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A cryptic species of *Eupithecia sardoa* Dietze, 1910, in Spain: *Eupithecia iberica* Lévêque, Skou, Tautel & Ranki, sp. nov. (Lepidoptera: Geometridae, Larentiinae, Eupitheciini)

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Abstract

The authors describe a new species, cryptic of *Eupithecia sardoa* Dietze, 1910, revealed by genetic studies. *Eupithecia iberica* sp. nov. was discovered in Spain (Ibiza and southern Andalusia). The species is described, and the male and female genitalia are presented. The new species is very close to *Eupithecia sardoa*, with which it is compared. The holotype is preserved in the collection of the second author and paratypes are distributed among several collections, including that of the Museo Nacional de Ciencias Naturales (Madrid, Spain). The authors take this opportunity to review the history of the discovery of *Eupithecia sardoa* and what is currently knowledge about this species. The two Mediterranean taxa *iberica* sp. nov. and *sardoa* belong to a group of related species associated with *Juniperus*.
Keywords: Lepidoptera, Geometridae, Larentiinae, Eupitheciini, *Eupithecia*, new species, Andalusia, Balearic Islands, Ibiza, Spain, Corse, France, Sardinia, Italy.

Una especie críptica de *Eupithecia sardoa* Dietze, 1910, en España: *Eupithecia iberica* Lévêque, Skou, Tautel & Ranki, sp. nov. (Lepidoptera: Geometridae, Larentiinae, Eupitheciini)

Resumen

Los autores describen una nueva especie, críptica de *Eupithecia sardoa* Dietze, 1910, revelada por estudios genéticos. *Eupithecia iberica* sp. nov. fue descubierta en España (Ibiza y sur de Andalucía). Se describe la especie y se presentan la genitalia del macho y de la hembra. La nueva especie está muy próxima a *Eupithecia sardoa*, con la que se compara. El holotipo se conserva en la colección del segundo autor y los paratipos están distribuidos en varias colecciones, entre ellas la del Museo Nacional de Ciencias Naturales (Madrid, España). Los autores aprovechan esta oportunidad para repasar la historia del descubrimiento de *Eupithecia sardoa* y lo que se sabe actualmente de esta especie. Los dos taxones mediterráneos *iberica* sp. nov. y *sardoa* pertenecen a un grupo de especies afines asociadas a los *Juniperus*.
Palabras clave: Lepidoptera, Geometridae, Larentiinae, Eupitheciini, *Eupithecia*, nueva especie, Andalucía, Islas Baleares, Ibiza, España, Córcega, Francia, Cerdeña, Italia.

Une espèce cryptique d'*Eupithecia sardoa* Dietze, 1910, en Espagne: *Eupithecia iberica* Lévêque, Skou, Tautel & Ranki, sp. nov. (Lepidoptera: Geometridae, Larentiinae, Eupitheciini)

Résumé

Les auteurs décrivent une nouvelle espèce, cryptique d'*Eupithecia sardoa* Dietze, 1910, révélée par des études génétiques. *Eupithecia iberica* sp. nov. a été découverte en Espagne (Ibiza et sud de l'Andalousie). L'espèce est décrite et les genitalia mâles et femelles sont présentés. La nouvelle espèce est très proche d'*Eupithecia sardoa*, avec laquelle elle est comparée. L'holotype est conservé dans la collection du deuxième auteur et les paratypes sont répartis au sein de plusieurs collections, dont celle du Museo Nacional de Ciencias Naturales (Madrid, Espagne). Les auteurs profitent de l'occasion pour faire le point sur l'histoire de la découverte d'*Eupithecia sardoa* et sur ce que l'on connaît actuellement de cette espèce. Les deux taxa méditerranéens *iberica* sp. nov. et *sardoa* appartiennent à un groupe d'espèces apparentées associées aux *Juniperus*.
Mots-clés: Lepidoptera, Geometridae, Larentiinae, Eupitheciini, *Eupithecia*, nouvelle espèce, Andalousie, îles Baléares, Ibiza, Espagne, Corse, France, Sardaigne, Italie.

Introduction

Many Lepidoptera specimens were collected during the "Our Planet Reviewed in Corsica 2019-2021" project, a multi-year scientific programme to explore biodiversity led by the Muséum National d'Histoire Naturelle in Paris (France), in partnership with the Collectivité de Corse and the Office Français de la Biodiversité, and in which the first author participated (Touroult et al. 2023). These specimens included several *Eupithecia* captured in Malaise traps and preserved in alcohol. Following DNA barcodes checks on these Pug Moths, the first author was surprised to find that several *Eupithecia* from the Balearic Islands (Ibiza, Spain), taken by the second author, then identified as *sardoa* in BOLD, differed by more than 6% from those found in Corsica (France) and whose sequences did not match to any others known in this same database moreover. From then on, the hypothesis of the existence of two different species hitherto confused under the name *sardoa* emerged.

DNA barcodes analysis, based on study material available as part of a project led by our Finnish colleague Pasi Sihvonen, also made it possible to highlight that several other specimens, captured by the fourth author in the extreme south of Spain, in Tarifa, initially also attributed to *Eupithecia sardoa*, belonged to the same species as those of Ibiza, distinct from that encountered in Corsica. The second author had previously to the record made by the fourth author found two specimens at the same locality. He has further found two specimens at another locality more to the west and finally he had been given two specimens from a third locality. These six specimens, which were not barcoded, have also previously been attributed to *Eupithecia sardoa*.

After a thorough study of external (habitus) and internal (male and female genitalia) characteristics, in addition to that of DNA barcodes, we can conclude that these *Eupithecia* from Spain form a new European taxon that we present and describe below. Its closeness to *E. sardoa*, particularly through the presence of dentate antennae in the male, has allowed us to take a new look at these two Mediterranean taxa associated with *Juniperus*.

Material and methods

Abbreviations used

BIN	Barcode Index Number
BOLD	Barcode of Life Data System (www.boldsystems.org)
CTC	Collection of Claude Tautel, Champagnac-le-Vieux, France
FMNH	Finnish Museum of Natural History, Helsinki, Finland
LPRC	La Planète Revisitée en Corse ("Our Planet Reviewed in Corsica")
MNCN	Museo Nacional de Ciencias Naturales, Madrid, Spain
MNHN	Muséum National d'Histoire Naturelle, Paris, France
NHMUK	Natural History Museum, London, United Kingdom
PSC	Collection of Peder Skou, Ollerup, Denmark
SNSB-ZSM	Staatlichen Naturwissenschaftlichen Sammlungen Bayerns - Zoologische Staatssammlung München, Munich, Germany
TRC	Collection of Timo Ranki, Schoenfels, Luxemburg

Study material

The specimens studied, belonging to the new species described below, were attracted by light on the island of Ibiza by the second author and in mainland Spain by the second and fourth authors. The second author has used light traps in both Ibiza and mainland Spain, equipped with 8-Watt superactinic light tubes. The light traps used by the fourth author in Tarifa were automatic traps with 2 W LED strips. These specimens were pinned, spread and preserved dry. The Corsican specimens, studied for comparison, were collected either by light trap (vertical light sheet illuminated by a 125 W mercury vapour bulb, by the third author, or the same light traps as Ibiza and mainland Spain, by the second author), then pinned, spread and preserved dry, or by Malaise Traps and, in the latter case, preserved in alcohol.

The abdomens of the dissected specimens were treated using a KOH solution in a water bath, to soften the tissues, dissolve the fats and extract the genitalia. The abdominal segments and genitalia were cleaned in water, dehydrated in alcohol, coloured with Chlorazol Black then mounted between slide and coverslip in Euparal®.

Photos of adult specimens were taken with a Nikon D7000 camera or a Nikon D800E camera, equipped with an AF-S Micro-Nikkor 105 mm f/2.8 lens. Photos of genitalia slides were taken with a Canon EOS 6D camera, combined with an MP-E 65 mm Macro f/2.8 lens and mounted on a semi-automatic Cognisys Rail macro StackShot device controlled by Helicon Remote software. The photographs were combined using Helicon Focus 6 software and processed using Adobe Photoshop CS6.

Molecular data and phylogenetic inference

The data relating to fourteen specimens (and associated sequences), initially determined to be *sardoa*, on which we are basing our study and description of the new species have been brought together in a dataset specially created for the occasion in BOLD. Entitled "Study of Eupithecia sardoa complex", this dataset bears the code DS-SARDOA03 and will be made public at the time of publication of this article. It includes ten specimens of *sardoa* and four specimens of the new species (Tables 1 and 2).

Table 1. Details of specimens included in the dataset DS-SARDOA03.

Specimen	Locality	Collector	Date	Sex	Institution storing
LPRC2022-0234	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	-	MNHN
LPRC2022-0237	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	-	MNHN
LPRC2022-0245	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	-	MNHN
LPRC2022-0321	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	-	MNHN
LPRC2022-0336	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	♀	MNHN
LPRC2022-0337	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	-	MNHN
LPRC2022-0338	Corsica, Haute-Corse, Ostriconi	LPRC	13–22-X-2020*	♂	MNHN
BC-CT-MNHN0003	Corsica, Haute-Corse, Marina di Pinarello	Cl. Tautel	27-X-2022	♂	CTC
BC-CT-MNHN0004	Corsica, Haute-Corse, Marina di Pinarello	Cl. Tautel	27-X-2022	♂	CTC
BC ZSM Lep 106582	Sardinia, Province of Sassari, Stagno di Platamona	P. Skou	23-V-2004	♂	SNSB-ZSM
BC ZSM Lep 106682	Balearic Island, Ibiza, Cala d'Hort	P. Skou	3–4-X-2018	♂	SNSB-ZSM
BC ZSM Lep 113000	Balearic Island, Ibiza, Cala d'Hort	P. Skou	3–4-X-2018	♂	PSC
BC ZSM Lep 113509	Balearic Island, Ibiza, Sant Llorenç de Balàfia	P. Skou	5-X-2018	♀	PSC
Sihvonen1574	Andalucía, Tarifa, Punta Paloma	T. Ranki	14-IV-2021	♀	TRC

Note: * Collected by a Malaise Trap.

Table 2. Details of sequences included in the dataset DS-SARDOA03.

Specimen	Sequence	Bases [Ambiguous]	Marker	%GC	BIN URI
LPRC2022-0234	LPRCL1474-22	654 [0n]	COI-5P	32.1	BOLD:AFA0192
LPRC2022-0237	LPRCL1477-22	653 [0n]	COI-5P	32.0	BOLD:AFA0192
LPRC2022-0245	LPRCL1485-22	654 [0n]	COI-5P	32.1	BOLD:AFA0192
LPRC2022-0321	LPRCL1561-22	652 [0n]	COI-5P	32.1	BOLD:AFA0192
LPRC2022-0336	LPRCL1576-22	652 [0n]	COI-5P	32.2	BOLD:AFA0192
LPRC2022-0337	LPRCL1577-22	651 [0n]	COI-5P	32.3	BOLD:AFA0192
LPRC2022-0338	LPRCL1578-22	654 [0n]	COI-5P	32.1	BOLD:AFA0192
BC-CT-MNHN0003	LPRCL2256-23	653 [0n]	COI-5P	32.0	BOLD:AFA0192
BC-CT-MNHN0004	LPRCL2257-23	654 [0n]	COI-5P	32.0	BOLD:AFA0192
BC ZSM Lep 106582	GWOTZ333-19	658 [250n]	COI-5P	20.4	-
BC ZSM Lep 106682	GWOUB701-19	658 [0n]	COI-5P	31.6	BOLD:ADZ9010
BC ZSM Lep 113000	GWOUH084-21	638 [0n]	COI-5P	32.3	BOLD:ADZ9010
BC ZSM Lep 113509	GWOUI023-21	658 [0n]	COI-5P	31.6	BOLD:ADZ9010
Sihvonen1574	MIXED004-24	632 [4n]	COI-5P	32.3	BOLD:ADZ9010

DNA was extracted from one or two legs of seven dry specimens (BC-CT-MNHN0003 and -0004; BC ZSM Lep 106582, -106682, -113000 and -113509; Sihvonen1574) and of seven specimens conserved in alcohol after to have collected by a Malaise trap (LPRC2022-0232, -0237, -0245, -0321, -0336, -0337 and -0338).

DNA extraction, amplification and sequencing for the nine Corsican specimens of *sardoa* were carried out by the CCDB's Team (Canadian Centre for DNA Barcoding, hosted by the Center Genomics at the University of Guelph, Ontario, Canada). Legs were placed in a 96-well plate and shipped for processing at the CCDB. The plate was processed using the SEQUEL (Pacific Biosciences, USA) high-throughput NGS pipeline for large numbers of samples, as described in Hebert et al. (2018). After quality control and validation, consensus sequences produced by the SEQUEL platform were uploaded to the BOLD (Ratnasingham & Hebert, 2007) where both specimen- and sequence-data are managed.

Our colleagues Axel Hausmann and Pasi Sihvonen kindly gave us access in BOLD to their data and sequences relating respectively to the three specimens from Ibiza and the specimen from Tarifa, all four pre-identified as *sardoa* but actually corresponding to the new species. Thanks to Axel Hausmann, we also had access in BOLD to a sequence of a specimen of *sardoa* from a Sardinian locality close to the type-locality of this species.

In order to obtain a broader overview, we also used 229 additional sequences available in BOLD (Table 3), bringing the total number of sequences taken into account to 243. So, a comparative genetic analysis of several European and North American *Eupithecia* species associated with *Juniperus* and belonging to the *interruptofasciata* species-group was carried out. The gene analysed is the mitochondrial gene coding for the cytochrome oxidase subunit I (COI - DNA Barcode).

Table 3. Details of the additional data from BOLD considered in our molecular analysis.

Species and total number of specimens	Locality	Number of sequences
E. interruptofasciata (3)*	Canada, British Columbia	2
	Canada, Ontario	1

E. niphadophilata (107)*	USA, Alaska	2
	Canada, British Columbia	82
	Canada, Alberta	6
	Canada, Ontario	17
E. pusillata (90)	Canada, British Columbia	1
	Greenland	1
	Norway	8
	Finland	16
	United Kingdom, England, Lancashire	1
	France, Indre-et-Loire	32
	Germany, Bavaria	3
	Austria	9
	Italy (Piedmont, South Tyrol, Abruzzo and Calabria)	11
	Spain, Aragon	1
	North Macedonia	2
	Armenia	2
	Russia, Altai	3
E. conquesta (4)	Cyprus	4
E. phoeniceata (9)	United Kingdom, England	4
	Portugal	3
	Italy, Sicily	2
E. oxycedrata (16)	France, Alpes-Maritimes	1
	France, Corsica	7
	Italy, Abruzzo	1
	Croatia	1
	Spain, Comunidad Valenciana	1
	Portugal	4
	Marocco	1

Note: * Identified as such in BOLD.

The 243 sequences, exported from BOLD in a FASTA file, were processed with MEGA11 software (Tamura et al. 2021). The sequences were aligned by MUSCLE. Two trees were constructed using the "Phylogeny" function in MEGA11. For the first (Figure 65), the evolutionary history was inferred using the Neighbor-Joining method (Saitou & Nei, 1987) and the evolutionary distances were computed using the p-distance method (Nei & Kumar, 2000); all ambiguous positions were removed for each sequence pair (pairwise deletion option). For the second tree (Figure 64), the evolutionary history was inferred by using the Maximum Likelihood method and Kimura 2-parameter model (Kimura, 1980). In the two cases, the analysis involved 243 nucleotide sequences, codon positions included were $1^{st}+2^{nd}+3^{rd}$+Noncoding and there was a total of 668 positions in the final dataset.

We also examined the BINs associated with the sequences analysed above. The Barcode Index Number System (Ratnasingham & Hebert, 2013), available in BOLD, clusters sequences using well established algorithms to produce operational taxonomic units that closely correspond to species. BINs are based on the divergence patterns of DNA barcodes. In Lepidoptera, there is generally a good congruence between BINs and the morphological delimitation of species, although this is not always the case, since there are species that share the same DNA barcode and, conversely, species within which there is genetic structuring into two or more BINs. These situations require more in-depth study, as they may reveal the existence, in the first case of synonymies that have not yet been established and, in the second case of twin species that have not yet been described or have yet to be rehabilitated.

Results

Taxonomy

***Eupithecia iberica* Lévêque, Skou, Tautel & Ranki, sp. nov.** (Figures 1-8, 17-20, 23-24)
https://zoobank.org/00F23CE2-8F82-4CB5-89AE-127A8FCE97EB

Holotype ♀: SPAIN, Balearic Islands, Ibiza, Sant Llorenç de Balàfia, 39.03ºN-1.47º E, 120 m, 5-X-2018, leg. Peder Skou, Sample ID BOLD: BC ZSM Lep 113509, in PSC.

Paratypes: SPAIN, Balearic Islands, Ibiza, 1.2 km ENE Cala d'Hort, 38.89ºN-1.23ºE, 100 m, 1 ♂, 3-4-X-2018, leg. Peder Skou, in MNCN; idem, 1 ♂, Sample ID BOLD: BC ZSM Lep 113000, in PSC; idem, 1 ♂, Sample ID BOLD: BC ZSM Lep 106682, in SNSB-ZSM; idem, 1 ♀, prep. gen. Cl. Tautel nº E306, in CTC (Figures 1-2, 17-18, 33, 37); idem, 1 ♂, prep. gen. Cl. Tautel nº E307, in CTC (Figures 3-4, 23-24, 44, 47, 59); Ibiza, 4.2 km SW Sant Rafel, Puig des Fornàs, 220 m, 1 ♂ and 1 ♀, 30-III-3-IV-2016, leg. Peder Skou, in PSC; Ibiza, Coll de sa Creu, 170 m, 1 ♂ and 4 ♀, 1-X-2018, leg. Peder Skou, in PSC. Andalucía, Cádiz, Tarifa, Punta Paloma, 36º3'55" N - 5º42'16"W, 40 m, 1 ♀, 14-15-IV-2021, leg. Timo Ranki, in MNCN; idem, 1 ♀, prep. gen. A. Lévêque n° AL40, in MNHN (Figures 5-6, 20, 31, 38); idem, 1 ♂, prep. gen. A. Lévêque nº AL41, in MNHN (Figures 7-8, 29, 43, 48-49, 55); idem, 1 ♀, Sample ID BOLD: Sivhonen1574, in TRC; idem, 1 ♀, 14-15-X-2021, prep. gen. Cl. Tautel nº E308, in CTC (Figures 19, 32); idem, 1 ♂ and 3 ♀, 3-V-2022, in TRC; idem, 1 ♂, 4-X-2022, in TRC; Cádiz, 8 km NW Tarifa, Punta Paloma, 10 m, 1 ♂ and 1 ♀, 12-13-IV-2007, leg. Peder Skou, in PSC; Andalucía, Huelva, 14 km SE Mazagón, Playa del Rompeculos, 20 m, 2 ♀, 20-IV-2007, leg. Peder Skou, in PSC; Andalucía, Cádiz, Novo Sancti Petri, 10 m, 1 ♂ and 1 ♀, 4-7-III-2005, leg. Bjarne Skule, in PSC.

Description: Forewing length: (8) 9-10 mm. Wingspan: (15) 16-17,5 (19) mm. Head: Antennae deeply dentate in the male (Figure 29), filiform in the female; first segment (scape) grey-beige; flagellum grey-beige interspersed with brown on top, uniformly light brown below. Labial palpi grey, with the lighter end (grey-beige). Frons grey-beige, light, with a few darker grey scales. Vertex almost uniformly light grey-beige. Thorax: Thoracic collar, tegulae, mesothorax and metathorax light grey-beige. A blackish transverse band crosses the anterior parts of the tegulae and the mesothorax. Legs grey-beige; articles of tarsus (tarsomeres) of the fore-, middle- and hind-legs with the light end, giving the tarsi a finely ringed appearance; hindtibia with two pairs of spurs, one medial, the other distal; tibia of the middle-legs with only one pair of spurs, distal; no spurs on the fore-legs. Abdomen: Upper side light grey, with the second tergum darker, blackish. Underparts lighter, grey-beige. Presence of small brownish to blackish scales on the sides. Sternum A8 shaped like an elongated triangle, with apex bifurcated and proximal margin slightly concave (Figures 47B, 49).

Forewing (upper side): Elongated, with a rather acute apex; the male has narrower wings than the female. Ground colour light grey-beige, with darker areas, greyish brown. Discal spot rather rounded (especially in male), quite small, black. Basal, antemedial and medial lines inconspicuous. Dark brown to blackish dashes, more or less elongated, on the veins M1, M2, M3 and CuA2, and between CuA2 and the vein A, in the post-medial area; a dark brown to blackish dash also along the bottom edge of the cell (in continuity, or almost, with the dash on CuA2). Terminal area with two elongated browns to blackish dashes near apex. A beige apical streak rather quite conspicuous. The wavy line faintly sinuate, pale, light grey-beige, contrasting with the darker ground of the terminal area. The terminal line dark brown, finely interrupted by beige at the veins. Fringe chequered greyish brown and beige. Hindwing (upper side): Ground colour light grey-beige, almost

everywhere slightly paler than the forewing, except near the anal margin and the terminal area. Basal area dark and transverse lines conspicuous only near the anal margin. The pale wavy line invisible. Discal spot small, rounded, greyish brown. Terminal line and fringe as on forewing. Under side of wings: Quite uniform light grey-beige, almost with no pattern except for the highlighting of the veins in the post-medial area, and an apparent dark grey to blackish discal spot. A lighter subterminal band, bending towards the costa below the apex. Terminal line and fringe as on the upper side. Variation: Low. The ground colour is more or less light. The dark dashes on the veins and near apex of the forewing are more or less strongly marked. The discal spots are more or less marked; the one on the hindwing is sometimes barely visible. The specimens from Tarifa seem to have a little more contrast and could be a little smaller than those from Ibiza. The spring specimens seem in average a little bigger than the autumn specimens.

Male genitalia (Figures 43-44, 61): Uncus hook-like and pointed apically, biapical, with the tip deeply bifid. Valva relatively broad; costa sclerotized almost until the apex; sacculus sclerotized, ending in a broad point; lateral margin of the valva slightly convex below the apex then slightly concave just above the point. Aedeagus (Figures 56, 59, 63): vesica small, half the length of the coecum and as wide as this latter, opens in the axis of the coecum, without angle; vesica with two elongated cornuti (one 2.1 to 2.4 times longer than the other) and two sclerotized area (one small, almost as wide as it is long, at the base of the vesica, and the other just above, elongated, almost as long as the smallest cornutus); the longest cornutus forms an angle of around 90º to the smallest when the vesica is everted.

Female genitalia (Figures 31-33, 41): Papillae anales relatively oval and rather large. Apophyses pointed, the anterior a little longer than the height of the tergum A8. The anterior margin of the tergum A8 is sclerotized, relatively straight. Colliculum absent. Ductus bursae long, rather narrow, with a regular width (only slightly wider in its posterior part), sclerotized; no longitudinal striations and no row of minute spines running up the side of the ductus bursae, in its anterior part (Figures 37-38). Corpus bursae small, rather narrow, with a crown of little but strong spines in its centre.

Etymology: The specific epithet "*iberica*" refers to the territory from which the new species is described, that of the Iberian and related peoples, who lived in particular in the coastal regions of the east and south of the Iberian Peninsula, but also in the Balearic Islands.

Diagnosis and related species: Very similar to *Eupithecia sardoa* Dietze, 1910 and also closed to *E. pusillata* ([Denis & Schiffermüller], 1775), *E. oxycedrata* (Rambur, 1833) and *E. ericeata* (Rambur, 1833).

In males, the dentate antennae can be used to distinguish *sardoa* and the new species from the three others.

Compared to *sardoa*, the new species seems to be distinguished by its relatively small size, in average slightly lower than that of *sardoa* (wingspan: (16) 17-20 (21) mm) but be careful with the smallest specimens of *sardoa* and some *iberica* sp. nov. specimens a little larger than average. On the upper side, the discal spots seem more marked than in *sardoa*, especially on the hindwings; the light apical streak is more conspicuous than in *sardoa* (in which it may even be absent, or barely visible, in some specimens) (cf. criterion a on Figures 17, 19 and 23); in the extension of the apical streak, a light oblique band is clearly visible in the new species, reaching the inner edge of the forewing, such a band not being so clearly delimited in *sardoa* (cf. criterion b on Figures 17, 19 and 23); the difference in contrast between the forewings and the hindwings seem generally more pronounced in *sardoa* than in the new species; the dark dash situated between the veins CuA2 and A is less elongated than in *sardoa* (in which this dash extends, almost always continuously, to the medial and antemedial lines) (cf. criterion c on Figures 17, 19 and 23). On the underside of forewing, the lighter subterminal band, bending towards the costa below the apex, is absent in *sardoa* (compare Figures 18, 20 and 24 with Figures 22 and 26, criterion d). The sternum A8 is more elongated than in *sardoa* (cf. Figure 47B, and compare Figure 54 and 55).

The genitalia are very similar to those of *sardoa*. In the male genitalia, the ratio between the length of the coecum and that of the vesica is 2 in the new species but about 1.8 in *sardoa*. The longest cornuti is less elongated than in *sardoa*; it is 2.1 to 2.4 times longer than the smallest, in the new species, against 2.5 to 2.8 in *sardoa* (compare Figures 56-57). The female genitalia of the new species have a wider, less elongated ductus bursae and a less spiny corpus bursae than those of *sardoa*. The ductus bursae of *sardoa* female genitalia have one more twist than that of the new species, and it has longitudinal striations in its anterior part, with a row of minute spines running up the side from the spiny crown of the corpus bursae (no striations or row of spines in the new species) (compare Figures 37-38 with Figures 39-40). The basal part of the corpus bursae without

spines distinguishes *sardoa* and the new species from the three others close species (*pusillata*, *ericeata* and *oxycedrata*).

Genetic data: The initial information that we have gathered using the tools directly available in BOLD show, on the one hand, that the nine Corsican sequences of *sardoa* studied are grouped together in the same BIN (BOLD:AFA0192) and, on the other hand, that the four Spanish sequences of *iberica* sp. nov. are clustered in a different BIN (BOLD:ADZ9010), an interesting result that supports our morphological analysis and the specific separation of the two taxa.

The unrooted Neighbour Joining tree constructed with MEGA11 after phylogenetic inference (Figure 65) shows that the populations of the *sardoa* complex in the broad sense are united in the same clade but are structured into two genetically well differentiated clusters, one grouping individuals originating from Corsica and Sardinia (true *sardoa*) and the other individuals from Ibiza and Tarifa (*iberica* sp. nov.). The patristic distances corresponding to this tree are given in Table 4.

The unrooted Maximum Likelihood tree obtained with MEGA11 after phylogenetic inference (Figure 64) and the associated patristic distances provided in Table 5 show very similar results. We find the same clade bringing together two genetically distinct groups corresponding to *sardoa* and the new species. The main difference between these two trees is the branching of the *oxycedrata* clade, which does not appear to be very robust, as indicated by the absence of a Bootstrap value associated with this node in the Neighbour Joining tree.

Table 4. Pairwise patristic distances between sequences associated to the Neighbour Joining tree of the figure 65. The analyse involved 243 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair (pairwise deletion option). There was a total of 668 positions in the final dataset. Evolutionary analyses were conducted in MEGA11. The mean divergences (%) among members associated with Junipers of the *Eupithecia interruptofasciata* species group are given in bold. The minimum (%) and maximum (%) are given in square brackets. The number of comparisons on which these distances are calculated is given in brackets. The BINs corresponding to the different species are indicated for each one in the first column. Intraspecific distances are shown in grey cells and interspecific distances in the other cells.

	niph / inte	**pusi**	**conq**	**phoe**	**oxyc**	**iber**	**sard**
niphadophilata / *interruptofasciata* BOLD:AAA3835	**0.42** [0.00 – 1.23] (n = 5,995)						
pusillata BOLD:ABZ6329	**2.60** [2.14 – 3.20] (n = 9,900)	**0.24** [0.00 – 1.45] (n = 4,005)					
conquesta BOLD:AFC0556	**5.32** [5.29 – 5.55] (n = 440)	**5.92** [5.48 – 6.30] (n = 360)	**0.00** [0.00 – 0.01] (n = 6)				
phoeniceata BOLD:AAF6413	**5.72** [5.59 – 6.14] (n = 990)	**6.32** [5.77 – 6.89] (n = 810)	**4.39** [4.28 – 4.59] (n = 36)	**0.49** [0.01 – 0.61] (n = 36)			
oxycedrata BOLD:AAB4293	**5.44** [5.30 – 5.85] (n = 1,760)	**6.05** [5.49 – 6.61] (n = 1,440)	**5.40** [5.28 – 5.59] (n = 64)	**5.80** [5.57 – 6.18] (n = 144)	**0.36** [0.00 – 0.91] (n = 120)		
iberica sp. nov. BOLD:ADZ9010	**7.06** [7.02 – 7.32] (n = 440)	**7.67** [7.21 – 8.08] (n = 360)	**7.03** [7.00 – 7.06] (n = 16)	**7.43** [7.29 – 7.65] (n = 36)	**6.37** [6.23 – 6.58] (n = 64)	**0.11** [0.02 – 0.21] (n = 6)	
sardoa BOLD:AFA0192	**6.91** [6.76 – 7.26] (n = 1,100)	**7.52** [6.95 – 8.01] (n = 900)	**6.87** [6.74 – 7.00] (n = 40)	**7.27** [7.04 – 7.59] (n = 90)	**6.22** [5.97 – 6.52] (n = 160)	**6.54** [6.40 – 6.70] (n = 40)	**0.39** [0.00 – 0.96] (n = 45)

Table 5. Pairwise patristic distances between sequences associated to the Maximum Likelihood tree of the figure 64. Analyses were conducted using the Kimura 2-parameter model. The analyse involved 243 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. There was a total of 668 positions in the final dataset. Evolutionary analyses were conducted in MEGA11. The mean divergences (%) among members associated with Junipers of the *Eupithecia interruptofasciata* species group are given in bold. The minimum (%) and maximum (%) are given in square brackets. The number of comparisons on which these distances are calculated is given in brackets. The BINs corresponding to the different species are indicated for each one in the first column. Intraspecific distances are shown in grey cells and interspecific distances in the other cells.

	niph / inte	**pusi**	**conq**	**phoe**	**oxyc**	**iber**	**sard**
niphadophilata / *interruptofasciata* BOLD:AAA3835	**0.43** [0.00 – 1.40] (n = 5,995)						
pusillata BOLD:ABZ6329	**3.21** [2.47 – 4.49] (n = 9,900)	**0.56** [0.00 – 2.61] (n = 4,005)					
conquesta BOLD:AFC0556	**6.82** [6.56 – 7.19] (n = 440)	**7.36** [6.89 – 8.27] (n = 360)	**0.00** [0.00 – 0.00] (n = 6)				
phoeniceata BOLD:AAF6413	**6.83** [6.41 – 7.35] (n = 990)	**7.37** [6.74 – 8.43] (n = 810)	**4.65** [4.50 – 4.80] (n = 36)	**0.42** [0.00 – 0.61] (n = 36)			
oxycedrata BOLD:AAB4293	**6.61** [6.14 – 7.38] (n = 1,760)	**7.15** [6.47 – 8.46] (n = 1,440)	**6.79** [6.58 – 7.19] (n = 64)	**6.79** [6.43 – 7.35] (n = 144)	**0.25** [0.00 – 0.76] (n = 120)		
iberica sp. nov. BOLD:ADZ9010	**9.00** [8.62 – 9.41] (n = 440)	**9.54** [8.95 – 10.49] (n = 360)	**9.18** [9.06 – 9.21] (n = 16)	**9.18** [8.91 – 9.37] (n = 36)	**7.79** [7.46 – 8.22] (n = 64)	**0.08** [0.00 – 0.15] (n = 6)	
sardoa BOLD:AFA0192	**8.89** [8.42 – 9.85] (n = 1,100)	**9.43** [8.75 – 10.93] (n = 900)	**9.06** [8.86 – 9.66] (n = 40)	**9.07** [8.72 – 9.82] (n = 90)	**7.67** [7.26 – 8.67] (n = 160)	**6.29** [5.98 – 6.93] (n = 40)	**0.34** [0.00 – 0.95] (n = 45)

The mean evolutionary divergence of the DNA barcodes of *sardoa* and *iberica* sp. nov. is more than 6% (see Tables 4 and 5), which is:

– far greater than the intraspecific genetic variability observed within *sardoa* (less than 0.4% on average) and *iberica* sp. nov. (0.1% on average).

– a divergence greater than the mean genetic distance noted between the DNA barcodes of *conquesta* and *phoeniceata*, for example, two valid species recently distinguished by Tabell et al. (2024) and now well established in specific rank.

– a much higher divergence (at least twice as great) than the mean distance measured between the DNA barcodes of *pusillata* and the *niphadophilata* / *interruptofasciata* complex.

In addition, it is notable that the minimum genetic distance between *iberica* sp. nov. and any of the other species studied here is always greater than the minimum distances observed between this latter and the other species (see Tables 4 and 5).

These genetic results corroborate those obtained from the morpho-anatomical study of the specimens and support our conclusion to separate the *sardoa* populations into two distinct species, one inhabiting mainly Sardinia, Sicily, the Italian western coast and Corsica (*sardoa*) and the other inhabiting the Balearic Islands and southern Spain (*iberica* sp. nov.).

Biology and distribution

Biology: This new species seems to have two generations (as *E. sardoa*), the first in early spring (particularly from the end of March until early May, with a peak in abundance around mid-April) and the second in early autumn (first half of October), according to the few data we have in the current state of our knowledge (Figures 66 and 67A). It is associated with sandy Mediterranean scrubs in which *Juniperus* are found, particularly *Juniperus* sp. *cf.* group *phoenicea* (Figure 74) and/or *J. macrocarpa* (Figures 71-

72), which could be its food plants, but the first stages are unknown. The sites where the new species were observed have slightly different habitats, but what they have in common is the presence of *Juniperus*. On the island of Ibiza, the species can be found until inland (Figure 69 for example), at altitudes of over two hundred meters, according to the observations we are aware of. The three localities known so far in mainland Spain are dunes or sandy places directly to the coast in ten to forty meters altitude (Figure 70 for example), which resembles the habitats in which *sardoa* occurs; it is interesting to note that these three sites coincide with the distribution of endemic association *Rhamno oleoidis-Juniperetum macrocarpae* Rivas-Martínez, 1965, along the Atlantic coast of Andalusia, where the largest populations of *J. macrocarpa* of the Iberian Peninsula are found (Diez-Garretas et al., 2022, p. 398 [figures 1 and 2], 401-402).

E. iberica sp. nov. does not appear to coexist with *sardoa*, which appears as a strictly coastal species, this latter growing on *J. macrocarpa*, a particular *Juniperus* adapted to coastal sandy sites (see below).

Distribution (Figure 68): Only known today from Ibiza (Figure 68B) and southernmost mainland Spain west of Tarifa (Figure 68C). It should be noted that the Spanish specimens from Punta Paloma, west of Tarifa, is located in the Strait of Gibraltar, on the Atlantic coast. In addition, there may have been or could have been some populations along the Spanish Mediterranean coast but if there were favourable habitats there in the past, then they have probably been destroyed (there seem to be very few potentially suitable places left today, based on a quick examination of satellite photos of this coast). There is a potential site with protected coastal dunes near Marbella (Andalusia, between Málaga and Gibraltar); unfortunately, the fourth author wasn't managed to get there at the right time (he only tried at the beginning of December without success, perhaps it was already too late in the year). It would also be interesting to look for the new species in the stabilised coastal dunes of the Albufera Natural Park, close to El Saler beach, south of Valencia, where *Juniperus macrocarpa* sub-association (*Phillyreo angustifoliae-Rhamnetum angustifoliae juniperetosum macrocarpae* Costa & Mansanet, 1981) occupies the dunes affected by sea air (see Diez-Garretas et al. 2022, p. 400 [figure 4] and 402).

Francesc Vallhonrat collected one male and two females of an *Eupithecia* that he identified as *sardoa* in Ibiza at the end of March 2011. These observations were published by Vallhonrat et al. (2011, p. 71), enabling them to confirm the presence of *sardoa* in the Balearic Islands (see below) and to add this species to the Ibiza's fauna. With the hindsight we today have, thanks to the fact that we have had access to true *sardoa* from Corsica, we can conclude that these specimens from Ibiza collected by Vallhonrat in 2011 most probably do in fact belong to *iberica* sp. nov., but this would require re-examining these specimens, which unfortunately were not figured in Vallhonrat's paper, to know for sure. We reproduce here the collection data associated with these three specimens from Ibiza: Forn des Saig, Santa Eulària des Riu, alt. 240 m, 26-III-2011, 1 ♀; Puig des Fornàs, Sant Rafel, alt. 220 m, 27-III-2011, 1 ♀; Puig de Cas Jai, Santa Agnès de Corona, alt. 220 m, 28-III-2011, 1 ♂ (all Vallhonrat *leg.*). These three sites are located in the interior of the island, not on the coast, which seems consistent with the second author's observation at Sant Llorenç de Bàlafia.

We were unable to examine the specimens associated with the Majorcan citations of *Eupithecia sardoa*: Riddiford (2002, p. 56, according to Barry Goater) and Mironov (2003, p. 144, also according to Barry Goater's data); this Majorcan record is however represented by a question mark on the map proposed by Mironov on page 143. Redondo et al. (2009, p. 235), treat the species *E. sardoa* in their work relating to the Geometrid moths of the Iberian-Balearic area on the sole basis of these two previous bibliographical references for Mallorca, which could therefore in all likelihood in fact concern the new species (in which case *E. sardoa* would be to exclude from the Iberian-Balearic fauna), without us being able to affirm it however (see also below); it should be noted indeed that the coastal dune habitat at this site seems to correspond fairly well to those where *sardoa* flies in Corsica or Italy.

Discussion

The tribe Eupithecinii comprises almost 1,900 species in the World and includes forty-seven genera, the largest of which is *Eupithecia* Curtis, 1825, that is also the most species-rich of the family Geometridae, with nearly 1,500 species (Mironov, 2014, p. 105). This high level of diversity continues to grow thanks to regular descriptions of new species, including in Europe, as for example the description of *Eupithecia gypsophilata* from Spain by Skou et al. (2017).

The *interruptofasciata* species group was introduced by Bolte (1990) after examining two North

American species (*E. interruptofasciata* Packard, 1873, and *E. niphadophilata* (Dyar, 1904)) and one European species (*E. pusillata*), all three associated with Juniper trees. According to Mironov (2003) and Mironov & Galsworthy (2014), this group included twenty-three species at that time: fourteen in Europe (*cocciferata* Millière, 1864, *abbreviata* Stephens, 1831, *lentiscata* Mabille, 1869, *dodoneata* Guenée, [1858], *reisserata* Pinker, 1976, *massiliata* Dardoin & Millière, 1865, *extremata* (Fabricius, 1787), *scopariata* (Rambur, 1833), *pusillata*, *sardoa*, *ericeata*, *phoeniceata* (Rambur, 1834), *oxycedrata* and *rosmarinata* Dardoin & Millière, 1865), two in northern Africa (*rusicadaria* Dietze, 1910, and *rhoisata* Chrétien, 1917), at least five in Asia (*dubiosa* Dietze, 1910, recently discovered also in Europa on the island of Samos (Müller et al. 2019, p. 547), *maerkerata* Schütze, 1938, *kozlovi* Viidalepp, 1973, *exrubicunda* Inoue, 1988, and *masuii* Inoue, 1980) and, so, two in northern America (*interruptofasciata* and *niphadophilata*). Very recently, an additional and unexpected species was described in this species group by Tabell et al. (2024): *Eupithecia conquesta* Tabell & Junnilainen, 2024, from Cyprus, close to *E. phoeniceata* and *E. oxycedrata*.

The discovery of *E. iberica* sp. nov. was just as surprising as that of *E. conquesta*, especially as they both concern the same species group and, within that, the same set of Pug moths associated with *Juniperus* (we can make the hypothesis indeed that *conquesta* is dependent on the Juniper trees as its sister species *phoeniceata*).

A few years ago, this group of species had already provided a surprise when the presence of *E. pusillata* was detected for the first time in Canada (in and around Vancouver) thanks the DNA barcodes (deWaard, 2010), whereas this Euro-Siberian Pug moth - which is widespread throughout Europe, including Iceland, and reaches the Kamchatka and the Sakhalin Island, in Asia - had previously only been known, in North America, from south-west Greenland (Mironov, 2003). This late discovery is probably partly explained by the fact that *E. pusillata*, *E. interruptofasciata* and *E. niphadophilata* form a complex of three particularly similar species, which are very difficult to identify on the basis of their wing patterns. This is often the case with the Pug moths in general. Therefore, examination of the male 8th sternite and genitalia, the female genitalia or DNA barcodes may prove decisive in making a reliable identification.

The relatively substantial differences noted by Tabell et al. (2024) between the male and female genitalia of *conquesta* and *phoeniceata* appear sufficient for a reliable determination of these two species with very similar wing patterns. It is quite surprising to see that the differences we described above between the male and female genitalia of *sardoa* and *iberica* sp. nov., two species that are also very similar in appearance, are more tenuous than those between *conquesta* and *phoeniceata*, even though the genetic divergence of DNA barcodes is much higher between *sardoa* and *iberica* sp. nov. than between *conquesta* and *phoeniceata*.

About *Eupithecia sardoa* Dietze, 1910

The history of the discovery and knowledge of *E. sardoa*

The first to reveal the existence of *Eupithecia sardoa* is its author Dietze (1910, pl. 77, fig. 703 and 704; 1913, p. 151). This latter describes the moth at the end of the part he devotes to Rambur's *Eupithecia oxycedrata*, assuming the species to be new, although he is not entirely sure, since he precedes the mention "spec. nov." with a question mark. Dietze had two specimens labelled "Sassari", which he figures in two black and white photographs in his book. These two Sardinian specimens were very likely bought from a French naturalist and insects' seller, Mr M. Damry († 1903), then based in Sardinia, who captured them most likely in 1896 and sold them to Dietze under the name *oxycedrata*. Indeed, the NHMUK has nine male specimens of *E. sardoa*, from the Charles Oberthür's collection, labelled with the little more detail, as follows: "Ile de Sardaigne - Sassari - Damry 1896". These specimens must have been caught on a beach near Sassari, as Damry (1897, p. 130) reported in his short note about his Lepidoptera hunts in Sardinia: «*Eupithecia oxycedrata* au bord de la mer en avril, sur le genévrier oxycèdre» (= "*Eupithecia oxycedrata* by the sea in April, on a juniper tree"). Since 1870, Dietze had been in possession of four other specimens from a consignment sent by Mabille, specimens that this latter had determined as *oxycedrata* and which he had caught in Corsica (these Corsican specimens most probably come from Porto-Vecchio, see below). On carefully examination of the three males he had of the six specimens in his collection, Dietze was astonished by the dentate antennae of these three individuals, whereas, according to him, neither *oxycedrata* nor any other known *Eupithecia* showed this characteristic. This discovery of dentate antennae in the male, an unusual phenomenon within this genus, enabled him to characterize and describe this species, which he compared to

the taxon *euxinata* Bohatsch, 1893. This author described his *euxinata* as a variety of *oxycedrata* (then valid at subspecific rank after the International Code of Zoological Nomenclature). However, Dietze (1910, pl. 77, fig. 701 and 702; 1913, p. 151) indicated that *euxinata* - that he deals with just before *sardoa* in his book - was not a form of *oxycedrata*, following so the opinion of Petersen (1909, pp. 273-274). Although Dietze thought he was dealing with a new species, he did not exclude the possibility that his *sardoa* might be a form of *euxinata* (in which he had noticed that the antennae were slightly notched). *Eupithecia euxinata* was synonymized with *E. ericeata* by Mironov (2003, p. 144), following a hypothesis that Petersen (1909, p. 274) had already put forward in his time.

Despite the mention by Dietze (1913, p. 151) of the presence of the species in Corsica based on the specimens sent to him by Mabille, Herbulot (1961, pp. 121-123) does not include *E. sardoa* in his list of Geometridae of France. But a few years later, after having taken note of it and intrigued by this passage dealing with Mabille's captures in Corsica in the description of *sardoa* given by Dietze, Claude Herbulot (1968, pp. 245-246) became interested in these Corsican specimens. Paul Mabille (1835 - † 1923) was a great explorer of the Corsican lepidofauna, following in the footsteps of his uncle Pierre Rambur (1801-† 1870). Claude Herbulot bought the collections of these two lepidopterists at the sale of the Léon Lhomme's collection, which included them, in 1953; they are now conserved with his own at the SNSB-ZSM in Munich. In the Mabille's collection that he owned, Claude Herbulot was so able to find three other male specimens of *sardoa*, whose one labelled "Porto-Vecchio" and the two others still labelled "*oxycedrata*". Herbulot was then able to confirm their belonging to *sardoa*. Indeed, these three males, very similar to each other, had dentate antennae and perfectly matched the description given by Dietze. The third author fondly remembers, during his visits, how Claude Herbulot liked to show him his three specimens of *sardoa*, which he considered to be one of the jewels in his collection, so little was known about this moth until the 2000s. Moreover, Herbulot prepared the genitalia of one of them and found that they differed profoundly from those of *oxycedrata*, finding that they were closer to those of *sobrinata* (taxon today considered as synonym of *pusillata*) and *ericeata*. Thus, Claude Herbulot confirmed the integration of this barely known species into the fauna of France.

In this paper published in *Alexanor*, Herbulot (1968, p. 246) included one assertion that today must be cast into doubt. Indeed, Herbulot cited Bitinski-Salz (1934, p. 167), that reported the presence of *E. sardoa* in the interior of Sardinia on the Mount Limbara (where the species would be common in mid-May at an altitude of 1,000 m) and at Aritzo (also at 1,000 m), according Sterneck, but this is most certainly a confusion with *oxycedrata*, as *sardoa* is strictly coastal. During the spring 2002 then in May 2004, in Sardinia, the second author has observed numerous adult moths in several coastal localities:

–Platamona Lido (8 km east of Porto Torres, prov. of Sassari), alt. 5 m, 30-III-2002, two specimens.

–Stagno de Platamona (6 km east of Porto Torres, prov. of Sassari), alt. 5 m, 13-V-2004, fifteen specimens, and 23-V-2004, six specimens.

–Capo Pecora (6 km north of Buggerru, prov. of South Sardinia), alt. 50 m, 15-V-2004, one specimen.

–Portixeddu (5 km north of Buggerru, prov. of South Sardinia), alt. 10 m, 17-V-2004, seventeen specimens.

In 1914, Wagner described a new *Eupithecia* from Tunisia (at originally in the genus *Tephroclystia*, a synonym of *Eupithecia*): *E. peterseni* (Wagner, 1914), which he compared to *E. oxycedrata*. He had obtained the adults in early September thanks to a breeding of caterpillars collected during the previous April month by beating an isolated Juniper tree on a beach in Hammam Lif, a seaside resort near Tunis, the appearance of these caterpillars strongly recalling that of the caterpillars of *sobrinata* (i. e. our *pusillata*). This species *peterseni* was synonymized with *E. sardoa* by Mironov (2003, p. 143).

It was only since Mironov (2003) that the moth finally became better known, especially with regard to its genitalia, because the representation proposed, for the first time, by Wiltshire (1985, p. 169, fig. G) only concerned the female and was a drawing that is not very faithful to reality.

Eupithecia sardoa was discovered on the Tuscan coast in 2000 (nine specimens), and again collected in 2001 (twenty specimens), by using Malaise traps, in the Parco Regionale della Maremma (Dapporto & Strumia, 2004, pp. 170, 178), a place situated just opposite the Bastia area, separated from the eastern Corsican coast by the Tuscan Archipelago. Nappini & Dapporto (2009, pp. 180, 186, 192) also reported the presence of this species several times during a light trapping campaign that they carried out in the same park every month of the year between December 1999 and February 2004; the species was thus observed during the months of March, April, May and October. Still on the Tuscan coast, but about 150 km further north, near Pisa, the

species was discovered in November 2004 in the Riserva di San Rossore, situated in the Parco Regionale di Migliarino-San Rossore-Massaciuccoli, during a trapping campaign carried out between June and November 2004 in a retrodunal station using an automatic light trap fitted with 8 W actinic tube (Dapporto et al. 2005, pp. 23, 25-27, 32, 42). Further south, in the central coastal part of the Italian peninsula, Grassi et al. (2007: 134; fig. 5 and 15), for their part, publish for the first time the presence of *E. sardoa* on the Lazio coast on the basis of old captures (eight specimens collected in 1977 and another in 1979) but also more recent observations (four specimens in 2004 and two in 2005) in the Parco Nationale del Circeo; these authors report the presence of the species during the months of February, March, May, September, October, November and December. While Mironov (2003, p. 144) reported only one generation, in May (according to Tunisian mentions), these different Italian papers show that the species is bivoltine on the west coast of the Italian peninsula, with a first generation in spring and the second in autumn.

At the same time, *E. sardoa* was also reported as new for the Sicilian fauna by Parenzan et al. (2006, p. 64), on the basis of several specimens identified by Axel Hausmann and collected in the Riserva naturale di Vendicari, in the south-east of the island, in January and September 1998, April 1999, November 2000, January and March 2001. These collecting dates show that the species is also bivoltine in Sicily. The second author has found himself two individuals in Sicily, 6.5 km east of Pozzallo, Santa Maria del Focallo, at an altitude of 5 m, on 20 and 21 September 2014; he also has three other Sicilian specimens in his collection, collected 5 km east of Pozzallo, at an altitude of 3 m, on 8 December 2019 (leg. D. Nilsson, C. Hviid & B. Skule).

Although the species had not been mentioned in Corsica since Mabille's historic captures in the 19th century, Jean-Claude Petit was the first to rediscover *sardoa* on the island in 2016 (pers. comm.). He is also the first to observe the first stages (which have never been the subject of a publication in a journal until now), along with its food plant, and to breed the species. Furthermore, the second author discovered one somewhat worn female of *sardoa* during light trapping carried out on 14 May 2017 at Sorbo-Ocagnano along a beach on the east coast, in a site rich in Junipers located as the crow flies some twenty kilometres south of Bastia. This same day, he also found around thirty caterpillars while beating the Junipers on the site, which enabled him to breed the species. At the same place (Figures 76-78), on 12 May 2022, Daniel Morel encountered the moth in large numbers (twenty adults and two caterpillars) and was able to take photos of it in vivo for the first time (Figure 79), which he posted on the *Artemisiae* website devoted to the Lepidoptera of France (Oreina, 2024, online). The third author visited the same Corsican site on 27 October 2022 where he was able to collect both the caterpillars at different stages and the moth simultaneously, which proves that the species is also bivoltine in Corsica, as it is mainland Italy and Sicily. Again, in this sandy site of Sorbo-Ocagnano, two caterpillars were found and photographed by Daniel Morel on 8 January 2023 while beating Juniper trees (*Artemisiae* Website). On 9 October 2023, this latter found *sardoa* in very large numbers during the autumn generation (Figures 80, 82-84), always in the same coastal site, in particular by scouring the dunes with his headlamp (pers. comm.). The following day, he discovered the species at another new site on the east coast, in Aléria (one female, Figure 81, genitalia examined; pers. comm. and *Artemisiae* website).

At the same time, the species was discovered for the first time on the west coast of Corsica, at Palasca, in the Ostriconi dunes to the south-west of the "Désert des Agriates", thanks to the trapping campaign carried out as part of the multidisciplinary "Our Planet Reviewed" mission. Several Malaise traps were installed at this site in October 2020 (Figure 75). The moths collected were stored in alcohol until this material was studied by barcoding in 2022, revealing the presence of *sardoa* in this sector of the island. In addition, the DNA barcodes obtained, which differed from those available for Ibiza (previously associated with *sardoa*) and which did not match any others known, have enabled us to highlight the existence of the cryptic species *iberica* sp. nov. described here.

Summary of current knowledge of *E. sardoa*

Biology: The species seems to fly in two generations. The first runs from the beginning of February (in Lazio), or even from the end of January (in Sicily) to the end of May. The peak of the greatest number of specimens encountered for this spring generation is around mid-May in Corsica and Sardinia. The second runs from mid-September (in the Lazio), or even from early September (in Tunisia) to around mid-December (in Sicily and Lazio). In Corsica, the autumn generation was observed in October; the large number of individuals

seen during this month (particularly during the first fortnight) suggests that October would represent the peak of the flight period of this second generation in Corsica. In summer, neither the adult moth nor the caterpillars seem present (the species is probably in the pupa stage at this time of year).

The phenology (Figures 66 and 67B) of the species is not simple to understand. In Corsica, the presence of caterpillars has mentioned in May, October and January (at the same time as the adults in May and October but not in January); according to the data available, the month of May seems to be a peak in abundance for both adults and caterpillars on this island. In Sicily, adults were observed in early December (2019) and late January (1998 and 2001), a short gap of only about six to seven weeks. Considering all the data available to us throughout its range, adults have been observed from the beginning of September to the end of May. How many generations are there really? Does this number vary according to geographical area? Could there be just one generation between September and May, with emergence staggered over time? Are the Sicilian adults at the end of January the last late arrivals of an autumn generation or the very first of a spring generation? The best hypothesis we can come up with, given the current state of knowledge, is that there are two generations, one in spring and the other in autumn, both spread out over a fairly long period of time (nine to ten weeks at least), with staggered emergence and a possible overlap during the winter.

The absence of autumn data in Sardinia is probably due to a lack of surveys in favourable sites at this time of year. There is no reason why the moth should not fly in autumn in Sardinia.

The eggs are not known, but the other stages have been observed. The caterpillars start life as greenish larvae, later turning green, pinkish brown or brown with a thin white lateral line. According to the rearing carried out by the third author, the light-brown pupa has a dark green underside, is housed in a small silky cocoon in the sand and can remain alive for at least one year if the conditions for emergence are not met.

E. sardoa is strictly adapted to *Juniperus macrocarpa* Sm., 1813 (= *J. oxycedrus* subsp. *macrocarpa* (Sm.) Ball, 1877), a coastal shrub found on dunes and sandy beaches mostly along the Mediterranean coasts but also along the Atlantic coasts of Spain and the Marocco beyond the Strait of Gibraltar. The habitat of *E. sardoa* (Figures 76-78) corresponds to the habitat type of community interest 2250* "Coastal dunes with *Juniperus* spp." of the Council Directive 92/43/EEC of 21 May 1992 (Annex 1). This is a priority habitat of the Directive. More precisely, the habitat of *sardoa* corresponds to the subtype 2250-1 (Corine Biotopes code 16.271 and EUNIS code N1-B21 [previously B1.631], "Dune prickly juniper thickets"). From a phytosociological point of view, this habitat corresponds in Corsica to the association *Asparago acutifolii-Juniperetum macrocarpae* (Molin. et Ro. Molin.) O. Bolòs, 1962. Due to the strong ecological constraints it undergoes (exposure to wind and sea spray, dryness of the substrate), this habitat does not show any dynamics towards a forest stage and generally corresponds to specialized permanent vegetation, most often presenting a subprimary character, in balance with the environmental conditions (Bensettti et al. 2004, p. 333). This habitat is localized and presents a high sensitivity to human impacts such as tourism (wild camping, trampling, motorized vehicle traffic) and urbanization; it is also threatened by the coastal erosion, forest fires or pollutions. The *Juniperus macrocarpa* tree, characteristic of this habitat, is a plant protected in Corsica.

Remark: The species *Eupithecia oxycedrata* is abundant in hilly or mountainous sites, and is related to *Juniperus oxycedrus* L., 1753 (= *J. oxycedrus* subsp. *oxycedrus* L., 1753), but is also found, in smaller numbers, on the coastal sites; for example, Daniel Morel found in May 2022 a female of *oxycedrata* (genitalia examined) on the same day and at the same site where he observed *sardoa*, the caterpillar of *oxycedrata* can therefore also live on *J. macrocarpa*.

Distribution (Figure 68): *E. sardoa* is a Central Mediterranean species; it is a Thyrrenian species, but not strictly. It is found very locally on the coasts of Corsica, Sardinia, Tuscany, Lazio, Sicily and North Africa where the species has been found in Tunisia. As far as we currently know, its range and that of *iberica* sp. nov. do not appear to overlap. Thus, *sardoa* and *iberica* sp. nov. seem to be two closely related species occupying the same ecological niche but in geographically distinct distribution areas (allopatry) and are therefore likely two vicariant species.

In the Balearic Islands, *E. sardoa* has been reported from Mallorca, on the northeast coast of the island, in the Parc Natural de s'Albufera, which is home to dune habitats. This mention, prior to 1998, published by Riddiford (2002, p. 56) as new for Spain, provides from Barry Goater. It is also based on Barry Goater's observation that Mironov (2003, p. 144) refers to the presence of the species on this island, although he displays a question mark on the map he proposes for this species (p. 143). These two bibliographical references were later taken up by Redondo et al. (2009, p. 235), who show on the map that they propose two

distinct points, not even located in the Park of s'Albufera, even though these two mentions a priori refer to the same observation by Barry Goater in this park. Few years ago, the second author asked Mironov why he had put a question mark over Mallorca, since Barry Goater had dissected the specimen, and Mironov replied that the reason was he had not been able to see this specimen for himself. Today, the collection of Barry Goater, died in the summer of 2022, is conserved in the Natural History Museum of Denmark in Copenhagen. In addition, Martin Honey has visited and collected in Mallorca several times and has got the species there. In an email to the second author, Martin Honey wrote: "Mallorca, Parc Natural de s'Albufera, Es Comú, 22-X-2003 (M. R. Honey and N. J. Riddiford) - confirmed by genitalia". We haven't had the possibility to examine these Mallorcan specimens. So, this site, which would be the most westerly locality of the range of *sardoa*, can no longer be confirmed without going back to the specimens because of the discovery and description here of *iberica* sp. nov., a sister species, quite similar in appearance and with close genitalia, found on the neighbouring island of Ibiza. So, it's not unreasonable to think that the species that flies in Mallorca might be *iberica* sp. nov., and not *sardoa*, both species can occur in the same type of coastal sandy habitats, but we can't say so here without further investigation.

The specimens collected in Ibiza and identified as *sardoa* in 2011 by Francesc Vallhonrat most probably belong to the new species *iberica* (see above).

Conclusion

It was unexpected to discover a new species of *Eupithecia* in Europe and, moreover, a sister species to *sardoa*, which we have only known better for a few years. Molecular analyses were particularly helpful in identifying this new taxon, as *sardoa* and *iberica* sp. nov. are morphologically very similar. However, after a thorough re-examination of the habitus and genitalia, we were able to highlight some diagnostic characters, particularly in the genitalia.

It was equally unexpected that this discovery should come at the same time as that of another new species, in the same species group, but in Cyprus, another Mediterranean island.

This recent description of *conquesta* and that of *iberica* sp. nov. here bear witness to the important speciation mechanism at work in the Mediterranean basin within the genus *Eupithecia*. The limited range of other known species, such as *E. sardoa*, *E. poecilata* Püngeler, 1888 (endemic to Corsica and Sardinia), *E. lentiscata* Mabille, 1869, or *E. dubiosa* Dietze, 1910, also supports this conclusion.

With this discovery, the island of Ibiza continues to surprise us, following the recent descriptions of the endemic species *Epirrhoe balearia* Fischer, 2011, and *Peribatodes ebusaria* Vallhonrat, 2012.

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Conflict of Interest

The authors declare that they have no known financial interest or personal relationship that could have influence the work presented in this article.

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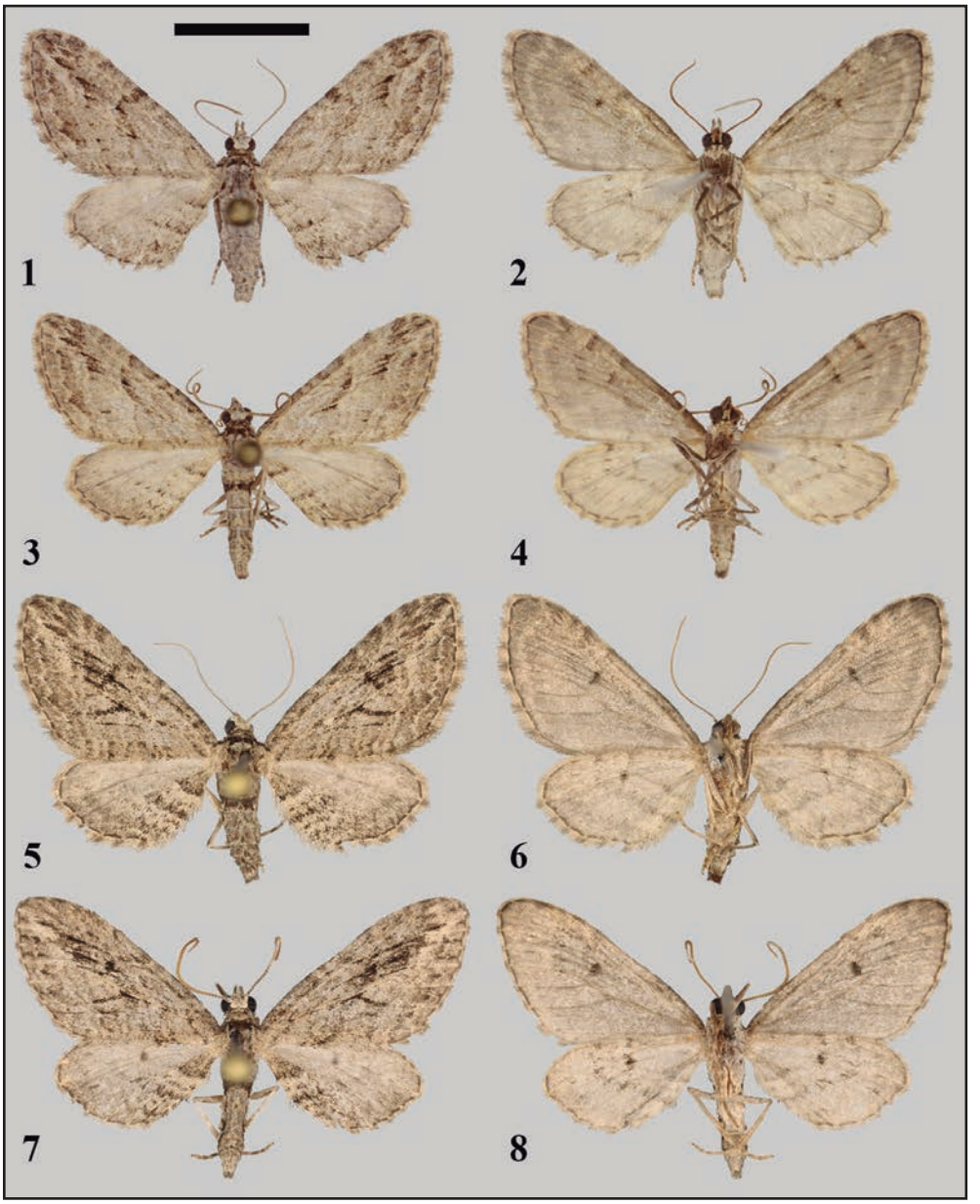
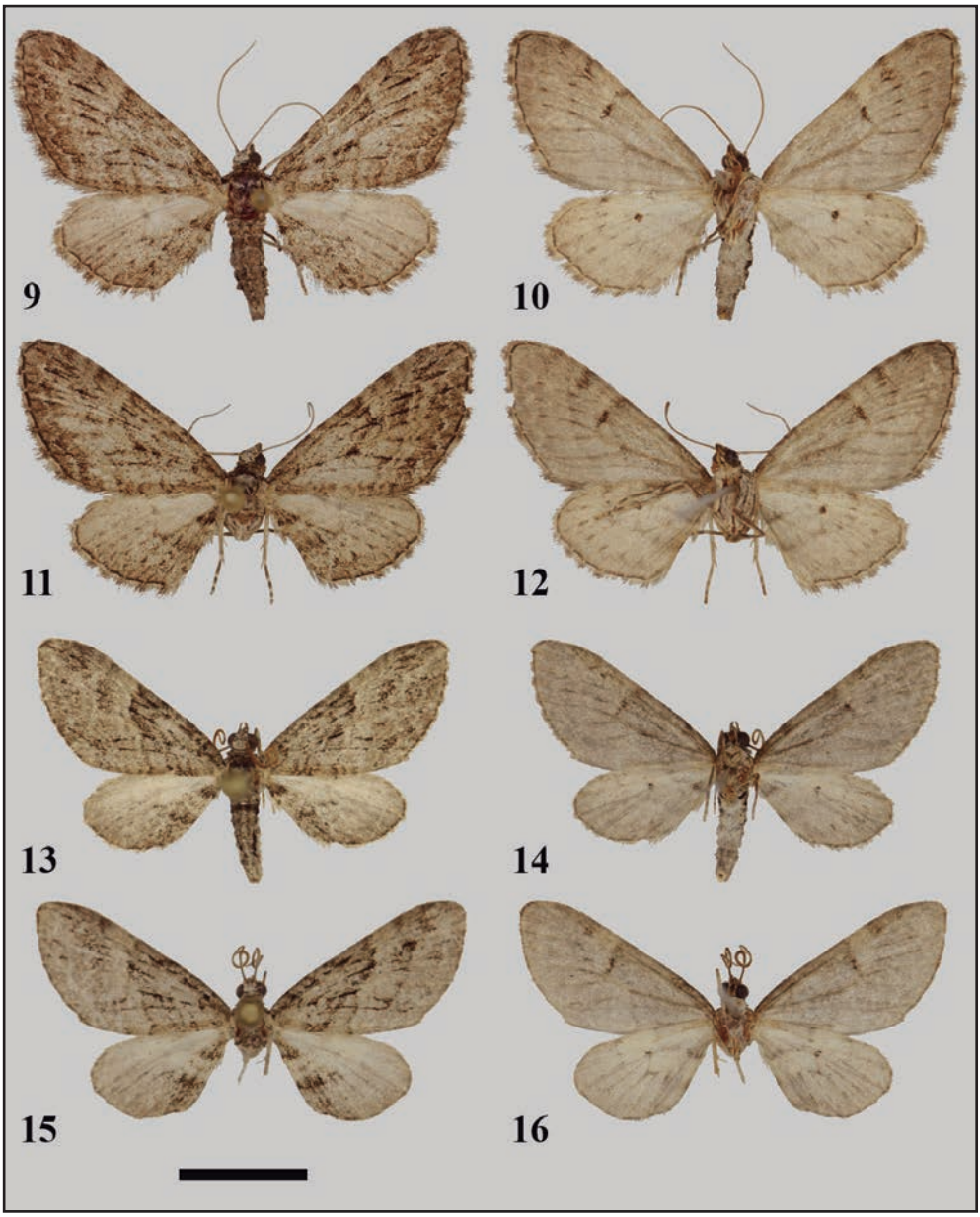
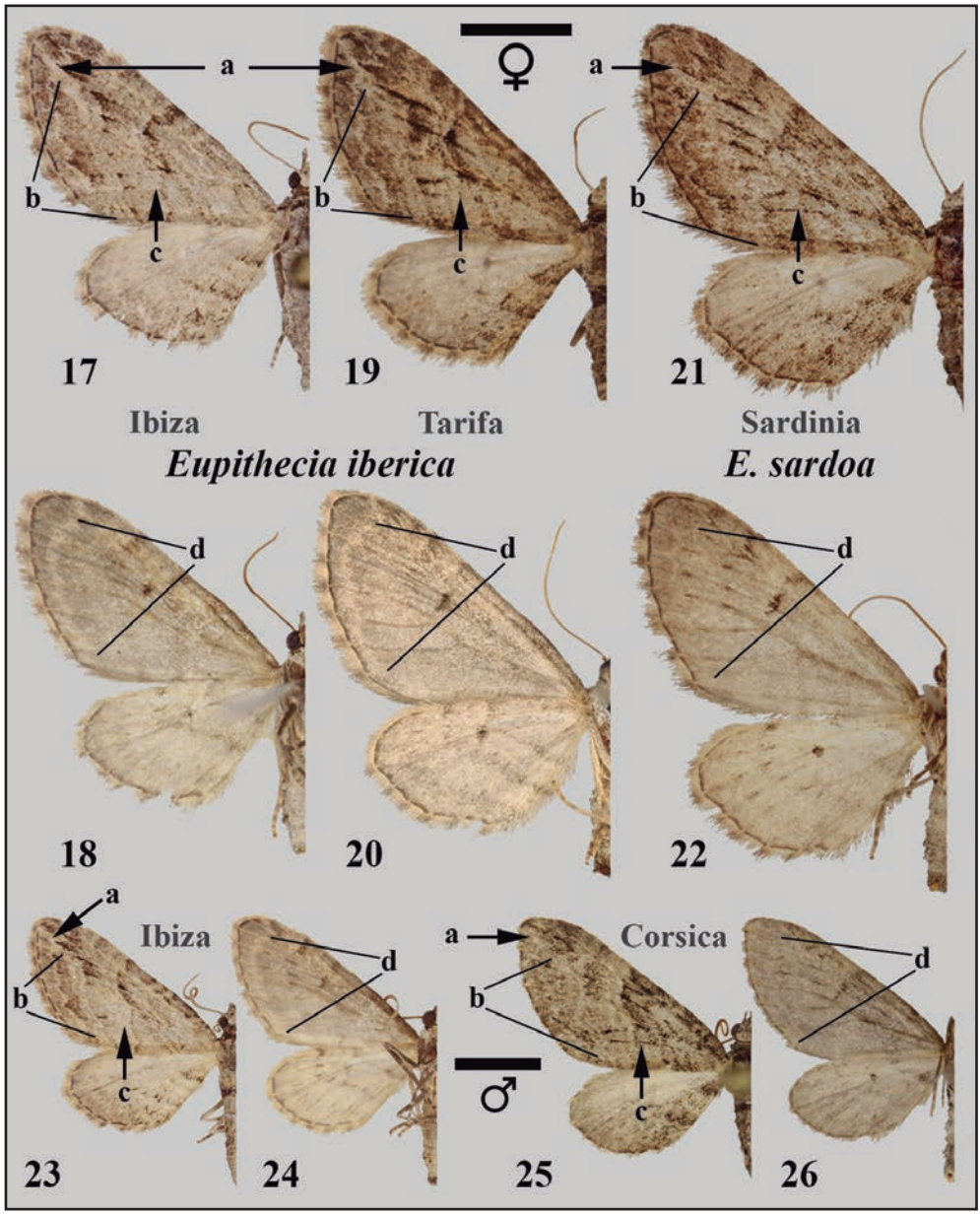
Figures 1-8. *Eupithecia iberica* sp. nov., paratypes. **1-2.** Female, upper and under sides, Ibiza. **3-4.** Male, upper and under sides, Ibiza. **5-6.** Female, upper and under sides, Tarifa. **7-8.** Male, upper and under sides, Tarifa. Scale bar: 0.5 cm (Photos 1-4: Cl. Tautel; 5-8: A. Lévêque).



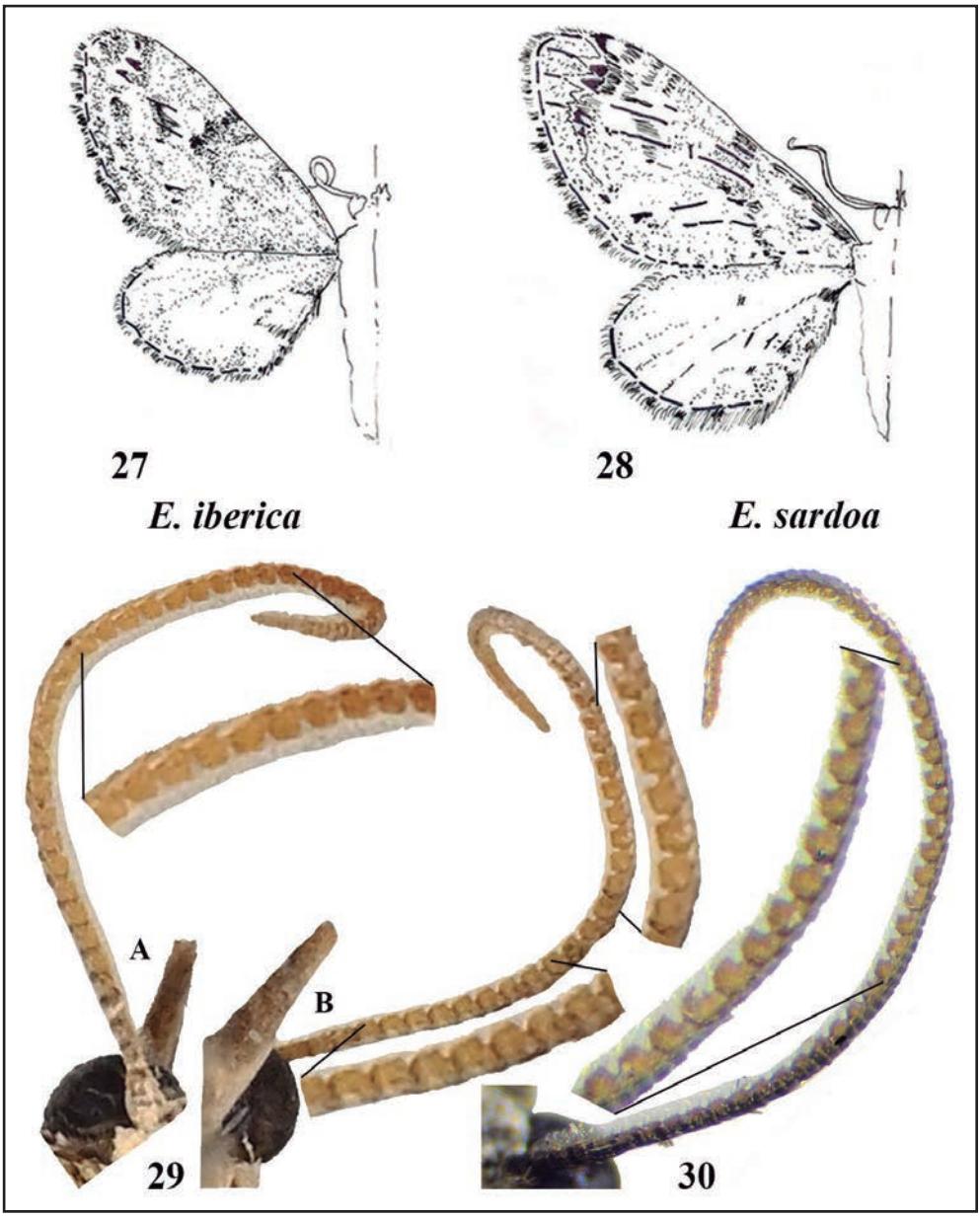
Figures 9-16. *Eupithecia sardoa* Dietze, 1910. **9-10.** Female, upper and under sides, Sardinia, Stagno de Platomona, 23-V-2004, P. Skou leg., slide Cl. Tautel E309. **11-12.** Female, upper and under sides, Sardinia, Stagno de Platomona, 13-V-2004, P. Skou leg., slide Cl. Tautel E200. **13-14.** Male, upper and under sides, Corsica, barcoded specimen nº BC-CT-MNHN0004. **15-16.** Male, upper and under sides, Corsica, barcoded specimen nº BC-CT-MNHN0003. Scale bar: 0.5 cm (All photos: Cl. Tautel).



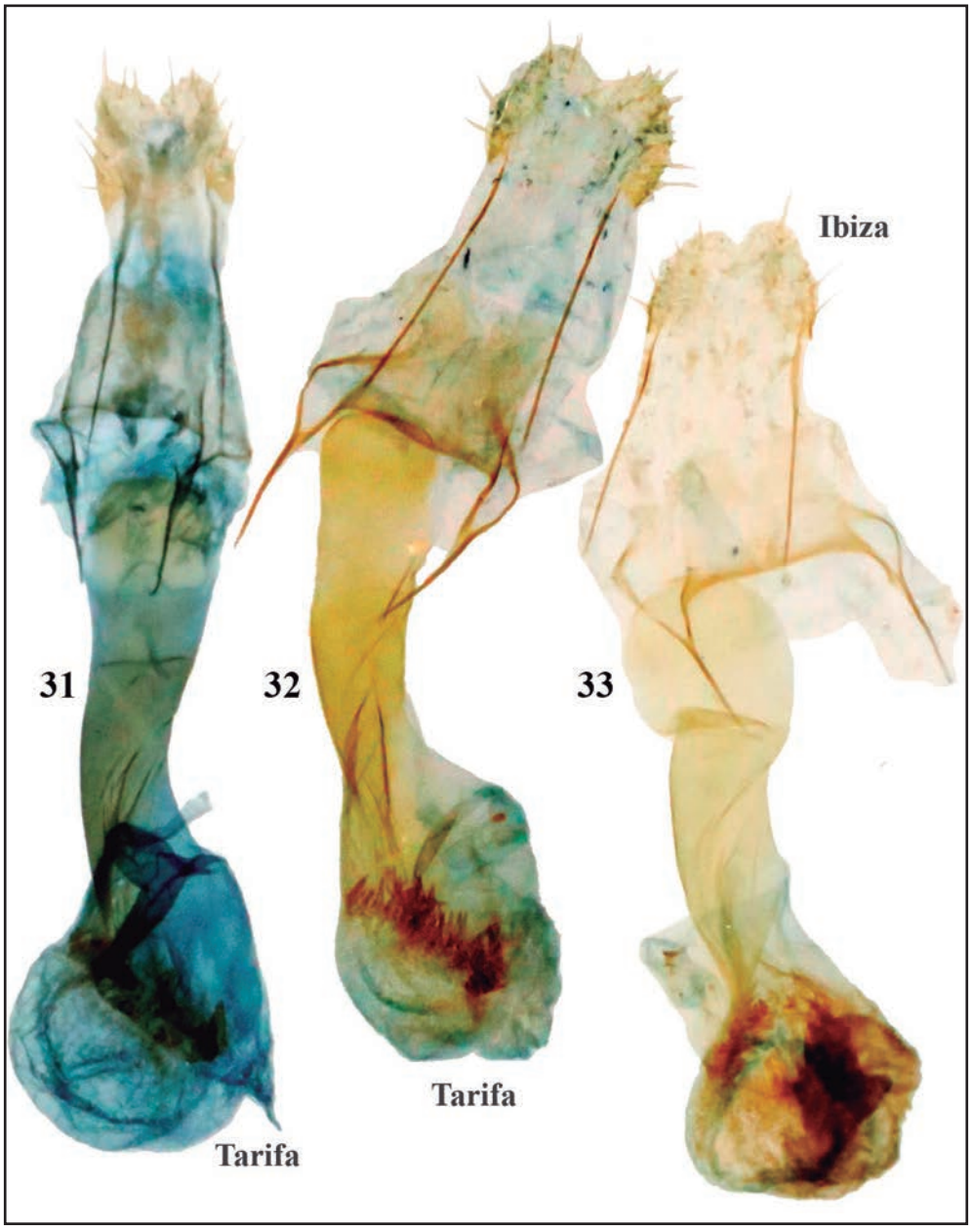
Figures 17-26. Comparison of the habitus of *E. sardoa* Dietze, 1910, and *E. iberica* sp. nov., and highlighting of the main distinctive characters: **a**, apical streak; **b**, light oblique band in the extension of the apical streak; **c**, dark dash between the veins CuA2 and A; **d**, curved subterminal light band on the underside. **17-18.** Same specimen as figures 1-2. **19.** Tarifa, X-2021. **20.** Same specimen as figure 6. **21-22.** Same specimen as figures 9-10. **23-24.** Same specimen as figures 3-4. **25-26.** Same specimen as figures 13-14. Scale bars: 0.3 cm (photo 19: Cl. Tautel).



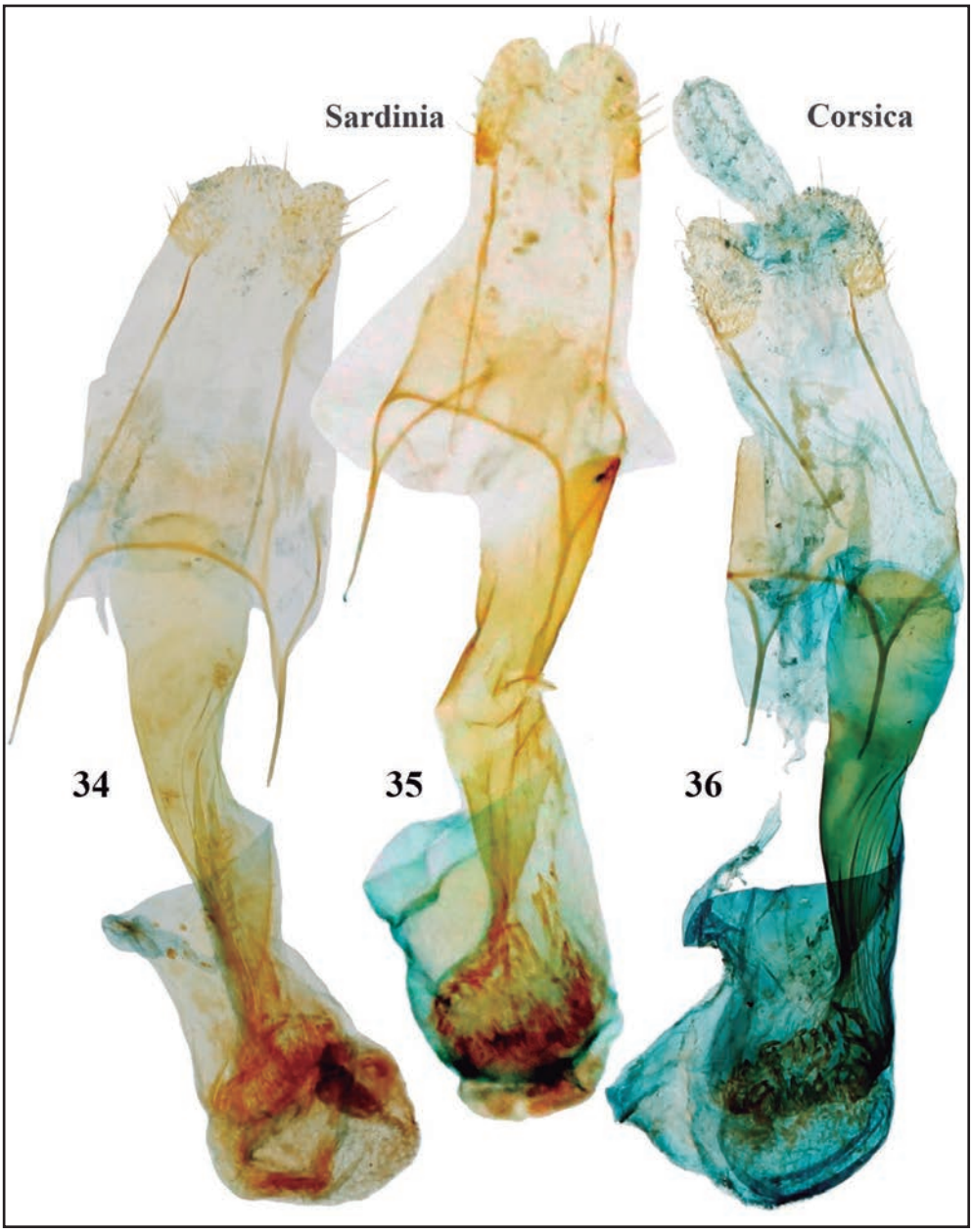
Figures 27-30. Comparison of *E. sardoa* Dietze, 1910, and *E. iberica* sp. nov. **27.** *E. iberica* (after a specimen from Ibiza). **28.** *E. sardoa* (after a specimen from Sardinia). **29.** Zoom on the antenna of male of *iberica*, with two different angles of view (A, dorsal view; B, ventral view), Tarifa (same specimen as figures 7-8). **30.** Zoom on the antenna of male of *sardoa*, Corsica (drawings and photo 30: Cl. Tautel; photos 29: A. Lévêque).



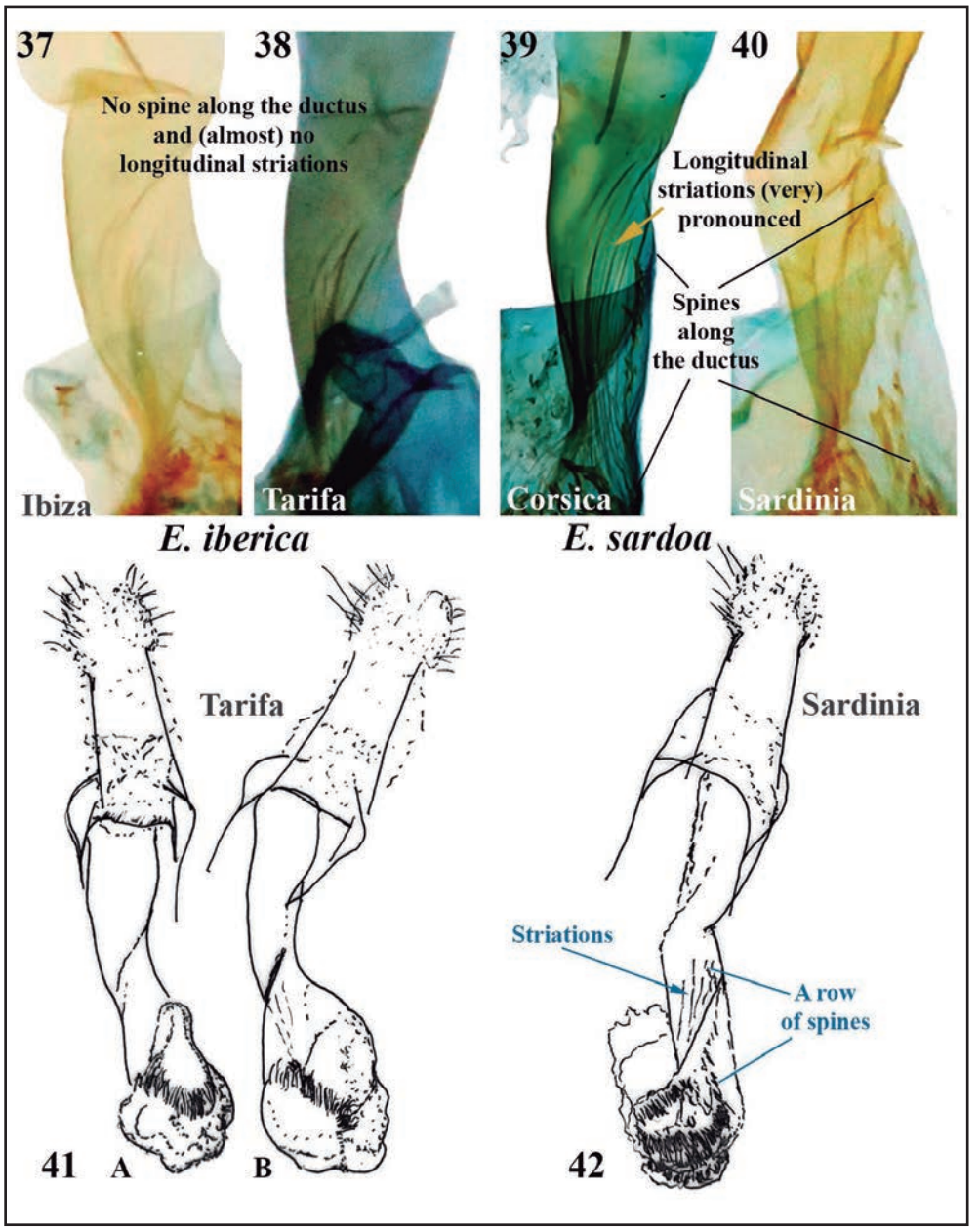
Figures 31-33. Female genitalia of *E. iberica* sp. nov. **31.** Same specimen as figure 5 (slide A. Lévêque AL40). **32.** Same specimen as figure 19 (slide Cl. Tautel E308). **33.** Same specimen as figure 1 (slide Cl. Tautel E306) (All photos: A. Lévêque).



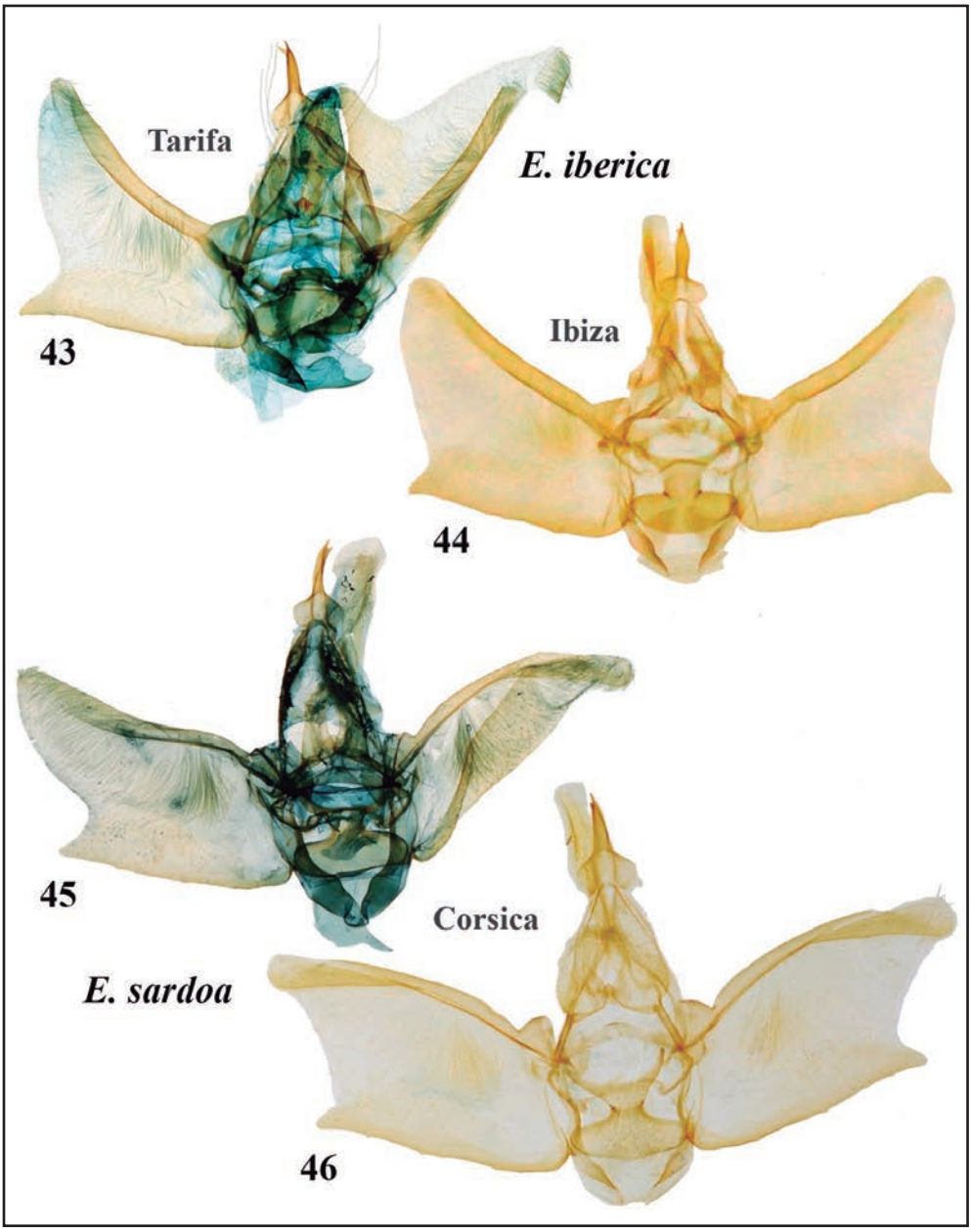
Figures 34-36. Female genitalia of *E. sardoa* Dietze, 1910. **34.** Same specimen as figure 11 (slide Cl. Tautel E200). **35.** Same specimen as figure 9 (slide Cl. Tautel E309). **36.** Barcoded specimen n° LPRC2022-0336, Corsica (slide A. Lévêque AL42) (All photos: A. Lévêque).



Figures 37-42. Comparison of the female genitalia of *E. sardoa* Dietze, 1910, and *E. iberica* sp. nov., and highlighting of the main distinctive characters. **37.** Zoom of figure 33. **38.** Zoom of figure 31. **39.** Zoom of figure 36. **40.** Zoom of figure 35. **41.** *E. iberica*, with two different angles of view (after a specimen from Tarifa). **42.** *E. sardoa* (after a specimen from Sardinia) (All photos: A. Lévêque; all drawings: Cl. Tautel).



Figures 43-46. Male genitalia of *E. iberica* sp. nov. and *E. sardoa* Dietze, 1910. **43.** Same specimen as figure 7 (slide A. Lévêque AL41). **44.** Same specimen as figure 3 (slide Cl. Tautel E307). **45.** Barcoded specimen nº LPRC2022-0338, Corsica (slide A. Lévêque AL43). **46.** Corsica, Sorbo-Ocagnano, 27-X-2022, Cl. Tautel leg., slide Cl. Tautel E199 (All photos: A. Lévêque).



Figures 47-63. 8th abdominal segment, aedeagus and valva of *E. iberica* sp. nov. and *E. sardoa* Dietze, 1910. **47-55.** 8th segment (tergite on the left, sternite on the right): *E. iberica*, whole abdomen (A) and zoom on the 8th sternite (B), slide E307 (47), and slide AL41 (48-49); *E. sardoa*, slides AL43 (50-51) and E199 (52-53); drawings of interpretation of the 8th sternite (54-55). **56-57.** Aedeagus with everted vesica: *E. iberica*, slide AL41 (56); *E. sardoa*, slide AL43 (57). **58-59.** Aedeagus with vesica not everted: *E. sardoa*, slide E199 (58); *E. iberica*, slide E307 (59). **60-61.** Drawings of interpretation of valva of *E. sardoa* (60) and *E. iberica* (61). **62-63.** Interpretation of figures 58-59 (All photos: A. Lévêque; all drawings: Cl. Tautel).

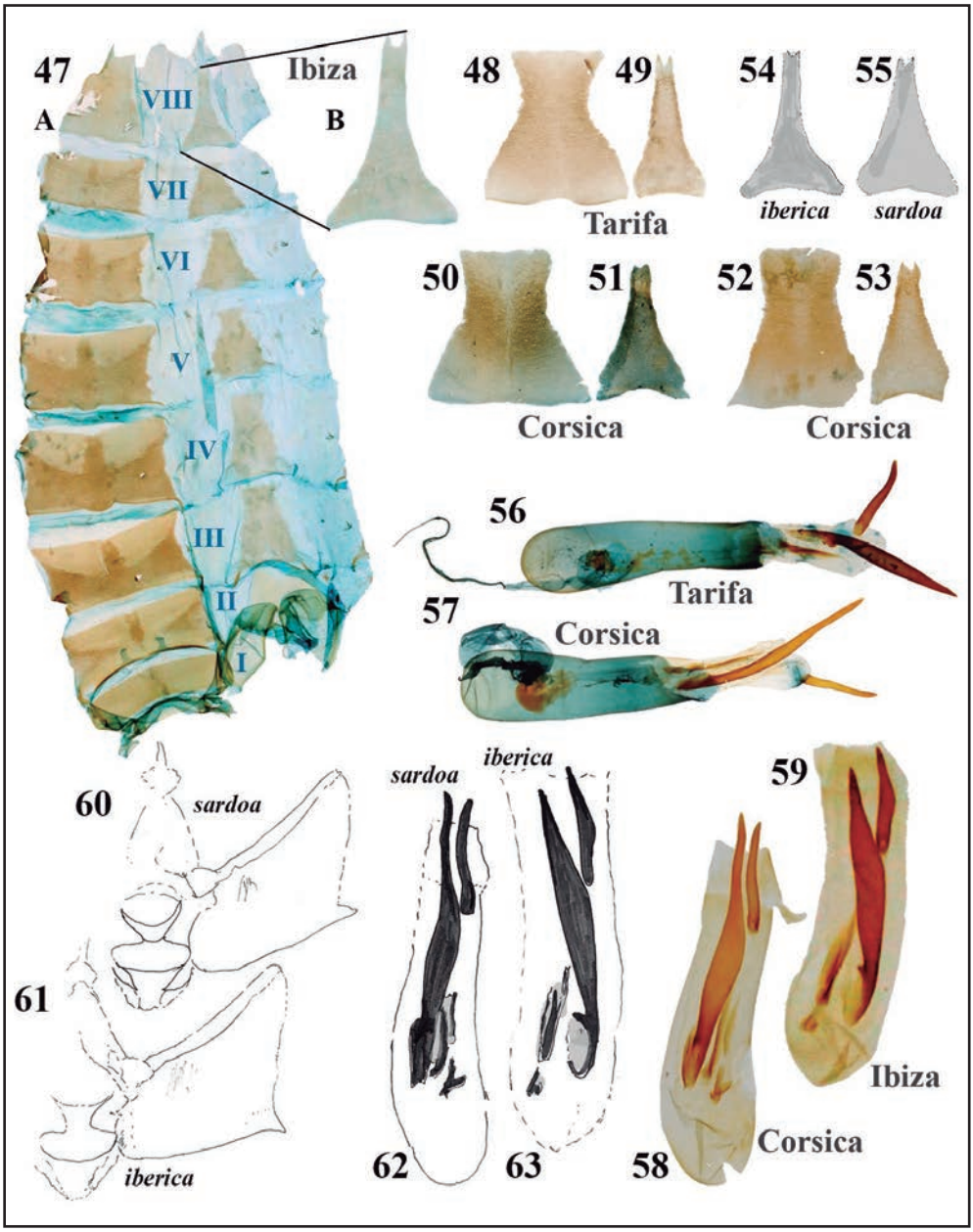


Figure 64. Maximum Likelihood tree reconstructed from 243 records of the *interruptofasciata* species-group for the standard DNA barcode fragment (part of mitochondrial COI gene). The tree with the highest log likelihood (-2,194.09) is shown. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pairwise distances estimated using the Maximum Composite Likelihood (MCL) approach and then selecting the topology with superior log likelihood value. Branch lengths are proportional to the number of substitutions per site (see scale in upper left corner and the grey number above each branch).

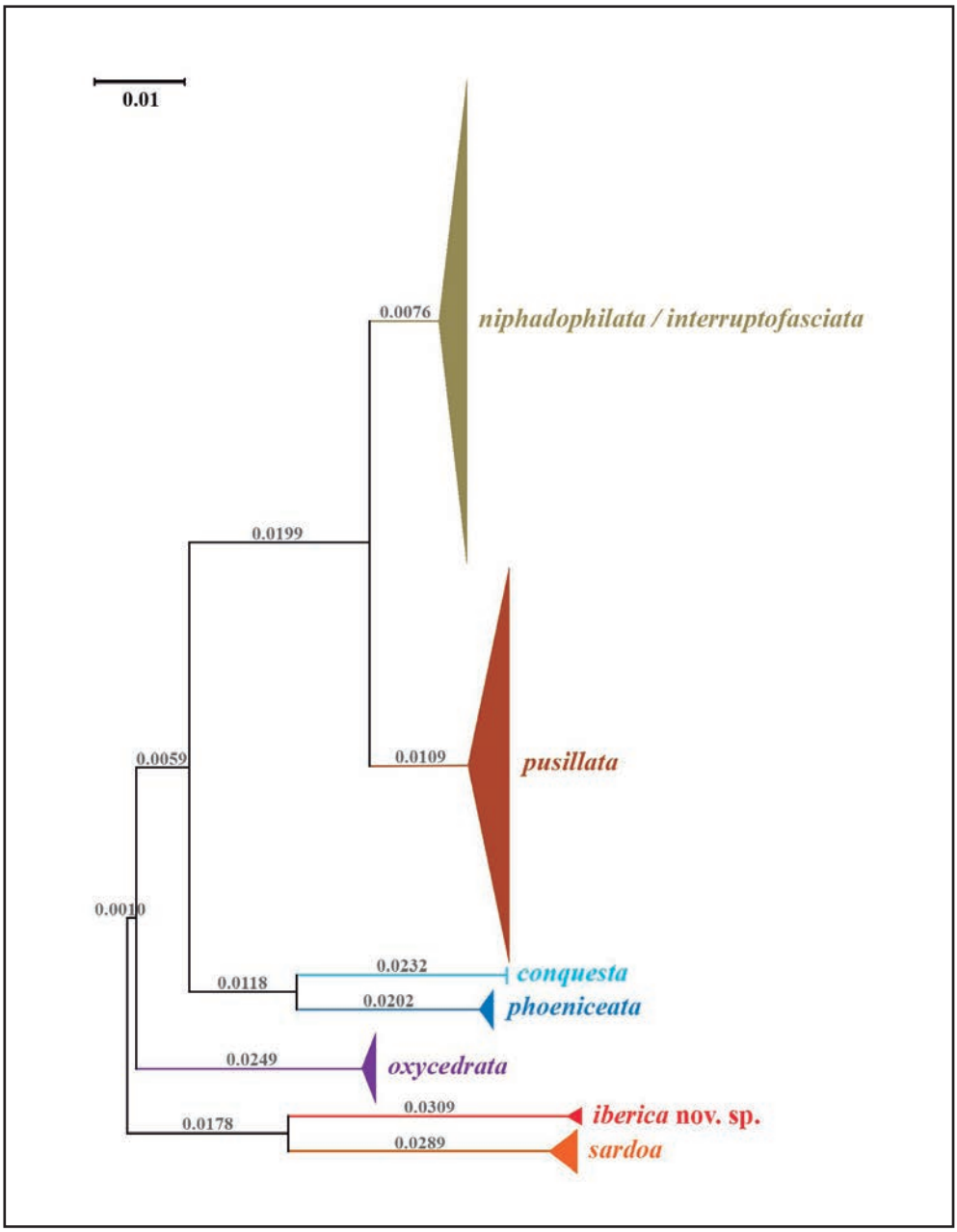
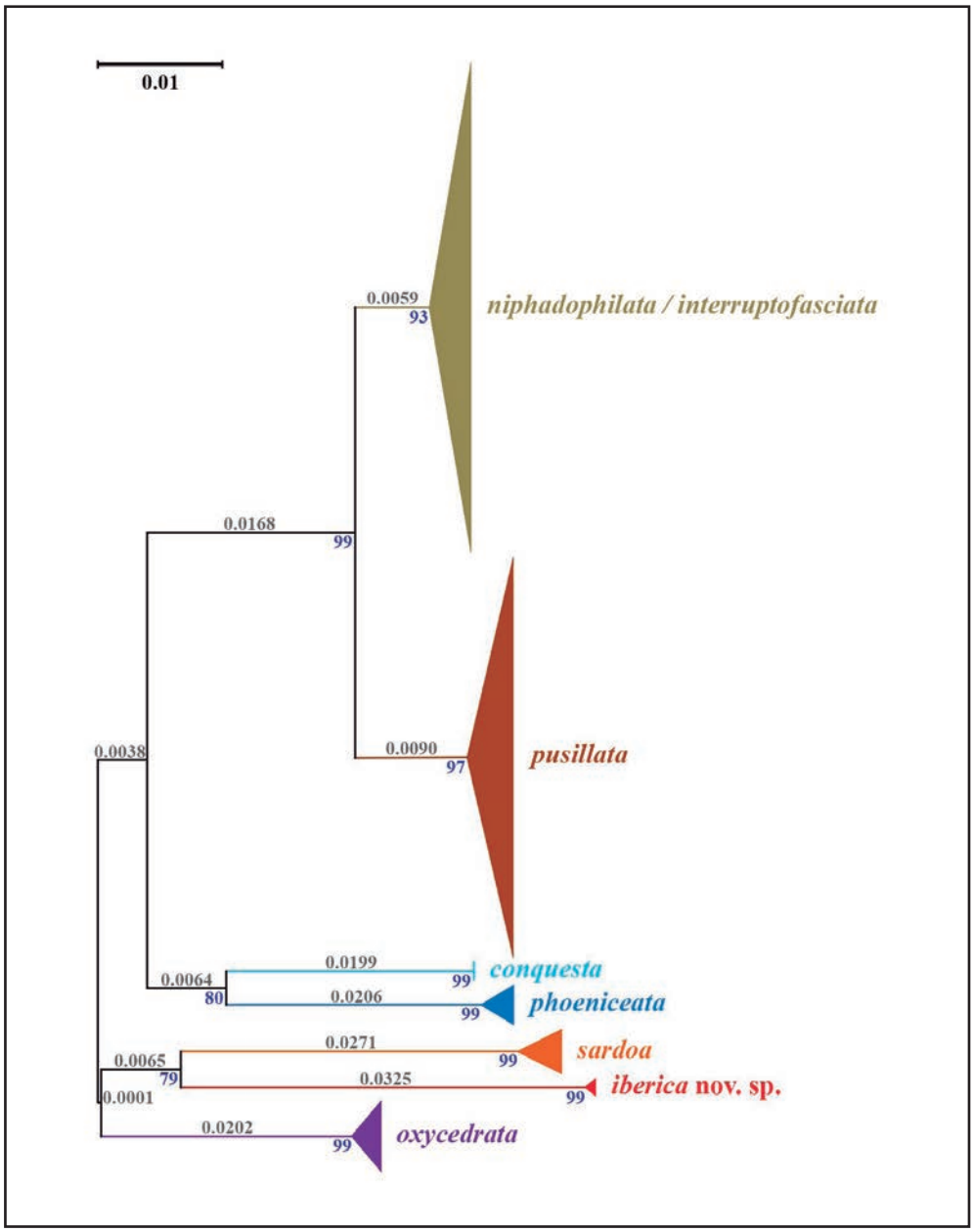


Figure 65. Neighbor-Joining optimal tree reconstructed from genetic distance analysis of 243 records of the *interruptofasciata* species-group for the standard DNA barcode fragment (part of mitochondrial COI gene). Branch lengths are proportional to genetic distance (p-distance; see scale in upper left corner and the grey number above each branch). The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (1,000 replicates) are shown in blue below the branches.



Figures 66-67. Larval phenology and flight period of *E. iberica* sp. nov. and *E. sardoa* Dietze, 1910, based on bibliographic data and our own observations. **66.** Monthly phenology, detailed by territory (*iberica*: n = 15; *sardoa*: n = 38). Larval phenology unknown for *iberica*. **67.** Flight period, detailed by decades (*iberica*: n = 15; *sardoa*: n = 31).

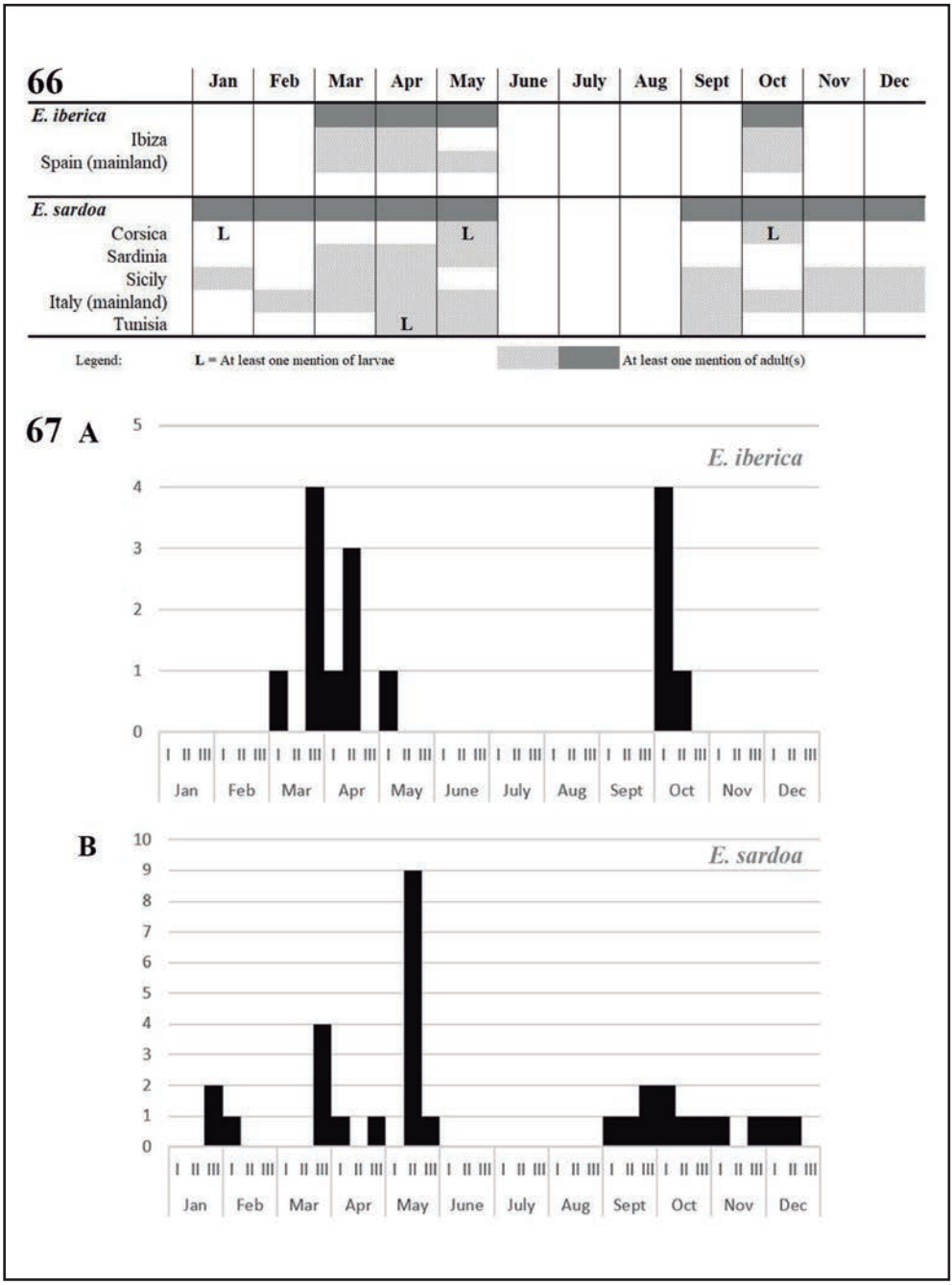
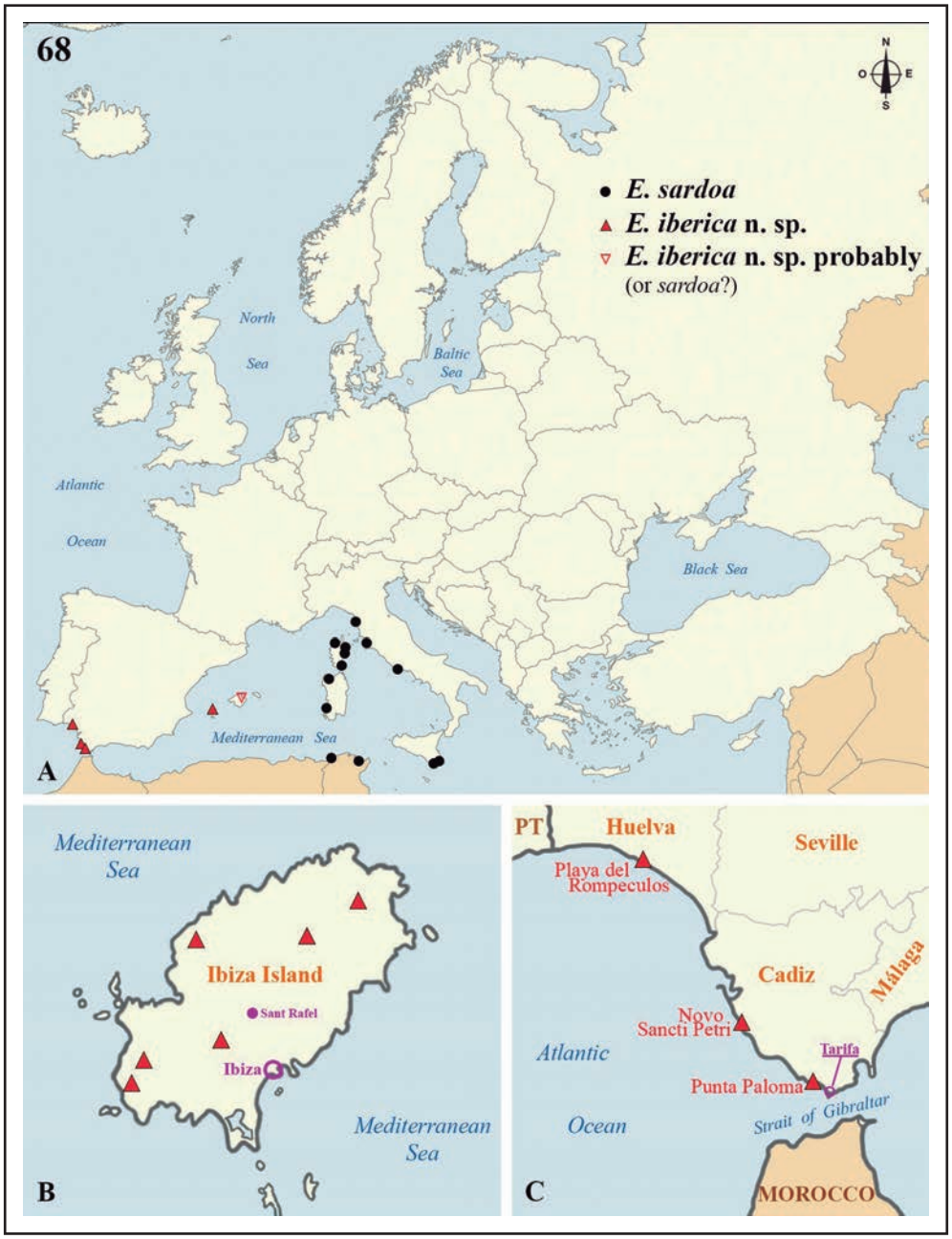


Figure 68. Distribution map of the vicariant species *E. sardoa* Dietze, 1910 (black dots) and *E. iberica* sp. nov. (red triangles). **A.** General map. **B.** Detailed map for *iberica* on the island of Ibiza. **C.** Detailed map for *iberica* in mainland Spain (map design: A. Lévêque, based on bibliographic data and our own observations).



Figures 69-70. Habitat of *E. iberica* sp. nov. **69.** On the island of Ibiza, 1.2 km ENE Cala d'Hort, 3-X-2018 (Photo: P. Skou). **70.** In mainland Spain, near Tarifa, at Punta Paloma, 15-IV-2021 (Photo: T. Ranki).

Figures 71-72. *Juniperus macrocarpa*, presumed host plant of *E. iberica* sp. nov., at Punta Paloma, 16-X-2021. **71.** Overview, in its coastal sandy habitat. **72.** Detailed view (All photos: T. Ranki).

Figures 73-74. Two different Juniper trees, which are present in a mixture at the Punta Paloma site, are likely to be host plants of *E. iberica* sp. nov.: a *Juniperus* sp. nr. *phoenicea* species-group (detailed on the figure 74, 14-IV-2021) and *J. macrocarpa*, 16-X-2021 (Photos: T. Ranki). **Figure 75.** Malaise Trap installed among Juniper trees in the Ostriconi dunes, at Palasca, which captured *E. sardoa*, X-2020 (Photo: Our Planet Reviewed in Corsica).

Figures 76-78. Different views of the habitat and the host plant (*J. macrocarpa*) of *E. sardoa* Dietze, 1910, on the coastal sandy site of Marina di Pinarello, at Sorbo-Ocagnano, Corsica, 16-X-2023 (All photos: A. Lévêque).

Figures 79-84. *Eupithecia sardoa* Dietze, 1910, in natura, Corsica. All at Sorbo-Ocagnano, except nº 81 at Aléria. All in October 2023, except nº 79 in May 2022. **79-81.** Females. **82-84.** Males (All photos: Daniel Morel).