Hindawi Publishing Corporation
Psyche
Volume 2012, Article ID 145930, 6 pages
doi:10.1155/2012/145930

Research Article

Flight Dynamics and Abundance of *Ips sexdentatus* (Coleoptera: Curculionidae: Scolytinae) in Different Sawmills from Northern Spain: Differences between Local *Pinus radiata* (Pinales: Pinaceae) and Southern France Incoming *P. pinaster* Timber

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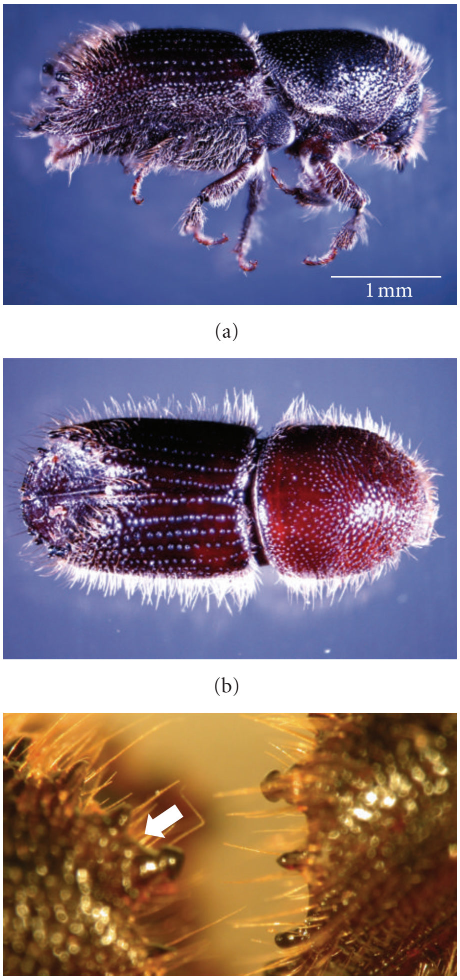
Received 12 April 2012; Accepted 22 May 2012

Academic Editor: Kleber Del-Claro

In January 2009, the windstorm "Klaus" struck the southern part of France, affecting 37.9 million m^3 of maritime pine *Pinus pinaster* Aiton (Pinales: Pinaceae). This breeding plant material favored the outbreak of *Ips sexdentatus* (Börner) (Coleoptera: Curculionidae: Scolytinae). As much of this timber is imported to the Basque Country (northern Spain), a potential risk to conifer stands is generated, due to the emergence of the incoming beetles. Thus, flight dynamics and beetle abundance were compared in different sawmills, according to the timber species (either local *P. radiata* D. Don or imported *P. pinaster*). A maximum flight peak of *I. sexdentatus* was observed in mid-June in *P. pinaster* importing sawmills, whereas a second lighter peak occurred in September. In contrast, only a maximum peak in mid-June was observed in *P. radiata* inhabiting beetles, being significantly smaller than in local *P. pinaster* trading sawmills. In addition, significant differences were found between imported *P. pinaster* and *P. radiata* regarding the number of insects beneath the bark. The development of IPM strategies for controlling *I. sexdentatus* populations is recommended, due to the insect abundance found in *P. pinaster* imported timber.

1. Introduction

Bark beetles (Coleoptera: Curculionidae: Scolytinae) are an insect group that contains at least 6,000 species from 181 genera around the world [1]. Bark beetles are considered as important agents of forest succession and initiate the sequence of nutrient cycling in infested tree material [2]. However, it is well known that some species are among the most destructive insects of coniferous forests, representing a continuous threat [1, 3]. Although bark beetles tend to colonize dead or weakened trees, it is well reported that some species can attack healthy trees under epidemic conditions. Frequently, improper forestry management or adverse abiotic and climatic conditions (e.g., storms, fires, and droughts) act as precursors by providing breeding substrate that unleashes population outbreaks for these bark beetles species [4–6]. For instance, the storms "Vivian/Wiebke" in February/March 1990 and "Lothar" in December 1999 triggered the propagation of *Ips typographus* (L.) in Centre Europe [7]. Recently, "Klaus" named windstorm affected 37.9 million m^3 of maritime pine *Pinus pinaster* Aiton (Pinales: Pinaceae) in Aquitaine (southern France) during January 2009 [8]. As a consequence a great amount of windthrown timber was left as suitable breeding material for the six-toothed beetle *I. sexdentatus* (Börner) Figure 1. Despite its preference for weak, decaying or dead trees, the six-toothed beetle can attack healthy trees under outbreak conditions. Much of this timber from Landes region is imported to many sawmill and timber-processing industries located at the Basque Country (northern Spain), due to its low cost. The long-time storage of such infested logs could put into risk the local forestry management, since new emerging *I. sexdentatus* would disperse beyond sawmills and attack the adjacent Monterey pine (*P. radiata* D. Don) stands,



(a)

(b)

(c)

Figure 1: *Ips sexdentatus* (Börner) (Coleoptera: Curculionidae: Scolytinae), lateral (a) and dorsal views (b), and detail of the elytral declivity of male (left) and female (right). Note the fusion at the base of the 3rd and 4th teeth in male (white arrow).

which is the most common tree species planted in the Basque Country [9].

Ips sexdentatus is a Palearctic species distributed throughout Europe which is capable of breeding in many coniferous genera, including *Pinus* L., *Picea* A. Dietr. (Pinaceae), *Larix* Mill. (Pinaceae), and *Abies* Mill. (Pinaceae) [10, 11]. Concerning the Basque Country, it has been trapped in both *P. radiata* and *P. sylvestris* L. stands [12]. It is associated with several species of ophiostomatoid fungi (Sordariomycetes: Ophiostomatales) [13, 14], which are involved in many tree diseases and sapstain [15]. Not only with blue-staining fungi, but also the association with the fungus *Fusarium circinatum* Niremberg and O'Donnell (= *F. subglutinans* f. sp. *pini* Correll et al. (Hypocreales: Nectriaceae), causal agent of the pitch canker disease, has been detected in *P. radiata* inhabiting populations in the Basque Country [16].

Thus, the aim of the current work was to determine the flight dynamics of *I. sexdentatus* in different sawmills

Table 1: Sampling sawmills located at the Basque Country (northern Spain). *Pinus* L. species (Pinales: Pinaceae) is also indicated within each row.

Locality	Province	Latitude and longitude	Timber
Amezketa	Guipuzcoa	43° 02′ N, 02° 04′ W	*P. pinaster* Aiton
Tolosa	Guipuzcoa	43° 07′ N, 02° 04′ W	*P. pinaster*
Aia	Guipuzcoa	43° 15′ N, 02° 09′ W	*P. pinaster*
Berrobi	Guipuzcoa	43° 08′ N, 02° 01′ W	*P. radiata* D. Don
Zalla	Biscay	43° 12′ N, 03° 08′ W	*P. radiata*
Legutiano	Alava	42° 58′ N, 02° 38′ W	*P. radiata*

from the Basque Country, according to different timber species (either *P. radiata* or imported *P. pinaster*). Secondly, in order to evaluate the infestation level of maritime pine, the density of beetles was evaluated, through direct observation on debarked logs. These primary objectives would allow inferring the significance and risk of importing maritime pine to the Basque Country.

2. Material and Methods

Monitoring trapping took place from 1st April to 31th October 2011. Six different commercial sawmills were chosen. Three of them use *P. radiata* planted in the Basque Country as primary resource, whereas the other three import maritime pine timber from Landes region (southwestern France). The locations of sampling sites are provided in Table 1.

Two eight-unit Lindgren multiple funnel traps (Econex S.L., Murcia, Spain) were placed in each sawmill. Each trap was hung with the top of the trap at 2 m above the ground and the distance between traps was at least 50 m. One trap was unbaited, as a blank control, whereas the other trap was baited with a synthetic *I. sexdentatus*-specific pheromone (a mixture of ipsdienol (212.9 mg), *cis*-verbenol (60.8 mg), and ipsenol (13.6 mg), SEDQ, Barcelona, Spain). Baits were replaced every two months. Fifty mL of propylene glycol were added to each trap cup to kill and preserve captured insects. Not only *I. sexdentatus*, but also other bark beetles species and other accidentally trapped beetles were collected. Samples were removed every fifteen days and taken to the laboratory. Voucher specimens have been deposited at the Entomology Collection of the NEIKER-Basque Institute for Agricultural Research and Development, Arkaute, Basque Country, Spain.

In order to determine what *Pinus* species showed the largest density of *I. sexdentatus*, sections of 70 cm × 30 cm of seven randomly chosen logs (from both *P. radiata* and *P. pinaster*) were peeled off every week from 2nd May to 31th July in each sawmill. Debarking was made with the aid of a chisel. All *I. sexdentatus* present in the galleries beneath the bark were collected. The number of galleries was also recorded.

Data of mean catches of flying beetles caught in baited traps were subjected to a two-way ANOVA analysis (with pine species and date considered as factors). Subsequent Tukey *post-hoc* tests at a significance level of $\alpha = 0.05$

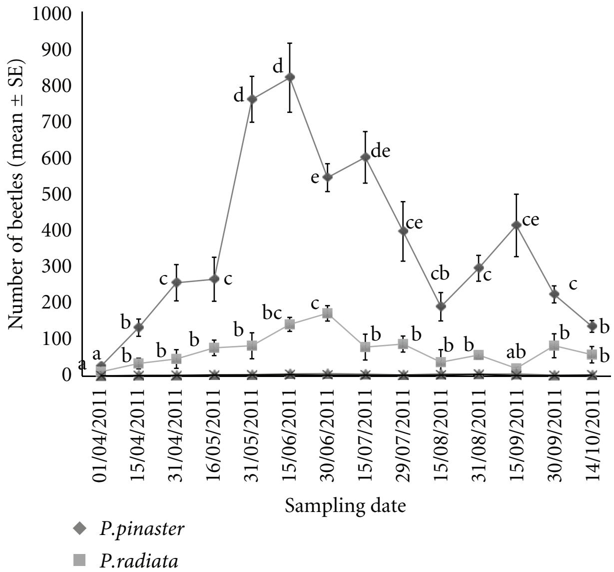


Figure 2: Number (mean ± SE) of *Ips sexdentatus* (Börner) (Coleoptera: Curculionidae: Scolytinae) captured in *Pinus pinaster* Aiton (Pinales: Pinaceae) (dark grey) and *P. radiata* D. Don (light grey) sawmills from 1 April to 14 October 2011. Dates within each *Pinus* L. species with different letters are significantly different at a significance level of $\alpha = 0.05$. Control catches in both cases were insignificant to perform any statistical analysis.

were applied to compare mean catches between dates within each *Pinus* species. Concerning density data, Student's *t*-test was used to compare mean number of galleries and beetle collections in different *Pinus* species for each month. A square root transformation was used to normalize the data and correct the heteroscedasticity. All the analyses were performed with the statistical software SPSS 2004 SYSTAT statistical package (version 13.0, SPSS, Chicago).

3. Results

A total of 15,184 specimens of *I. sexdentatus* were trapped in *P. pinaster* importing sawmills, whereas 2,774 were captured in *P. radiata* sawmills. As expected, pheromone-baited traps caught significant more insects in *P. pinaster* sawmills when compared with captures in *P. radiata* sawmills ($F = 108.927$, df = 1, $P < 0.001$). An interaction between sampling dates and *Pinus* species was found ($F = 7.2440$, df = 13, $P < 0.001$). A maximum flight peak was observed from the end of May to middle June for maritime pine, whereas a slighter peak occurred on September (Figure 2). Regarding *P. radiata* sawmills, a significant peak was observed only at the end of June. No statistical differences were observed in catches of other accidentally trapped insects.

Significant differences were found between the mean number of beetles and galleries under the bark during the three months. Maritime pine sections showed significant more galleries (May: $t = 4.152$, df = 12, $P = 0.002$; June: $t = 5.928$, df = 12, $P < 0.001$; July: $t = 5.063$, df = 12, $P < 0.001$) (Figure 3(a)) and beetles (May: $t = 9.367$, df = 12, $P < 0.001$; June: $t = 8.538$, df = 12, $P < 0.001$; July: $t = 7.900$, df = 12, $P < 0.001$) (Figure 3(b)) than in local *P. radiata*.

In addition, many other bark and ambrosia beetles species were accidentally captured in pheromone-baited traps. Table 2 details the different bark and ambrosia beetles caught per locality, along with other xylophagous species (Coleoptera: Cerambycidae) and bark beetle predators (Coleoptera: Cleridae).

4. Discussion

Current work demonstrates that maritime pine timber imported from France to commercial sawmills is highly infested compared to *P. radiata* timber, according to observed differences in the amount of insects caught in both field trapping and log debarking.

The six-toothed beetle has two generations per year, with adult flight periods from April to May and July to August. However, *I. sexdentatus* can undergo a third generation in Mediterranean regions of Europe [17]. Our results are consistent with other studies. Similar maximum flight peaks have been observed in *Picea orientalis* (L.) Link (in Turkey) and *Pinus sylvestris* (in Romania) stands [18, 19]. In contrast, *I. sexdentatus* showed three different peak flights in *P. pinaster* stands at the province of Leon (northern Spain), with the maximum peak occurring in September [20]. It has been suggested that this latter increase might be due to a strong increasing of the population during that season or a seasonal pheromone production, as it occurs in *I. pini* (Say) [21].

Ips sexdentatus is a polygamous species in which male is the pioneer sex which initiates the host seeking process. Afterwards, up to 2–5 females join each male within the gallery systems [10]. Galleries are star shaped, with a central nuptial chamber built by the male and in which mating occurs. Females bore egg galleries, which radiate outwards from the nuptial chamber. All the observed galleries in the current study had more than two arms.

Among accidentally trapped bark beetles species, it is worth noting the find of a female exemplar of the small spruce bark beetle *Polygraphus poligraphus* (L.), which would represent the first record for the Iberian Peninsula. *Polygraphus poligraphus* inhabits *Picea abies* (L.) H. Karst. and *P. obovata* Ledeb. [11], rarely breeding in *Pinus sylvestris* and *P. strobus* L. [10, 11, 22]. This unique specimen was trapped in the sawmill located at Berrobi, in which *P. radiata* timber is used. In addition, its distribution area is supposed to extend from Central Europe to Northern Europe and Siberia [11], being absent in the Mediterranean region [10]. Thus, the presence of this insect in the sampling area should be clearly stated.

Moreover, two species of *Monochamus* Dejean (Coleoptera: Cerambycidae) were also trapped, mainly in two *P. pinaster* trading sawmills: *M. sutor* (L.) and *M. galloprovincialis* (Olivier). The latter shows special relevance, as it is known to be the vector of the pine wood nematode, *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle (Aphelenchida, Parasitaphelenchidae), causal agent of the pine wilt

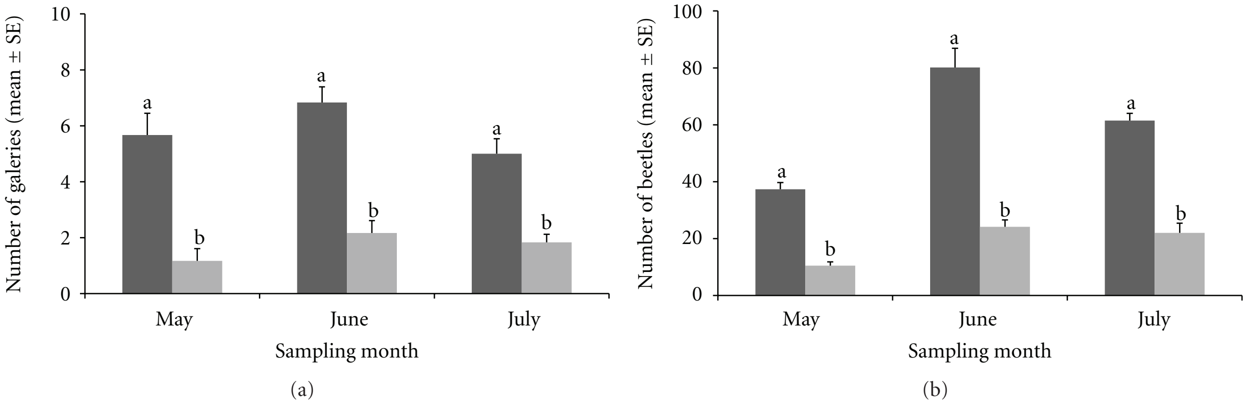


Figure 3: Number (mean ± SE) of (a) galleries and (b) *Ips sexdentatus* (Börner) (Coleoptera: Curculionidae: Scolytinae) found under the bark of *Pinus pinaster* Aiton (Pinales: Pinaceae) (dark grey) and *Pinus radiata* D. Don (Pinales: Pinaceae) (light grey) logs from May to July ($n = 28$). Means within each month with different letters are significantly different at a significance level of $\alpha = 0.05$.

Table 2: Total number of accidentally trapped species of bark and ambrosia beetles (Curculionidae: Scolytinae), cerambycid (Cerambycidae) and checkered beetles (Cleridae). Species within family/subfamily are sorted by alphabetical order.

Species/Locality	Amezketa	Tolosa	Aia	Berrobi	Zalla	Legutiano
Coleoptera: Curculionidae: Scolytinae						
Dryocoetes autographus (Ratzeburg)	5	0	0	1	0	0
Dryocoetes villosus (F.)	9	0	3	2	0	0
Gnathotrichus materiarius (Fitch)	249	7	112	23	22	23
Hylastes ater (Paykull)	22	0	0	3	0	22
Hylurgops palliatus (Gyllenhal)	2	0	1	0	0	0
Hylurgus ligniperda (F.)	137	20	33	3	1	3
Kissophagus hederae (Schmitt)	3	0	0	0	0	0
Orthotomicus erosus (Wollaston)	111	14	57	2	26	95
Orthotomicus laricis (F.)	86	0	18	7	12	1
Pityogenes calcaratus (Eichhoff)	11	1	0	0	9	54
Polygraphus poligraphus (L.)*	0	0	0	1	0	0
Xyleborinus saxeseni (Ratzeburg)	0	0	0	0	0	16
Xyleborus eurygraphus (Ratzeburg)	35	0	11	0	0	0
Xyleborus dryographus (Ratzeburg)	1	0	7	1	0	0
Xylosandrus germanus (Blandford)	1	0	4	2	0	0
Coleoptera: Cerambycidae						
Monochamus galloprovincialis (Olivier)	12	0	2	0	0	0
Monochamus sutor (L.)	28	0	4	0	0	1
Coleoptera: Cleridae						
Allonyx quadrimaculatus (Schaller)	2	0	0	0	0	0
Clerus mutillarius F.	1	0	0	0	0	0
Thanasimus formicarius (L.)	337	157	33	43	25	45

*Indicates first record for the Iberian Peninsula.

disease in different countries, including in Europe (Portugal and Spain) [23–26]. The kairomonal attraction to bark beetle pheromone components has been previously reported in some long-horned beetles, including *M. galloprovincialis* in Spain, another North American species of the genus [27–29].

The checkered beetle *Thanasimus formicarius* (L.) (Coleoptera: Cleridae) was the most common predator found in traps (527 individuals in *P. pinaster* sawmills and 113 in *P. radiata* sawmills). This insect is a common predator of European conifer bark beetles [30], and it is capable of locating their preys by detecting bark beetle produced-pheromones as kairomonal signals [31]. Moreover, it has been reported that they recognize conifer volatiles and even volatiles from angiosperm trees that act as nonhost volatiles to conifer bark beetles [32]. *Allonyx quadrimaculatus* (Schaller) is also considered as a predatorof *Tomicus* *piniperda* L. [33], although there are not concrete studies about the mechanisms involved in prey detection.

As in other species of the genus, management programs should be focused on minimizing attacks on living trees, the sanitation of infested trees and the establishment of a trapping system [7]. The use of semiochemicals with antiaggregative effects should be considered as a useful management tool for trees protection. (1*S*, 4*S*)-(-)-Verbenone (4,6,6-trimethylbicyclo-[3.1.1]hept-3-en-2-one, hereafter (-)-verbenone), has been demonstrated to be capable of disrupting the pheromone-mediated attraction of *I. sexdentatus* [16, 34]. Romón et al. [16] detected a significant negative dose-dependent relationship between different (-)-verbenone release rates (0.01, 0.2, 1.8, and 3.1 mg/24 h) and catches of *I. sexdentatus* in a *P. radiata* stand. Etxebeste and Pajares [34] also found significant reduction in catches when testing (-)-verbenone at 2 and 40 mg/day in a mixed pine stand (ca. 40-year-old *P. pinaster* with younger ca. 30-year-old *P. sylvestris*). In addition, the spyroketal *trans*-7-methyl-1,6-dioxaspiro[4.5]decane (commonly known as *trans*-conophthorin) has also shown promising results. There are evidences of its electrophysiological detection by *I. sexdentatus* [35],and the antiaggregative effect is supported by field assays, although with some disparities. Despite Jactel et al. did not find any significant reduction in trap catches when testing *trans*-conophthorin at 5 mg/day [35], a 16-time lower release rate (i.e., 0.3 mg/day) is capable of reducing the response of *I. sexdentatus* to aggregation pheromone [34]. Moreover, *trans*-conophthorin seems to achieve stronger effects when combined either with (-)-verbenone or NHV alcohols [34, 35]. Thus, taken into account these results, we suggest the development of "push-pull" strategies [36], using pheromone-baited traps inside the park (to favor insect mass trapping) and blends of disruptant semiochemicals at the edges of close pine stands, in order to repel incoming beetles. Long-time buildup of logs should also be not recommended. Future field studies are needed to evaluate the impact of these incoming *I. sexdentatus* populations upon local conifer stands.

Acknowledgments

The authors would like to express thanks to the Basque Country Forest Confederation for financial support and the owners of sampling sawmills for allowing our experimental work. They would like to thank to members of NEIKER for technical assistance. The present study was funded by The Government of the Basque Country.

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