


**Research Article**

## Flight-life and Flight-fight in Amber Fossil Environments

José de la Fuente<sup>1,2\*</sup>, Agustín Estrada-Peña<sup>3,4</sup>, Rodrigo F. Krüger<sup>5</sup>

### Abstract

Insects have been described in fossil amber inclusions and reflect the evolution of ancient environments. However, amber insect syninclusions with predatory behavior are less common. Flight-life in insects represents a behavior for feeding, reproduction and rapid dispersal. Within flight-life, flight-fight is in winged insects the way for predation, to escape predators and compete for resources such as food, mating and habitats. In this study, we represent flight-life in three amber pieces (two from Burmese Cretaceous and one from Baltic Eocene) with syninclusions of different organisms. Although amber syninclusions may be associated with random processes representing the ancient ecosystem, the study was focused on possible interspecific flight-fight predator-prey interactions represented in two pieces from Cretaceous and Eocene epochs. This evidence represents fossil environment with evolutionary behavioral implications.

**Keywords:** Arthropoda; Amber; Behavior; Evolution; Fossil; Insect; Syninclusion

### Introduction

Sampling and characterization of arthropods in the amber forest is important to better understand fossil environments [1,2]. The phylum Arthropoda are common in amber fossil syninclusions (e.g., [3]) with rare cases of predatory behavior [4-6].

Ecological communities include coexistence with and without interactions and competition between different species [7,8]. The study of amber fossil syninclusions can provide information to addresses questions about the composition and evolution of ancient terrestrial ecological communities [3, 9].

"Flight or fight" response was originally defined as body physiological reactions to confront (fight) or escape (flight) a threat [10]. This response is considered the first stage of the general adaptation syndrome that regulates stress responses in vertebrates and other organisms. Based on these definitions, in this study we propose flight-life in insects as a behavior for feeding, reproduction and rapid dispersal, and within flight-life, flight-fight in winged insects as the way for predation, to escape predators and compete for resources such as food, mating and habitats. Accordingly, flight-life and flight-fight can define insect behavior that can be detected in amber fossil environment.

In this study, we selected three amber pieces with syninclusions of fossil arthropods and other organisms such as plant, vertebrate and mollusk remains. Ecological communities represented in amber syninclusions were

### Affiliation:

<sup>1</sup>Health and Biotechnology-SaBio. Instituto de Investigación en Recursos Cinegéticos IREC-CSIC-UCLM-JCCM, Ronda de Toledo 12, 13005 Ciudad Real, Spain

<sup>2</sup>Department of Veterinary Pathobiology, College of Veterinary Medicine, Oklahoma State University, Stillwater, OK 74078, USA

<sup>3</sup>Universidad de Zaragoza, Spain (Retired)

<sup>4</sup>CSAI Foundation, Ministry of Human Health, Madrid, Spain

<sup>5</sup>Parasite and Vector Ecology Group (LEPAV), Universidade Federal de Pelotas (UFPeL), Campus Universitário Capão do Leão, s/n, Instituto de Biologia, Prédio nº 18, 96.010-900 Pelotas, RS, Brazil

### \*Corresponding author:

José de la Fuente, Health and Biotechnology-SaBio. Instituto de Investigación en Recursos Cinegéticos IREC-CSIC-UCLM-JCCM, Ronda de Toledo 12, 13005 Ciudad Real, Spain.

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classified as flight-life for coexistence and flight-fight for predator-prey interactions between different organisms. The study was then focused on flight-fight interactions to provide additional information on predator-prey arthropods.

## Materials and Methods

### Fossil amber syninclusions

Three amber pieces were included in the study, piece 1 (Burmese amber, Hukawng Valley, Myanmar, Cretaceous, ca. 99 Mya, 17 x 13 mm, 2.0 g; Figures 1 and 2), piece 2 (Baltic amber, Kaliningrad, Russia, Eocene, 35-47 Mya, 30 x 15 mm, 1.0 g; Figures 3-6) and piece 3 (Burmese amber, Hukawng Valley, Myanmar, Cretaceous, ca. 99 Mya, 21 x 14 mm, 2.5 g; Figures 7-9). Amber pieces were polished under natural conditions and were certified by tests with UV light, saltwater floating, sinks in fresh water, acetone resistant, and heat-smell of pine resin. Amber pieces originated from author's J. de la Fuente KGJ Collection (Ciudad Real, Spain) and ensures that "Amber provider knows that in line with the laws and regulations in his country it is allowed to sell/export these objects".

### Image capture and morphological analysis

Images of amber pieces were captured as previously reported [6,8,11] using a Leica (L'Hospitalet de Llobregat, Barcelona, Spain) M80 routine stereomicroscope with a 1X PLAN objective and a 2X-6X zoom (<https://www.leica-microsystems.com/products/light-microscopes/stereomicroscopes/p/leica-m80/>) and a Carl Zeiss stereomicroscope (SteREO Discovery V12, Munich, Germany) using the ZEN 2 pro software. Microscope images were analyzed using Image J program (<https://imagej.net/ij/>) and interpretative camera drawings were generated with the Befunky application (<https://www.befunky.com/features/photo-to-sketch/>) or composed with CorelDraw 2020 (<https://www.coreldraw.com/en/>, accessed on March 3, 2026). For classification of insect fossil inclusions, morphology references by Fossil Identifier (<https://www.identifyrock.net/tools/fossil-identifier>), experts opinion and published literature were used (Table 1).

## Results

### Morphological classification of amber fossil inclusions

Morphological classification for fossil amber inclusions in pieces 1-3 are disclosed in Table 1. The morphological analysis depended on the preservation quality of inclusions and the resolution of obtained images. Accordingly, some of the classifications may be considered as putative only. Furthermore, the study was focused on flight-fight predator-prey arthropod interactions described in amber pieces 2 and 3.

Arthropods were the most common amber fossil inclusions, representing 84% (16 of 19) of the organisms identified in pieces 1-3 (Table 1). Of them, 75% (12 of 16) were insects and 25% (4 of 16) arachnids (Table 1). Less common inclusions included one for each plant, vertebrate and mollusk remains (Table 1).

### Piece 1. Representation of flight-life in Cretaceous Burmese amber fossil environment (Figures 1 and 2 A-G)

Amber syninclusions support the coexistence of multiple organisms such as arthropods and vertebrates without evidence of interactions. The morphological identification of arthropods at different levels was based on selected reference studies (Table 1). The coprolite displayed a distinct amorphous, organic-looking mass with a dark phosphatic appearance typical of fossilized feces with indigestible remains of preys such as cephalopods found in marine predators (Figures 1C and 2C). Additional inclusions probably associated with plant and insect (e.g., leg close to Figure 1B) partial remains were not included in the analysis.

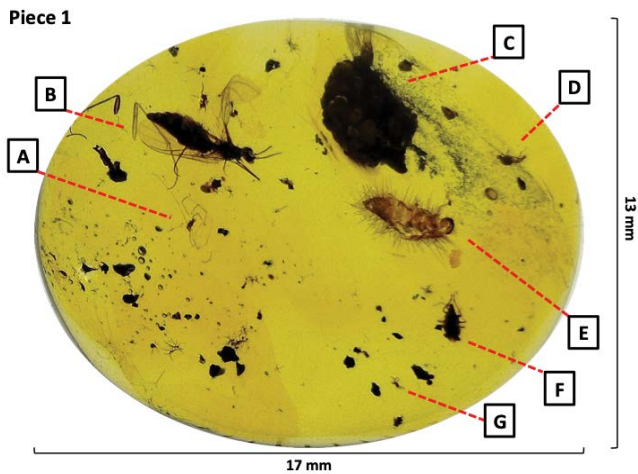
### Piece 2. Flight-fight in Eocene Baltic amber syninclusions (Figures 3-6)

The beetle specimen (Arthropoda: Insecta: Coleoptera: Curculionidae: Scolytinae, putative related to Hylesinini) is more consistent with a bark beetle, and its association with a moth fly in Baltic amber is best interpreted as ecological co-occurrence (Arthropoda: Insecta: Diptera: Nematocera: putative *Psychodidae* sp.; Newman, 1834) (Table 1, Figures 3-6). The beetle exhibits a compact, moderately robust body with an elongate, subparallel outline (Table 1, Figure 4). The pronotum appears subquadrate and slightly narrower than the elytra, which fully cover the abdomen. The elytra are strongly sculptured, with a deeply impressed pattern that appears reticulate under certain viewing conditions, and bear erect setae or spine-like projections. Such sculpture may reflect a combination of true cuticular ornamentation (punctures, interstriae, and possible tubercles) and preservation effects typical of amber inclusions, including refractive distortion and microfractures. The head is approximately as wide as the pronotum, with laterally positioned, well-developed eyes. The antennae are relatively short and robust, with an apical region that may correspond to a compact club, although its segmentation is not clearly resolved. This antennal configuration, together with the overall body form, is consistent with bark beetles (Coleoptera: Curculionidae: Scolytinae). As emphasized for fossil Scolytinae, reliable determination requires details of the antennal club and tarsal formula, which are currently obscured. The combination of a cylindrical to subparallel body, compact antennae, punctate to strongly sculptured elytra, and setose integument is broadly compatible with Scolytinae, a group of phloeophagous beetles associated with subcortical habitats. In extant

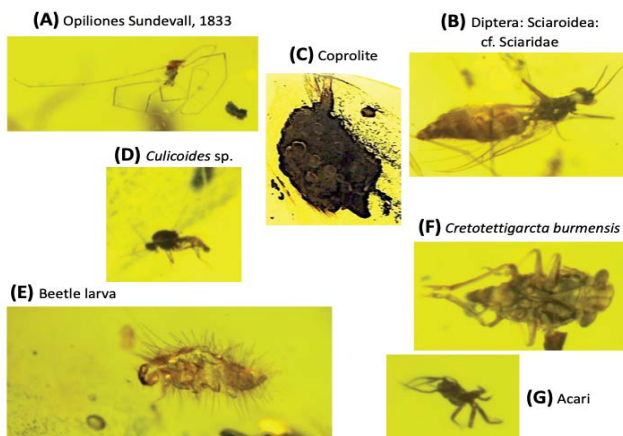
**Table 1:** Morphological analysis of amber fossil inclusions.

Classification (References)	Taxonomy
<b>Piece 1 (Figures 1 and 2 A-G)</b>	
(A) Opiliones; Sundevall, 1833 [12, 13]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Chelicerata Class: Arachnida Order: Opiliones Genus: Unknown Species: Unknown
(B) Diptera: Sciaroidea: cf. <i>Sciaridae</i> [14]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Diptera (flies) Genus: Unknown Species: Unknown
(C) Coprolite	Fossil vertebrate feces
(D) <i>Culicoides</i> sp., putative family Ceratopogonidae [15]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Diptera (midges) Genus: <i>Culicoides</i> ; Latreille, 1809 Species: Unknown
(E) Beetle larva	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Coleoptera Genus: Unknown Species: Unknown
(F) <i>Cretotettigarcta burmensis</i> [16]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Hemiptera (true bugs) Genus: <i>Cretotettigarcta</i> Species: <i>C. burmensis</i>
(G) Acari	Kingdom: Animalia Phylum: Arthropoda Subphylum: Chelicerata Class: Arachnida Order: Unknown Genus: Unknown Species: Unknown
<b>Piece 2 (Figures 3-6)</b>	
Bark beetle (Coleoptera: Curculionidae: Scolytinae), putative related to Hylesinini [17-19]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Coleoptera (beetles) Genus: <b>Unknown</b> Species: Unknown
Moth fly <i>Psychodidae</i> sp. [20]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Diptera Genus: <i>Psychodidae</i> Species: <i>Psychodidae</i>

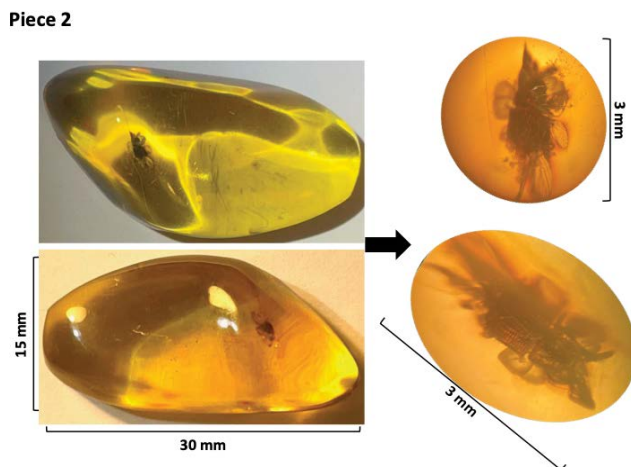
<b>Piece 3 (Figures 7 and 8 A-J, and 9)</b>	
(A) Gall midge or gall gnat. Family Cecidomyiidae (Newman, 1835) [21]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Diptera Genus: Unknown Species: Unknown
(B) Praying mantis nymph [22]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Mantodea (Mantids) Genus: Unknown Species: Unknown
(C) Spider	Kingdom: Animalia Phylum: Arthropoda Subphylum: Chelicerata Class: Arachnida Order: Araneae (true spiders) Genus: Unknown Species: Unknown
(D) Land snail shell	Kingdom: Animalia Phylum: Mollusca Class: Gastropoda Order: Unknown Genus: Unknown Species: Unknown
(E) Coprolite	Fossil vertebrate feces
(F) Pygmy mole cricket, putative family Tridactylidae	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Orthoptera Genus: Unknown Species: Unknown
(G) Plant seed (Copeland 1956)	Kingdom: Plantae
(H) Opiliones <i>Petroburma tarsomeria</i> (n. sp.) [23]	Kingdom: Animalia Phylum: Arthropoda Subphylum: Chelicerata Class: Arachnida Order: Opiliones (Harvestmen) Genus: <i>Petroburma</i> (n. gen.) Species: <i>Petroburma tarsomeria</i> (n. sp.)
(I) Litter bug <i>Ceratocombidae</i>	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Hemiptera (True bugs) Genus: <i>Ceratocombus</i> Species: <i>Ceratocombus</i> sp.
(J) Insect prey	Kingdom: Animalia Phylum: Arthropoda Subphylum: Hexapoda Class: Insecta Order: Diptera Genus: Unknown Species: Unknown



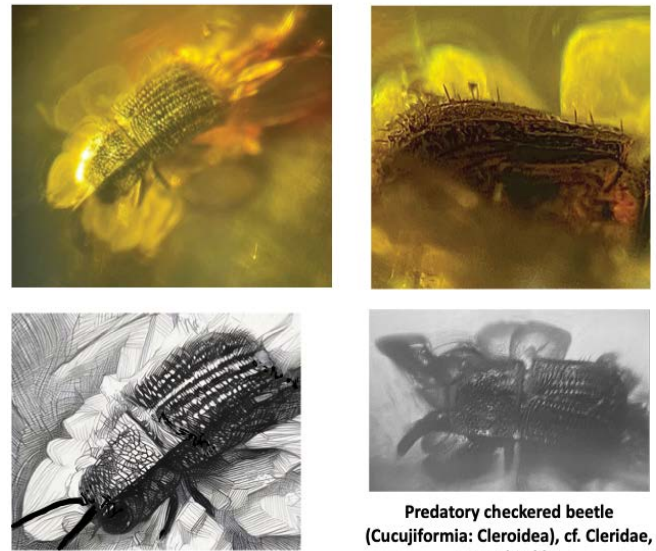
**Figure 1:** Piece 1. Flight-life in Cretaceous amber fossil environment. Burmite (Cretaceous, ca. 99 Mya) with seven syninclusions without evidence of interactions. Identified organisms A-G are described in Table 1 and Figure 2.



**Figure 2:** Organism syninclusions identified in amber piece 1 (Figure 1).



**Figure 3:** Piece 2. Flight-fight in Eocene amber syninclusions. Baltic amber (Eocene, ca. 35-47 Mya) with arthropod syninclusions with predator-prey interactions. Identified organisms are described in Table 1 and Figures 4 and 5 with interactions shown in Figure 6.



**Figure 4:** Bark beetle (Coleoptera: Curculionidae: Scolytinae), putative related to Hylesinini, preserved in amber piece 2.

representatives, adults colonize host trees and excavate galleries in the phloem, where reproduction and larval development occur. Elytral sculpture in this group is typically organized in longitudinal striae and interstriae; however, in fossil material, these patterns may appear irregular or reticulate due to preservation artifacts or optical effects. From a paleoecological perspective, the occurrence of this beetle together with a moth fly (Psychodidae) is consistent with a shared microhabitat, likely associated with moist, decomposing wood or tree cavities. Such environments are suitable both for bark beetles and for psychodid flies, which are commonly linked to humid, organic-rich substrates. Therefore, the association between these taxa is best interpreted as ecological co-occurrence within the same habitat rather than evidence of a direct trophic interaction. With the available evidence, the specimen is most plausibly interpreted as a bark beetle (Curculionidae: Scolytinae), possibly related to Hylesinini or allied bark beetle tribes.

The moth fly Psychodidae insect shows the characteristic protrusions on the thorax and teardrop-shaped wings and dense venation typical of moth flies (Table 1, Figure 5). The wings are held in a roof-like position over the body, and the presence of fine hairs or scales on the wing margins and veins is visible, which is a hallmark of this family when preserved in amber (Figure 5). The body and wings appear densely covered in hairs or scales, which is a hallmark of this family of nematoceran flies. The lack of cross-veins and the presence of a forked appearance in the radial and medial veins confirm this identification and discards Trichoptera caddisflies [24].

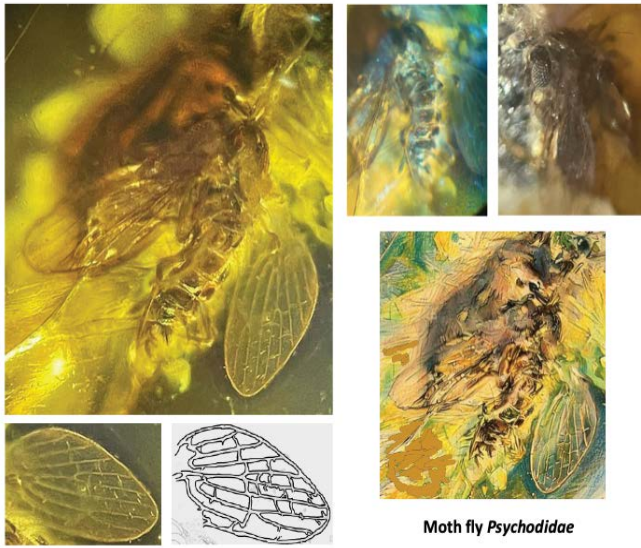


Figure 5: Moth fly *Psychodidae* identified in amber piece 2.

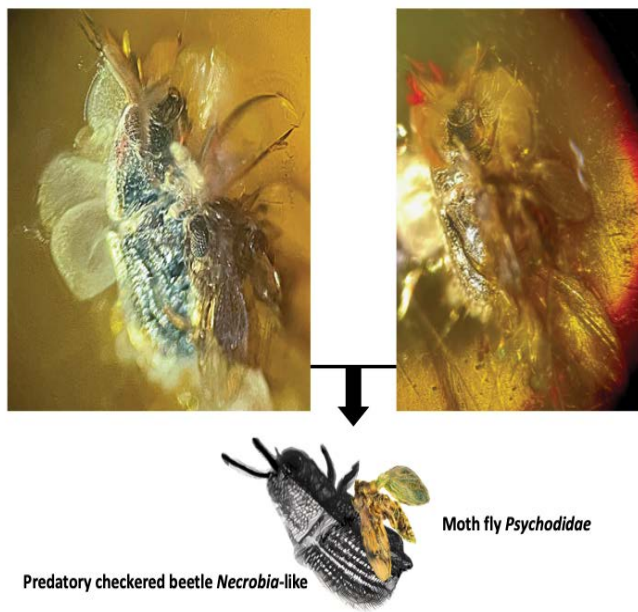


Figure 6: Predatory cleroid checkered beetle (Cleroidea: cf. Cleridae/ *Necrobia*-like)-moth fly (Diptera: Nematocera: *Psychodidae*) predator-prey interaction in amber piece 2. Identified organisms are described in Table 1 and Figures 4 and 5.

### Piece 3. Flight-life with flight-fight in Cretaceous Burmese amber fossil environment (Figures 7-9)

As in amber piece 1, syninclusions support the coexistence of multiple organisms including arthropods, mollusks and plants with and without evidence of interactions (Figures 7 and 8 A-J). The morphological identification of arthropods at different levels was based on available selected reference studies (Table 1).

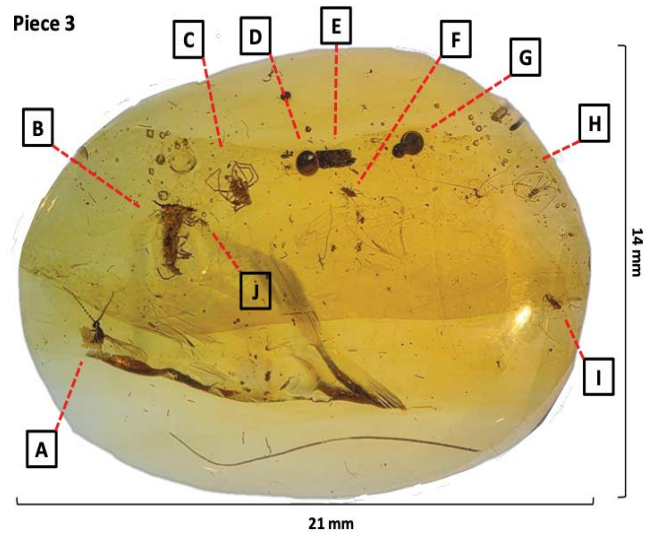


Figure 7: Piece 3. Flight-life with flight-fight in Cretaceous Burmese amber fossil environment. Burmite (Cretaceous, ca. 99 Mya) with nine A-J syninclusions. Inclusions B and I with predator-prey interactions. The other syninclusions without evidence of interactions. Identified organisms A-J are described in Table 1 and Figure 8 with predator-prey interactions between insects praying mantis (B) and Diptera (J) shown in Figure 9.

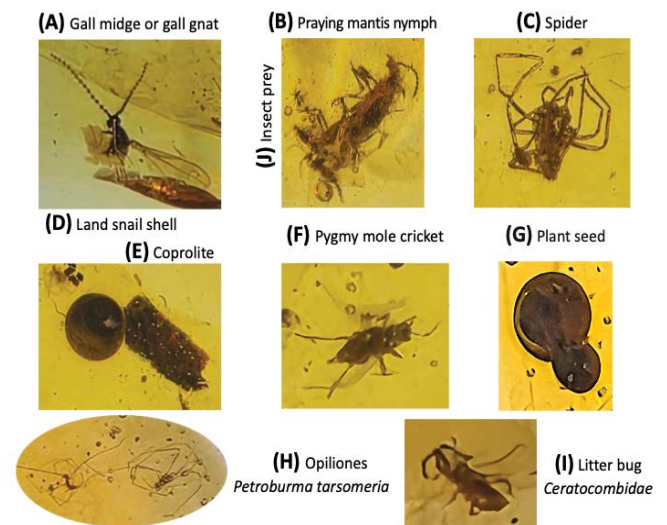
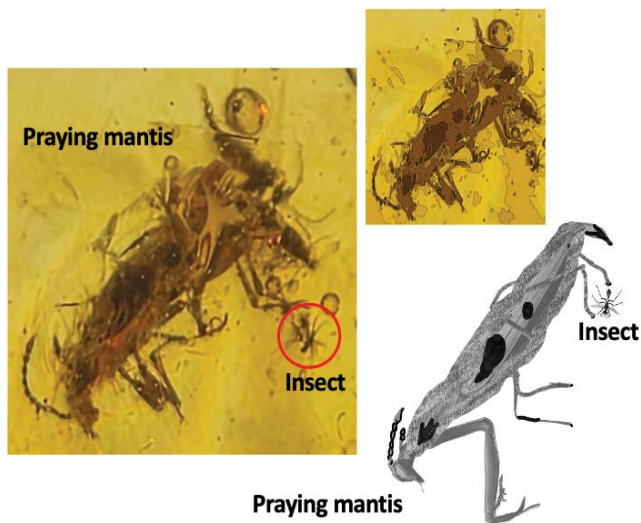


Figure 8: Organism syninclusions identified in amber piece 3 (Figure 7).

Predator-prey interactions were identified between a putative praying mantis nymph (Arthropoda: Insecta: Mantodea) and an unclassified insect (Arthropoda: Insecta: Diptera) (Figures 7B, 7J, 8B, 8J and 9). For praying mantis nymph, the raptorial appendages support the identification but without preservation quality for genus and species definition. The insect prey was also not possible to identify at genus and species levels.



**Figure 9:** Praying mantis nymph – insect possible predator-prey interactions in piece 2. Identified organisms are described in Table 1 and Figures 7 and 8.

## Discussion

Arthropod syninclusions in amber are common (e.g., [8,25]) and are mostly associated with random trapping in resin suggesting coexistence in the same environment with and without ecological interactions. However, syninclusions with predatory behavior are rare and do reflect ecological interactions between these organisms (e.g., spider-tick interactions in [5, 6]). In this context, the concepts of flight-life and flight-fight provide a useful framework to interpret insect behavior in fossil environment, not only as indicators of predation but also as expressions of movement, escape, and interaction under stress conditions within a viscous medium.

The flight-fight response should not be restricted to predator-prey interactions. In amber fossil environment, it may also represent a broader set of behavioral and physical responses associated with immobilization, including escape attempts, mechanical contact, and stress-induced positioning during resin entrapment. Resin viscosity, flow dynamics, and progressive hardening can influence organism positioning, bringing individuals into close proximity or preserving reflex actions such as grasping or leg extension [26]. Therefore, apparent interactions in amber must be evaluated by integrating spatial configuration with the biological plausibility of the taxa involved.

The syninclusions analyzed in this study illustrate multiple possibilities. In piece 2, the beetle is best interpreted as a bark beetle (Coleoptera: Curculionidae: Scolytinae), based on its morphology and overall body organization [17-19]. Scolytinae are phloeophagous or xylomycetophagous insects associated with subcortical habitats, where adults excavate galleries in host trees for reproduction [27]. From this biological perspective, a predatory interpretation is not

supported. Instead, the association between the bark beetle and the moth fly (Psychodidae) is more consistently explained as ecological co-occurrence within a shared microhabitat, likely involving moist, organic-rich substrates such as decomposing wood or tree cavities [28].

From a paleoecological perspective, the syninclusions with a moth fly is consistent with a humid, organic-rich microhabitat, such as tree cavities, decomposing wood, or detritus-accumulating niches adjacent to resin-producing trunks [29,30]. Two non-exclusive scenarios may be considered. First, a trunk-associated setting in which the bark beetle (Scolytinae) and the moth fly (Psychodidae) co-occurred within subcortical or adjacent microhabitats, such as bark crevices or moist cavities in decaying wood. In this context, the beetle likely inhabited phloem tissues, constructing galleries, while the moth fly exploited nearby humid, organic-rich substrates for larval development [27]. Second, a broader decompositional microenvironment near the resin source. Rather than indicating trophic interaction, this association reflects ecological co-occurrence driven by shared habitat preferences, as both groups are linked to moist, decomposing organic matter [28]. Within the proposed framework, this association can still be interpreted under flight-life, reflecting coexistence within the same ecological space, and potentially also as a flight-fight-like configuration generated during entrapment in a viscous medium. In this case, the spatial proximity between individuals does not imply trophic interaction but may instead reflect behavioral responses to resin flow, including escape attempts or passive repositioning during immobilization.

In contrast, piece 3 provides a more plausible example of flight-fight associated with biological interaction. The praying mantis have been described in Burmese amber [31-34]. Nymphs are voracious generalist predators with a predator-eats-predator" dynamic that begin hunting immediately after hatching. Using agile, spined forelegs, they ambush a variety of small insects such as aphids, flies, mosquitoes, and smaller nymphs. They are also highly cannibalistic, often feeding on their siblings if other preys are scarce. While they are beneficial for pest control, as generalists will also eat beneficial insects such as ladybugs and bees. Although praying mantis nymphs do not fly, adults are capable of flying to find mates, for quick movements, escaping predators or nighttime navigation.

## Conclusions

In conclusion, the analysis of amber fossil syninclusions is a challenge for morphological classifications based on reference studies (e.g., [35-40]), but provides insights into ancient ecosystems, revealing both ecological co-occurrence and possible interactions among organisms. Within the proposed framework, flight-life represents the coexistence and

activity of organisms within shared environments, whereas flight-fight encompasses a broader spectrum of responses associated with predation, escape behavior, and stress under entrapment in a viscous medium. The studied material illustrates that most syninclusions are better interpreted as expressions of flight-life, reflecting shared microhabitats rather than direct trophic interactions, as exemplified by the bark beetle-moth fly association. However, in some cases, such as the mantis nymph, flight-fight may correspond to biologically interactions consistent with predatory behavior. These findings showed that apparent interactions in amber must be interpreted with caution, considering both biological plausibility and taphonomic processes. The integration of morphological evidence, ecological knowledge of extant taxa, and resin entrapment dynamics provides a more robust framework for distinguishing between true ecological interactions and configurations generated during fossilization. This approach contributes to a more nuanced understanding of arthropod behavior and community structure in Cretaceous and Eocene environments.

### Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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