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A review of the “summer” *Thaumetopoea* spp. (Lepidoptera: Notodontidae, Thaumetopoeinae) associated with *Cedrus* and *Pinus*

Andrea Basso^a, Mauro Simonato^a, Pierfilippo Cerretti^{a,b,c}, Paolo Paolucci^a, Andrea Battisti^a

Abstract: The species of the genus *Thaumetopoea* (Lepidoptera, Notodontidae, Thaumetopoeinae) are important from the point of view of forestry and human health as they are defoliators of trees and they release urticating hairs at the larval stage that are a source of allergy. Within the genus, there are two groups associated with conifers which are characterized by larval feeding in winter or in spring-summer, so the groups are called 'winter' and 'summer' processionary moths. This review collects the information about the species of the 'summer' *Thaumetopoea* species from Eurasia. Information includes morphological, biological, and ecological traits of *Th. bonjeani*, *Th. cheela*, *Th. ispartaensis*, *Th. libanotica*, *Th. pinivora* and *Th. sedirica*. *Thaumetopoea cheela* is proposed to be included in this group based on indirect evidence presented in this paper. Information is collected from the literature and checked, where it was possible, with museum and collected specimens. An identification key based on morphological and biological traits is proposed. The conifers of the genus *Cedrus* seem to be associated with the summer *Thaumetopoea*, although more work is needed in order to clarify the evolutionary history of the group.

Keywords: *Thaumetopoea* summer, *Thaumetopoea cheela*, Morphological traits

Cedrus ve *Pinus* ile ilişkili “yazlık” *Thaumetopoea* spp. (Lepidoptera: Notodontidae, Thaumetopoeinae) türlerine yönelik bir değerlendirme

Özet: *Thaumetopoea* familyasında yer alan türler (Lepidoptera, Notodontidae, Thaumetopoeinae), yaprak zararlısı böcekler olmaları ve alerji kaynağı olarak larva evresinde kaşıntıverici kılları olması nedeniyle ormancılık ve insan sağlığı açısından önemlidir. Bu familya içerisinde, ibrelili ağaçlarla ilişkili olan ve larvaları ilkbahar ve yaz aylarında beslenen iki grup yer almaktadır, bu gruplar 'kışlık' ve 'yazlık' çam kese böcekleri olarak adlandırılmaktadır. Bu çalışmada, Avrasya bölgesinde yayılan 'yazlık' *Thaumetopoea* türleri hakkında bilgi toplanmıştır. Bu bilgiler, *Th. bonjeani*, *Th. cheela*, *Th. ispartaensis*, *Th. libanotica*, *Th. pinivora* ve *Th. sedirica* türleri hakkında morfolojik, biyolojik ve ekolojik özellikleri içermektedir. Bu tebliğde sunulan dolaylı kanıtların ışığında *Thaumetopoea cheela* türünün bu grupta yer aldığı öne sürülmektedir. Bilgiler literatürden elde edilerek mümkün olduğunca müze ve toplanan örneklerle kontrol edilmiştir. Morfolojik ve biyolojik özelliklere dayalı bir tanımlama anahtarı önerilmiştir. *Cedrus* cinsinde yer alan ibrelili ağaçların yazlık *Thaumetopoea* ile ilişkili olduğu anlaşılmaktadır ancak bu grubun evrimsel geçmişini açıklamak için daha fazla çalışmaya ihtiyaç duyulmaktadır.

Anahtar kelimeler: Yazlık *Thaumetopoea*, *Thaumetopoea cheela*, Morfolojik özellikler

1. Introduction

The subfamily Thaumetopoeinae includes several species called processionary moths. These moths are of great importance for ecology and forestry because the larvae feed on trees and shrubs of different families (both broadleaved and coniferous) menacing both growth and survival of trees, especially in the Mediterranean countries (Masutti & Battisti, 1990). Moreover, these species threaten human and animal health because of the presence of urticating setae in larvae and / or adults (Battisti et al.,

2011). These hairs are likely used as a defense strategy against vertebrate predators and are responsible for allergic reactions also of strong intensity in humans (Maier et al., 2003).

Historically, the subfamily has been considered as a self-standing family and divided into three subgroups according to their geographic distribution (Kiriakoff, 1970), then treated as a subfamily of Notodontidae based on a cladistics analysis (Miller, 1991). Recent studies, based on morphological (Schintlmeister, 2013) and molecular (Zahiri

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et al., 2011; Zahiri et al., 2013) data, confirm the subfamily status of *Thaumetopoeinae* within the *Notodontidae*.

In this subfamily, the genus of *Thaumetopoea sensu lato* contains the most studied species, for which a recent molecular analysis has defined the phylogenetic relationships, and the evolution of biological traits, in some Palearctic species (Simonato et al., 2013), which are mainly distributed in the Mediterranean and Iranoturanic areas (Agenjo, 1941; Kiriakoff, 1970) (Figure 1).

Some authors split this genus in three genera (de Fréina & Witt, 1987; Schintlmeister, 2013): a) *Traumatocampa* (*bonjeani* Powell, *ispartaensis* Doganlar & Avci, *jordana* Staudinger, *libanotica* Kiriakoff & Talhouk, *pinivora* Treitschke, *pityocampa* Denis & Schiffermüller, *sedirica* Doganlar, *torosica* Doganlar, *wilkinsoni* Tams); b) *Thaumetopoea* (*apologetica* Strand, *cheela* Moore, *dhofarensis* Wiltshire, *processionea* Hübner, *solitaria* Frey), and c) *Heliantocampa* (*herculeana* Rambur). However, this morphological partition is not completely supported from a reassessment of the key morphological traits and by the recent molecular phylogeny of Simonato et al. (2013), suggesting that these species should be provisionally treated as part of a single genus. Within the *Thaumetopoea* species feeding on coniferous trees, Simonato et al. (2013) identified two clusters based on the timing of larval feeding in winter or in spring-summer, confirming the groups called 'winter' and 'summer' processionary moths by Démolin (1989).

The aims of this paper are to review the information about the summer *Thaumetopoea* species, which include *Th. bonjeani*, *Th. ispartaensis*, *Th. libanotica*, *Th. pinivora* according to Simonato et al. (2013), and two other species (*Th. sedirica* and *Th. cheela*) which were not included in that study. The final aim is to organize and synthesize the knowledge about this group and produce a key based on the wing traits as developed by Agenjo (1941).

2. Materials and methods

2.1. Systematics

Information about types, collections and number of specimens were obtained from catalogue of Schintlmeister (2013). Descriptions, biogeographic information, and morphological traits were collected from literature and checked with specimens from museum collections. Wings morphology and name of fasciae are based on Heath and Emmet (1976).



Figure 1. Geographic distribution of the summer *Thaumetopoea* spp.

2.2. Materials

Thaumetopoea bonjeani: 3♂, 2♀: likely from Morocco, Witt Museum, Munich.

Thaumetopoea cheela: 2♂: Afghanistan, Surobi district, 1100 m, 07.VII.1961 and 08.VII.1961; legit G. Ebert, 1970 - The Bavarian State Collection of Zoology; Munich.

Thaumetopoea ispartaensis: 3♂, 1♀: Turkey, Isparta - Senirkent, 1100 - 1600 m. Collected on *Cedrus libani* and sent by Mustafa Avci from Isparta Suleyman Demirel University to Department of Agronomy, Food, Natural Resources, Animals and the Environment; University of Padua.

Thaumetopoea libanotica: holotype ♂, allotype; Lebanon, Bcharre, Eklosion Beirut, 8.VIII.1974; collection A.S. Talhouk - The Bavarian State Collection of Zoology; Munich.

Thaumetopoea pinivora: 1♂: unintelligible collected site; IX.1917; collection Thurner - The Bavarian State Collection of Zoology; Munich. 1♀: from Russia, Ostpreussen (Oblast' Kaliningrad), VI.1909; collection Forster - The Bavarian State Collection of Zoology; Munich.

Thaumetopoea sedirica: 1♂, 1♀: from Turkey, Isparta-Sarkikaragac, 1400m, 38°02' 18"N, 31°22'35"E, 28.VIII.1967; legit (Det.) by M. Doganlar, 2005. Collected on *Cedrus libani* and sent by M. Doganlar to Department of Agronomy, Food, Natural Resources, Animals and the Environment; University of Padua.

3. Results

3.1. General morphological traits

Moths of this subfamily are small or medium size. Body covered by grayish hairs (de Fréina & Witt, 1987). Eyes naked; ocelli absent such as chaetosome; palpi small and rudimentary, proboscis atrophied (Kiriakoff, 1970). Forewing shape and veins very similar to the *Notodontidae* ones; without tooth on dorsum and with apices rounded (de Fréina & Witt, 1987). Vein, using Hampson & Meyrick classification, (Heath & Emmet, 1976) 2 start at 4/5 of cell, 3 and 4 separated, 5 start at middle of discal spot; they are concave (de Fréina & Witt, 1987; Kiriakoff, 1970). Veins 6, 7, 8 + 9 and 10 are stalked. Width of forewing is about twice hindwing (Kiriakoff, 1970).

3.2. Description of species

3.2.1. *Thaumetopoea bonjeani* (Powell, 1922): 188; (*Cnethocampa bonjeani*)

Syntype: unspecified number of ♂♂ and ♀♀, Morocco, d'Azrou Forest, 500 m to North of Douar de Garde - The Natural History Museum, London. Not examined.

Description (Figure 2): According to Agenjo (1941) this species is really similar to *Th. pinivora*. This statement is strongly corroborated by molecular analysis (Simonato et al., 2013).

Male. Antennae bipectinate, long and yellowish in ground color (Agenjo, 1941; de Fréina & Witt, 1987). Palpus with first segment longer and thicker than second segment (Agenjo, 1941). Canthus present; with 5 teeth and

upper side straight (Agenjo, 1941). Upper tooth smaller (de Fréina & Witt, 1987). Foreleg epiphysis present and well developed. Thorax blackish, with some whitish hairs, which turn into brownish-gray ventrally (de Fréina & Witt, 1987). Abdomen ochreous (de Fréina & Witt, 1987) or golden and blackish (Agenjo, 1941). Wingspan 30-34 mm. Forewing ground color ash gray, generally. Three dark fasciae present, with yellow edge (Agenjo, 1941). Basal fascia, more or less straight, from radial vein to inner margin of wing (Agenjo, 1941); this fascia is often barely visible (de Fréina & Witt, 1987). Shape of ante-median and post-median fasciae clearly distinguish *Th. bonjeani* from *Th. pinivora*, i. e. ante-median fascia forms an obtuse angle outwardly, changing direction straight just before dorsum (Agenjo, 1941). External edge of post-median fascia jagged. Ante and post-median fasciae more or less parallel, especially near costa and dorsum (Agenjo, 1941). A V-shaped discal spot present. Fringes on termen present, alternatively gray and white-yellow (Agenjo, 1941). Hindwing whitish with reddish fluff at margin. Fluff more abundant at anal margin. Fringes alternatively gray and whitish. Anal spot present and well developed (Agenjo, 1941).

Male genitalia. Up to 4 mm when fully stretched. Uncus shorter than gnathos and thin (Doganlar and Avci, 2001). Tegument thin. Valvae basally concave turning into convex apically. Valvae narrow, with a small protuberance on tip. Fultura distinctive, big, with jagged edges similar to that *Th. processionea* (Agenjo, 1941). Aedeagus broad basally (Doganlar and Avci, 2001) and curved, such as *Th. pinivora*, but bigger.

Female. Similar to *Th. pityocampa* and *Th. pinivora* (Agenjo, 1941). Wingspan 34-38 mm, with the wing ground color pale and not well defined (de Fréina & Witt, 1987). Anal scales straight, long acute, with sharpened base; poorly pigmented at the center (Agenjo, 1941). From literature we know that ratio, between length and width, greater than 2.5 (El Yousfi, 1989; Simonato et al., 2013).

Remarks: head covered by a tuft on scapus of brownish hairs, like in *Th. pinivora*. Canthus small. Discal spot brownish.

Larva. Larva has been described by Démolin (1989) mainly on a comparison with *Th. pityocampa*, from which it can be easily distinguished because of the long white hairs implanted on the trapezoid plates at both sides of the body. In addition, the urticating setae are black instead of orange-red and the anterior edge of the integumental areas carrying them (the 'mirror') is characterized by very long white hairs. Démolin (1989) provides a pictorial description of the hairs among the five larval instars (Planche 12 and 12 bis) as well as photographs of the mature larvae (Planche 13 and 14) which are compared to those of *Th. pinivora*.

Life history: Larvae are social and monophagous on *Cedrus atlantica* (Démolin, 1989; El Yousfi, 1989; Rahim et al., 2014), preferring low humidity forests (de Fréina and Witt, 1987). The adults emerge between August and September, mating at night, immediately after emergence. The oviposition occurs on the underside of the cedar branches, during the night. The eggs are then covered with bark-colored scales, making them less visible. The number of eggs per egg batch is extremely variable. After 8 months, between March and April, larvae hatch and group in colonies, building very light silk tents, until to achievement the fifth instar (between June and July) (Rahim et al., 2014).

Then larvae leave the tree in a procession, in the early hours of the morning and pupate in the soil (El Yousfi, 1989). *Thaumetopoea bonjeani* has an annual development cycle (Démolin, 1989; Rahim et al., 2014) (Table 1). The sex pheromone has been identified and results similar to that of *Th. pinivora* and *Th. libanotica* (Frérot, 2014).

Distribution: *Thaumetopoea bonjeani* was found originally in the Atlas Mountains of Morocco (Agenjo, 1941) and later in mountains of Algeria (de Fréina and Witt, 1987; Rahim et al., 2014) (Figure 1).

3.2.2. *Thaumetopoea cheela* Moore, 1883: 18;

Syntype: 1 ♂, 1 ♀, North-West India, Umballa district – The Natural History Museum, London. Not examined.

Description (Figure 2): Based on the original description of Moore (1883), who defined it as very similar to *Th. pinivora*.

Male. Antennae yellow. Head covered by grayish-brown hairs. Legs thickly clothed with grayish-brown hairs in femur and tibia. Tarsi yellow. Thorax hairs grayish-brown. Ochreous yellow segmental bands present on abdomen. Wingspan 31 mm. Forewing brownish-gray ground color with sparse white scaled; scales disposed longitudinally. Forewings have 3 dark fasciae in basal, ante-median and post-median positions. Post median fascia zig-zagged. Each fasciae bordered with a marked ochreous-yellow edge like in *Th. pinivora*. Fringes alternately gray and white. Hindwing whitish with a dark spot in the anal angle.

Female. Wingspan 35 mm. Wing ground color paler than male and not well defined. Head darker brownish-gray; thorax and abdomen have darker brown tuft.

Remarks: dark tuft on scapus. Canthus present and notched, with 6 or 7 teeth. Foreleg epiphysis present. Forewing basal line reduced to some dark points; a brown discal spot bordered present, with white scale; a dark brown pre-apical spot present. Fringes of hindwings more whitish than in the forewing.

No information about genitalia, female scale, larvae and life history is available.

Distribution: from Afghanistan, Surobi district (specimens collected by G. Ebert, see above), to N-W of India, Umballa district (Moore, 1883).

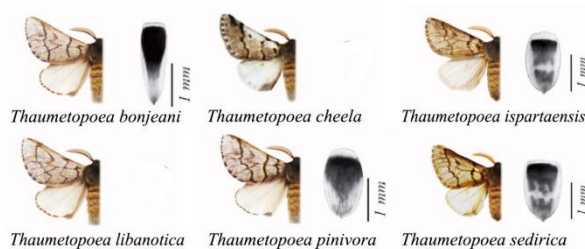


Figure 2. Males of summer *Thaumetopoea* spp. considered in the study, together with the scales of the anal tuft of female moths, whenever available.

3.2.3. *Thaumetopoea ispartaensis* Doganlar & Avci, 2001: 20 (*Traumatocampa ispartaensis*);

Holotype: ♂, Turkey, Isparta, Kapidagi: Senirkent (1100-1500 m) – Plant protection Department, Mustafa Kemal University, Antakya, Turkey. Not examined.

Description (Figure 2): This species is very similar to *Th. bonjeani* (Doganlar & Avci, 2001).

Male. Antennae light brown and bipectinate (Doganlar and Avci, 2001). Palpus thin, with second segment long twice as first (Doganlar et al., 2005). Head covered by dark brown hairs (Doganlar and Avci, 2001). Canthus notched, developed, with 7 teeth, 2 long and 5 small (Doganlar and Avci, 2001). Foreleg epiphysis present (Simonato et al., 2013). Thorax dorsally covered by dark brown hairs (Doganlar and Avci, 2001). Abdomen light brown, with reddish hairs and dark bands laterally (Doganlar and Avci, 2001). Wingspan 26-29 mm. Forewing ground color whitish-gray, with three typical dark brown fasciae. According with Doganlar and Avci (2001), forewing has a really small basal fascia; ante-median and post-median fasciae more or less parallel between costa and dorsum. Post-median fascia more serrated in the middle (Doganlar and Avci, 2001) like in *Th. pinivora*. Discal spot vague with light brown color and halfmoon-shaped (Doganlar and Avci, 2001). Hindwing whitish, without fasciae. Fringes grayish-brown. A vague anal spot sometimes present. Grayish fasciae on anal margin present. Reverse sides of all wings without any particular ground colors (Doganlar and Avci, 2001).

Male genitalia. Uncus long large with curved tip; gnathos long, triangular and broad. Pedunculus, which is inferiorly articulated with the vinculum (Steinmann and Zombori, 1984), well developed and broad in the middle. Valvae with a short apical projection on ventral margin, thicker towards tip. Internal margin of valvae slightly concave while costal margin curved apically; tip of valvae narrow. Ventral side without teeth (Doganlar and Avci, 2001).

Aedeagus slightly longer than valva, curved basally and widen medially. Saccus not developed (Doganlar and Avci, 2001).

Female. Wingspan 34-37 mm. Wing ground color paler than male and not well defined; hindwing without dark margin or anal spot (Doganlar and Avci, 2001). Head and thorax dark with grayish hairs; abdomen yellowish with light brown bands. Last tergite with many scales, pointed with 2 spots (Doganlar et al., 2005). Ratio between length and width near to 2 (Doganlar et al., 2005; Simonato et al., 2013).

Remarks: head with a tuft of whitish-yellow hairs that cover scapus; brown hairs present near canthus. Legs thin with few hairs. A pair of spurs present in the others legs. Thorax covered ventrally by whitish-yellow hairs. Three fasciae on forewing with yellow edges in the same positions such as in *Th. pinivora*. Basal fascia with yellow edge that is most visible in the internal side. Ante-median fascia C shaped with outwardly smooth tip. Ends near dorsum of ante-median and post-median fasciae divergent. Forewing with vague pre-apical light brown spot and gray fringes. Light grayish band present at anal margin. Hindwing lighter at anal margin and pale on reverse side; a vague light brown spot in the center present; scales with two black spot: one to

the apex and a big one near the base. Fultura hexagonal as long as wide.

Life history: Larvae are social and monophagous on *Cedrus libani* (Doganlar and Avci, 2001). Adults emerge between August and September, mating at night, immediately after emergence. Eggs are laid on the underside of cedar branches, during the same night. Eggs are covered with bark-colored scales, such as in *Th. bonjeani*. The number of eggs per egg batch is extremely variable. After almost 7 months, between the end of March and the end of April, larvae hatch and group in colonies, spinning light silk tents, until to achievement the fifth instar (end of June to mid-July). Then, mature larvae pupate on sunny soil near cedar forest. No extended diapause was observed (Avci and İpekdağ, 2014) (Table 1).

Distribution: Turkey, Isparta region (Doganlar and Avci, 2001) (Figure 1), in cedar stands of the Taurus Mountains (Avci and İpekdağ, 2014).

3.2.4. *Thaumetopoea libanotica* Kiriakoff & Talhouk, 1975: 1

Holotype: ♂, Lebanon, Eklosion, Bcharre – Faculty of Agricultural Sciences, American University of Beirut. Not examined.

Description (Figure 2): **Male.** Antennae bipectinate and light brown (Kiriakoff and Talhouk, 1975). Palpus small. Head ochreous-brown dorsally and blackish ventrally; a tuft of whitish-gray hairs cover scapus (Kiriakoff and Talhouk, 1975). Canthus notched, not well developed, with 5 teeth; the upper ones smaller (Doganlar and Avci, 2001). Legs with pale hairs, as well as in thorax ventral side; tarsi yellow (Kiriakoff and Talhouk, 1975). Foreleg epiphysis present (Simonato et al., 2013). Thorax dorsally brown with grayish hairs. Abdomen gray, slightly brown with whitish segmental bands. Lateral and anal tufts are grays (Kiriakoff and Talhouk, 1975). Wingspan 26 mm. Forewing ground color brownish-gray, with 3 dark fasciae with pale edges (Kiriakoff and Talhouk, 1975). Fasciae in basal, ante-median and post-median positions. Basal fascia and ante-median fascia V-shaped, with tip outwardly. Basal fascia sometimes discontinued near costa; ante-median fascia with a sharp angle just before dorsum. Post-median fascia continuous and serrated, often with a sharp angle just before dorsum. Upper ends of medians fasciae more or less parallel; instead lower ends more convergent (Kiriakoff and Talhouk, 1975). Discal spot triangular shaped, brownish-gray colored. Vague pre-apical spot present. Fringes whitish, alternate with grayish-brown ones. Hindwing whitish with light brown margin and a vague brownish anal spot. Whitish-gray fringes present. Undersides of wings pale and not well defined (Kiriakoff and Talhouk, 1975).

Male genitalia. Uncus short, curved and tapered distally. Gnathos triangular with rounded corners (Kiriakoff and Talhouk, 1975), bigger than uncus (Doganlar and Avci, 2001); Vinculum narrow. Valvae oval, with tip slightly elongated and rounded, without projection. Aedeagus slightly longer than valvae; wide basally and narrow distally; slightly curved. Fultura pentagonal (Kiriakoff and Talhouk, 1975). Saccus not developed (Doganlar and Avci, 2001; Kiriakoff and Talhouk, 1975).

Female. Wingspan 32 mm. Wing ground color pale and less defined than male. Antennae described as filiforms by

Kiriakoff and Talhouk (1975). Head and thorax grayish; abdomen pale with ochreous hairs and dark fasciae (Kiriakoff & Talhouk, 1975). Scale ratio between length and width near to 2 (Simonato et al., 2013).

Remarks: discal spot is similar to halfmoon-shaped. Fultura as long as wide. Antennae in female shortly bipectinate to apex.

Larva. Mature larva is 25-26 mm long, with a background light gray, almost white color. Abdominal tergites have integumental fields carrying urticating setae bordered with red color and intermixed with bundles of long, white hairs (Kiriakoff and Talhouk, 1975).

Life history: Larvae are social and monophagous on *Cedrus libani*. They were found on young trees at high elevation (1900 m) on Lebanon Mountains, in temperate forests, with an average rainfall of 1200 mm/year (Kiriakoff and Talhouk, 1975). Larvae reach the fifth instar at the end of June and they pupate in soil. Adults emerge in August. This data was collected by Kiriakoff and Talhouk (1975) from a single colony found on a tree and bred in the laboratory (Table 1).

Distribution: was found in the Lebanon forest by Kiriakoff and Talhouk (Kiriakoff and Talhouk) (Figure 1).

3.2.5. *Thaumetopoea pinivora* (Treitschke, 1834): 194; (*Gastropacha pinivora*).

Lectotype: ♂, Northern Germany (probably Sternberg, SW of Rostock according to Schintlmeister, 2013) – Magyar Természettudományi Múzeum, Budapest. Not examined.

Infrasubspecific, according to Schintlmeister (2013):

Th. pinivora ab. *nigromaculata* Peters, 1899: 245.

Th. pinivora ab. *plutonia* Schultz, 1905: 115.

Description (Figure 2): External morphology of *Th. pinivora* is very similar to *Th. pityocampa* although showing significant differences (Agenjo, 1941; De-Gregorio and Redondo, 1994; de Frëina and Witt, 1987).

Male. Antennae short, bipectinate and more grayish than yellow (Agenjo, 1941). Palpus stretched (Doganlar et al., 2005), with first segment longer and thicker than second sharpened segment (Agenjo, 1941). Head covered by brownish hairs (de Frëina and Witt, 1987). Canthus notched, not well developed (Agenjo, 1941), with 7 teeth, 6 small and 1 big (de Frëina and Witt, 1987). Leg thin. Foreleg epiphysis present. A pair of spurs in the other legs present. Thorax brown and very hairy; abdomen yellowish (Agenjo, 1941; de Frëina and Witt, 1987). Wingspan 27-37 mm. Forewing ground color ash gray. Forewings with 3 dark fasciae in basal, ante-median and post-median positions. All of them with yellow edge. In the basal fascia, edge yellow on both sides; in the ante-median fascia yellow edge on external side; in the post-median fascia yellow edge on internal sides (Agenjo, 1941; de Frëina and Witt, 1987). These edges often discontinuous. Direction of the dark fasciae slightly different from *Th. pityocampa*, in particularly between ante-median and post-median fascia that converge near dorsum (Agenjo, 1941). Forewing marked from a brown halfmoon-shaped discal spot (de Frëina and Witt, 1987). Fringes alternately brown and white for the entire length of termen. Forewing reverse side pale (Agenjo, 1941; de Frëina and Witt, 1987). Upper side of hindwings white with dark external margin and with whitish-gray fringes. Anal spot

sometimes present. Hindwings reverse side pale (Agenjo, 1941; de Frëina & Witt, 1987).

Male genitalia. Up to 3,5 mm when fully stretched (Agenjo, 1941). Uncus small, broad and circular, triangular-shaped with thin and straight tips of lateral appendices. Tegument thin. Valvae distinctive, very short and sharp, with straight bottom edge and rounded at the end; upper edge initially perpendicular to the external margin and turning into convex apically. Inner edge almost straight. Outer end of upper edge produces a process with a right angle and a thicker terminal tip. This joins to the inner margin of the distal end. protuberance present, with many bristles, inserted in well-defined cavities (Agenjo, 1941; de Frëina and Witt, 1987). Fultura pentagonal and very characteristic. Aedeagus not curved (Agenjo, 1941).

Female. Similar to *Th. pityocampa* and *Th. wilkinsoni* (Agenjo, 1941). Wingspan 34-38 mm, with the wing ground color pale and not well defined (de Frëina and Witt, 1987). Antennae wider but shorter than male (Agenjo, 1941). Head and thorax brown with grayish hairs; abdomen lighter with yellow fasciae (Agenjo, 1941). Anal scales that cover egg batches narrow and short, with base, much pointed. Scales pigmented typically, with wide elliptic dark spot near apex bordered on three sides by a lighter line before the terminal edge (Agenjo, 1941); there are no other black regions except this (Doganlar et al., 2005). Moreover scales ratio between length and width near to 2 (Simonato et al., 2013).

Remarks: head with tuft of whitish-gray hairs that cover scapus, and a line of brown hairs between antennae and canthus. Thorax and legs covered with some whitish-gray hairs. On forewings the fasciae with yellow-whitish margin in the upper portion. Light brown spot between the 2 arms of discal spot often present on forewing. Brown pre-apical spot present at costal margin; it can be extended to half of wing. Forewing reverse side pale and with only a dark spot under costal margin of post-median fasciae. Anal spot on hindwing sometimes vague.

Larva. The only description available refers to Démolin (1989) comparison with *Th. bonjeani* (see above). This author considers the larva of *Th. pinivora* not distinguishable from that of *Th. bonjeani*.

Life history: Larvae are highly social (Aimi et al., 2008). In the southern Europe they prefer mountain environments where their host plant growth typically, while in northern Europe, they can be found in the lowland forest (Cassel-Lundhagen et al., 2013). They feed mainly on *Pinus sylvestris* (Cassel-Lundhagen et al., 2013; de Frëina and Witt, 1987) but occasionally they are found on *Pinus nigra* and *Pinus mugo* (Larsson and Battisti, 2014). They prefer slow-growing trees on poor soils (Cassel-Lundhagen et al., 2013). In northern Europe, *Th. pinivora* has a 2 years development cycle. Adults emerge between July and August and mating soon after. Female lays 100-200 eggs on pine needle, from the tip to the base (in contrast to *Th. pityocampa*). Eggs hatch in the early spring. Larvae start to feed on mature needles, mainly during the night, and reach the fifth instar to the end of July. Then they leave the tree in a typical procession to search a suitable site to dig and pupate to a depth of 5-20 cm. Adults emerge in late July of the following year; although a certain proportion of the cocoons have a prolonged diapause (Larsson and Battisti, 2014) (Table 1). Larvae do not build thick tents, in contrast

to *Th. pityocampa* and *Th. processionea* (Larsson and Battisti, 2014).

Distribution: *Th. pinivora* was originally known from Northern Europe and later from France and central Spain (Cassel-Lundhagen et al., 2013; Larsson and Battisti, 2014) (Figure 1).

3.2.6. *Thaumetopoea sedirica* Doganlar et al., 2005: 231; (*Traumatocampa sedirica*)

Holotype: ♂, Turkey, Isparta, Sarkikaragac – m, 38°02' 18"N, 31°22'35"E, ex *Cedrus libani*, 17 August 1968, legit Tosun, Museum of the Agricultural Faculty, Mustafa Kemal University, Hatay, Turkey. Not examined.

Description (Figure 2): External morphology very similar to *Th. ispartaensis*.

Male. Antennae yellow and bipectinate with ramie (Doganlar et al., 2005). Palpus small, with second segment long as the first segment; first segment swollen outwardly (Doganlar et al., 2005). Head dark brown but with lighter hairs in the upper side. tuft with long dark hairs and white broad scales present to cover scapus (Doganlar et al., 2005); the lines of hairs near canthus pale yellow (Doganlar et al., 2005). Canthus notched, with 3-5 broad teeth (Doganlar et al., 2005); Thorax covered by brownish black hairs. Abdomen with golden hair-like setula (Doganlar et al., 2005). Wingspan 30-37 mm. Forewing with dark brown basal, ante-median and post-median fasciae. Apical ends of ante-median and post-median fasciae divergent on anal margin (Doganlar et al., 2005). A typical light brown discal spot present (Doganlar et al., 2005). Hindwing whitish with apical gray fringe, and without anal-spot (Doganlar et al., 2005).

Male genitalia. Uncus large with curved tip. Valvae broad basally, with a short apical projection on ventral margin that becomes thicker towards the tip. Apex of valva turned almost 95°. Internal margin slightly concave while costal one sharply curved apically; the tip of valva narrow (about 1/3 of valvae). Ventral side without tooth (Doganlar et al., 2005).

Female. Wingspan 33-40 mm. Wing ground color paler than male and less defined. Antennae bipectinate with short ramie (Doganlar et al., 2005). Last tergite with many scales and pointed basally with black dots below apical black spot (Doganlar et al., 2005). Moreover scales ratio between length and width near to 2 (Doganlar et al., 2005).

Remarks: hairs dark. Legs thin. Forewing epiphysis present. A pair of spurs in the other legs present. Thorax ventrally covered by lighter hairs. Forewing ground color in whitish-gray; all fasciae with typically yellow edges, like in *Th. pinivora*. Apical ends of ante-median and post-median fasciae parallel on costal margin. Discal spot with halfmoon-shaped present. Fringes brownish-gray. A darker marker can be present in the anal margin of hindwings. Wings reverse sides pale, without any particular ground colors, with only a vague light brown spot in the center of hindwings.

Larva: No information is available.

Life history: Larvae are social and probably monophagous on *Cedrus libani*. The eggs batches are flat, symmetrical and hexagonal on the host bark (Doganlar et al., 2005).

Distribution: Turkey, Isparta region (Doganlar et al., 2005), (Figure 1).

Table 1. Summary of some biological traits of *Thaumetopoea* spp. ? = unknown trait

Species	Life cycle	Diapause	Flight period	Larval period	Host genus
<i>Th. bonjeani</i>	Univoltine	Egg	August - September	March - July	<i>Cedrus</i>
<i>Th. cheela</i>	?	?	?	?	<i>Cedrus</i> ?
<i>Th. ispartaensis</i>	?	?	?	?	<i>Cedrus</i>
<i>Th. libanotica</i>	Univoltine	Egg	August (rearing)	April - June (rearing)	<i>Cedrus</i>
<i>Th. pinivora</i>	Univoltine (south) Biannual (north)	Egg (south), Egg + Pupa (north)	July - August	March - July	<i>Pinus</i>
<i>Th. sedirica</i>	?	?	?	?	<i>Cedrus</i>

3.3. Key to the identification of the moths of *Thaumetopoea* genus, with special reference to the 'summer' feeding species

- | | | |
|---|---|------------------------------|
| 1 | Canthus convex and smooth | to <i>solitaria</i> group |
| - | Canthus with teeth | 2 |
| 2 | Patter of forewing greyish | 3 |
| - | Patter of forewing brownish or whitish | 4 |
| 3 | Male with dark fasciae on forewings without yellowish edge; Female with anal scales upper than 2 mm of length or with scales not pointed to proximal part | |
| | | to <i>pityocampa</i> group |
| - | Male with dark fasciae on forewings with yellowish edge; Female with anal scales lower than 2 mm of length or with scales pointed to proximal part | |
| | | to <i>pinivora</i> group (5) |
| 4 | Forewing with discal spot | <i>herculeana</i> |
| - | Forewing without discal spot | to <i>jordana</i> group |
| 5 | Ante-median fasciae and post-median of forewing much more converged on termen than costa; Discontinued basal fasciae | <i>pinivora</i> |
| - | Ante-median fasciae and post-median of forewing are equidistant or divergent on termen and costa; Discontinued basal fasciae | 6 |
| 6 | Ante-median fasciae and post- median of forewing are equidistant on termen and costa; | |
| | | <i>bonjeani</i> |
| - | Ante-median fasciae and post-median of forewing are more divergent on termen than costa; | 7 |
| 7 | With a strong acute angle on ante-median and post-median fasciae on forewing | <i>libanotica</i> |
| - | Without a strong acute angle on ante-median and post-median fasciae on forewing | 8 |
| 8 | Basal fasciae on forewing probably reduced to some point; discal spot with white edge | <i>cheela</i> |
| | | <i>ispartaensis/sedirica</i> |
| - | Basal fasciae on forewing well developed; discal spot without white edge | |

4. Discussion

The analysis of morphological traits and available data from the literature has identified several similarities between the species considered in this study. Most obvious similarity is based on the wing bands, as all species have 3 thin, dark bands, in basal, ante-median and post-media positions, and they have yellow-whitish edge. Basal fascia is bordered on both internal and external sides; this fascia is discontinuous, often also in *Th. pinivora*. Ante-median fascia is bordered on the external side while the post-median fascia is on the internal side. Moreover a pre-apical spot, more or less marked, is often present. Hindwing has an anal spot, that is visible, although vaguely, also in *Th. ispartaensis*. In fresh specimens probably it could be more marked. Canthus has always teeth, more or less serrated, generally smaller than that of *Th. pityocampa*. Toothed canthus is also present in *Th. cheela*, to give further support to the relatedness of the species to this group. Another important trait could be the shape and pigmentation of the scales used to cover the egg batches; in fact, they are wide and similar in *Th. pinivora*, *Th. ispartaensis* and *Th. sedirica*; while they are narrower and longer in *Th. bonjeani*. Also the analysis of the male genitalia has identified many similarities, especially in the valvae and their apical process but also in fultura that it is pentagonal and similar in *Th. pinivora* and *Th. libanotica*; and it is hexagonal and similar in *Th. ispartaensis* and *Th. bonjeani*. Uncus is small and rounded and aedeagus is generally broader basally and curved, both with a similar shape, although they change in size.

These traits, in addition to those on biology and behavior of larvae, has allowed us to hypothesize that also *Th. cheela* has the same behavior and habits of the other summer *Thaumetopoea*. To further support this hypothesis, we overlapped the collection sites of the specimens and the geographic distribution of *Cedrus deodara* and *Pinus* spp. (*P. gerardiana*, *P. roxburghii* and *P. wallichiana*) (Critchfield and Little, 1966; Vidakovic, 1982), in order to estimate a possible matching with host plant. As both *Cedrus* and *Pinus* occur in the area where the specimens of *Th. cheela* were collected, we cannot conclude about which one is more likely to be the host plant of this species. Unfortunately, micro-scale data about the sites is not available and the issue can be solved only with new collections, possibly of larvae that have to be searched on these host plants.

In addition, the analysis of specimens of *Th. ispartaensis* and *Th. sedirica* has not revealed substantial differences on wing ground color, or on the fasciae inclination. The traits used in the key by Doganlar et al. (2005) did not allow to unambiguously discriminating female scales (Figure 2).

As most of the summer *Thaumetopoea* are associated with *Cedrus*, we compared *Cedrus* phylogeny provided by Qiao et al. (2007) with phylogeny analysis developed by Simonato et al. (2013) for *Thaumetopoea*, to investigate the evolutionary history of this group in relation to their host plants, as suggested by Wahlberg et al. (2013). Qiao et al. (2007) state that *C. deodara* was the first species to diverge from the common ancestor, and then the split concerned *C. atlantica*, *C. libani*, and *C. brevifolia*. With a molecular

clock they estimate that the split between *Cedrus deodara* and the others occurred about 60 Mya (millions years ago); *C. atlantica* from North Africa split about 20 Mya and the separation between *C. libani* and *C. brevifolia* occurred 6-7 Mya. Combining data obtained from Simonato et al. (2013) with sequences available in Genbank, a multiple alignment including the mitochondrial genes *cox1*, *cox2*, and *atp6* was then used for dating the split events among *Thaumetopoea* species. The substitution rate was set to 0.00022 according to (Gaunt and Miles, 2002). Calculations were performed using Beast 1.8.0 software (Drummond et al., 2012). The results obtained from this analysis show that the separation between the summer and the winter *Thaumetopoea* happened about 16.3 Mya (95% HDP interval: 8 to 25). Moreover, the first split in the summer clade between *Th. ispartaensis*/*Th. libanotica* and *Th. bonjeani*/*Th. pinivora* is dated at about 5.5 Mya (95% HPD interval 2.8 to 8.6). The further splits between *Th. pinivora*/*Th. bonjeani* and between *Th. ispartaensis*/*Th. libanotica* occurred about 2.7 Mya (95% HDP interval: 1.2 to 4.4) and about 2.6 Mya (95% HDP interval: 1.2 to 4.2), respectively. As *Th. cheela* is missing from the analysis, we cannot conclude about its possible association with *Cedrus deodara*. Split of the summer clade follows that of *Cedrus atlantica* from the other *Cedrus*, and could be somewhat linked to it. It seems in general that insect species have split later than their host plants, with one of them (*Th. pinivora*) associated with *Pinus* and separated from the sister species *Th. bonjeani* much after the separation of *Cedrus atlantica* from the other *Cedrus*.

Although these results indicate that more studies have to be made, especially for the poorly known species, there are some evidences that *Cedrus* could be the host on which most of speciation in the summer clade has happened. Research should be focused on finding new material on which morphological characters of both adults and larvae have to be tested, together with biological and ecological traits. Moreover, molecular data from this material could complement the evolutionary history and define the phylogenetic relationships within the *Thaumetopoea s.l.*

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