INTRODUCTION

Wood & Bright (1992: 787-801) listed 52 Xylosandrus species native to tropical and subtropical areas of the world. To date, four of them, have been accidentally introduced into Europe: Xylosandrus crassiusculus (Motschulsky), X. morigerus (Blandford), X. germanus (Blandford) and X. compactus (Eichhoff) (Kirkendall & Faccoli, 2010; Fitolab, 2011; Francardi et al., 2012; Pennacchio et al., 2012; Wood, 2007). In Italy, Xylosandrus crassiusculus, X. compactus and X. germanus have rapidly spread becoming important primary pests of numerous cultivated, wild and ornamental timber species (Bossio et al., 2012; Kirkendall & Faccoli, 2010; Francardi et al., 2012; Pennacchio et al., 2012). More recently, in 2016, a widespread dieback of branches and twigs of different plant species was observed in several sites in the province of Latina (Lazio), such as the National Park of Circeo (Sabaudia), the neighbouring area of San Felice Circeo, the Villa Fogliano’s Botanic Garden and a nursery in Fogliano. Plants mainly affected by dieback were: Ceratonia siliqua, Laurus nobilis, Quercus ilex, Q. robur, Q. pubescens, Q. suber, Acer pseudoplatanus, Cercis silicquastrum, Euonymus europaeus, Magnolia grandiflora, Liquidambar styraciflua, Ficus carica and Magnolia grandiflora. In Italy, X. crassiusculus was reported for the first time in 2003 in pine-mixed woods of Tuscany. Moreover, since 2011, the congeneric species X. compactus has been also recorded on some ornamental plants in Campania, on Ceratonia siliqua in Sicily and on Laurus nobilis in Tuscany and Liguria. In the present work, taxonomic keys of the four Xylosandrus species introduced into Europe were provided together with data on their essential morphological and bio-ecological features with particular emphasis on X. crassiusculus and X. compactus. Furthermore, since X. crassiusculus and X. compactus are vectors of pathogenic fungi such as Fusarium solani, a special focus was placed on their control measures.

KEY WORDS: Black twig borer, Asian ambrosia beetle, scolytids, biological invasion.
INVESTIGATION AREAS

THE NATIONAL PARK OF CIRCEO

The Park of Circeo, which was established in 1934, is one of the oldest protected natural areas in Italy. It is located along the Tyrrhenian coast close to Sabaudia (south of Rome) and covers 8,484 hectares of land. Five different environments characterize the park: the State forest, the Promontory of Circeo (541 m above sea level), The Wetlands, The Coastal Dune and the Zampanone Island. This Park has earned, for the variety of its habitats, the designation of “Biodiversity Park” and in 1997 it was recognized by UNESCO as a “World Heritage Site”.

The current phytosanitary investigations were carried out in the first two biocenoses. The State Forest is represented by Mediterranean species with typical trees such as Pinus pinea, Quercus ilex and Q. suber. The undergrowth is rich in Crataegus monogyna, Prunus spinosa, Malus sp., Pyrus sp., Arbutus unedo, Erica arborea and Ruscus aculeatus. The promontory of the Park is divided in two sides: the first, named “Quarto VILLA FOGLIANO’S BOTANICAL GARDEN”, and the second one, named “Quarto Caldo”, has a southern exposure and it is very sunny; it is mostly characterized by rocky Mediterranean vegetation including mainly Q. ilex, Juniperus sp., Euphorbia dendroides, Myrtus communis, Pistacia lentiscus, Rosmarinus officinalis and Erica arborea.

FOGLIANO NURSERY

The Fogliano nursery hosts several Mediterranean plant species, typical trees and the above-mentioned ornamental plants.

MORPHOLOGICAL DESCRIPTION OF GENUS XYLOSANDRUS

Very stout body. Female 1.3-5.0 mm length; color pale brown to black. Eye deeply emarginate, antennal funicle 5-segmented, club obliquely truncate, with conoern area occupying the basal third of club length; anterior margin of pronotum armed by serrarions. Procoxae widely separated. Elytra stout, slightly longer than pronotum, weakly striate; declivity commencing anteriorly to middle of elytral length; broadly convex, unarmored, ventrolateral margin acutely costate from apex of suture to interstriae 7. Males are rare, haploid, smaller, dwarfed and flightless with the anterior slope of pronotum convex; its anterior margin is not armed by a denticle, while the ventrolateral margin of elytral declivity is not costate.

TAXONOMIC KEY OF XYLOSANDRUS Species occurring in Italy based on female morphology

1. Strial punctures obsolete, interstrial punctures scattered on disc, obsolete on declivity; declivity dull, surface with dense, confused small tubercles uniformly distributed from base to apex; body colour reddish brown; 2.1-2.9 mm
   - Strial and interstitial punctures in uniseriate rows at least on disc ........................................... 2

2. Declivity commencing at one-third of elytral length from base, elytra 1.0 times as long as wide, sides of elytra sometimes devoid of punctures; body colour yellowish or reddish brown; 1.4-1.7 mm
   - Declivity commencing at one-half of elytral length from base, elytra 1.1-1.2 times as long as wide; body colour brown to black ........................................... 3

3. Smaller species, body 2.1 times as long as wide; strial setae on declivity present, at least one-third as long as those of interstriae, body colour dark brown to black; 1.4-1.7 mm
   - Larger species, 2.3 times as long as wide; strial setae on declivity absent; body colour dark brown; 2.0-2.3 mm

4. X. CRASSIUSCULUS
   - Strial and interstitial punctures in uniseriate rows at least on disc ........................................... 2

5. X. COMPACTUS
   - Strial and interstitial punctures in uniseriate rows at least on disc ........................................... 3

6. X. GERMANUS

BIOLOGY OF GENUS XYLOSANDRUS

All species are xylomycetophagous and generally breed in stems ranging in diameter from 0.3 to 15 (30) cm. Females initially bore a radial entrance tunnel (0.5-3 cm length) directly into the wood and then make a narrow tubular expansion cavity (above and/or below the tunnel) where egg clusters are laid together with ambrosial fungus inocula carried by highly specialized organs named mycangia. Subsequently, larvae expand the tubular cavity as they feed on the mycelium of the ambrosia fungus developed on the wooden walls and complete their development inside this structure until pupal stage. Mating occurs among siblings in the brood chamber (inbreeding) before leaving the plants in search of new hosts suitable for the formation of maternal galleries and oviposition. The young adults exit the chamber through the parental entrance hole. Some species are very important from an economic viewpoint.

BIOLOGICAL AND MORPHOLOGICAL NOTES ON X. CRASSIUSCULUS AND X. COMPACTUS

X. CRASSIUSCULUS

This species is native to tropical and subtropical Asia from where it has been gradually introduced into many areas of the world such as Africa (Atkinson et al., 2000), the Hawaiian Islands, Micronesia, New Caledonia, New Guinea and the southeastern USA (Brown, 1961; Scheld, 1962; Wood, 1982; Wood & Bright, 1992; Kovach & Gorsuch, 1985; Chapin & Oliver, 1986; DeFrey & Atkinson, 1987). In Europe (Italy) the species (captured in black funnel traps baited with ethanol, a-pinene and the pheromone of Ips sexdentatus (Börner)) was identified for the first time in Tuscany in 2003 in a mixed wood of Pinus pinea Aiton and Quercus cerris L. with dense shrubby undergrowth (Pennacchio et al., 2003). Afterwards, it was also recorded on Ceratonia siliqua (carob tree) in Liguria (Tinivella et al., 2010). X. crassiusculus is a widely
polyphagous species, able to colonize at least one hundred species belonging to various genera of forest, agricultural and ornamental trees such as *Alnus*, *Castanea*, *Ficus*, *Lagerstroemia*, *Malus*, *Populus*, *Prunus*, *Quercus*, *Sorbus* and *Pinus* (Wood, 1992). In the last decades, damages had been already observed on nursery trees and in young orchards (Wood, 1982; Kovach & Gorsuch, 1985; Hudson & Mizell, 1999) but, in 2016, severe attacks were also recorded on *Ceratonia siliqua* in the National Park of Circeo.

The female has a squat and cylindrical reddish-brown body with the distal half of the elytra fading to dark brown. Pronotum as long as wide; in dorsal view completely hides the head (Fig. I).

As already mentioned above, females colonize small-to-medium-diameter (2-30 cm) twigs, branches and trunks digging a small hole (approximately 1.5 mm diameter) in the sapwood or sometimes into the heartwood. Females burrow maternal galleries where they introduce the symbiotic ambrosia fungus from organs (*mycangia*) located on the mesonotum. Small groups of eggs are then laid in little cavities.

Females stay with their brood until maturity. During the burrowing, frass is pushed out in the form of typical narrow and compact cylinders protruding out of trunks, branches and twigs; they are fragile and may be completely removed by wind and/or rain (Fig. II, 1 and 2). It is worth noting that adult females and larvae do not feed on wood and pith of their plant hosts but on the ectosymbiotic fungi developed on tunnel walls. Moreover, eggs, larvae, and pupae are found together in the tunnel system formed by females. Males measure 1.6 mm. *X. crassiusculus* colonizes stressed, weak and/or unhealthy plants as well as freshly cut material (Kovach & Gorsuch, 1985). When extensive infestations occur this behaviour inevitably leads to tree death (Atkinson et al., 2000) due to female digging activity and growth of symbiotic fungi inside the vascular system of the host plant.

Furthermore, some potentially pathogenic fungi of *Ceratonia siliqua* such as *Fusarium solani*, *Botryosphaeria obtusa* and *Phomopsis theicola* were isolated in association with large longitudinal necroses observed in proximity to the small holes made by *X. crassiusculus*. The role played by this species as vector of fungi has been also confirmed by tests where insects were maintained in Petri dishes for about 1 h on potato dextrose agar (PDA). An updated list of fungi recently found in association with *X. crassiusculus* is reported in Table 1. Though *X. crassiusculus* is considered a serious pest, its biological cycle in Italy has not been thoroughly investigated yet.

*X. Compactus*

This species is a bark beetle probably native to tropical and subtropical Asia from where it was introduced into Africa, Indian Ocean islands, North and South America and the Caribbean islands. It has been also recorded in New Caledonia, New Zealand, Hawaii, Samoa and Fiji (Schedl, 1962; Beaver, 1976; Wood 1977, 1980, 1982; Samuelson, 1981; Chapin & Oliver, 1986; Deyrup & Atkinson, 1987; Delgado & Couturier, 2010, 2012). In Europe (Italy) *X.
compactus was collected on Laurus nobilis, Quercus ilex and Viburnum tinus in some sites close to Naples and then identified by the Phytopathological Laboratory of the Phytosanitary Service of Campania, (FITOLAB, 2011). More recently it has been recorded in Tuscany where it is rapidly spreading causing extensive withering and dieback of Laurus nobilis hedges in several areas of the Versilia coast (province of Lucca) (PENNACCHIO et al., 2012; FRANCARDI et al., 2012). Equally affected by this pest are either Ceratonia siliqua in Sicily (LONGO & GARZIA, 2016), or Cupressus sempervirens and L. nobilis whose decline has been observed in several urban areas in Rome (Lazio). Currently, more than 220 host plants are vulnerable to attacks, among which there are several species of economic, ecological and ornamental importance such as coffee, tea, mango, avocado, cacao and lychee. These plants mainly belong to the genera Acacia, Acer, Azalea, Celtis, Cornus, Eucalyptus, Ficus, Hibiscus, Khaya, Liquidambar, Magnolia, Malus, Ostrya, Platanius, Swietenia, Castanea, Vitis, Laurus, Quercus, Viburnum, Pittosporum, Magnolia, Azalea, Rhododendron, Camellia, Gardenia, Citrus and Olea (NGOAN et al., 1976; HARA & BEARDSLEY, 1979; WOOD, 1982; DIXON & WOODRUFF, 1982; HARA & SEWAKE, 1990; MESHRAM et al., 1993; INTACHAT & KIRTON, 1997; YAN et al., 2001; DAHLER & DUDLEY, 2002; MATSUMOTO, 2002; FITOLAB, 2011).

Females have a stout, cylindrical body, shiny and dark brown or black. Elytrae are 1.2 times as long as wide and elytral slope presents a regularly arcuate profile (Fig. III, 1). Males are much smaller than females (0.8-1.1 mm). Pronotum is narrowly rounded, flattened or slightly concave in the median part. Elytral striae and interstriae show irregular spotting.

Females normally dig maternal galleries on the less-exposed side of thin twigs with a diameter between 2.5 and 12 mm. They start from an entrance hole of about 0.8 mm diameter until they reach the pith where oviposition occurs. After 4-6 days eggs hatch and larvae (Fig. III, 2) begin to develop feeding almost exclusively on Ambrosia-type fungi grown inside the maternal galleries (LHOSTE & ROCHE, 1959). Unfertilized females and those that have exhausted their sperm reserve lay eggs that only produce haploid males (ENTWISTLE, 1964). The entire cycle lasts from 27 to 40 days depending on the physiological conditions of the host tree and on climatic conditions (BRADER, 1964; HARA & BRADSLEY, 1979). In Tuscany, between the end of April and late November, the species can complete at least two generations and start a third one. Newly emerged females tend to colonize the original or nearby host plants showing that X. compactus spreads slowly even in the presence of a wide availability of host plants, as observed in Tuscany on Laurus hedges (PENNACCHIO et al., 2012).

The attacks may cause the dieback of either the thinner branches of the canopy or of the entire young plants (1-2 years old) as observed in Laurus nobilis in the Fogliano’s plant nursery and in Magnolia grandiflora in the Villa Fogliano’s Botanical Garden (Fig IV). This phenomenon is due to the tunnelling activity carried out by females within the twigs or at the base of young plants. However, equally relevant might be also the presumed phyto-pathogenicity of symbiotic Ambrosia fungi belonging to the species Fusarium solani (Mart.) Sacc (NGOAN et al., 1976; HARA & BEARDSLEY, 1979; DAHLER & DUDLEY, 2002; BAMBARA, 2003; DIXON et al., 2003), Ambrosiella xylebori (BRADER, 1964; BHAT & SREEDHARAN, 1988) and Ambrosiella macrospora (Fr.-Grossman) Batra (MUTHAPPA & VENKATASUBBAIAH, 1981). Is worth noting, though, that the latter fungus was considered by FRANCKE-GROSSMAN, (1952) important for larval feeding and not pathogenic for the host plant. However, more recently, Verticillium and

### Table 1 – Fungi reported from X. crassiusculus in literature and in bold fungi isolated in this study.

<table>
<thead>
<tr>
<th>Beetle specie</th>
<th>Isolated fungi</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xylosandrus crassiusculus</td>
<td>Raffaelea lauricola</td>
<td>Harrington et al., 2010</td>
</tr>
<tr>
<td></td>
<td>Ambrosiella sp.</td>
<td>Harrington &amp; Fraedrich, 2010</td>
</tr>
<tr>
<td></td>
<td>Ambrosiella xylebori</td>
<td>Roepert, 1996</td>
</tr>
<tr>
<td></td>
<td>Ambrosiella roeperi</td>
<td>Harrington et al., 2014</td>
</tr>
<tr>
<td></td>
<td>Fusarium solani</td>
<td>In this study</td>
</tr>
<tr>
<td></td>
<td>Botryosphaeria obtusa</td>
<td>In this study</td>
</tr>
<tr>
<td></td>
<td>Phomopsis theicola</td>
<td>In this study</td>
</tr>
</tbody>
</table>
activities (e.g. with multifunnel traps baited with ethanol) are essential in order to implement effective control strategy against scolityds. The purpose is not only to quickly evaluate the spread of insects in new areas but also to identify female flight periods suitable to perform the control strategies (Abreu et al., 1997, 2012; Oliver & Mannion, 2001; Burbano et al., 2012). Furthermore it cannot be excluded that plants already weakened by exceptional drought periods and/or by particular edaphic conditions may be more susceptible to scolityd attacks.

For this reason, all integrative cultivation practices increasing plant vigour (above all, land ploughing, balanced fertilization strategies and emergency irrigation) can be useful to promote a good vegetative recovery of attacked plants mitigating possible pest damages on the colonized trees (Dixon & Woodruff, 1982; Bambara, 2003).

Literature reports suggest that natural enemies generally play a minor role in limiting X. compactus populations, especially in areas of new introduction. Studies conducted in Indonesia by Le Pelley (1968) on the activity of some parasitoids showed an irregular efficacy. However, some positive results regarding the effects of an eulophid wasp (Tetrastichus sp.) and a bethylid wasp were reported for Sumatra Island by Keuchenius (1931). Moreover, on September 2011, a larva of the braconid wasp Heterospilus leptostoma Fischer associated with a larva of X. compactus was isolated from a laurel twig in Marina di Pietrasanta (Lucca, Tuscany.) (Pennacchio et al., 2012). Unfortunately, despite the faunistic importance of this record, the rare occurrence of this wasp prevents further speculation on its role in pest control.

CONCLUSIONS

The results of our investigation indicate that X. crassiusculus and X. compactus may represent a serious phytosanitary risk in the Circeo Park because of the wide variety of plants susceptible to their attacks either in the park itself or in the neighbouring areas. In fact, the coexistence of these species in the same area and their ability to carry potentially pathogenic fungi may lead to negative synergies with dramatic phytosanitary implications difficult to predict even in the short term. Moreover, the wide polyphagy of both species could cause difficulties in implementing pest control in the next future, particularly if insect populations should find ecologically favourable conditions. There is growing concern, specially for X. compactus, in the light of the severe damages recorded on the colonized host plants and for its rapid spread in the different investigated environments. Such scenario might be even more critical considering the absence so far of a well-established control strategy against these pests. Specifically, there are three factors that deserve particular attention: 1) the peculiar cryptic behaviour of both immature and adult stages, 2) the insufficient knowledge of their life cycle and 3) the legal restrictions on the use of chemical insecticides in natural protected areas.

Therefore, more researches are desirable on the bioecology of X. crassiusculus and X. compactus. In particular, a deeper investigation on the adult flight periods and on the indigenous complex of natural enemies active against them in the field are essential to develop effective and ecofriendly control measures. To this end, it is necessary to implement more targeted and integrated control techniques such as sanitation, silvicultural practices and insect trapping.
strategies to prevent and/or control pest population growth and spread in new territories.

ACKNOWLEDGEMENTS

The Authors would like to thank Mr. Paolo Giannotti - Sezione di Entomologia Agraria, Dipartimento di Scienze Agrarie, Ambientali e Agroalimentari of the University of Pisa, for providing pictures of X. compactus.

REFERENCES


Burbano E.G., Wright M.G., Gillette N.E., Mori S., Dudley N., Jones T., Kaufmann M., 2012 – Efficacy of Traps, Lures, and Repellents for Xylosandrus compactus (Coleoptera, Curculionidae) and Other Ambrosia Beetles on Coffea arabica Plantations and Acacia koa Nurseries in Hawaii. - Environ. Entomol. 41 (1): 133-140.


Harrington T.C., Aghayevo D.N., Fraedrich S.W., 2010 – New combinations in Raffaelea, Ambrosiella, and Hyalorhinocladiella, and four new species from the redbay ambrosia beetle, Xyleborus glabratus. - Mycetaxon, 111: 337-361.

Harrington T.C., Fraedrich S.W., 2010 – Quantification of propagules of the laurel wilt fungus and other mycangial fungi from the redbay ambrosia beetle, Xyleborus glabratus. - Phytopathology, 100: 1118-1123.

Harrington T.C., McNew D., Mayers C., Fraedrich S.W., Reed S.E., 2014 – Ambrosiella roeperi sp. nov. is the mycangial symbiont of the granulate ambrosia beetle, Xylosandrus crassiusculus. - Mycologia, 106 (4): 835-845.


COEXISTENCE OF XYLOSANDRUS CRASSIUSCULUS (MOTSCULSKY) AND X. COMPACTUS (EICHHOFF)...


PENNACCHIO F., ROVERSI P.F., FRANCARDI V., GATTI E., 2003 – Xylosandrus crassiusculus (Motschulsky) a bark beetle new to Europe. - Redia, 86: 77-80.

PENNACCHIO F., SANTINI L., FRANCARDI V., 2012 – Bioecological notes on Xylosandrus compactus (Eichhoff) (Coleoptera, Curculionidae, Scolytinae), a species recently recorded into Italy. - Redia, 95: 67-77.


156 - Blank Page