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Pest categorisation of *Ips duplicatus*

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Abstract

The Panel on Plant Health performed a pest categorisation of the double-spined bark beetle, *Ips duplicatus* (Sahlberg, 1836) (Coleoptera: Curculionidae, Scolytinae), for the EU. *I. duplicatus* is a well-defined and distinguishable species, native to Europe and attacking mainly spruce (*Picea* spp.) but also observed on pine (*Pinus* spp.) and larch (*Larix* spp.). It is distributed in 15 EU Member States and is locally spreading in some of them. *I. duplicatus* is listed in Annex IIB of Council Directive 2000/29/EC. Protected zones are in place in Ireland, Greece and the United Kingdom. Wood, wood products, bark, and wood packaging material are considered as pathways for this pest, which is also able to disperse by flight. The insects mostly attacks scattered individual standing trees in the stands, often when the trees are weakened by dry conditions or by pathogens, and they very rarely infest fallen or cut logs. The males produce pheromones that attract conspecifics of both sexes. Each male attracts 1–5 females and they establish a brood system; each female produces 1–60 offspring. The insects also inoculate their hosts with pathogenic fungi. There are one to three generations per year. The current geographic range of *I. duplicatus* suggests that it is able to establish in most of the EU, including the protected zones, where its hosts are present. Sanitary thinning or clear-felling and pheromone trapping are the usual control methods. All criteria for consideration as potential protected zone quarantine pest are met. The criteria for considering *I. duplicatus* as a potential regulated non-quarantine pest are not met since plants for planting are not viewed as a pathway.

Keywords: Curculionidae, double-spined bark beetle, European Union, pest risk, plant health, plant pest, quarantine

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

1.1.1. Background

Council Directive 2000/29/EC[1] on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community establishes the present European Union plant health regime. The Directive lays down the phytosanitary provisions and the control checks to be carried out at the place of origin on plants and plant products destined for the Union or to be moved within the Union. In the Directive's 2000/29/EC annexes, the list of harmful organisms (pests) whose introduction into or spread within the Union is prohibited, is detailed together with specific requirements for import or internal movement.

Following the evaluation of the plant health regime, the new basic plant health law, Regulation (EU) 2016/2031[2] on protective measures against pests of plants, was adopted on 26 October 2016 and will apply from 14 December 2019 onwards, repealing Directive 2000/29/EC. In line with the principles of the above mentioned legislation and the follow-up work of the secondary legislation for the listing of EU regulated pests, EFSA is requested to provide pest categorizations of the harmful organisms included in the annexes of Directive 2000/29/EC, in the cases where recent pest risk assessment/ pest categorisation is not available.

1.1.2. Terms of Reference

EFSA is requested, pursuant to Article 22(5.b) and Article 29(1) of Regulation (EC) No 178/2002[3], to provide scientific opinion in the field of plant health.

EFSA is requested to prepare and deliver a pest categorisation (step 1 analysis) for each of the regulated pests included in the appendices of the annex to this mandate. The methodology and template of pest categorisation have already been developed in past mandates for the organisms listed in Annex II Part A Section II of Directive 2000/29/EC. The same methodology and outcome is expected for this work as well.

The list of the harmful organisms included in the annex to this mandate comprises 133 harmful organisms or groups. A pest categorisation is expected for these 133 pests or groups and the delivery of the work would be stepwise at regular intervals through the year as detailed below. First priority covers the harmful organisms included in Appendix 1, comprising pests from Annex II Part A Section I and Annex II Part B of Directive 2000/29/EC. The delivery of all pest categorisations for the pests included in Appendix 1 is June 2018. The second priority is the pests included in Appendix 2, comprising the group of Cicadellidae (non-EU) known to be vector of Pierce's disease (caused by Xylella fastidiosa), the group of Tephritidae (non-EU), the group of potato viruses and virus-like organisms, the group of viruses and virus-like organisms of Cydonia Mill., Fragaria L., Malus Mill., Prunus L., Pyrus L., Ribes L., Rubus L. and Vitis L.. and the group of Margarodes (non-EU species). The delivery of all pest categorisations for the pests included in Appendix 2 is end 2019. The pests included in Appendix 3 cover pests of Annex I part A Section I and all pests categorisations should be delivered by end 2020.

For the above mentioned groups, each covering a large number of pests, the pest categorisation will be performed for the group and not the individual harmful organisms listed under "such as" notation in the Annexes of the Directive 2000/29/EC. The criteria to be taken particularly under consideration for these cases, is the analysis of host pest combination, investigation of pathways, the damages occurring and the relevant impact.

Finally, as indicated in the text above, all references to 'non-European' should be avoided and replaced by 'non-EU' and refer to all territories with exception of the Union territories as defined in Article 1 point 3 of Regulation (EU) 2016/2031.

[1] Council Directive 2000/29/EC of 8 May 2000 on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. OJ L 169/1, 10.7.2000, p. 1–112.

[2] Regulation (EU) 2016/2031 of the European Parliament of the Council of 26 October 2016 on protective measures against pests of plants. OJ L 317, 23.11.2016, p. 4–104.

[3] Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. OJ L 31/1, 1.2.2002, p. 1–24.

1.1.2.1. Terms of Reference: Appendix 1

List of harmful organisms for which pest categorisation is requested. The list below follows the annexes of Directive 2000/29/EC.

Annex IIAI

(a) Insects, mites and nematodes, at all stages of their development

Aleurocantus spp.
Anthonomus bisignifer (Schenkling)
Anthonomus signatus (Say)
Aschistonyx eppoi Inouye
Carposina niponensis Walsingham
Enarmonia packardi (Zeller)
Enarmonia prunivora Walsh
Grapholita inopinata Heinrich
Hishomonus phycitis
Leucaspis japonica Ckll.
Listronotus bonariensis (Kuschel)
Numonia pyrivorella (Matsumura)
Oligonychus perditus Pritchard and Baker
Pissodes spp. (non-EU)
Scirtothrips aurantii Faure
Scirtothrips citri (Moultex)
Scolytidae spp. (non-EU)
Scrobipalpopsis solanivora Povolny
Tachypterellus quadrigibbus Say
Toxoptera citricida Kirk.
Unaspis citri Comstock

(b) Bacteria

Citrus variegated chlorosis
Erwinia stewartii (Smith) Dye
Xanthomonas campestris pv. *oryzae* (Ishiyama) Dye and pv. *oryzicola* (Fang. et al.) Dye

(c) Fungi

Alternaria alternata (Fr.) Keissler (non-EU pathogenic isolates)
Anisogramma anomala (Peck) E. Müller
Apiosporina morbosa (Schwein.) v. Arx
Ceratocystis virescens (Davidson) Moreau
Cercoseptoria pini-densiflorae (Hori and Nambu) Deighton
Cercospora angolensis Carv. and Mendes
Elsinoe spp. Bitanc. and Jenk. Mendes
Fusarium oxysporum f. sp. *albedinis* (Kilian and Maire) Gordon
Guignardia piricola (Nosa) Yamamoto
Puccinia pittieriana Hennings
Stegophora ulmea (Schweinitz: Fries) Sydow & Sydow
Venturia nashicola Tanaka and Yamamoto

(d) Virus and virus-like organisms

Beet curly top virus (non-EU isolates)
Black raspberry latent virus
Blight and blight-like
Cadang-Cadang viroid
Citrus tristeza virus (non-EU isolates)
Leprosis
Little cherry pathogen (non- EU isolates)
Naturally spreading psorosis
Palm lethal yellowing mycoplasm
Satsuma dwarf virus
Tatter leaf virus
Witches' broom (MLO)

Annex IIB

(a) Insect mites and nematodes, at all stages of their development

Anthonomus grandis (Boh.)
Cephalcia lariciphila (Klug)
Dendroctonus micans Kugelan
Gilphinia hercyniae (Hartig)
Gonipterus scutellatus Gyll.
Ips amitinus Eichhof
Ips cembrae Heer
Ips duplicatus Sahlberg
Ips sexdentatus Börner
Ips typographus Heer
Sternochetus mangiferae Fabricius

(b) Bacteria

Curtobacterium flaccumfaciens pv. flaccumfaciens (Hedges) Collins and Jones

(c) Fungi

Glomerella gossypii Edgerton

Gremmeniella abietina (Lag.) Morelet

Hypoxylon mammatum (Wahl.) J. Miller

1.1.2.2. Terms of Reference: Appendix 2

List of harmful organisms for which pest categorisation is requested per group. The list below follows the categorisation included in the annexes of Directive 2000/29/EC.

Annex IAI

(a) Insects, mites and nematodes, at all stages of their development

Group of Cicadellidae (non-EU) known to be vector of Pierce's disease (caused by *Xylella fastidiosa*), such as:

1) *Carneocephala fulgida* Nottingham
2) *Draeculacephala minerva* Ball
3) *Graphocephala atropunctata* (Signoret)

Group of Tephritidae (non-EU) such as:

1) *Anastrepha fraterculus* (Wiedemann)
2) *Anastrepha ludens* (Loew)
3) *Anastrepha obliqua* Macquart
4) *Anastrepha suspensa* (Loew)
5) *Dacus ciliatus* Loew
6) *Dacus curcurbitae* Coquillet
7) *Dacus dorsalis* Hendel
8) *Dacus tryoni* (Froggatt)
9) *Dacus tsuneonis* Miyake
10) *Dacus zonatus* Saund.
11) *Epochra canadensis* (Loew)
12) *Pardalaspis cyanescens* Bezzi
13) *Pardalaspis quinaria* Bezzi
14) *Pterandrus rosa* (Karsch)
15) *Rhacochlaena japonica* Ito
16) *Rhagoletis completa* Cresson
17) *Rhagoletis fausta* (Osten-Sacken)
18) *Rhagoletis indifferens* Curran
19) *Rhagoletis mendax* Curran
20) *Rhagoletis pomonella* Walsh
21) *Rhagoletis suavis* (Loew)

(c) Viruses and virus-like organisms

Group of potato viruses and virus-like organisms such as:

1) Andean potato latent virus
2) Andean potato mottle virus
3) Arracacha virus B, oca strain
4) Potato black ringspot virus
5) Potato virus T
6) non-EU isolates of potato viruses A, M, S, V, X and Y (including Yo, Yn and Yc) and Potato leafroll virus

Group of viruses and virus-like organisms of Cydonia Mill., Fragaria L., Malus Mill., Prunus L., Pyrus L., Ribes L.,Rubus L. and Vitis L., such as:

1) Blueberry leaf mottle virus
2) Cherry rasp leaf virus (American)
3) Peach mosaic virus (American)
4) Peach phony rickettsia
5) Peach rosette mosaic virus
6) Peach rosette mycoplasm
7) Peach X-disease mycoplasm
8) Peach yellows mycoplasm
9) Plum line pattern virus (American)
10) Raspberry leaf curl virus (American)
11) Strawberry witches' broom mycoplasma
12) Non-EU viruses and virus-like organisms of *Cydonia Mill., Fragaria L., Malus Mill., Prunus L., Pyrus L., Ribes L., Rubus L.* and *Vitis L.*

Annex IIAI

(a) Insects, mites and nematodes, at all stages of their development

Group of *Margarodes* (non-EU species) such as:

1) *Margarodes vitis* (Phillipi)
2) *Margarodes vredendalensis* de Klerk
3) *Margarodes prieskaensis* Jakubski

1.1.2.3. Terms of Reference: Appendix 3

List of harmful organisms for which pest categorisation is requested. The list below follows the annexes of Directive 2000/29/EC.

Annex IAI

(a) Insects, mites and nematodes, at all stages of their development

Acleris spp. (non-EU)
Amauromyza maculosa (Malloch)
Anomala orientalis Waterhouse
Arrhenodes minutus Drury
Choristoneura spp. (non-EU)
Conotrachelus nenuphar (Herbst)
Dendrolimus sibiricus Tschetverikov
Diabrotica barberi Smith and Lawrence
Diabrotica undecimpunctata howardi Barber
Diabrotica undecimpunctata undecimpunctata Mannerheim
Diabrotica virgifera zeae Krysan & Smith
Diaphorina citri Kuway
Heliothis zea (Boddie)
Hirschmanniella spp., other than *Hirschmanniella gracilis* (de Man) Luc and Goodey
Liriomyza sativae Blanchard
Longidorus diadecturus Eveleigh and Allen
Monochamus spp. (non-EU)
Myndus crudus Van Duzee
Nacobbus aberrans (Thorne) Thorne and Allen
Naupactus leucoloma Boheman
Premnotrypes spp. (non-EU)
Pseudopityophthorus minutissimus (Zimmermann)
Pseudopityophthorus pruinosus (Eichhoff)
Scaphoideus luteolus (Van Duzee)
Spodoptera eridania (Cramer)
Spodoptera frugiperda (Smith)
Spodoptera litura (Fabricus)
Thrips palmi Karny
Xiphinema americanum Cobb sensu lato (non-EU populations)
Xiphinema californicum Lamberti and Bleve-Zacheo

(b) Fungi

Ceratocystis fagacearum (Bretz) Hunt
Chrysomyxa arctostaphyli Dietel
Cronartium spp. (non-EU)
Endocronartium spp. (non-EU)
Guignardia laricina (Saw.) Yamamoto and Ito
Gymnosporangium spp. (non-EU)
Inonotus weirii (Murril) Kotlaba and Pouzar
Melampsora farlowii (Arthur) Davis
Mycosphaerella larici-leptolepis Ito et al.
Mycosphaerella populorum G. E. Thompson
Phoma andina Turkensteen
Phyllosticta solitaria Ell. and Ev.
Septoria lycopersici Speg. var. *malagutii* Ciccarone and Boerema
Thecaphora solani Barrus
Trechispora brinkmannii (Bresad.) Rogers

(c) Viruses and virus-like organisms

Tobacco ringspot virus
Tomato ringspot virus
Bean golden mosaic virus
Cowpea mild mottle virus
Lettuce infectious yellows virus
Pepper mild tigré virus
Squash leaf curl virus
Euphorbia mosaic virus
Florida tomato virus

(d) Parasitic plants

Arceuthobium spp. (non-EU)

Annex IAII

(a) Insects, mites and nematodes, at all stages of their development

Meloidogyne fallax Karssen
Popillia japonica Newman
Rhizoecus hibisci Kawai and Takagi

(b) Bacteria

Clavibacter michiganensis (Smith) Davis et al. ssp. *sepedonicus* (Spieckermann and Kotthoff) Davis et al.
Ralstonia solanacearum (Smith) Yabuuchi et al.

(c) Fungi

Melampsora medusae Thümen
Synchytrium endobioticum (Schilbersky) Percival

Annex I B

(a) Insects, mites and nematodes, at all stages of their development

Leptinotarsa decemlineata Say
Liriomyza bryoniae (Kaltenbach)

(b) Viruses and virus-like organisms

Beet necrotic yellow vein virus

1.2. Interpretation of the Terms of Reference

Ips duplicatus is one of a number of pests listed in the Appendices to the Terms of Reference (ToR) to be subject to pest categorisation to determine whether it fulfils the criteria of a quarantine pest or those of a regulated non-quarantine pest (RNQP) for the area of the European Union (EU) excluding Ceuta, Melilla and the outermost regions of Member States (MSs) referred to in Article 355(1) of the Treaty on the Functioning of the European Union (TFEU), other than Madeira and the Azores.

Since *I. duplicatus* is regulated in the protected zones (PZs) only, the scope of the categorisation is the territory of the PZ (Greece, Ireland and the United Kingdom); thus, the criteria refer to the PZ instead of the EU territory.

2. Data and methodologies

2.1. Data

2.1.1. Literature search

A literature search on *I. duplicatus* was conducted at the beginning of the categorisation in the ISI Web of Science bibliographic database, using the scientific name of the pest as search term. Relevant papers were reviewed and further references and information were obtained from experts as well as from citations within the references and grey literature.

2.1.2. Database search

Pest information, on host(s) and distribution, was retrieved from the European and Mediterranean Plant Protection Organization (EPPO) Global Database (EPPO, 2017).

Data about the import of commodity types that could potentially provide a pathway for the pest to enter the EU was obtained from EUROSTAT (Statistical Office of the European Communities).

The Europhyt database was consulted for pest-specific notifications on interceptions and outbreaks. Europhyt is a web-based network launched by the Directorate General for Health and Consumers (DG SANCO) and is a subproject of PHYSAN (Phyto-Sanitary Controls) specifically concerned with plant health information. The Europhyt database manages notifications of interceptions of plants or plant products that do not comply with EU legislation as well as notifications of plant pests detected in the territory of the MSs and the phytosanitary measures taken to eradicate or avoid their spread.

2.2. Methodologies

The Panel performed the pest categorisation for *I. duplicatus*, following guiding principles and steps presented in the EFSA guidance on the harmonised framework for pest risk assessment (EFSA PLH Panel, 2010) and as defined in the International Standard for Phytosanitary Measures No 11 (FAO, 2013) and No 21 (FAO, 2004).

In accordance with the guidance on a harmonised framework for pest risk assessment in the EU (EFSA PLH Panel, 2010), this work was initiated following an evaluation of the EU plant health regime. Therefore, to facilitate the decision-making process, in the conclusions of the pest categorisation, the Panel addresses explicitly each criterion for a Union quarantine pest and for a Union RNQP in accordance with Regulation (EU) 2016/2031 on protective measures against pests of plants and includes additional information required in accordance with the specific ToR received by the European Commission. In addition, for each conclusion, the Panel provides a short description of its associated uncertainty.

Table 1 presents the Regulation (EU) 2016/2031 pest categorisation criteria on which the Panel bases its conclusions. All relevant criteria have to be met for the pest to potentially qualify either as a quarantine pest or as a RNQP. If one of the criteria is not met, the pest will not qualify. Note that a pest that does not qualify as a quarantine pest may still qualify as a RNQP that needs to be addressed in the opinion. For the pests regulated in the PZs only, the scope of the categorisation is the territory of the PZ; thus, the criteria refer to the PZ instead of the EU territory.

It should be noted that the Panel's conclusions are formulated respecting its remit and particularly with regard to the principle of separation between risk assessment and risk management (EFSA founding regulation (EU) No 178/2002); therefore, instead of determining whether the pest is likely to have an unacceptable impact, the Panel will present a summary of the observed pest impacts. Economic impacts are expressed in terms of yield and quality losses and not in monetary terms, whereas addressing social impacts is outside the remit of the Panel, in agreement with EFSA guidance on a harmonised framework for pest risk assessment (EFSA PLH Panel, 2010).

Table 1: Pest categorisation criteria under evaluation, as defined in Regulation (EU) 2016/2031 on protective measures against pests of plants (the number of the relevant sections of the pest categorisation is shown in brackets in the first column)

Criterion of pest categorisation	Criterion in Regulation (EU) 2016/2031 regarding Union quarantine pest	Criterion in Regulation (EU) 2016/2031 regarding protected zone quarantine pest (articles 32–35)	Criterion in Regulation (EU) 2016/2031 regarding Union regulated non-quarantine pest
Identity of the pest (Section 3.1)	Is the identity of the pest established, or has it been shown to produce consistent symptoms and to be transmissible?	Is the identity of the pest established, or has it been shown to produce consistent symptoms and to be transmissible?	Is the identity of the pest established, or has it been shown to produce consistent symptoms and to be transmissible?
Absence/ presence of the pest in the EU territory (Section 3.2)	Is the pest present in the EU territory? If present, is the pest widely distributed within the EU? Describe the pest distribution briefly!	Is the pest present in the EU territory? If not, it cannot be a protected zone quarantine organism.	Is the pest present in the EU territory? If not, it cannot be a regulated non-quarantine pest. (A regulated non-quarantine pest must be present in the risk assessment area).
Regulatory status (Section 3.3)	If the pest is present in the EU but not widely distributed in the risk assessment area, it should be under official control or expected to be under official control in the near future.	The protected zone system aligns with the pest-free area system under the International Plant Protection Convention (IPPC). The pest satisfies the IPPC definition of a quarantine pest that is not present in the risk assessment area (i.e. protected zone).	Is the pest regulated as a quarantine pest? If currently regulated as a quarantine pest, are there grounds to consider its status could be revoked?

Criterion of pest categorisation	Criterion in Regulation (EU) 2016/2031 regarding Union quarantine pest	Criterion in Regulation (EU) 2016/2031 regarding protected zone quarantine pest (articles 32–35)	Criterion in Regulation (EU) 2016/2031 regarding Union regulated non-quarantine pest
Pest potential for entry, establishment and spread in the EU territory (Section 3.4)	Is the pest able to enter into, become established in and spread within the EU territory? If yes, briefly list the pathways!	Is the pest able to enter into, become established in and spread within the protected zone areas? Is entry by natural spread from EU areas where the pest is present possible?	Is spread mainly via specific plants for planting, rather than via natural spread or via movement of plant products or other objects? Clearly state if plants for planting is the main pathway!
Potential for consequences in the EU territory (Section 3.5)	Would the pests' introduction have an economic or environmental impact on the EU territory?	Would the pests' introduction have an economic or environmental impact on the protected zone areas?	Does the presence of the pest on plants for planting have an economic impact, as regards the intended use of those plants for planting?
Available measures (Section 3.6)	Are there measures available to prevent the entry into, establishment within or spread of the pest within the EU such that the risk becomes mitigated?	Are there measures available to prevent the entry into, establishment within or spread of the pest within the protected zone areas such that the risk becomes mitigated? Is it possible to eradicate the pest in a restricted area within 24 months (or a period longer than 24 months where the biology of the organism so justifies) after the presence of the pest was confirmed in the protected zone?	Are there measures available to prevent pest presence on plants for planting such that the risk becomes mitigated?
Conclusion of pest categorisation (Section 4)	A statement as to whether (1) all criteria assessed by EFSA above for consideration as a potential quarantine pest were met and (2) if not, which one(s) were not met.	A statement as to whether (1) all criteria assessed by EFSA above for consideration as potential protected zone quarantine pest were met, and (2) if not, which one(s) were not met.	A statement as to whether (1) all criteria assessed by EFSA above for consideration as a potential regulated non-quarantine pest were met, and (2) if not, which one(s) were not met.

The Panel will not indicate in its conclusions of the pest categorisation whether to continue the risk assessment process but, following the agreed two-step approach, will continue only if requested by the risk managers. However, during the categorisation process, experts may identify key elements and knowledge gaps that could contribute significant uncertainty to a future assessment of risk. It would be useful to identify and highlight such gaps so that potential future requests can specifically target the major elements of uncertainty, perhaps suggesting specific scenarios to examine.

3. Pest categorisation

3.1. Identity and biology of the pest

3.1.1. Identity and taxonomy

> *Is the identity of the pest established, or has it been shown to produce consistent symptoms and to be transmissible?*
>
> **Yes**, the identity of the pest is established. *Ips duplicatus* is an insect of the family Curculionidae, subfamily Scolytinae.[4] It can be identified at species level using conventional entomological keys.

3.1.2. Biology of the pest

A general description of the biology and ecology of *I. duplicatus* is provided by Holuša and Grodzki (2008), Holuša et al. (2010a) and CABI (2016). The adults overwinter in the bark or in the litter, and disperse in the spring, flying in search of new hosts. These are most often standing trees (very rarely fallen individuals or cut logs), often scattered in the stands, weakened by drought stress or by pathogens, and older than 60 years (Holuša and Grodzki, 2008; Holuša et al., 2010a). A common attack pattern is that *I. duplicatus* concentrates on the upper part of the tree stems and the large branches, but whole trees can be colonised at high population densities. The males emit aggregation pheromones composed of a blend of ipsdienol and *E*-myrcenol (Bakke, 1975; Byers et al., 1990; Ivarsson et al., 1993; Ivarsson and Birgersson, 1995). After having excavated a nuptial chamber in the phloem, each male is joined by 1–5 females, which bore each a maternal gallery in the phloem parallel to the fibres. Single eggs are laid at regular intervals along these galleries. Each larva excavates an individual gallery perpendicular to the maternal gallery. Pupation occurs in a small niche in the phloem, at the end of the larval gallery. The young adults remain under the bark for a few days or weeks and proceed to maturation feeding. 1–60 offspring per female are produced. After egg-laying, the parent adults often re-emerge and establish sister broods on the same tree or in a new host. There are 1–3 generations per year, influenced by the local climatic conditions.

3.1.3. Intraspecific diversity

Lakatos et al. (2007) compared populations of *I. duplicatus* from China (Inner Mongolia), northern Poland, the Czech Republic and Slovakia by analysing 520 bp fragments of the cytochrome oxidase I (COI) gene in the mitochondrial DNA. They detected four haplotypes (three in Europe, one in China), and found a sequence divergence between the populations from China and Europe, which associates with differences in the aggregation pheromones of both groups (reviewed in Chen et al., 2010).

3.1.4. Detection and identification of the pest

> *Are detection and identification methods available for the pest?*
>
> **Yes**, the organism can be detected by visual searching, often after damage symptoms are seen or with pheromone trapping. The species can be identified by examining morphological features, for which taxonomic keys exist, e.g. Balachowsky (1949); Grüne (1979); Schedl (1981); Wood (1982).

The standing trees attacked by *I. duplicatus* die during the colonisation process, with an obvious discolouration of their crown, which becomes brown, and then grey after the needles have shed. During the attacks, brown sawdust is expelled from the entry holes and, when the broods have metamorphosed and the young adults start feeding on the phloem around the galleries, the bark can

[4] Although the leading taxonomists in the 2000s (Wood, 1982; Bright and Skidmore, 2002) still considered the Scolytidae to be a family distinct from the Curculionidae according to morphological criteria, modern phylogenetics supports the position of scolytine beetles (Scolytinae) within the family Curculionidae (Knížek and Beaver, 2004; Hulcr et al., 2015). This is reflected by the growing number of citations in Scopus (2017) referring to Scolytinae (18 in 1990 vs 177 in 2016), as opposed to citations referring to Scolytidae (50 in 1990 vs 15 in 2016). The Scolytinae includes two subcategories, the 'bark beetles' which live in the phloem and the 'ambrosia beetles' which live in the sapwood.

flake off. This phenomenon can be amplified by the action of woodpeckers. Within and behind the phloem, maternal galleries, parallel to the fibres and transversal larval galleries can be seen. The galleries of *I. duplicatus* are however very similar to those of *Ips typographus* (Balachowsky, 1949). The sapwood shows blue staining due to the fungi introduced by the beetles. Pheromone traps can also be used for detection (see, e.g., Chen et al., 2010), although they do not provide precise information regarding the origin of the trapped beetles. The adult beetles are dark brown, cylindrical, 2.8–4 mm long. The larvae are apodous, with a dark amber cephalic capsule.

3.2. Pest distribution

3.2.1. Pest distribution outside the EU

Ips duplicatus is present in two continents, Europe and Asia (Figure 1). In non-EU Europe, the insect has been reported from Norway, Russia, Serbia and Ukraine.

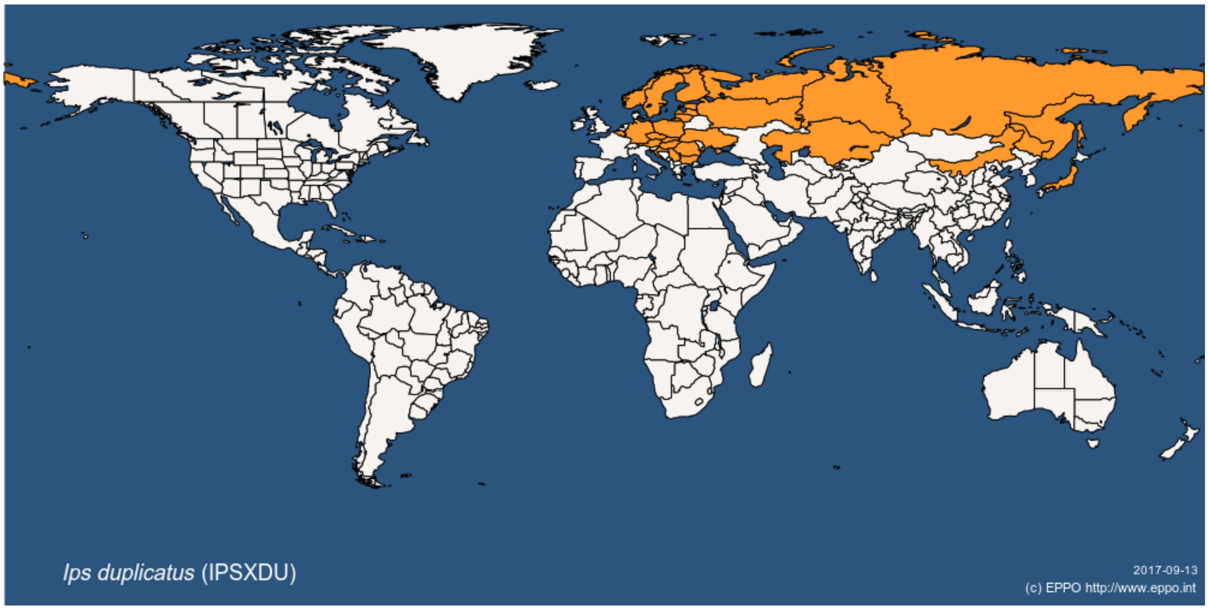


Figure 1: Global distribution map for *Ips duplicatus* (extracted from the EPPO Global Database accessed on 13 September 2017)

3.2.2. Pest distribution in the EU

Is the pest present in the EU territory? If present, is the pest widely distributed within the EU?

Yes, *I. duplicatus* is present and widely distributed in the EU, it has been reported from 15 MS (Table 2), and is spreading in Central Europe (Holuša et al., 2010a). The pest is absent in the protected zones (Greece, Ireland and the UK).

Table 2: Current distribution of *Ips duplicatus* in the 28 EU MS based on information from the EPPO Global Database and other sources if relevant

Country	EPPO Global Database (Last update: 12/7/2017 Last accessed: 13/9/2017)	Comments
Austria	Present, no details	
Belgium	Present, few occurrences	The only reported occurrence (pheromone trap catches on a quay where imported conifer logs from Russia had been unloaded) is most probably an interception (Piel et al., 2006)
Bulgaria	Present, widespread	

Country	EPPO Global Database (Last update: 12/7/2017 Last accessed: 13/9/2017)	Comments
Croatia	Present, restricted distribution	
Cyprus	No information	
Czech Republic	Present, widespread	
Denmark	No information	
Estonia	Present, no details	
Finland	Present, restricted distribution	
France	Absent, invalid record	
Germany	Present, restricted distribution	
Greece	Absent, confirmed by survey	
Hungary	Present, restricted distribution	
Ireland	Absent, confirmed by survey	
Italy	No information	
Latvia	Present, no details	
Lithuania	Present, restricted distribution	
Luxembourg	No information	
Malta	No information	
Poland	Present, restricted distribution	
Portugal	Absent, confirmed by survey	
Romania	Present, no details	
Slovak Republic	Present, restricted distribution	
Slovenia	No information	
Spain	Absent, confirmed by survey	
Sweden	Present, widespread	
The Netherlands	No information	
United Kingdom	Absent, confirmed by survey	

3.3. Regulatory status

3.3.1. Council Directive 2000/29/EC

Ips duplicatus is listed in Council Directive 2000/29/EC. Details are presented in Tables 3 and 4.

Table 3: *Ips duplicatus* in Council Directive 2000/29/EC

Annex II, Part B	**Harmful organisms whose introduction into, and whose spread within, certain protected zones shall be banned if they are present on certain plants or plant products**		
(a)	Insects, mites and nematodes, at all stages of their development		
	Species	Subject of contamination	Protected zones
6 (c)	*Ips duplicatus*	Plants of *Abies* Mill., *Larix* Mill., *Picea* A.Dietr. and *Pinus* L. over 3 m in height, other than fruit and seeds, wood of conifers (Coniferales) with bark, isolated bark of conifers	EL, IRL, UK

3.3.2. Legislation addressing plants and plant parts on which *Ips duplicatus* is regulated

Table 4: Regulated hosts and commodities that may involve *Ips duplicatus* in Annexes III, IV and V of Council Directive 2000/29/EC

Annex III, Part A	**Plants, plant products and other objects the introduction of which shall be prohibited in all Member States**		
	Description		Country of origin
1.	Plants of *Abies* Mill., [. . .] *Larix* Mill., *Picea* A. Dietr., *Pinus* L., [. . .], other than fruit and seeds		Non-European Countries
Annex IV, Part B	**Special requirements which shall be laid down by all member states for the introduction and movement of plants, plant products and other objects into and within certain protected zones**		
	Plants, plant products and other objects	Special requirements	Protected zone(s)
2.	Wood of conifers (*Coniferales*)	Without prejudice to the requirements applicable to the wood listed in Annex IV(A)(I)(1.1), (1.2), (1.3), (1.4), (1.5), (1.6), (1.7), where appropriate, and Annex IV(B)(1), (a) the wood shall be stripped of its bark; or (b) official statement that the wood originates in areas known to be free from *Ips duplicatus* Sahlberg; or (c) there shall be evidence by a mark 'Kiln-dried', 'KD' or another internationally recognised mark, put on the wood or on its packaging in accordance with current commercial usage, that it has undergone kiln-drying to below 20% moisture content, expressed as a percentage of dry matter, at time of manufacture, achieved through an appropriate time/temperature schedule.	EL, IRL, UK
8.	Plants of *Abies* Mill., *Larix* Mill., *Picea* A. Dietr. and *Pinus* L., over 3 m in height, other than fruit and seeds	Without prejudice to the provisions applicable to the plants listed in Annex III(A)(1), Annex IV(A)(I)(8.1), (8.2), (9), (10), Annex IV(A)(II)(4), (5), and Annex IV(B)(7), where appropriate, official statement that the place of production is free from *Ips duplicatus* Sahlberg.	EL, IRL, UK
14.4	Isolated bark of conifers (*Coniferales*)	Without prejudice to the provisions applicable to the bark listed in Annex IV(B)(14.1), (14.2), (14.3), official statement that the consignment: (a) has been subjected to fumigation or other appropriate treatments against bark beetles; or (b) originates in areas known to be free from *Ips duplicatus* Sahlberg.	EL, IRL, UK
Annex V	**Plants, plant products and other objects which must be subject to a plant health inspection (at the place of production if originating in the Community, before being moved within the Community—in the country of origin or the consignor country, if originating outside the Community) before being permitted to enter the Community**		
Part A	Plants, plant products and other objects originating in the Community		
Section II	Plants, plant products and other objects produced by producers whose production and sale is authorised to persons professionally engaged in plant production, other than those plants, plant products and other objects which are prepared and ready for sale to the final consumer, and for which it is ensured by the responsible official bodies of the Member States, that the production thereof is clearly separate from that of other products		
2.1	Plants intended for planting other than seeds of the genera *Abies* Mill., [. . .] *Larix* Mill., [. . .], *Picea* A. Dietr., *Pinus* L., [. . .]		

3.3.3. Legislation addressing the organisms vectored by *Ips duplicatus* (Directive 2000/29/EC)

Kirisits (2004) lists the following ophiostomatoid fungi as vectored by *I. duplicatus*: *Ceratocystis polonica*; *Ophiostoma bicolor*; *Ophiostoma penicillatum*; *Ophiostoma piceae*; *Ophiostoma piceaperdum*; *Ophiostoma* sp.; *Pesotum* sp. Kirisits (2004) considers *C. polonica* as a particularly virulent pathogen. None of the organisms above are regulated.

3.4. Entry, establishment and spread in the EU

3.4.1. Host range

According to Holusa and Grodzki (2008), *I. duplicatus* mainly attacks spruce (*Picea abies*, *Picea obovata*, *Picea jezoensis*) but can also attack pine (*Pinus sylvestris*, *Pinus cembra, Pinus sibirica*) and has also been occasionally reported on larch (*Larix decidua, Larix sibirica*, *Larix dahurica*), and exceptionally on fir (*Abies* spp.) and juniper (*Juniperus* spp.).

From the above host list, *Juniperus* is not mentioned in Annex IIB of Council Directive 2000/29/EC.

3.4.2. Entry

Is the pest able to enter into the EU territory? If yes, identify and list the pathways!

Yes, the pest is already established in 15 MS and can enter the protected zones by human assisted spread or by natural spread from EU areas where the pest is present.

The main pathways of entry are:

- wood of *Picea, Pinus, Larix, Abies* and *Juniperus* from countries where the pest occurs;
- wood chips of conifers from countries where the pest occurs;
- bark of conifers from countries where the pest occurs;
- wood packaging material and dunnage from countries where the pest occurs.

There are no records of interception that indicate that plants for planting can be a pathway for *I. duplicatus*. Plants for planting are not considered a pathway for *I. duplicatus* since young plants are not attacked by the pest.

Ips species are regularly intercepted on wood, wood packaging material and dunnage. However, although 485 *Ips* spp. were intercepted in the USA between 1985 and 2000 from crating, pallets and dunnage, no *I. duplicatus* were found (Haack, 2001). *I. duplicatus* was not intercepted during the period 1950–2000 in New Zealand either (Brockerhoff et al., 2006). In the Europhyt database, between 1994 and 2017, there are in total 66 records of *Ips* species (39 of which are at species level), all on coniferous wood or packaging material, but only one record (on dunnage, from Belgium) for *I. duplicatus* in 1998.

Given the overlap in host plants with *Ips typographus,* the conifer wood trade data presented for *I. typographus* (EFSA PLH Panel, 2017) could also apply to *I. duplicatus*. This would imply that there is trade of wood (0.4 million tonnes from 2011–2015) from EU countries to PZ countries.

3.4.3. Establishment

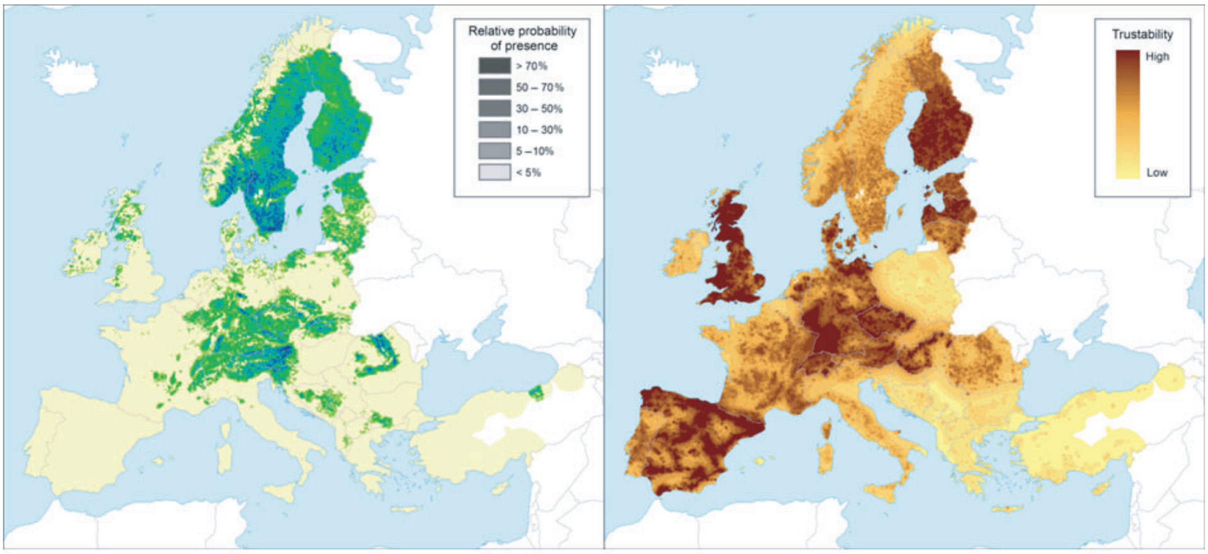
Is the pest able to become established in the EU territory?

Yes, the pest is already established in 15 MS. The climate of the EU protected zones is similar to that of the MS where *I. duplicatus* is established, and the pest's main host plants are present (Figure 2)

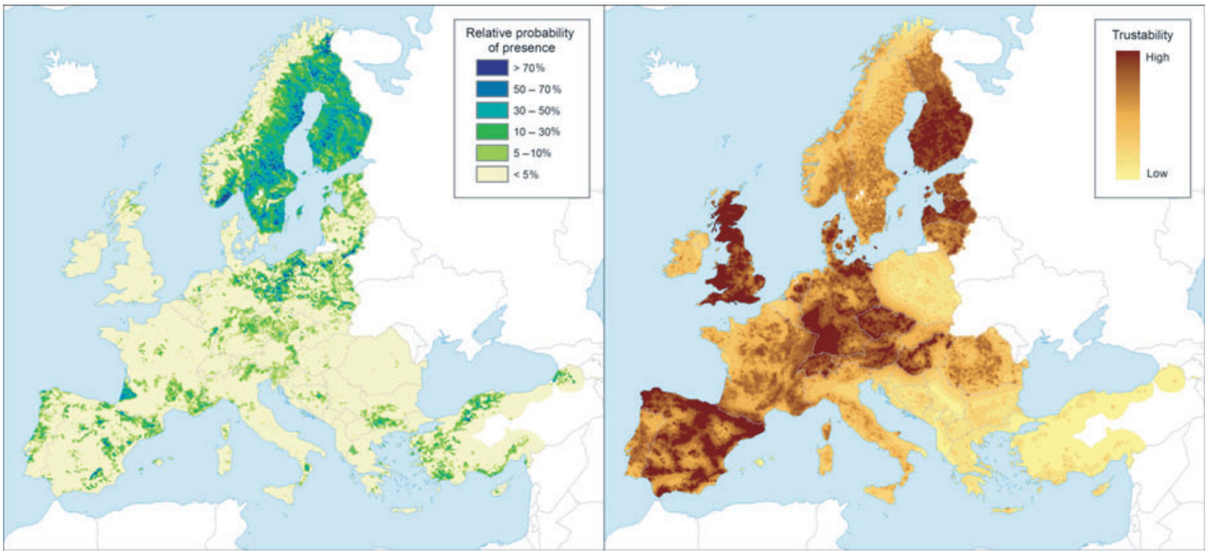
3.4.3.1. EU distribution of main host plants

The wide distribution of host trees in the EU territory (Figure 2A,B) allowed *I. duplicatus* to establish in most MS (see Table 2).

A



B



A) Distribution map of the genus *Picea* in the European Union territory (based on data from the species: *P. abies, P. sitchensis, P. glauca, P. engelmannii, P. pungens, P. omorika, P. orientalis*) B) Distribution map of the genus *Pinus* in the European Union territory (based on data from the species: *P. sylvestris, P. pinaster, P. halepensis, P. nigra, P. pinea, P. contorta, P. cembra, P. mugo, P. radiata, P. canariensis, P. strobus, P. brutia, P. banksiana, P. ponderosa, P. heldreichii, P. leucodermis, P. wallichiana*).

Figure 2: Left panel: Relative probability of presence (RPP) of the genus Picea and Pinus in Europe, mapped at 100 km^2 resolution. The underlying data are from European-wide forest monitoring data sets and from national forestry inventories based on standard observation plots measuring in the order of hundreds m^2. RPP represents the probability of finding at least one individual of the taxon in a standard plot placed randomly within the grid cell. For details, see Appendix A (courtesy of JRC, 2017). Right panel: Trustability of RPP. This metric expresses the strength of the underlying information in each grid cell and varies according to the spatial variability in forestry inventories. The colour scale of the trustability map is obtained by plotting the cumulative probabilities (0–1) of the underlying index (for details see Appendix A).

3.4.3.2. Climatic conditions affecting establishment

According to the Köppen–Geiger climate classification (Kottek et al., 2006) and given the current distribution of *I. duplicatus*, most of the EU area (including the PZs) is suitable for establishment (Figure 3).

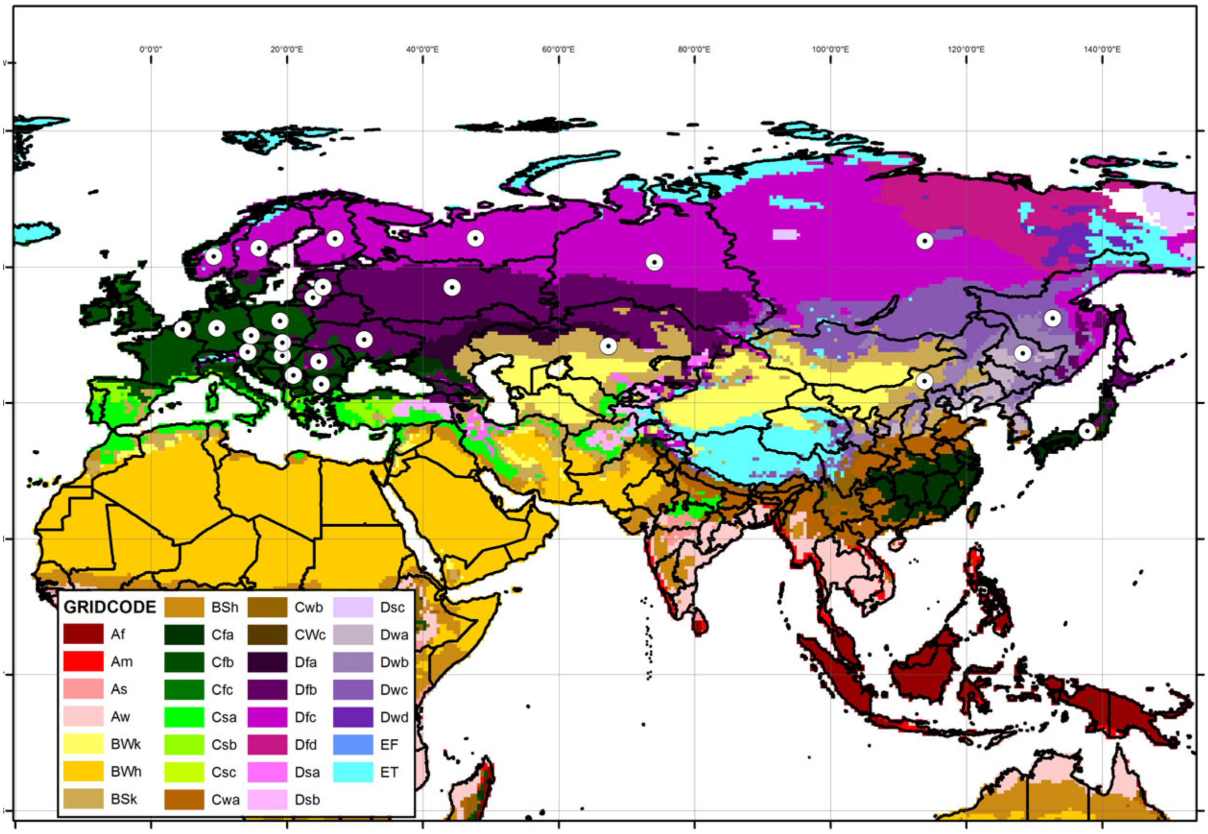


Figure 3: The current distribution of *Ips duplicatus* presented by (°) on the Köppen-Geiger climate classification map (Kottek et al., 2006)

3.4.4. Spread

Is the pest able to spread within the EU territory following establishment? How? **Yes,** adults can disperse naturally or with human assistance. *RNQPs: Is spread mainly via specific plants for planting, rather than via natural spread or via movement of plant products or other objects?* **No**, plants for planting are not considered a pathway.

3.5. Impacts

Would the pests' introduction have an economic or environmental impact on the EU territory? **Yes.** *I. duplicatus* kills standing trees in Poland and the Czech Republic. It also vectors pathogenic fungi (see Section 3.3.3). *RNQPs: Does the presence of the pest on plants for planting have an economic impact, as regards the intended use of those plants for planting?* **No**, Young trees are not attacked by *I. duplicatus*, therefore, impacts in nurseries are not expected.

Holuša et al. (2010a) report outbreaks in Poland and the Czech Republic, with an increase between 2003 and 2009 (average losses over 30,000 m^3, with around 200,000 m^3 in 2007 and 2008). *I. duplicatus* is considered as the most damaging species in natural spruce forests in Inner Mongolia, China (Chen et al., 2010).

3.6. Availability and limits of mitigation measures

Are there measures available to prevent the entry into, establishment within or spread of the pest within the EU such that the risk becomes mitigated?

Yes, in isolated areas (e.g. islands) that cannot be reached by natural spread, measures can be put in place to prevent the introduction with wood and bark. Debarking wood and heat treatment of wood, bark and chips is effective as specified in Annex IVB of 2000/29/EC. When such geographical barriers do not exist, the pest will eventually be able to enter new territories by natural dispersal.

RNQPs: Are there measures available to prevent pest presence on plants for planting such that the risk becomes mitigated?

Yes. Eradication is possible, provided incipient populations are localised very early (i.e. preferably before the new brood has emerged), the attacked material can be removed and destroyed. However, eradication is difficult because all suitable host material in the surrounding area within a radius of several km should be localised and removed.

3.6.1. Biological or technical factors limiting the feasibility and effectiveness of measures to prevent the entry, establishment and spread of the pest

- It is difficult to eradicate successfully the pest from forest areas after an introduction. All infested trees have to be detected and removed within a suitable radius of several kilometres.
- Limitations of silvicultural control: in areas where it is established, the pest continues to develop outbreaks whenever climatic conditions are favourable.
- Monitoring based on the visual identification of attacked trees is difficult because *I. duplicatus* usually attacks trees scattered within the stands and concentrates in the crowns. Moreover, the crown colours only change after the life cycle is completed (Holuša et al., 2013).
- Inspections of large shipments of wood at entry are difficult to perform with complete accuracy.

3.6.2. Control methods

- Silvicultural practices are the usual control methods. They include sanitation thinning and clear-felling with rapid removal of the infested material (Holuša et al., 2013; Stadelmann et al., 2013; Fettig and Hilszczanski, 2015; Grégoire et al., 2015).
- Pheromone trapping can be used for monitoring and mass trapping the pest (Chen et al., 2010).
- Baited trap trees have shown encouraging prospects for mass trapping (Holuša et al., 2010b).

3.7. Uncertainty

I. duplicatus attacks only standing trees, mostly those stressed by drought and pathogens (Holuša et al., 2010a). The actual aggressiveness of the species (how much and under which conditions it is able to attack healthy trees) is not yet fully known.

4. Conclusions

I. duplicatus meets the criteria assessed by EFSA for consideration as a potential PZ quarantine pest for the territory of the PZs: Greece, Ireland and the United Kingdom (Table 5).

Table 5: The Panel's conclusions on the pest categorisation criteria defined in Regulation (EU) 2016/2031 on protective measures against pests of plants (the number of the relevant sections of the pest categorisation is shown in brackets in the first column)

Criterion of pest categorisation	Panel's conclusions against criterion in Regulation (EU) 2016/2031 regarding protected zone quarantine pest (articles 32–35)	Panel's conclusions against criterion in Regulation (EU) 2016/2031 regarding Union regulated non-quarantine pest	Key uncertainties
Identity of the pest (Section 3.1)	The identity of the pest is established. It can be identified to the species level using conventional entomological keys.	The identity of the pest is established. It can be identified to the species level using conventional entomological keys.	None
Absence/ presence of the pest in the EU territory (Section 3.2)	*I. duplicatus* is present and widely distributed in the EU; it has been reported from 15 EU MSs. The protected zones, Greece, Ireland and the United Kingdom, are free from the pest.	*I. duplicatus* is present and widely distributed in the EU; it has been reported from 15 EU MSs. The protected zones, Greece, Ireland and the United Kingdom, are free from the pest	None
Regulatory status (Section 3.3)	The pest is currently officially regulated by 2000/29/EC on plants of *Abies, Larix, Picea* and *Pinus* over 3 m in height, other than fruit and seeds, wood of conifers (Coniferales) with bark, isolated bark of conifers. *I. duplicatus* is regulated as a quarantine pest in protected zones (Annex IIB): Ireland, Greece and the United Kingdom	The pest is currently officially regulated by 2000/29/EC on plants of *Abies, Larix, Picea* and *Pinus* over 3 m in height, other than fruit and seeds, wood of conifers (Coniferales) with bark, isolated bark of conifers. *I. duplicatus* is regulated as a quarantine pest in protected zones (Annex IIB): Ireland, Greece and the United Kingdom	The pest is regularly reported on *Picea* and *Pinus,* occasionally on *Larix*, exceptionally on *Abies* and *Juniperus*. This latter species is not mentioned in 2000/29/EC.
Pest potential for entry, establishment and spread in the EU territory (Section 3.4)	Entry: the pest is established in 15 MSs. Since entry by natural spread from EU areas where the pest is present is possible, only isolated areas (e.g. islands) can be long-term protected zones. Establishment: the climate of the EU protected zones is similar to that of MSs where *I. duplicatus* is established, and the pest's main host plants are present. Spread: adults can disperse naturally. The pest can also spread by human assistance, e.g. with the transportation of wood, wood chips, bark, wood packaging material and dunnage of conifers.	Plants for planting are not a pathway for the spread of *I. duplicatus.*	None
Potential for consequences in the EU territory (Section 3.5)	The pest attacks mostly or solely standing trees and is still spreading within the EU. It has been reported as causing outbreaks in Poland and the Czech Republic, killing several hundred thousand m^3 of weakened spruce.	Young trees are not attacked by *I. duplicatus*, therefore impacts in nurseries are not expected.	The aggressiveness (attack rate of healthy trees) of the beetle is not yet fully described and understood

Criterion of pest categorisation	Panel's conclusions against criterion in Regulation (EU) 2016/2031 regarding protected zone quarantine pest (articles 32–35)	Panel's conclusions against criterion in Regulation (EU) 2016/2031 regarding Union regulated non-quarantine pest	Key uncertainties
Available measures (Section 3.6)	In isolated areas (e.g. islands) that cannot be reached by natural spread, measures can be put in place to prevent the introduction of the pest. For wood, wood products, wood chips and bark this can be achieved by debarking wood and heat treatment of wood, bark and chips. When such geographical barriers do not exist, there is no possibility to prevent the entry, establishment and spread of *I. duplicatus* by natural dispersal.	Young plants are not attacked by *I. duplicatus*	Inspections of large shipments at entry are difficult to perform with complete accuracy
Conclusion on pest categorisation (Section 4)	All criteria assessed by EFSA above for consideration as potential protected zone quarantine pest are met.	The criteria for considering *I. duplicatus* as a potential regulated non-quarantine pest are not met since plants for planting are not a pathway.	See above
Aspects of assessment to focus on/ scenarios to address in future if appropriate	The capacity of *I. duplicatus* to develop full outbreaks on healthy trees as well as the factors triggering the outbreaks still need to be clarified by further research		

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Abbreviations

CLC	Corine Land Cover
COI	cytochrome oxidase I
DG SANCO	Directorate General for Health and Consumers
EPPO	European and Mediterranean Plant Protection Organization
EUFGIS	European Information System on Forest Genetic Resources
EU MS	European Union Member State
FAO	Food and Agriculture Organization
GD^2	Georeferenced Data on Genetic Diversity
IPPC	International Plant Protection Convention
JRC	Joint Research Centre of the European Commission
PLH	EFSA Panel on Plant Health
PZ	Protected Zone
RNQP	regulated non-quarantine pest
RPP	relative probability of presence
RRO	risk reduction option
SMFA	spatial multiscale frequency analysis
TFEU	Treaty on the Functioning of the European Union
ToR	Terms of Reference

Appendix A – Methodological notes on Figure 2

The relative probability of presence (RPP) reported here for *Picea* and *Pinus* spp. in Figure 2 and in the European Atlas of Forest Tree Species (de Rigo et al., 2016; San-Miguel-Ayanz et al., 2016) is the probability of that genus to occur in a given spatial unit (de Rigo et al., 2017). In forestry, such a probability for a single taxon is called 'relative'. The maps of RPP are produced by means of the constrained spatial multiscale frequency analysis (C-SMFA) (de Rigo et al., 2014, 2017) of species presence data reported in geolocated plots by different forest inventories.

A.1. Geolocated plot databases

The RPP models rely on five geodatabases that provide presence/absence data for tree species and genera: four European-wide forest monitoring data sets and a harmonised collection of records from national forest inventories (de Rigo et al., 2014, 2016, 2017). The databases report observations made inside geolocalised sample plots positioned in a forested area, but do not provide information about the plot size or consistent quantitative information about the recorded species beyond presence/ absence.

The harmonisation of these data sets was performed within the research project at the origin of the European Atlas of Forest Tree Species (de Rigo et al., 2016; San-Miguel-Ayanz, 2016; San-Miguel-Ayanz et al., 2016). Given the heterogeneity of strategies of field sampling design and establishment of sampling plots in the various national forest inventories (Chirici et al. 2011a,b), and also given legal constraints, the information from the original data sources was harmonised to refer to an INSPIRE compliant geospatial grid, with a spatial resolution of 1 km^2 pixel size, using the ETRS89 Lambert Azimuthal Equal-Area as geospatial projection (EPSG: 3035, http://spatialreference.org/ref/epsg/etrs89-etrs-laea/).

A.1.1. European National Forestry Inventories database

This data set was derived from National Forest Inventory data and provides information on the presence/absence of forest tree species in approximately 375,000 sample points with a spatial resolution of 1 km^2/pixel, covering 21 European countries (de Rigo et al., 2014, 2016).

A.1.2. Forest Focus/Monitoring data set

This project is a Community scheme for harmonised long-term monitoring of air pollution effects in European forest ecosystems, normed by EC Regulation No 2152/2003.[5] Under this scheme, the monitoring is carried out by participating countries on the basis of a systematic network of observation points (Level I) and a network of observation plots for intensive and continuous monitoring (Level II). For managing the data, the JRC implemented a Forest Focus Monitoring Database System, from which the data used in this project were taken (Hiederer et al., 2007; Houston Durrant and Hiederer, 2009). The complete Forest Focus data set covers 30 European Countries with more than 8,600 sample points.

A.1.3. BioSoil data set

This data set was produced by one of a number of demonstration studies performed in response to the 'Forest Focus' Regulation (EC) No 2152/2003 mentioned above. The aim of the BioSoil project was to provide harmonised soil and forest biodiversity data. It comprised two modules: a Soil Module (Hiederer et al., 2011) and a Biodiversity Module (Houston Durrant et al., 2011). The data set used in the C-SMFA RPP model came from the Biodiversity module, in which plant species from both the tree layer and the ground vegetation layer were recorded for more than 3,300 sample points in 19 European Countries.

[5] Council of the European Union, 2003. Regulation (EC) No 2152/2003 of the European Parliament and of the Council of 17 November 2003 concerning monitoring of forests and environmental interactions in the Community (Forest Focus). Official Journal of the European Union 46 (L 324), 1–8.

A.1.4. European Information System on Forest Genetic Resources (EUFGIS)

EUFGIS (http://portal.eufgis.org) is a smaller geodatabase providing information on tree species composition in over 3,200 forest plots in 34 European countries. The plots are part of a network of forest stands managed for the genetic conservation of one or more target tree species. Hence, the plots represent the natural environment to which the target tree species are adapted.

A.1.5. Georeferenced Data on Genetic Diversity (GD^2)

GD^2 (http://gd2.pierroton.inra.fr) provides information about 63 species of interest for genetic conservation. The database covers 6,254 forest plots located in stands of natural populations that are traditionally analysed in genetic surveys. While this database covers fewer species than the others, it covers 66 countries in Europe, North Africa, and the Middle East, making it the data set with the largest geographic extent.

A.2. Modelling methodology

For modelling, the data were harmonised in order to have the same spatial resolution (1 km^2) and filtered to a study area comprising 36 countries in the European continent. The density of field observations varies greatly throughout the study area and large areas are poorly covered by the plot databases. A low density of field plots is particularly problematic in heterogeneous landscapes, such as mountainous regions and areas with many different land use and cover types, where a plot in one location is not representative of many nearby locations (de Rigo et al., 2014). To account for the spatial variation in plot density, the model used here (C-SMFA) considers multiple spatial scales when estimating RPP. Furthermore, statistical resampling is systematically applied to mitigate the cumulated data-driven uncertainty.

The presence or absence of a given forest tree species then refers to an idealised standard field sample of negligible size compared with the 1 km^2 pixel size of the harmonised grid. The modelling methodology considered these presence/absence measures as if they were random samples of a binary quantity (the punctual presence/absence, not the pixel one). This binary quantity is a random variable having its own probability distribution which is a function of the unknown average probability of finding the given tree species within a plot of negligible area belonging to the considered 1 km^2 pixel (de Rigo et al., 2014). This unknown statistic is denoted hereinafter with the name of 'probability of presence'.

C-SMFA preforms spatial frequency analysis of the geolocated plot data to create preliminary RPP maps (de Rigo et al., 2014). For each 1 km^2 grid cell, the model estimates kernel densities over a range of kernel sizes to estimate the probability that a given species is present in that cell. The entire array of multiscale spatial kernels is aggregated with adaptive weights based on the local pattern of data density. Thus, in areas where plot data are scarce or inconsistent, the method tends to put weight on larger kernels. Wherever denser local data are available, they are privileged ensuring a more detailed local RPP estimation. Therefore, a smooth multiscale aggregation of the entire arrays of kernels and data sets is applied instead of selecting a local 'best performing' one and discarding the remaining information. This array-based processing, and the entire data harmonisation procedure, are made possible thanks to the semantic modularisation which defines the Semantic Array Programming modelling paradigm (de Rigo, 2012).

The probability to find a single species (e.g. a particular coniferous tree species) in a 1 km^2 grid cell cannot be higher than the probability of presence of all the coniferous species combined. The same logical constraints applied to the case of single broadleaved species with respect to the probability of presence of all the broadleaved species combined. Thus, to improve the accuracy of the maps, the preliminary RPP values were constrained so as not to exceed the local forest-type cover fraction with an iterative refinement (de Rigo et al., 2014). The forest-type cover fraction was estimated from the classes of the Corine Land Cover (CLC) maps which contain a component of forest trees (Bossard et al., 2000; Büttner et al. 2012).

The resulting probability of presence is relative to the specific tree taxon, irrespective of the potential co-occurrence of other tree taxa with the measured plots, and should not be confused with the absolute abundance or proportion of each taxon in the plots. RPP represents the probability of finding at least one individual of the taxon in a plot placed randomly within the grid cell, assuming that the plot has negligible area compared with the cell. As a consequence, the sum of the RPP associated with different taxa in the same area is not constrained to be 100%. For example, in a forest with two co-dominant tree species which are homogeneously mixed, the RPP of both may be 100% (see e.g. the Glossary in San-Miguel-Ayanz et al. (2016), http://forest.jrc.ec.europa.eu/media/atlas/Glossary.pdf).

The robustness of RPP maps depends strongly on sample plot density, as areas with few field observations are mapped with greater uncertainty. This uncertainty is shown qualitatively in maps of 'RPP trustability'. RPP trustability is computed on the basis of the aggregated equivalent number of sample plots in each grid cell (equivalent local density of plot data). The trustability map scale is relative, ranging from 0 to 1, as it is based on the quantiles of the local plot density map obtained using all field observations for the species. Thus, trustability maps may vary among species based on the number of databases that report a particular species (de Rigo et al., 2014, 2016).

The RPP and relative trustability range from 0 to 1 and are mapped at a 1 km spatial resolution. To improve visualisation, these maps can be aggregated to coarser scales (i.e. 10 $\times$ 10 pixels or 25 $\times$ 25 pixels, respectively, summarising the information for aggregated spatial cells of 100 and 625 km^2) by averaging the values in larger grid cells.