Did *Microhyla kodial* (Anura: Microhylidae) disperse naturally or through humans?

The frog genus *Microhyla* Tschudi (1838) (family Microhylidae) is restricted to South and Southeast (SE) Asia and comprises 50 described species[1]. A significant proportion of the *Microhyla* diversity occurs in SE Asia[1], followed by South Asia. India has 13 valid species among which six are endemic and the rest are distributed in South and SE Asia. Biogeographically, Indian members of *Microhyla* show into-India dispersal during the late Oligocene, mid-Miocene and late Miocene[1]. An alternative to this argument is a recent human-mediated (accidental) dispersal of *Microhyla kodial* from SE Asia to India due to anthropogenic activities such as timber trade[2]. However, Gorin *et al.*[1] suggested that *M. kodial* could also be naturally dispersed.

Here we consider the origins of a recently described species, *M. kodial*. Its phylogenetic position is intriguing. It is interesting to note that *M. kodial* is closely related to the species from Myanmar instead of microhylid members of the Western Ghats or other parts of India[1]. Previous studies show *M. kodial* nested within the SE Asian *M. achatina* species group[1–4]. Given its phylogenetic position and distribution, Vineeth *et al.*[2] hypothesized that *M. kodial* must have reached the west coast of India due to human-mediated dispersal. However, a recent comprehensive phylogenetic and biogeographic study on all described members of the genus suggested that *M. kodial* ancestors might have dispersed naturally during the late Miocene[1]. During this period, the Indian sub-continent had started undergoing aridification with the intensification of the Indian monsoon[5].

Let us assume that *M. kodial* is naturally dispersed. Then there must have been evidence of its distribution other than the current known locality of less than 500 m^2. Despite several intensive surveys in the entire Dakshina Kannada and Udupi districts in western India since 2017, we failed to locate any population other than where it was first sighted, indicating that this species is restricted to the type locality (Figure 1). The locality where *M. kodial* is found is 6 m amsl and 500 m from the coast. On the eastern side of the type locality is National Highway 66, beyond which no individuals were recorded. The possibility of extinction of *M. kodial* from other areas and surviving only in the type locality is hard to accept because of the highly disturbed habitat. There are other similar types of habitat that are suitable and less disturbed, but *M. kodial* has not been reported. This suggests that *M. kodial* failed to colonize other areas and perhaps, the road acted as a barrier. The locality where *M. kodial* is found is a former timber yard adjacent to New Mangalore Port, Mangaluru, Karnataka. This port is a major hub for the import of timber from Myanmar, Malaysia and Indonesia[2]. Also, this locality at present is highly disturbed by anthropogenic activities such as garbage dumping, truck parking and other disturbances. Despite this, there is a thriving population of this species[2]. Dispersal barriers such as a road on the east, railway line on the north and seaport on the south may have restricted its dispersal beyond the present locality. Hence, we argue that *M. kodial* is not dispersed naturally. In addition, the sea level on the west coast of India since the Neogene (23 Ma to present) was up to 3 m higher than the current level. This would make the current range of *M. kodial* distribution under water and could have resulted in extinction. Recent colonization remains the only option as the divergence dating of *M. kodial* is between 16.2 and 8.9 Ma (ref. 1), which could not have happened had it been naturally dispersed.

The closest relative *of M. kodial*, *M. irrawaddy* from Myanmar inhabits seasonally dry savannah areas with low rainfall[1,4]. It is argued that during aridification, this lineage dispersed into India[1]. The west coast where *M. kodial* is present is humid and receives high rainfall (over 3500 mm). On the contrary, the locality where *M. irrawaddy* occurs is relatively dry with less than 800 mm of rainfall. Hence, the above scenario seems unlikely.

Vineeth *et al.*[2] hypothesized that a few individuals of *M. kodial* might have been transported along with imported timber and subsequently established a population. The type locality for this species is adjacent to the New Mangalore Port, where timber logs were being imported and dumped predominantly from Myanmar, and to a lesser extent from Indonesia until recently[6]. Therefore, the observed pattern could be due to the species being accidentally introduced from SE Asia along with the timber logs. There are several examples across the animal kingdom in the world to support this argument (see below).

Global trade and the movement of people tend to transport biota across the globe, either accidentally or deliberately[7], and this trend will only increase in the years to come. Several studies show that the movement of goods, including timber, has resulted in the accidental introduction of species that have become invasive[8,9]. It is estimated that about 10% of the introduced species become

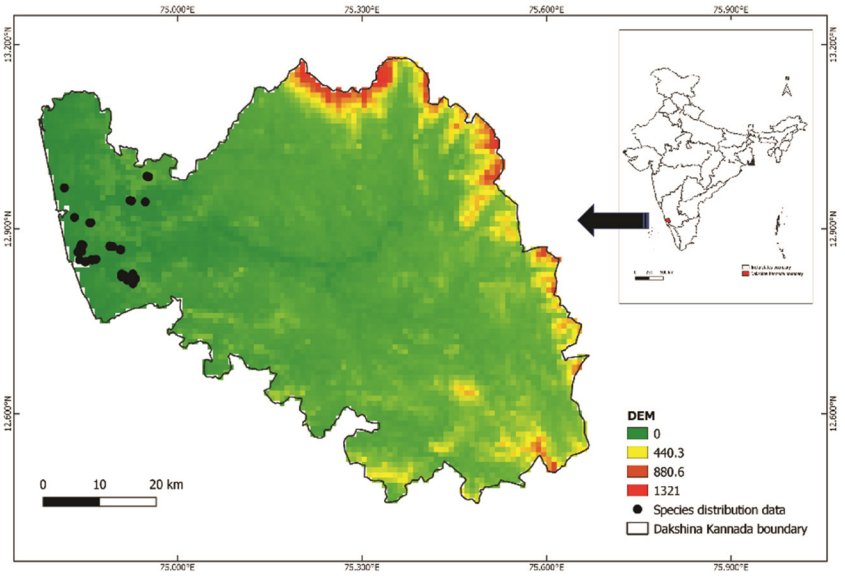

Figure 1. Map showing sampling locations for *Microhyla* spp. in Mangaluru region of western India.

established in the non-native region, and about 10% of them attain pest status[9–11]. Several studies from other parts of the world have reported many species of frogs, reptiles and others species caught along with the imported consignment[12–14]. Thus, the accidental introduction of animals through trade is not a new phenomenon[9–16].

India imports timber mainly from Malaysia, Indonesia, Nigeria, Myanmar, Australia and a few African countries[17]. These imported timber logs are in different conditions, either alive or dead, with or without bark, fresh or old, moist or dry, cut size or long log form, exposed or covered, and provide ample opportunity for organisms to survive en-route to non-native regions[9,17]. There are several examples of insects and fungi being transported to India along with timber logs from different major ports[9,17–19]. These studies have reported over 50 species of insects and 32 types of fungi. Among these is the ant *Acanthomyrmex luciolae* Emery that is not only a new species to India, but also a new genus that was not known to occur in the country[9], and a bug *Neuroctenus serrulatus*, another new report for India[18,19]. In particular, since 1984, the Mangaluru port has been actively importing timber logs predominantly from the Port of Yangon in Myanmar.

Hemidactylus robustus found only from the port city of Porbandar in Gujarat, India, has been attributed to accidental introduction due to trade from the Middle East[20]. Another species, *Hemidactylus gujaratensis* was also reported from a single locality in Junagadh, Gujarat, through natural dispersion[21]. However, we consider that this is also a case of accidental introduction along with timber import. Similarly, the record of colubrid snake, *Dendrelaphis caudolineatus* from Surat, Gujarat, which has distribution from Thailand to Sundaland; its presence in Gujarat is attributed to timber import[22]. Given the evidence of a long history of trade with Myanmar and other SE Asian countries[23], and also the evidence from other taxa and regions[9,17–19], we conclude that *M. kodial* was also introduced along with timber trade.

With all these pieces of evidence, we strongly consider that *M. kodial* could be one such case of unintentional introduction from SE Asia. This is just a case of an undescribed lineage that came along with the timber and not through natural dispersion. There are other species such as *Kaloula pulchra* that need to be studied for human transport. Continuous and long-term monitoring is required to assess whether *M. kodial* will expand its range. There is a need for extensive surveys in SE Asian regions, including Myanmar from where this species could have possibly been introduced through timber trade, resulting in additional populations. Also, it is important to determine if *M. kodial* is competing with native anurans in the same area, and if so, how this competition is affecting the native biodiversity.

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N. A. ARAVIND[1,2,*]
VINEETH K. KUMAR[3]
K. V. GURURAJA[4]
PRAVEEN KARANTH[5]

[1]*Ashoka Trust for Research in Ecology and the Environment,*
Royal Enclave,
Srirampura, Jakkur PO,
Bengaluru 560 064, India
[2]*Yenepoya Research Centre,*
Yenepoya (Deemed-to-be) University,
Derlakatte,
Mangaluru 575 018, India
[3]*Centre for Advanced Learning,*
Kottara Cross, Bejai,
Mangaluru 575 004, India
[4]*Srishti Manipal Institute of Art, Design and Technology,*
Yelahanka,
Bengaluru 560 064, India
[5]*Centre for Ecological Sciences,*
Indian Institute of Science,
Bengaluru 560 012, India
**For correspondence.*
e-mail: aravind@atree.org