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Interactions between insects and fungal pathogens of forest and ornamental trees

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Abstract

The Authors have analyzed the interactions between insects and fungal pathogens of chestnut, cypress, elm, oak and pine trees in the natural environment and in urban areas. A brief description of the insect's life cycle is provided by relating some of its phases with the vectored fungus. The purpose of this work is to relate the different insect/pathogen associations with their environment in order to bring out the role of such symbioses in determining, together with abiotic factors, the destabilization of forest and urban ecosystems. The ascertained and possible interactions, as well as the ones that might occur in the future between immigrant and resident insects and fungal pathogens as a consequence of new introductions, are treated separately, taking into account the available control strategies, in particular those that are feasible in human-frequented areas.

Keywords: forest and ornamental trees; insects; fungal pathogens; interactions

Riassunto

Gli Autori hanno analizzato le interazioni tra insetti fitofagi e agenti fungini patogeni del castagno, cipresso, olmo, pini e querce in ambienti naturali ed in ambito urbano. È riportata una breve descrizione del ciclo vitale dell'insetto ponendo in relazione determinate sue fasi di sviluppo con il fungo che viene veicolato. Il fine di tale lavoro è di rapportare le varie tipologie associative insetto/patogeno fungino con l'ambiente che li ospita in modo da far emergere il ruolo di tali simbiosi nel determinare, assieme ovviamente ai fattori di natura abiotica, la destabilizzazione degli ecosistemi forestali ed urbani. Le interazioni accertate e possibili, come pure quelle che potrebbero verificarsi in futuro tra insetti e funghi patogeni immigranti e residenti in conseguenza di nuove introduzioni, vengono trattate separatamente, tracciando le linee di lotta prevedibili e perseguibili, con particolare riferimento all'ambiente urbano.

Parole chiave: piante forestali ed ornamentali; insetti; patogeni fungini; interazioni

Introduction

Plant pathogenic microorganisms like fungi, and animal organisms (such as arthropods, and especially insects), very far in terms of structural and functional organization, can contract associative relationships

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with reciprocal advantages. The most important difference in life-history traits between these two types of organisms is that insects are mobile, thus able to colonize space autonomously, while most fungal pathogens need to be passively transported, and perhaps this limitation is one of the main factors at the basis of insect-fungus interactions. The topic might appear at first glance scarcely connected with the recovery of stressed forests, where phenomena of ecological instability can be triggered. However, it is known that these imbalances are more and more frequently caused by phytophagous insects, often in combination with plant pathogenic microorganisms, such as fungi and, more rarely, bacteria.

These situations are becoming increasingly common, and their complexity explains why, starting from the last decades of the 20th century, a specific field of research on phytosanitary control has been established. The scientific and practical importance of these studies is remarkable and, in the restoration of declining forests as a result of the action of insects and fungal pathogens, measures directed to the control of new attacks should be developed, since the eradication of already established parasites is no longer feasible.

During interactions between insects and pathogenic fungi of woody plants, many circumstances occur that may allow them to become linked, more or less closely and permanently, so that benefits are granted to both. A clear example is given by bark beetles, which require plants stressed by various causes, including fungal infections, to breed. It is in fact common for fungi and insects to get in touch inside the woody plant tissues establishing special relationships (BEAVER 1989; TIBERI *et al*., 2002a, 2002b; JANKOWIAK, 2006; ÁLVAREZ *et al*., 2015). Although less frequently, relationships between pathogenic microorganisms and defoliating insects associated with green parts of the plant may also be established.

The onset of these phenomena has a different importance in natural or semi-natural ecosystems, compared with urban and peri-urban systems and with areas maintained for recreational and landscaping purposes. In the first case, insects and pathogenic microorganisms are an integral part of the biotic component, and therefore, until their activity does not exceed the carrying capacity of the system, they turn out useful as they contribute to the modification of the structure and composition of the forest, shaping the stand in relation also to environmental conditions. In human-modified environments, and thereby not only in towns, insects and pathogenic microorganisms, individually or in combination, are usually a problem because their attacks may threaten heritage trees. In these environments, even individual plants are of fundamental importance, mostly when inserted in particularly valuable landscaped contexts. It becomes therefore crucial a prompt identification of the best strategies for plant protection.

In such circumstances, the main problem consists in having to cope with different agents of different nature, for which differentiated control measures exist. Not an easy task considering the costs and, above all, the safety concerns typical of urban areas. The relationships that develop between insects and fungal pathogens are not always true obligate symbioses, but the non-mutualistic ties that may be established are nonetheless able to influence both the insect's development and the physiological state of the host plants. These relationships are very dangerous since they can trigger extended, and often irreversible, weakening phenomena (WEBBER and BRASIER, 1984; BATTISTI and COVASSI, 1991; TIBERI *et al*., 2002a).

In some cases, insects strictly depend on the relationship with fungal pathogens, so as to have developed special body structures to transport fungi in order to increase their chances of survival. These structures, called mycangia, can appear as pits or pouches of various sizes, in which a substance, secreted by their associated glands, creates the best conditions for the survival of the fungus, inhibiting, at the same time, the antagonistic microorganisms (FRANCKE-GROSMANN, 1963; BEAVER, 1989).

In the case of facultative symbioses, the transport of the pathogen seems to be a random phenomenon. This may occur simply through the adhesion of spores to insect setae or other tegumental structures, or even through its excrements. However, we cannot exclude the occurrence of specific invaginations, which represent optimum locations for the pathogenic fungus, being insects sometimes equipped with glands

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secreting substances having the function of preventing spore desiccation. This has been demonstrated for the fungus *Ophiostoma ulmi* (Buisman) Nannf., the causative agent of Dutch Elm Disease (DED), and for the bark beetle *Scolytus multistriatus* (Marsham) (FRANCKE-GROSMANN, 1963; WEBBER, 1990; FAVARO and BATTISTI, 1993).

Ascertained interactions between insects and plant fungal pathogens

The role of insects in spreading fungal pathogens of chestnuts, cypresses, oaks and pines has been proven over the course of multi-year surveys carried out also in Italy. In particular, the xylophagous insects infesting these plants are the most important vectors of some plant pathogens.
However, in the case of cypress and pine trees, the ability of some insects, which colonize cones and seeds, to transport fungal pathogens was also demonstrated (Fig. 1). These types of interactions are facultative, the transport mechanism being in all cases the simple adhesion to insect’s body or through excrements. The interaction between insects and pathogens of cypress, due to their diffusion and importance in Italy, will be treated first.

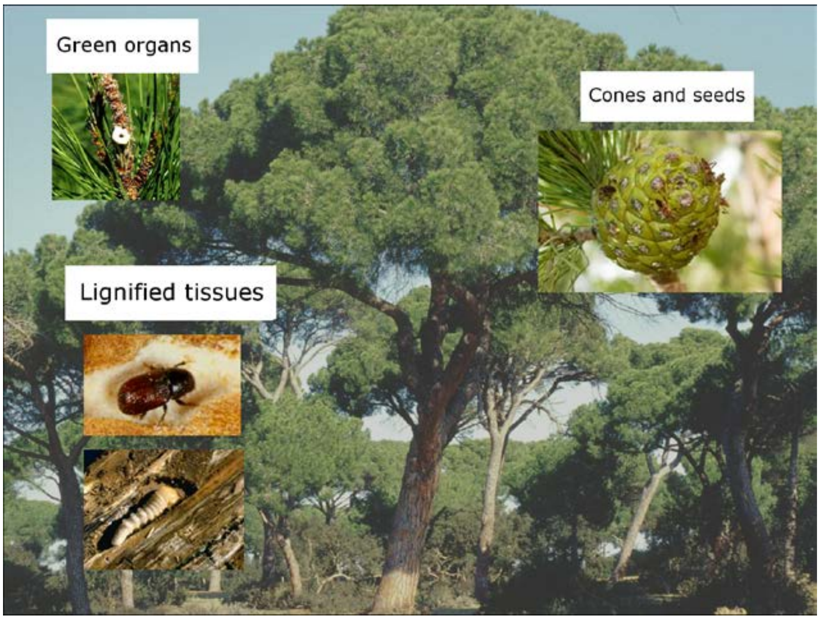

Fig. 1. Trophic diversity of dangerous forest insects.
Fig. 1. Diversità trofica degli insetti forestali dannosi.

Cupressus spp.

In the facultative symbiosis between *Seiridium cardinale* (W.W. Wagener) B. Sutton et I.A.S. Gibson, the agent of cypress canker (Fig. 2), and phytophagous insects (COVASSI *et al*., 1975), the two parasites may get in contact on cypress bark, both of trunk and branches, as well as on cones and seeds. In the first case, bark beetles are mainly involved, but even wood boring insects and some vertebrates, such as birds and rodents, can play a role in the spread of the fungus. Conidia occurring outside or inside cones and seeds can adhere to the body of various insects. However, some vertebrates can also transport the fungus if they feed on infected cones. It might also be possible, though it has not been proven, that both xylophagous insects and cone/seed insects may ingest fungal mycelium during feeding, spreading it through their excrements.
Surveys carried out in Italy on the role of insects in the spread of *S. cardinale* showed that, among xylophagous insects, the bark beetle *Phloeosinus aubei* Perris deserves particular attention (COVASSI, 1975). This species, found in Central and Southern Europe, North Africa and Asia Minor, is associated with the

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Cupressaceae, with a preference for the genus *Cupressus*. Like similar bark beetles, it attacks its host in two distinct phases.

Fig. 2. *Cupressus sempervirens* trees with large crown dieback by *Seiridium cardinale*, agent of cypress canker
Fig. 2. Piante di *Cupressus sempervirens* con vistosi disseccamenti della chioma da *Seiridium cardinale*, agente di cancro corticale.

The reproductive activity takes place in trunk and branch phloem of cypress trees stressed by biotic or abiotic causes (1st phase): e.g. infestations with the aphid *Cinara cupressi* (Buckton) or vegetative impairment due to site conditions. For the maturation of gonads, however, the newly formed adults must move on twigs of vigorous trees (2nd phase), where they dig feeding tunnels (indeed called maturation galleries), which are also used for overwintering. In the case of strong activity on twigs, trees can become stressed as a result, and then they are attacked by mature adults for reproduction.
In Italy, *P. aubei* completes two generations per year, overwintering being carried out by adults of the second generation (ZOCCHI, 1956; TIBERI and NICCOLI, 1991). In the northern regions and in colder environments the bark beetle develops a single reproductive cycle, or it can start a second one, which will be completed during the following spring; in this case the species overwinters as larvae in the reproduction galleries. In Mediterranean regions with milder climates, such as in Israel, the species may develop 3 to 4 generations, partially overlapping; this implies the presence of adults virtually all year round (MENDEL, 1984).
The newly formed adults can come in contact with *S. cardinale*. They can load conidia present on the bark during emergence from the subcortical layers, where the insect’s preimaginal development took place. Conidia adhere to the insect’s setae or other body structures. The bark beetle then flies on the shoots of vigorous cypress trees to dig maturation galleries, thus carrying the conidia to healthy trees. Considering the coincidence in time between the appearance of adults (spring and late summer-early fall) and conidia discharge from the acervula, the chances that adults of the bark beetle may get contaminated by propagules of the fungus are substantial (MORIONDO, 1972).
The seed insect *Orsillus maculatus* (Fieber) is also able to transport the conidia of *S. cardinale*. In fact, conidia of the fungus can be produced also on the cones, on which *O. maculatus* nymphs and adults feed. The insect has a thick pubescence to which conidia can adhere, thus fungal propagules can be transported to healthy cones during insect feeding or oviposition. Its phenology makes this hemipteran particularly

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dangerous, since it completes several reproductive cycles, widely overlapping, during one year. Therefore, the presence of nymphs and adults on the cones is almost continuous from spring to autumn (BATTISTI *et al*., 1997).

Quercus spp.

It is known that xylophagous insects and many fungal pathogens play a key role in oak decline, both in Italy and in other European countries. In fact, they can initiate and sustain the decline of the host plant by acting individually or simultaneously (TIBERI and RAGAZZI, 1996 RAGAZZI *et al*., 2000).

In the spread of oak fungal pathogens, the insects involved are mainly beetles belonging to the family *Buprestidae* as well as bark beetles (*Curculionidae: Scolytinae*). All these xylophagous insects can play a remarkable role in the spread of many fungal pathogens that grow in woody tissues. For example, the buprestid *Agrilus graminis* Kiesenwetter is an active vector for some species of the genus *Verticillium*; the bark beetle *Scolytus intricatus* (Ratzeburg) for *Fusarium solani* (Mart.) Sacc. and *Verticillium dahliae* Kleb.; and the wood boring beetle *Xyleborus dispar* (F.) for *Fusarium eumartii* C.V. Carp., *F. solani* and *V. dahliae*. As regards *Fusarium* spp., the contact between the insect and the pathogen can take place on the outer bark as well as in the subcortical and woody layers.

It remains unclear where the contact with species of *Verticillium* takes place, in particular in the case of *V. dahliae* and the buprestid *A. graminis*. In fact, microsclerotia of the fungus occur in the soil, a site less visited by the beetle, and therefore it is assumed that the contact can only take place at the base of the trunk of infected oaks (TIBERI *et al*., 2002b).

Pinus spp.

During the last decades of the 20th century, pines also entered a phase of gradual decline. This phenomenon may be connected with the chronological succession of attacks by insects and fungal pathogens and to vegetative difficulties of trees. Many researches have provided evidence that insects and fungal pathogens are important factors in the progressive decline of pine stands (JANKOWIAK, 2006; ÁLVAREZ *et al*., 2015) and, in this connection, many of these formations may be at risk of survival in Europe.

We list some bark beetles and pathogenic fungi which, due to the high damage they cause, are among the major concerns in the protection of pine forests. As regards insects, the main species are *Ips sexdentatus* (Börner) (Fig. 3), and those of the genus *Tomicus*. The latter occurs in Italy with three species: *T. minor* (Htg.), *T. piniperda* (L.) and *T. destruens* (Woll.). As concerns fungi, some members of the *Ophiostomatales*, responsible for vascular infections and discoloration of the timber, are active and damaging agents contributing to pine decline (CAPRETTI and RAGAZZI, 2009).

Insects, in particular bark beetles such as the aforementioned species, transport many of these fungi (DELORME and LIEUTIER, 1990; BOIS *et al*., 1999). Research carried out in pine forests of coast and inland Tuscany demonstrated, for example, the ability of *T. destruens* to transport conidia of *Leptographium serpens* (Goid) Siemaszko and *Diplodia sapinea* (Fr.) Fuckel (SABBATINI PEVERIERI *et al*., 2006) (Fig. 4). This insect/pathogen association is believed to be facultative, as the isolation of the fungus was achieved only from substrates on which the insect had been placed, or using the washing technique. Insect and fungal propagules can get together either in the phloem, where the preimaginal development of the insect occurs, or on the bark. Here the insects remain for a while, before flying in search of vigorous pine shoots for gonad maturation. This succession of phases resembles the one already described for *P. aubei*.

These same studies have also demonstrated the association between *D. sapinea* and the coreid *Leptoglossus occidentalis* Heidemann, a seed insect associated with conifers. Again, as with *O. maculatus* and *S. cardinale* on cypress, nymphs and adults of *L. occidentalis* can get in touch with fungal propagules on the

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surface of infected cones; these conidia, adhering to body setae of *L. occidentalis*, may be vehiculated on other plants (MANCINI *et al*., 2010).

Fig. 3. *Ips sexdentatus* galleries under pine bark. The dark color is given by the infection of *Leptographium* sp., which can be transported by the bark beetle.
Fig. 3. Gallerie sottocorticali di *Ips sexdentatus*. Il colore scuro è dato dall'infezione di *Leptographium* sp., di cui lo scolitide può essere un vettore.

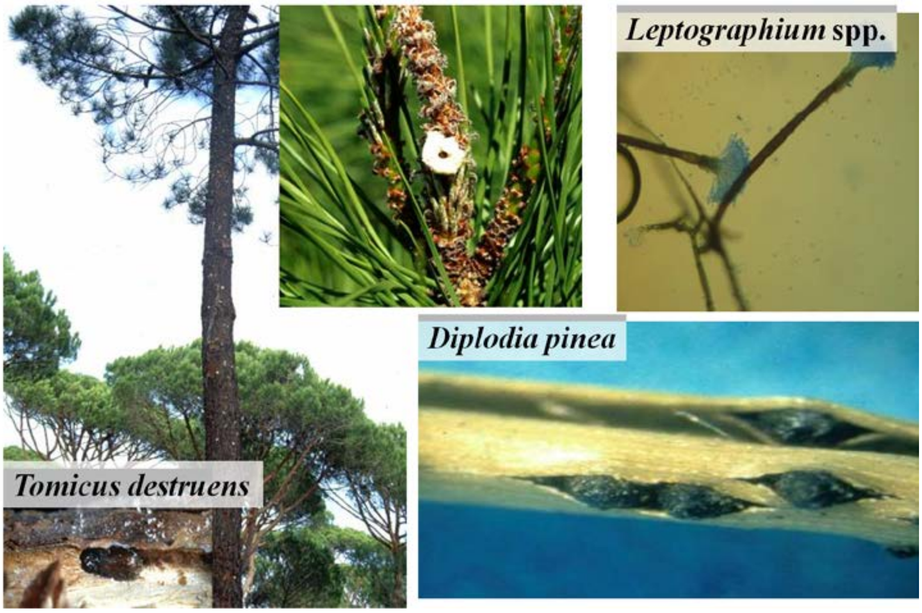

Fig. 4. *Tomicus destruens* association with fungal pathogens may result, for example, in the spread of *Diplodia pinea* and *Leptographium* spp., whose fruiting bodies are shown in the picture.
Fig. 4. Le associazioni di *Tomicus destruens* con patogeni fungini possono portare, ad esempio, alla diffusione di *Diplodia pinea* e *Leptographium* spp., di cui nella foto si possono osservare le fruttificazioni.

Castanea sativa

The chestnut blight fungus *Cryphonectria parasitica* (Murrill) M. E. Barr, can be spread by bark mites. The mycelium of the fungus is in fact part of the diet of these small arthropods and, consequently, its conidia can occur in their excreta while hyphae can adhere to their body (NANNELLI et al., 1998).

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Possible interactions

With "possible interactions" we mean those interactions which could be established between insects and pathogenic microorganisms occurring on the same examined samples, but at different times, though the pathogens have never been isolated from the body of investigated insects (TIBERI et al., 2002a). Among the possible interactions between phytophagous insects and fungal pathogens, it is worth mentioning those that might occur on cypress, oak and pine.

Cupressus spp.

While continuing to keep separate insects that exploit trunks and branches from those feeding on reproductive organs, there are more species, in addition to those already mentioned, which feed on cypress and that could be effective in spreading *S. cardinale*. Among xylophagous beetles, two other bark beetles of the genus *Phloeosinus*, namely *P. armatus* Reitter and *P. thujae* (Perris), are worth mentioning. The first species, native to the Eastern Mediterranean, was reported in Italy (Liguria) by COVASSI in 1991 and more recently in Tuscany (PENNACCHIO *et al*., 2013). This bark beetle develops two generations per year (up to four in Israel), overwintering as adults. It can be considered oligophagous on *Cupressaceae* but, similarly to the congeneric *P. aubei*, it shows a preference for *Cupressus sempervirens* L. *P. thujae* is present in many countries of Central and Eastern Europe as well as in Mediterranean countries, and even in England. It is associated with *Cupressaceae* as well, with a marked preference for species in the genera *Juniperus* and *Thuja*. Generally, it has a behavior similar to *P. aubei* and *P. armatus*, but it develops only one generation per year and it overwinters as mature larvae in the subcortical layers of attacked trees. Adults, which emerge in spring, may be already sexually mature, since they do not always need to feed on young shoots of vigorous plants to mature gonads. This assumes a lesser importance in *P. thujae* than other *Phloeosinus* species as concerns the transport of *S. cardinale*. Other xylophagous insects associated with cypress could play a significant role in the dispersal of the agent of cypress canker, as they can encounter conidia on the bark of infected trees.

Many species of phytophagous insects are associated with cypress cones and seeds. One of the most feared species, given its wide distribution in Italy, is the tortricid moth *Pseudococcyx tessulatana* Staudinger, whose larvae feed on cone and seed tissues. This species completes three generations per year in central Italy. Adults, emerging from infected cones, may accidentally collect a load of *S. cardinale* conidia and transport them away, flying in search for new cones for oviposition. The seed chalcid *Megastigmus wachtli* Seitner is more dangerous where it is more common, and therefore it turns particularly harmful to cypress seeds. Less worrying, due to its lower frequency, is the twirler moth *Brachyacma oxycedrella* Millière (Gelechiidae). The possibility for scavenging insects, like barkflies, to contract casual relationships with *S. cardinale* on old infected cones, should not be underestimated. Recently, in fact, conidia of *S. cardinale* have been detected in the laboratory on the body of these insects (BATTISTI, unpublished data). On the other hand, the presence of various fungi, such as *D. sapinea* and *Seiridium* spp., has already been ascertained in the gut of barkflies collected on cypress in the field (PORCELLI *et al*., 1996).

Also the role of some vertebrates should not be underestimated. More specifically the role of birds, which use lignified parts of the crown for nesting or simply as roost. Other possible vectors of the pathogen are rodents, which climb on plants to feed on cones. They can also get in contact with *S. cardinale* by eating seeds contained in infected cones or by moving over infected bark.

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Quercus spp.

More numerous are the insects which may establish mutual relationships with pathogenic fungi on oaks. These are mainly xylophagous beetles. Worth mentioning, as potential vectors of some pathogenic fungi like *Diplodia mutila* (Fr.) Mont. and *Phomopsis quercina* (Sacc.) Höhn. Ex Died, are *Sinoxylon sexdentatum* (Olivier) and *S. perforans* (Schrank) (*Bostrichidae*). Other four beetles belonging to the family *Buprestidae*, such as *Coroebus florentinus* (Herbst), *Chrysobotris affinis* (F.), *Agrilus biguttatus* (F.) and *Anthaxia millefolii* (F.), may establish interactions with *D. mutila*, *Verticillium* spp., *F. eumartii*, and *Sporothrix* spp. Finally, the beetle *Platypus cylindrus* (F.) (*Curculionidae*) may be associated with *V. dahliae*.

D. mutila and *P. quercina* are endophytic fungi, but many other well-known potential pathogens live as endophytes in healthy, asymptomatic plants, deploying their virulence only when infected hosts undergo stress conditions, ultimately contributing to their death (MORICCA and RAGAZZI, 2008).

The following species display such a behavior on oaks: *Biscogniauxia mediterranea* (De Not.) Kuntze (Fig. 5), *Botryosphaeria dothidea* (Moug.) Ces. & De Not. (Fig. 6), *Diplodia seriata* De Not., *Phoma cava* Schulzer, *Neofusicoccum parvum* (Pennycook & Samuels) Crous, Slippers & A.J.L. Phillips. These endophytic pathogens, similarly to *D. mutila* and *P. quercina*, may be transported by the above insect vectors, or by other bark beetles occurring on the same oak trees (RAGAZZI, 2004; TIBERI and ROVERSI, 2004).

Fig. 5. Large stromata of *Biscogniauxia mediterranea*, agent of charcoal canker on oaks. The perithecia are immersed in the inner layer of stromata, in contact with the woody tissue; at maturity they release the ascospores which can contaminate potential insect vectors.

Fig. 5. Stroma di *Biscogniauxia mediterranea*, agente del cancro carbonioso delle querce. I periteci sono immersi nello strato interno dello stroma, a contatto con il tessuto legnoso; a maturità, essi liberano le ascospore che possono contaminare potenziali insetti vettori.

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Fig. 6. Longitudinal lesions caused by *Botryosphaeria dothidea* on the stem of many *Acer pseudoplatanus* trees. Deep bark cracks induce tree death.
Fig. 6. Lesioni longitudinali provocate da *Botryosphaeria dothidea* sul fusto di numerose piante di *Acer pseudoplatanus.* Profonde lacerazioni del tessuto corticale portano a morte le piante.

Pinus spp.

What reported for oaks can be in part true also for pine trees. However, reliable data on the possibility that other insects, and among these xylophagous beetles, can contract relationships with various pathogenic fungi of lignified parts and in particular with blue-stain fungi, such as the species in the genus *Leptographium* (CAPRETTI and RAGAZZI, 2009), are not yet available.

Possible new associations because of extra-range spread into new areas

Alien plant parasites pose a serious threat to natural and artificial ecosystems on our planet (PANCONESI *et al*., 2014). In the past, the colonization of new areas by living organisms occurred through long lasting patterns of natural dispersal, which have in part contributed to nourish that ecological mechanism which represents the basis for natural selection. Evolutionary processes triggered by newly introduced species often represented real co-evolution between organisms, in the fight for survival.

In recent decades, due to the intensification of world trade and the greater ease of travelling from one continent to another, these natural processes have changed considerably, owing to the accidental dispersal of plants, animals and microbes or their deliberate release for varied purposes (PICCO *et al*., 2011). This has given rise to severe alterations of native ecosystems, which often led to the extinction of one or more native species. In this framework, it is highly possible that exotic fungal pathogens introduced to Italy can meet local insects, establishing new associations, or viceversa.

Quercus spp.

Among the associations that could arise in our country between introduced and native parasites, one in particular causes today major concern. It is the possible association between the fungus *Ceratocystis fagacearum* (Bretz) J. Hunt, widespread in North America, where it causes a disease known as "oak wilt" on *Quercus rubra* L. and *Q. velutina* Lam., and suitable vectors such as bark beetles of the genus *Scolytus*, as well as in some buprestids belonging mainly to the genus *Agrilus* (BATTISTI and COVASSI, 1991).

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Pinus spp and other conifers

Another phytosanitary emergency, which involves insects as vectors, regards the dreaded introduction of the nematode *Bursaphelenchus xylophilus* Nikle, parasitic on conifers, especially pines. This species, native to North America, has long been introduced into East Asia. Recently, it was reported from pine forests in Portugal, France and in Scandinavian countries, suspected to have been introduced with timber imported from North America. In natural conditions various insects, especially longhorn beetles of the genus *Monochamus*, which are users of lignified organs of conifers (including pines), favor the spread of this parasite (SOUSA et al., 2011).

Discussion and conclusions

The environmental impact deriving from the combined action of insects and fungal pathogens undoubtedly affects forest ecosystems and, as a consequence, the unique beauty of the landscape. Ecosystem alteration and devastation by xylophagous insects and their associated pathogenic fungi are the cause of huge ecological and economic losses.

Many trees attacked by insects and their associated pathogenic fungi are an important component of natural forests. Trees are also an important asset for public health in artificial forests and parks. Indeed, outdoor sport activity has been especially in recent years revalued together with a greater need of contact with nature, due to an increased human awareness. Not by chance the "welfare of population" was sponsored by the *United Nations Environmental Programme* with the *Millennium Ecosystem Assessment Project* (UNEP, 2012), undertaken to identify environmentally-friendly development strategies, and to consolidate the culture of exploitation of "multiple benefits provided by ecosystems to mankind". These benefits, which can be synthesised in the sentence "*ecosystem services*", refer to the relationships between environmental resources, economic systems and man (TOMAO *et al*., 2013).

The spread of a fungal pathogen by insect vectors, and their joint action, may induce, in some cases, the extinction of attacked species. Such events would result undoubtedly in severe losses of that priceless heritage that takes the name of "biodiversity". Such a heritage is unquestionably worthy of being preserved and protected because it provides an important source of economic, ecological, biochemical and medical resources which represent a priceless value for mankind.

Insect and pathogen control in forest stands has some limitations in the intervention costs, but also in the risk of environmental impact. The now established principle of environmentally-friendly control tends to "rediscover" the good silvicultural practices, especially those aiming at avoiding the associations between phytophagous insects and fungal pathogens. More specifically, it can be summarized as follows: 1) working on the host plant, to reduce its susceptibility; 2) acting against both the insect and the fungus, to prevent their establishment and hinder possible relationship between them, thus limiting their spread; 3) modifying the environmental conditions, making them unfavorable for both the insects and the infectious microorganisms.

In urban environments, however, the particular ecological conditions may often favor harmful insects and fungal pathogens, thus hindering the above mentioned practices, which cannot be always adequately applied. In fact, in urban systems some insect/fungus associations show a higher incidence; here, the two organisms represent always a problem as their attacks, singly or in combination, have major implications in the conservation of historical or valuable tree heritage. Insect/fungus relationships, as already mentioned, can substantiate in "obligate symbioses" or "non mutualistic symbioses": both are very harmful since they can trigger extensive and irreversible *in situ* and *ex situ* epidemics.

In urban environments, control strategies must take into account the nature and the context of the damage, thus requiring a deeper assessment and more intense work than in natural systems. In the urban setting, in

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fact, the hygienic-sanitary function, the safety of citizens, and the aesthetic/recreational aspects become much more important than the mere production of timber. The preferred approach should be an integrated control strategy, with preventive and curative measures applied in an ideal balance.

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