Phytoparasitica (2021) 49:841–849
https://doi.org/10.1007/s12600-021-00923-x

ORIGINAL ARTICLE

Naturalization and spread of the alien species *Ozognathus cornutus* (LeConte, 1859) (Coleoptera: Ptinidae: Ernobiinae) in Italy

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Received: 22 January 2021 / Accepted: 21 April 2021 / Published online: 31 May 2021

Abstract *Ozognathus cornutus* (LeConte, 1859) (Coleoptera: Ptinidae: Ernobiinae), species native to North America, is a saproxylophagous species and is known to feed on decaying tissues within conspicuous galls and on vegetal decaying organic material such as dried fruits or small wood shavings and insect excrements in galleries made by other woodboring species. A few years after the first record in 2011, its naturalization in Italy is here reported. The insect was found as successor in galls of *Psectrosema tamaricis* (Diptera Cecidomyiidae), *Plagiotrochus gallaeramulorum*, *Andricus multiplicatus* and *Synophrus politus* (Hymenoptera Cynipidae). The galls seem to have played an important ecological role in speeding up the naturalization process. The lowest proportion of galls used by *O. cornutus* was recorded for *P. tamaricis* (23%), the only host belonging to Cecidomyiidae, while the percentages recorded for the other host species, all Cynipidae forming galls on oaks, were higher: 43.6%, 61.1% and 76.9% in *A multiplicatus*, *S. politus* and *P. gallaeramulorum,* respectively. Although *O. cornutus* is able to exploit other substrates like dried fruits and vegetables, for which it could represent a potential pest, it prefers to live as a successor in woody and conspicuous galls, which thus can represent a sort of natural barrier limiting the possible damages to other substrates.

Keywords Gall · Biology · Alien species · Successor · Ecological accelerator · Naturalization

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Introduction

The family Ptinidae is distributed worldwide and currently contains about 2200 species in approximately 230 genera (Philips & Bell, 2010; Peris et al., 2020). The genus *Ozognathus* includes 11 species described from North America (3 species), Mexico (2 species), Central America (1 species), Chile (4 species) and Columbia (1 species) (Trócoli et al., 2020). *Ozognathus cornutus* (LeConte, 1859) was firstly described under the genus *Anobium* from insects hatched in great numbers from some galls collected in California (LeConte, 1859), and then transferred to the genus *Ozognathus*, coined just for this species (LeConte, 1862). Few years later, Müller (1873) obtained adults of *O. cornutus* from galls of *Andricus quercuscalifornicus* (Bassett, 1881) (under *Cynips* cf. *californica*), collected in California by the entomologist C. V. Riley, and confirmed the behaviour of *O. cornutus* as a gall-successor. The same author also observed that exit-holes made by the successor were smaller than exit holes of the cynipid gall-inducer. He described the frass, consisting of "isolated brown snuff-like grains" and reported that Riley "documented in notes

and figures the adolescent stages" (Müller, 1873). Moreover Riley (1881) remarked that the beetle bred in the dry galls and still continued its development in galls that were in the cabinet over five years.

Ozognathus cornutus (Fig. 1a–h) is native to North America, and in the last decades its occurrence was recorded in the following countries: Mexico (Philips, 2002), Chile (Honour & Rothmann, 2017), Madeira, Malta and Tunisia (Djerba Island) (Zahradnik & Mifsud, 2005), Spain (Bercedo et al., 2005; Viñolas & Verdugo, 2012; Trócoli et al., 2020; Viñolas, 2020), Germany and France (Allemand et al., 2008; Bathon, 2014), Italy (Cusimano et al., 2014; Trócoli et al., 2020), North Latvia (Telnov et al., 2016), Switzerland (Germann & Schmidt, 2017; Chittaro & Sanchez, 2019), Canary Islands (La Palma, Lanzarote, Tenerife) (García et al., 2016; Viñolas, 2017; Viñolas et al., 2018), United Kingdom (Eccles in Greater Manchester)

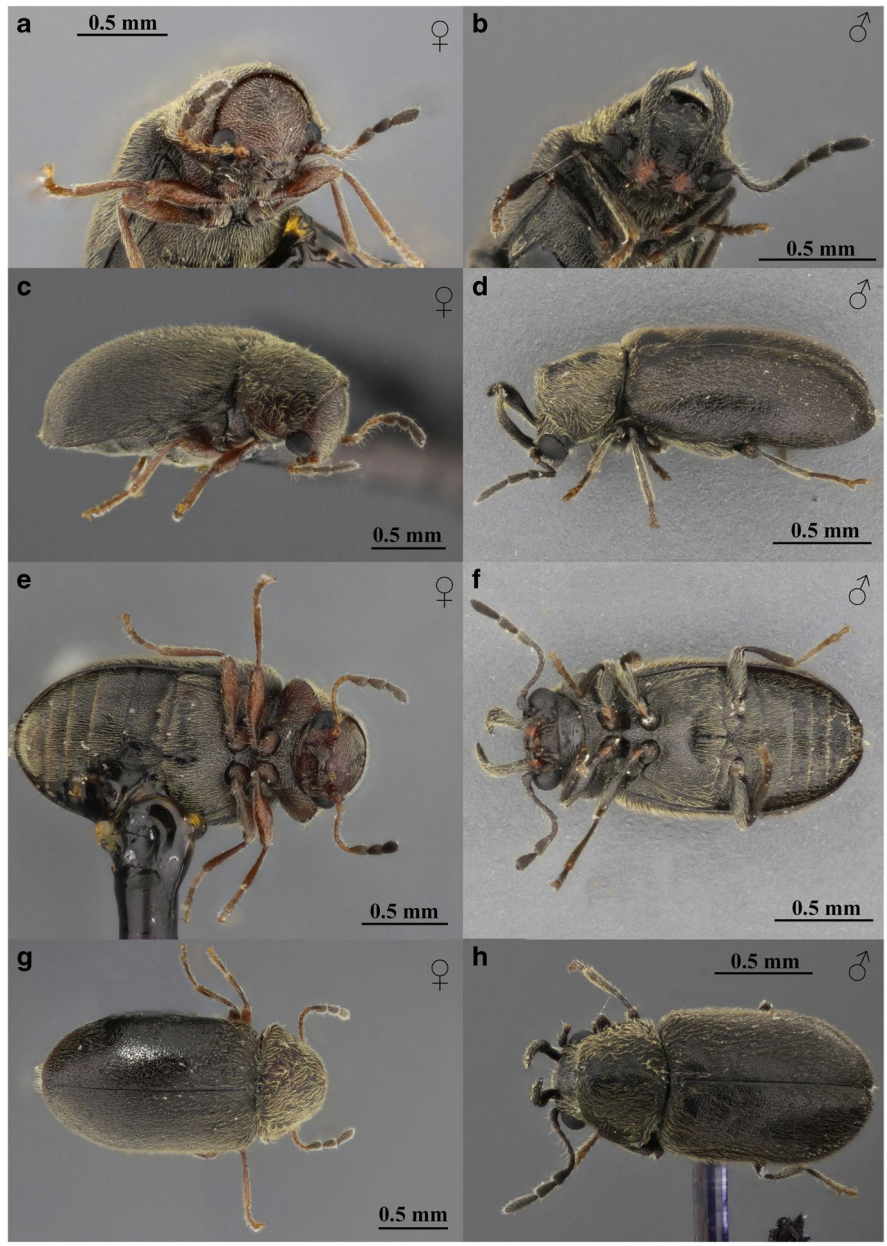

Fig. 1 *Ozognathus cornutus*, male and female: **a–b**. head (front ventral view); **c–d**. body (lateral view); **e–f**. body (ventral view); **g–h**. body (dorsal view)

(Stenhouse, 2017), Israel (Miłkowskio, 2019), Australia and La Reunion Island (Trócoli et al., 2020).

The species was found for the first time in the Palaearctic Region, in Madeira Island, in 1996, later in 2003 in Malta and in 2004 in Tunisia (Zahradnik & Mifsud, 2005). In Italy *O. cornutus* was collected for the first time in February 2011 in Campania and in August 2011 in Sicily, during a sampling performed by means of a Johnson-Taylor suction trap (Cusimano et al., 2014, 2016). Moreover, a female and a male of *O. cornutus* were recently collected in Sicily, at Mazara del Vallo (province of Trapani) on 26 December 2020 and January 2021, respectively (A. Ditta and S. Surdo, pers. comm.).

Galls are abnormal plant growths induced by physical-chemical interactions with other organisms such as insects, mites, nematodes, fungi, bacteria, and viruses and provide the inducers with nutritious tissues and sometimes shelter from natural enemies (Price et al., 1987; Stone & Cook, 1998; Sugiura & Yamazaki, 2009). Gall-inducers are referred to as "ecosystem engineers" because the galls are important resources not only for the cecidogenous, but also for other organisms, generally classified as either: parasitoids, hyperparasitoids, inquilines, cecidophages, predators, successors or symbionts (Sugiura & Yamazaki, 2009). Sugiura and Yamazaki (2009) divide the organism guilds associated with galls into two groups: organisms that interact directly with the inducer (predators, parasitoids, symbionts, and kleptoparasites) and organisms that interact primarily with galls and can interact secondarily and occasionally with gall-inducers (inquilines, cecidophages and successors). Successors use the gall after the emergence of the gall-inducer (Mani, 1964) as shelter or for laying eggs and include, inter alia, mites, spiders, pseudoscorpions, millipedes, thrips, springtails, booklices**,** beetles, earwigs, ants, and grasshoppers (Sugiura & Yamazaki, 2009; Cerasa & Massa, 2016; Luz & Mendonça, 2019).

Three years after the first record for Italy, we obtained adults of *O. cornutus* as successor of galls of Cynipidae and Cecidomyiidae; we describe here some biological aspects and ecological implications of this finding.

Materials and methods

During the years 2013–2016 galls of Cynipidae and Cecidomyiidae were collected on *Quercus coccifera L.* (≡ *Q. calliprinos* Webb), *Quercus suber* L. (Fagaceae) and *Tamarix gallica* L. (Tamaricaceae) in different Sicilian localities; galls were kept at room temperature (15–25 °C) in small plastic boxes covered by tulle until the emergence of the gall-inducers and the other organism guilds associated with them. Adults of *O. cornutus* were examined through a Wild-Heerbrugg M8 stereomicroscope and with a Zeiss Universal Photomicroscope III light. Images of adult insects were taken using a Leica DM2500 compound microscope and a Leica DFC420C mounted camera with Leica Application Suite software. Galls were photographed with a Canon 7D or Canon 350D digital camera provided with a Canon MP-E 65 mm macrolens (Canon Inc., Tokyo, Japan). All photos were integrated using the freeware CombineZP (Hadley, 2011) and processed in Adobe Photoshop. Collected specimens and galls are preserved in the collection of the Department SAAF, University of Palermo and in the collection of Giuliano Cerasa, Giuliana, Palermo (Sicily, Italy). The alternating generation of the life cycle is reported after the specific name of the gall-inducing insect using the following abbreviations: [sex] = sexual generation, [ag] = asexual generation.

Results

We have obtained adults of *Ozognathus cornutus* as successor in galls of the gall midge *Psectrosema tamaricis* (De Stefani, 1902) on *T. gallica*, and of the gall wasps *Plagiotrochus gallaeramulorum* (Boyer de Fonscolombe, 1832) on *Q. calliprinos*, *Synophrus politus* Hartig, 1843 and *Andricus multiplicatus* Giraud, 1859 sexual generation) on *Q. suber*. The development of *O. cornutus* inside galls was confirmed by the presence of its larvae and pupae in *P. tamaricis* and by the size of exit holes of the insect, which are larger than those of the gall inducer species.

Psectrosema tamaricis (De Stefani, 1902) (Diptera Cecidomyiidae).

Material examined. ITALY: Sicily, Palermo, loc. Capo Gallo ex galls of *Psectrosema tamaricis* on *Tamarix gallica*, 4.IV.2016, 9♂ and 6♀ emerged on January 2017 (sample N. 6113, 35 galls) G. Cerasa; ITALY: Sicily, Palermo, loc. Capo Gallo ex galls of *Psectrosema tamaricis* on *Tamarix gallica*, 18.III.2016, 8♂ and 4♀ emerged on January 2017 (sample N. 5979, 38 galls) G. Cerasa; ITALY: Sicily,

Palermo, loc. Capo Gallo ex galls of *Psectrosema tamaricis* on *Tamarix gallica*, 18.III.2016, 4♂ and 2♀ emerged 1.IV.2016–30.V.2016 (sample N. 6012, 47 galls) G. Cerasa; ITALY: Sicily, Palermo, loc. Capo Gallo ex galls of *Psectrosema tamaricis* on *Tamarix gallica*, 18.III.2016, 13♂ and 5♀ emerged 01.IV.2016–30.V.2016, (samples N. 6003, 6004, 5977, 87 galls) G. Cerasa.

The gall described by De Stefani (1902) consists of a widening of the extremity of the branches of *T. gallica*, of a brown-purple color (Figs. 2i, j), often on its surface protrude the apical parts of the squamiform leaves incorporated in the surface itself. Adults of *P. tamaricis* emerge from December until the end of March, often leaving the exuvia protruding from the emerging hole. The galls remain on the plant for several years after the gall inducer emergence. They have a large and elongated larval chamber and over time they take on a woody consistency, leading to desiccation of the terminal part of the twig concerned. The old galls become the ideal refuge for the successor *O. cornutus*; the beetle female with its long ovipositor lays the eggs inside the larval chamber. The successor larvae (Figs. 2k, l) develop inside the galls which they fill with feeding activity residuals; they feed on both the float tissues and the surrounding dead woody tissues by digging tunnels in hard wood. Mature larvae pupate in the large larval chamber of the inductor (Fig. 2m), which is often modified and enlarged by the larva of the successor himself. The adults of *O. cornutus* (Fig. 2n) then chew a rounded hole through which they leave the gall.

Plagiotrochus gallaeramulorum (Boyer de Fonscolombe, 1832) (Hymenoptera Cynipidae).

Material examined. ITALY: Sicily, Palermo, Mt. Catalfano ex galls of *Plagiotrochus quercusilicis* [ag] on *Quercus calliprinos*, 21.III.2013, 6♂ and 4♀ emerged 1–28.II.2014, (sample N. 4266, 13 galls) G. Cerasa.

Plagiotrochus gallaeramulorum induces galls on twigs of oaks from section *Cerris*, *Ilex* group. Galls are conspicuous woody, plurilocular and consist of

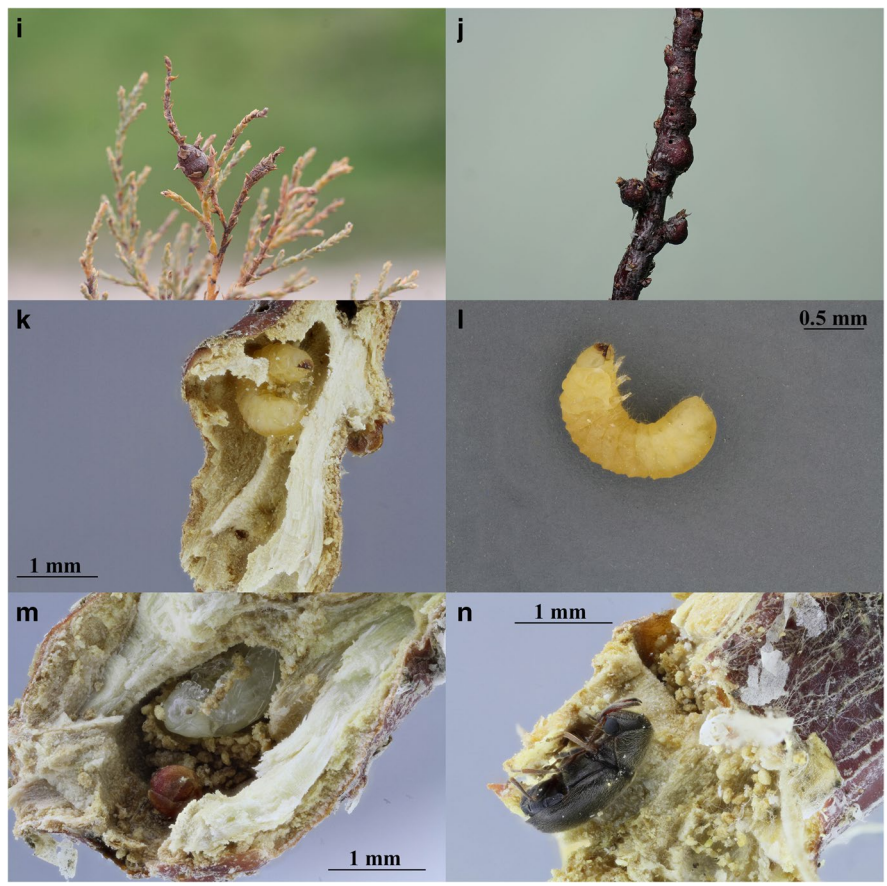

Fig. 2 Galls of *Psectrosema tamaricis* and postembrional stages of *Ozognathus cornutus*: **i–j.** general appearance of old galls; **k**. section of the gall showing the *O. cornutus* larva inside a large and elongated larval chamber; **l**. the same larva extracted from the gall; **m**, pupal stage almost completely surrounded by frass; **n**. newly-emerged adult

an enlargement of the branch assuming a globular or fusiform shape (Figs. 3o, p). *Ozognathus cornutus* lays eggs inside the gall inducer larval chambers, where the successor larvae feed on the woody tissues of the surface creating tunnels that incorporate them (Fig. 3q); the adults then emerge leaving an exit hole significantly larger than the inductor holes (Fig. 3r). *Plagiotrochus gallaeramulorum* was previously reported for Italy by Pagliano (1995) under the synonym *Plagiotrochus kiefferianus* Tavares, 1901 without any locality information, and then found in northern Italy by Tomasi (2013). The present record can be considered the first for Sicily.

This species was supposed to be the probable asexual generation of *Plagiotrochus quercusilicis* (Fabr.) (Askew et al., 2013), which induces galls on oak leaves and catkins. The occurrence of *P. quercusilicis* in Sicily was reported by De Stefani (1898) and recently confirmed (Cerasa, 2015; Cerasa & Lo Verde, 2020).

Synophrus politus Hartig, 1843 (Hymenoptera Cynipidae).

Material examined. ITALY: Sicily, Palermo, Cefalù (PA) ex galls of *Synophrus politus* on *Quercus suber*, 21.III.2013, 8♂ and 3♀ emerged 1–30. IV.2014, (sample N. 5085, 18 galls) G. Cerasa.

The woody gall of *S. politus* is spherical in shape with a diameter of 10–20 mm (Fig. 4s). The gall has a single large central larval chamber with a very hard wood wall. Larvae of *O. cornutus* developing inside galls enlarge the originary larval chamber and produce a tangle of frass.

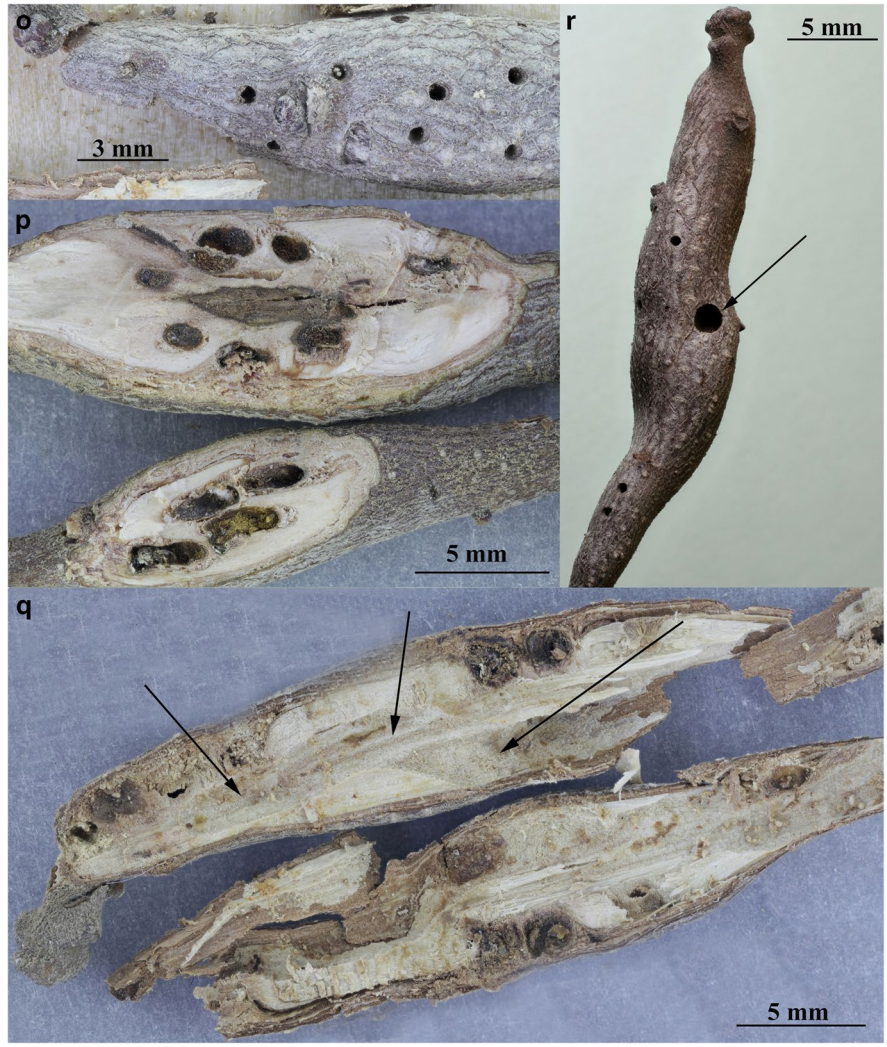

Fig. 3 Plurilocular galls of *Plagiotrochus gallaeramulorum*: **o**. general appearance of old galls with small emergence hole of the gall-inducer; **p**. larval chambers of the gall-inducer; **q**. section of the same gall, the arrows indicate the tunnels made by *O. cornutus* in the hard woody tissues of the gall; **r**. gall from which both the gall inducer (small holes) and the successor *O. cornutus* (large hole) emerged

Fig. 4 **s.** Old gall of *Synophrus politus* on *Quercus suber*; **t–v**. galls of *Andricus multiplicatus*: **t**. general appearance of old galls; **u**. the arrow indicates the large emergence hole of *Ozognathus cornutus*; **v**. section of the gall from which *O. cornutus* emerged, the arrows indicate the presence of frass in the interstices between the galls

Andricus multiplicatus Giraud, 1859 [sex] (Hymenoptera Cynipidae).

Material examined. ITALY: Sicily, Palermo, Cefalù (PA) ex galls of *Andricus multiplicatus* on *Quercus suber*, 11.VII.2013, 4♂ and 6♀ emerged 1–31.III.2014, (sample N. 4801, 25 galls) G. Cerasa; ITALY: Sicily, Palermo, Cefalù (PA) ex galls of *Andricus multiplicatus* on *Quercus suber*, 11.VII.2013, 6♂ and 8♀ emerged 10–31.III.2014, (sample N. 4827, 30 galls) G. Cerasa.

The galls of *A. multiplicatus* [sex] consist of muddled agglomerate of leaves (Fig. 4t) in which larval chambers are located in groups at their bases. As observed on *P. gallaeramulorum* and on *P. tamaricis*, the exit hole of *O. cornutus* is greater than the hole produced by the gall inducer (Fig. 4u). The presence of frass in the interstices between the cynipid larval chambers characterize the galls from which *O. cornutus* adults emerged (Fig. 4v).

Discussion

At the present time, biology of *O. cornutus* is not sufficiently understood and the species has been found in various microbiotopes and on several host plants. Müller (1873) obtained it as successor from galls of *A. quercuscalifornicus* and in a recent study on the arthropod community associated with these galls on *Quercus lobata* Née in California, *O. cornutus* was found in 37.4% of galls where it feeds on woody material (Wetzel et al., 2015). Concerning these galls, Joseph et al. (2011) observed that larvae of *O. cornutus* feed voraciously on desiccated gall material, often leaving only the outermost layer of the gall and that it can pass through multiple generations within the gall. In southern California, Pence (1950) found the species on dead flower stalks and dried twig tips of Avocado tree *Persea americana* Mill.; after the inner contents of a dried twig has been consumed, larva fed on the living tissue, until completing its life cycle. White (1974) recorded the species in North America on coyote brush *Baccharis pilularis* DC. (Asteraceae), on galls induced by Lepidoptera Gelechiidae of the genus *Gnorimoschema*, on pine bark and on dead stems of flowers and small dry branches of Avocado tree but does not confirm the attack on live tissue for this latter plant species. In Mexico, *O. cornutus* has been also found in galls of *Quercus crassipes* Bonpl. and *Q. obtusata* Bonpl. induced by the Cynipidae *Melikaiella bicolor* Pujade-Villar, 2014 and by a species of the genus *Disholcaspis* Dalla Torre & Kieffer, 1910 (Viñolas, 2017). The species was also recorded on bark of Loquat tree (*Eriobotrya japonica* Lindl.) in California (USDA, 1964) and on Pine tree (*Pinus* sp.) blossom in Mexico (Philips, 2002). In Spain the species was reared from tissues

or dead wood of *Ficus carica* L., *Foeniculum vulgare* L., *Retama monosperma* (L.) Boiss., *Q. suber, Scolymus hispanicus* L. and thistle head (Asteraceae) (Bercedo et al., 2005). Moreover, in Spain, Yus Ramos et al. (2019) have found *O. cornutus* on stems of *Eryngium campestre* L. and define for the first times the feeding regime of the species as saproxylophagous. Zahradnik and Mifsud (2005) have obtained *O. cornutus* adults from decaying seaweed collected in Malta and from a not specified dry fruit collected in Tunisia, while Allemand et al. (2008) have found *O. cornutus* in 2005 in Germany and in 2007 in France in dried almonds (*Prunus dulcis* L.). In Switzerland, Germann and Schmidt (2017) reported theat the species was imported unintentionally with a garlic braid bought in an Italian market (Sicily); the insect was reared only in dead foliage material but not in garlic cloves; in the same braid the authors found also *Stegobium paniceum* L., 1758, *Lasioderma serricorne* (Fabricius, 1792), and the parasitoid *Anisopteromalus quinarius* Gokhman & Baur, 2014 (Pteromalidae). More recently, the species has been recorded from Israel on a partially rotten branch of *Fraxinus angustifolia* subsp. *syriaca* (Boiss.) attacked by the Cerambycidae *Trichoferus fasciculatus* (Falderman, 1837) and on a dead branch of *F. carica* already attacked by *T. fasciculatus* and by the Curculionidae *Hypoborus ficus* Erichson 1836 (Miłkowskio, 2019). *Ozognathus cornutus* was also obtained in 2013 from galls of the chestnut gall wasp, *Dryocosmus kuriphilus* Yasumatsu, 1951 (Hymenoptera: Cynipidae), in Italy, Sicily (Sidoti et al., 2016) and Spain in 2019 (Trócoli et al., 2020). Interestingly, the chestnut gall wasp, native to southeastern Asia, was recorded in these two countries only recently: in Sicily, after the first Italian record in 2002 (Brussino et al., 2002), it was found in 2010 (Longo & Sidoti, 2011; EPPO, 2011), whereas in Spain it was reported in 2012 (DOGC, 2012; Pujade-Villar et al., 2013), although earlier detections in 2010 and 2011 are mentioned by Borowiec et al. (2014) and Rubio (2014).

We here confirm the saproxylophagous feeding regime of *O. cornutus*; dead or decaying gall tissue as well as galleries of Cerambycidae where it was found in Israel by Miłkowskio (2019) are rich in decaying organic material such as small wood shavings and insect excrements and are probably attacked by fungi that also can serve as food. The four galls from which we obtained *O. cornutus* as successor are conspicuous and can provide adequate space for the development of larval stages and a good source of nutrients.

In general, successors prefer conspicuous galls that remain connected to plants over a long period of time and are involved in specific food webs within the abandoned galls (Luz & Mendonça, 2019). The species of the successor's communities are ecologically closely dependent on the plant galls and the interrelations with host plant and inhabitant's organisms are extremely complex (Mani, 1964; Sanver & Hawkins, 2000; Luz & Mendonça, 2019). The galls, with their particular microhabitat, providing shelter, protection and a source of immediate food supply, are convenient for the colonization by *O. cornutus* and create an ecological contiguity between the place of origin and landing place of the alien species, mainly if favored by suitable climatic situation. On the other hand, whenever no galls are available, successors can adapt to using other sources as refuges or food, showing their opportunistic strategy. In our case, *O. cornutus* was able, in a short time, to acclimatize in the warm area of the Euro-Mediterranean Region, and the galls seem to have played an important ecological role in this process, by acting also as 'ecological accelerators' in the naturalization process. This seems confirmed also by the percentage of galls from which the beetle emerged, ranging from 23.2 to 76.9%. Interestingly, the lowest proportion of galls used by *O. cornutus* was recorded for *P. tamaricis* (23%), the only host belonging to Cecidomyiidae, while the percentages recorded for the other host species, all Cynipidae forming galls on oaks, were higher: 43.6%, 61.1% and 76.9% in *A multiplicatus*, *S. politus* and *P. gallaeramulorum,* respectively.

The biological traits of *O. cornutus* as described in the literature and in the present paper indicate that *O. cornutus* is a 'non-obliged' successor, which is able to exploit other substrates like dried fruits and vegetables, for which it could represent a potential pest. The insect prefers to live as a successor in woody and conspicuous galls, therefore the galls can represent a sort of natural barrier limiting the possible damages to other substrates. At present, *O. cornutus* cannot be considered a pest of economic interest of any cultivated species, although its detection in dried fruits and other plant products could turn it into a pest of stored products (Trócoli et al., 2020). On the other hand, the almost complete lack of information about the

ecological network of this species in the native areas and the scarce knowledge on the successor communities of gall wasps in the newly colonised regions makes currently impossible to assess its potential impact in natural ecosystems.

Acknowledgements Autors are grateful to Angelo Ditta and Salvatore Surdo for the two recent Sicilian records and to two anonymous reviewers for their useful suggestions.

Authors' contribution All the authors equally contributed to this study, wrote and approved the manuscript.

Funding Open access funding provided by Università degli Studi di Palermo within the CRUI-CARE Agreement.

Declarations

Conflict of interest The authors declare no conflict of interest.

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