P. aduncum* never grew in closed forest. Several rivers up to 30 m wide occur, which the road crosses by bridges, but these have not influenced the distribution and spread of *P. aduncum*.

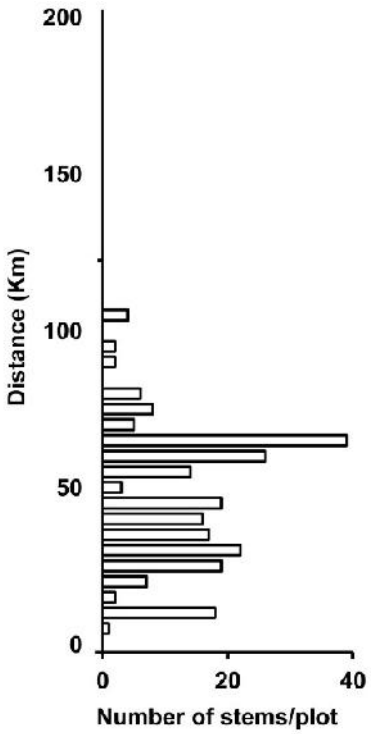

Fig. 3. Stem density in road side plots along the logging roads by distance

If we allow a naïve null hypothesis, which assumes each plot can be treated as an independent observation from a distribution with no trend by distance or relation to the road's year of construction, we can test it. Distance along the road and age of the road are strongly correlated in these data. A Kendall's rank correlation of distance with stem density in the first 40 plots is significant (tau = -0.620, $p<0.001$), as is density with date of road building (tau = -0.694, $p<0.001$, n= 40). If we remove the long tail of more recently constructed and more distant empty plots, the relationship remains significant for both density versus distance (tau = -0.402 p=0.007 n = 24) and density versus date of road construction (tau =-0.433, p= 0.006 n=24). If we only look at the pattern of stem density in plots where the tree is actually present, there is no longer a significant relationship to distance (tau = -0.246 p = 0.123, n= 21) or date of road construction (tau = -0.2282 p = 0.094, n= 21).

Additional observations of *P. aduncum* in the concession area show that it is widely spread, not only along logging roads but also around camps, villages, young fallows (i.e. less than 5 years), and occasionally on river banks in the southern portions of the concession. Within all of our 100 m^2 plots, most of the *P. aduncum* plants are small trees — few reach diameters over 10 cm. In addition to *P. aduncum*, we noted that understories commonly included grass, herbs, shrubs, and ferns such as *Gleichenia linearis* (Burm. f.) C.B. Clarke*, Nephrolepis exaltata* (L). Schott, and *Meremia* sp.. We occasionally observed seedlings and poles of native species such as *Syzygium* spp., *Litsea* spp., *Shorea* spp., Borneo kauri (*Agathis borneensis* Warb.), *Diospyros* spp., and rough laurel (*Gironniera nervosa* Planch.) inside the plots.

Local use and perceptions

According to our interviews with people of Dayak Kenyah and Dayak Bahau, who are farmers and forest resources gatherers, *P. aduncum* is not regarded as useful by local communities in and around the concession. Instead, they consider it a weed when it occurs in fields and in fallows, and they slash it to prevent it encroaching on crops. There were no stories either from concession staff or local people on wider ecological impacts in the concession area.

Discussion

Our results are consistent with our hypothesis that logging roads facilitate the spread of *Piper aduncum* throughout a forest landscape where it would otherwise be absent. During our study we observed that the roadsides support high densities of *P. aduncum* seedlings and trees. We did not record flower and fruit production specifically, but our impression was that even small saplings often bore fertile structures. The role of riversides and of local agriculture were not fully assessed, though both appear likely to contribute to the distribution of *P. aduncum* and to increase the local connectivity of the landscape for wider dispersal, establishment and spread of this shade-intolerant species.

Impacts

The threat *P. aduncum* poses has been better characterized in other regions, e.g. in Papua New Guinea, Fiji, Hawaii, Solomon Islands, and Florida [1-2]. It is considered an aggressive species that out-competes native trees in disturbed forest and can become a significant weed in fallows. Despite these concerns, *P. aduncum* is sometimes viewed as having some values, e.g., improving soil fertility and controlling soil erosion [13]. Based on these other studies we assume that if it becomes

established in tropical forest landscapes, it is likely to become a significant weed in neighboring farmlands. The fact that *P. aduncum* is not found inside the closed canopy forests might reflect its limited germination in shade [21-22]. The RIL applied in the concession reduces the likelihood of extensive gaps after tree felling. However, *P. aduncum* might be a concern in areas being managed for timber in a more destructive fashion, and may become a problem even in natural forest areas in the long-term, especially if the canopy was opened up by a recurrence of the major droughts and fires that caused major tree death in nearby regions in 1998 [23] or indeed if these forests are subject to any other destructive events. Despite these conjectures, at this point we still believe that the primary concern is that forest operations will facilitate dispersal of *P. aduncum* across areas that would otherwise be barriers to its dispersal.

Control

Any conclusions regarding control are provisional. But delays, too, have costs. While we support plans for additional research, we emphasize that action is urgently required [24-25]. Clearing *P. aduncum* along the roadsides in the concession, though costly, would not be impossible. Either repeat slashing or chemical control would reduce the abundance and fruit production of the plant [16]. The rapid maturity of these plants suggests that any such treatment would initially be required every two to three months. The fact that the plant can apparently jump over 20 km along the road suggests that extensive coverage and considerable vigilance would be required to locate and kill plants before they have time to reproduce. Our observations suggest that farming practices and open river banks may also allow the establishment, maintenance and spread of *P. aduncum*, and these too would need to be addressed in any management process. But in terms of crossing intact forest, roads are the main route and our primary concern.

Our brief study suggests that logging roads already provide routes that allow *P. aduncum* to spread to locations where it would otherwise be unlikely to establish. Any effort to reduce this connectivity and control the spread across Borneo would require intensive and broad-scale control measures. Though such efforts may slow the advance of the tree, they are unlikely to stop it in the long-term unless additional eradication efforts can be maintained. Without rapid and coordinated attention, any such efforts will be too late.

Implications for conservation

The forests of Borneo, and in particular Malinau, contain remarkable biodiversity values. More than one-third of the island's flora are endemic and Malinau is especially rich [18, 20]. Our simple methods yield preliminary information on how the invasive species *Piper aduncum* is spreading from West Kutai District, where it is already established, to the rich forest in Malinau via logging roads. Our provisional conclusions are that logging roads provide a means by which *P. aduncum*, and other weedy species, may be able to spread across otherwise inhospitable habitats. It is likely that such spread will have environmental and social impacts that are difficult and costly to mitigate [1, 26]. The large number of flowers and fruits produced by *P. aduncum* will directly impact animal species that can utilise these resources, which will inevitably have knock-on effects for other species that interact with these animals, and the species that interact with these in turn, etc., thus potentially causing changes through the entire ecosystem. It is likely that generalist species, by being better able to take advantage, will be favoured at the expense of more specialised species – but ultimately winners and losers can be idiosyncratic and unpredictable [27]. Considerable resources would be required to understand these processes in any detail in the species-rich forests of Borneo.

It seems clear that some investment is required to define appropriate actions to manage logging roads in order to mitigate the spread and impacts of alien species such as *P. aduncum*. Conservation practitioners and researchers should address the pre-emptive management of invasive alien species [28]. As logging roads can clearly facilitate the spread of *Piper aduncum*, a coherent strategy to prevent its spread from invaded to uninvaded regions is required – if it is not already too late.

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