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Addresses
[1] **Ensis, P.O. Box 29237, Christchurch 8540**
[2] **INRA, 69 Route d'Arcachon, 33612 Cestas Cedex, France**
[3] **NEIKER, Granja Modelo Arkaute Apdo. 46, 010080 Vitoria-Gasteiz, Spain**
[4] **Ensis, Private Bag 3020, Rotorua**

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EXECUTIVE SUMMARY

Reports from southern Europe indicate that *Pinus radiata* planted there is highly susceptible to attack by several European pests of pines. In particular, repeated outbreaks of the pine processionary moth (*Thaumetopoea pityocampa*) have caused much damage in pine plantations in Spain and adjacent countries. Anecdotal reports suggest that *P. radiata* is more affected by insect pests than the native pines, although there is limited experimental evidence. We undertook a study that combined (1) a review of published and unpublished information on pests affecting *P. radiata* in Europe and (2) experimental work on insect pests of *P. radiata* in plantation forests in the Spanish Basque Country and in south-west France. The objectives were:

- to summarise the key characteristics of European pests of *Pinus radiata* and the damage they can cause,
- to compare the susceptibility of *Pinus radiata* and other exotic and native pines to these pests,
- and to discuss the implications for forest biosecurity in New Zealand.

Based on our observations, the principal insect pests that affect *P. radiata* where it is planted in southern Europe are (in decreasing order) the pine processionary moth, the bark beetle *Ips sexdentatus*, and the pine stem borer *Dioryctria sylvestrella*. Numerous other bark beetles, moths, and other insects can also cause some damage. Damage from the pine processionary moth was highly noticeable in many *P. radiata* stands, and a comparison of attack and damage in several mixed stands revealed that *P. radiata* is indeed significantly more attacked and damaged than the common native pines in the area, *Pinus pinaster* (maritime pine) and *Pinus nigra* (Corsican pine). No such preference for *P. radiata* was observed for *Ips sexdentatus* in our comparison between eight pine species, but observations in the field indicated that *Ips sexdentatus* can attack and kill an entire stand of trees of *P. radiata* that were previously stressed by a hail storm. Both these insects could become major pests if they invaded New Zealand. However, the pine processionary moth is a comparatively poor disperser and *Ips sexdentatus*, while it is often transported with wood packaging materials, appears to be less invasive than other bark beetles. Nevertheless, incursions and establishments of many related species have occurred in New Zealand and elsewhere. We make a number of recommendations to improve border biosecurity.

TABLE OF CONTENTS

Information for Ensis abstracting:

Contract number	**FHRC project No. 2004-04**
Client Report No.	**12216**

INTRODUCTION

The New Zealand forestry industry is well aware of the biosecurity threats posed by insects and diseases from North America where radiata pine and many other economically important tree species originate. However, it is not widely known that *P. radiata* planted in Europe are badly affected by European pests of pines. For example, there have been repeated outbreaks of the pine processionary moth (*Thaumetopoea pityocampa*) that ravaged pine forests in southern Europe, and *P. radiata* planted there is apparently more affected than the native pines, based on mostly anecdotal evidence. Currently there are also outbreaks of several other important pests of pines in that region, including the pine bark beetle (*Ips sexdentatus*), and the pine stem borer (*Dioryctria sylvestrella*), all of which are capable of either severely damaging or even killing pines. Because *P. radiata* is only a minor plantation forest species in southern Europe, most studies on these pests have focussed on the more widespread native pine species such as *Pinus pinaster* (maritime pine), *Pinus nigra* (Corsican pine) and *Pinus sylvestris* (Scots pine). The most substantial plantings of *P. radiata* are in Spain (approximately 300,000 ha, primarily in the northern Basque Region) and a smaller area in the south of France, Portugal, and other countries around the Mediterranean Sea. Comparatively little research in Europe has specifically addressed *P. radiata*, and much of that work has not been published in English so that our access to this research is limited. Given the high susceptibility of *P. radiata* to these pests and the possibility of importing these into New Zealand by way of trade or tourism, we undertook a literature review and conducted studies in Europe to obtain more information on the exact nature of this threat to our plantation forests.

The objectives of this study were

- to summarise the key characteristics of European pests of *Pinus radiata* and the damage they can cause,
- to compare the susceptibility of *Pinus radiata* and other exotic and native pines to these pests,
- and to discuss the implications for forest biosecurity in New Zealand.

MATERIALS AND METHODS

We conducted a comprehensive assessment of the pest problems experienced by *P. radiata* and selected other pines planted in south west Europe, in close collaboration with local scientists at INRA in SW France and at NEIKER in the Spanish Basque Country. This involved a literature review as well as field work in plantation forests in those areas.

Literature review

For the literature review on European pests of *P. radiata* we searched databases (e.g., CABI Abstracts) as well as web-based information sources on forest pests. Published papers and unpublished information obtained from colleagues were collected, and a list of abstracts was compiled (see appendix). We also queried the French National Forest Health Database (information provided by Dominique Piou). Based on information we received from colleagues in Europe about the main pests of pines in Spain and France, where *P. radiata* is for commercial plantations, we focused our literature review primarily on the pine processionary moth (*Thaumetopoea pityocampa*) and pine bark beetles (*Ips sexdentatus* and others), and, to a lesser extent, the pine stem borer (*Dioryctria sylvestrella*) and other insect pests that were encountered. We were particularly interested in information on the damage and impact on tree health caused by these pests.

Field work - overview

Preliminary field surveys and search for study sites

Our French collaborator Hervé Jactel (HJ) and his colleagues at INRA Pierroton have substantial knowledge of a wide range of pests that occur regionally, and they also have excellent connections with European forest health networks through their ongoing collaboration with colleagues in several European Union funded projects. Information about recent pest problems of *P. radiata* in SW Europe was obtained at the beginning of the project by contacting French forest health officers, district foresters, and scientists. A search for localities where pests of *P. radiata* had been recorded was conducted by Dominique Piou by querying the French National Forest Health Database.

A search for possible study sites was done by EB and HJ between 26 September and 8 October 2004. Several privately owned *P. radiata* plantations in the French Basque region (Department Pyrenees-Atlantiques) were visited with district forester Alain Berton (Navarrenx). Evidence of attack by numerous insect pests was found (see results). Several billets were cut at one stand for use with our comparison of bark beetle attack of different pine species. There was some evidence of pine processionary nests and damage, but in that region we did not find any suitable study sites with mixed stands of *P. radiata* and other pine species for our comparison of pine processionary moth attack of different pine species. We also visited the INRA arboretum Le Ruscas (Department Var) where two small stands of *P. radiata* were planted. There was not much pest attack noted at Le Ruscas so these stands were not considered for further work either. However, our visit to the NEIKER laboratory near Vitoria in the Spanish Basque region showed that this was an ideal base for a study on pine processionary moth. NEIKER scientist / forest entomologist Arturo Goldarazena was very helpful, and a field trip showed that there were numerous stands of *P. radiata* and other pines in the Spanish Basque region that showed substantial attack by pine processionary moth. We returned to Pierroton to complete the setup of the bark beetle study during the remainder of the October 2004 visit (see below). We also proceeded with planning a field study on pine processionary moth in Spain in the following spring (April 2005) when big nests of mature caterpillars would be best observed.

Pine processionary moth and bark beetle studies 2005

EB returned to Europe from 10–26 April 2005 with assistance from Lisa Berndt to conduct the pine processionary moth study in the Basque Region (see below). We received substantial support from Arturo Goldarazena and two NEIKER technicians who accompanied us to field sites and helped with our study. We also completed the assessment of the bark beetle attack experiment at the INRA laboratory in Pierroton, again with support from HJ and an INRA technician.

A progress report and initial results from this study were presented at the FHRC meeting in Napier in May 2005.

Data analysis, report preparation 2006

Finally, EB returned for a last visit from 18–26 June 2006 to complete the data analysis of the pine processionary moth and bark beetle experiments, to complete the literature review at the INRA laboratory in Pierroton (in collaboration with HJ), and to draft the contents of this report.

Pine processionary moth experiments

To compare damage from pine processionary moth caterpillars on *P. radiata* and other pine species we visited several stands in the Spanish Basque country in April 2005. This is the ideal time of year because damage from caterpillars of the pine processionary moth can be best assessed when the caterpillars are about fully grown and when the flush of new shoots and needles has not yet begun, which is generally in early spring. The criteria for selection of a stand as a study site were that (i) at least some pine processionary nests were present, (ii) there was a mix of *P. radiata* and other pine species within stands or at least in close proximity, and (iii) trees of different species were of approximately similar size (to avoid potential bias due to tree size effects). In addition to the plantations of *P. radiata* in this part of Spain there are stands of native European pines *P. nigra* (Corsican or black pine), *P. pinaster* (maritime pine), and some *P. sylvestris* (Scots pine). We visited many possible study sites and several of these met the above criteria.

For assessments of *pine processionary* damage we counted the number of nests present per tree and estimated the percent defoliation, on tall trees with the aid of binoculars. For damage classes refer to the legend of Fig. 6. We also recorded tree species, tree height (using height poles or a digital hypsometer), and on larger trees we took a core sample to estimate tree age. In most cases trees were chosen so that there were *P. radiata* in close proximity to other pines (to allow the comparison of tree species). For the young stand at Esolamakil (Fig. 1) we did separate assessments of *P. radiata* and adjacent *P. nigra* and of all trees along transects across the entire stand (mostly *P. nigra*) to enable the comparison between *P. nigra* growing near or far from *P. radiata*.

Figure 1: Study site at Esolamakil in the Spanish Basque region inland from San Sebastian. We assessed a mixed stand of *P. nigra* and *P. radiata* seen in the foreground.

Bark beetles

We recorded observations of bark beetle infestations that were encountered during visits of *P. radiata* stands (see above) and we conducted experiments to assess bark beetle attack of *P. radiata* and other pine species. A replicated trial was set up in October 2004, involving eight different pine species or subspecies, including four exotic (North American) pines, *P. radiata* (radiata pine or Monterey pine), *P. contorta* (lodgepole pine), *P. palustris* (longleaf pine) and *P. taeda* (loblolly pine), and four native (European) pines, *P. nigra nigra* (black pine or Austrian pine), *P. nigra laricio* (Corsican pine), *P. pinaster* (maritime pine), and *P. sylvestris* (Scots pine). A total of 192 billets (short sections of logs) of ca. 0.5 m length were cut, from four trees of each species. Six billets were cut from each tree thus giving 24 billets from each of these eight species (Fig. 13). Billets were laid out in no-choice and multiple choice experiments on the grounds of the INRA laboratory at Pierroton, France. No-choice experiments consisted of groups of eight billets of the same species laid out independently with two replicates, with a minimum spacing of about 50 m between groups of different species. For multiple choice experiments billets of all eight pine species were placed together randomly, with two billets of each species, giving a total of 16 billets for each of four replicates (Fig. 14). To both no-choice and multiple choice trials, lures of *Ips sexdentatus* pheromone were added to attract these beetles, and attacks were then recorded until the end of the flight period in November 2004. In April 2005 breeding success on the different pines was assessed from a subset of billets by removing the bark to reveal galleries, larvae, and teneral adults of the different species.

Other pests

The presence of other pests and signs of their damage were recorded during field visits to numerous *P. radiata* stands. In addition, we queried the French National Forest Health Database for records of pest and disease damage to *P. radiata*, and we conducted a comprehensive literature survey for records of insect attack and damage of *P. radiata* in Europe (see also above).

Data analysis

Attack and damage from pine processionary moth and bark beetles were compared between *P. radiata* and other pine species by conducting analyses of variance (ANOVAs). For the bark beetle study, data from no-choice and multiple-choice experiments were pooled to compensate for the relatively low level of attack. Details of the statistical tests are reported with the corresponding results (below).

RESULTS AND DISCUSSION

Pine processionary moth

Life cycle

The pine processionary moth [*Thaumetopoea pityocampa* (Denis & Schiffermüller) (Lepidoptera: Thaumetopoeidae] is an important pest of pines and cedars in Europe. Recently, damage of Douglas-fir has been recorded. There are two subspecies which occur in southern Europe, north Africa and the Middle East, around most of the Mediterranean sea and some distance inland. Its presence on trees is easily recognised because its larvae make silken nests that engulf parts of twigs (Figs. 2B, 3) and because of the often serious defoliation of pine trees (Fig. 3). In late summer females lay up to 300 eggs in masses around needle bases (Fig. 2A).

The larvae of each clutch stay together and spend the days in their silken nests. From there they undertake excursions at night to eat pine needles under the cover of darkness. Most of the feeding occurs during the winter months, even at temperatures below freezing, which is most unusual. In spring, by around April, the larvae are mature and leave the tree in single-file head-to-tail processions (hence their name) to find sites that are suitable for pupation in the soil (Fig. 4). A detailed description of the life cycle and other information on this insect is provided in Appendix A.

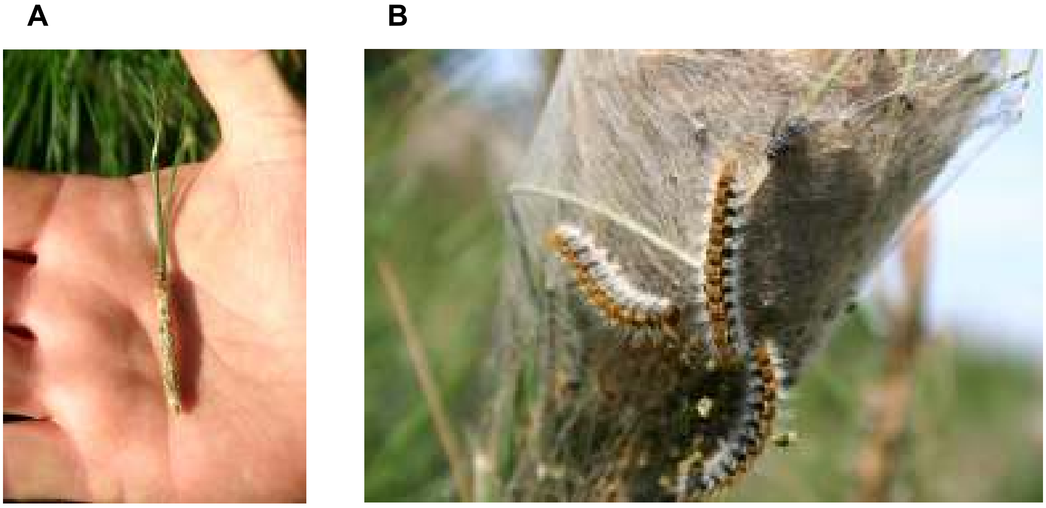

Figure 2: (A) An egg mass of pine processionary moth around the base of pine needles and (B) mature caterpillars on the outside of a silken nest in which they normally shelter during the day.

Figure 3: A stand of P. radiata (near San Roke, Basque Region, Spain) badly defoliated by caterpillars of the pine processionary moth. Many silken nest are noticeable as white spots. Trees have suffered approximately 80–100% defoliation.

Figure 4: Mature caterpillars of the pine processionary moth in a head-to-tail single-file procession (from EB's hand towards the bottom margin of the photo) on their way from a P. radiata to a pupation site in the soil (San Roke, Basque Region, Spain).

Defoliation by pine processionary caterpillars

Esolamakil – young stand of *P. nigra* and *P. radiata*

We assessed a mixed stand of *Pinus nigra* (Corsican or black pine) with some *P. radiata* (Fig. 1). Trees were mostly about 1.2 m – 2.5 m height. We assessed 59 *P. radiata* of which 23 were attacked, mostly with one nest but three trees had two nests and one tree had three nests. Of the attacked *P. radiata*, 10 were complete defoliated, the others were between less than 10% and up to 50% defoliated. The average defoliation class was about 1.3 (Fig. 6). We assessed all the adjacent *P. nigra*, a total of 172 trees, of which 147 had no pine processionary nests, 24 had one nest, and one tree had two nests. Overall, there were fewer nests on *P. nigra* than on *P. radiata* and the average defoliation class was also much lower (Fig. 6).

In addition, we assessed 479 trees in 14 transects to determine the background level of attack across the stand, and to be able to compare the effects on *P. nigra* of being close to a potentially more susceptible *P. radiata*. This showed that *P. nigra* had on average 0.04 nests per tree when it was far from a *P. radiata* but 0.14 nests per tree when it was close to a *P. radiata* ($P = 0.02$), which suggests that there was a 3-fold increase of attack risk when *P. nigra* was near a *P. radiata*.

Figure 5: *Pinus radiata* completely defoliated by caterpillars of the pine processionary moth, in a young stand of *P. nigra* and *P. radiata*. Similar sized trees of *P. nigra* were generally much less attacked (Esolamakil, Basque Region, Spain). Persons in the photo are (from left) Hervé Jactel (INRA, France), Patxi Saenz (NEIKER, Spain), Ander Isasmendi (NEIKER, Spain).

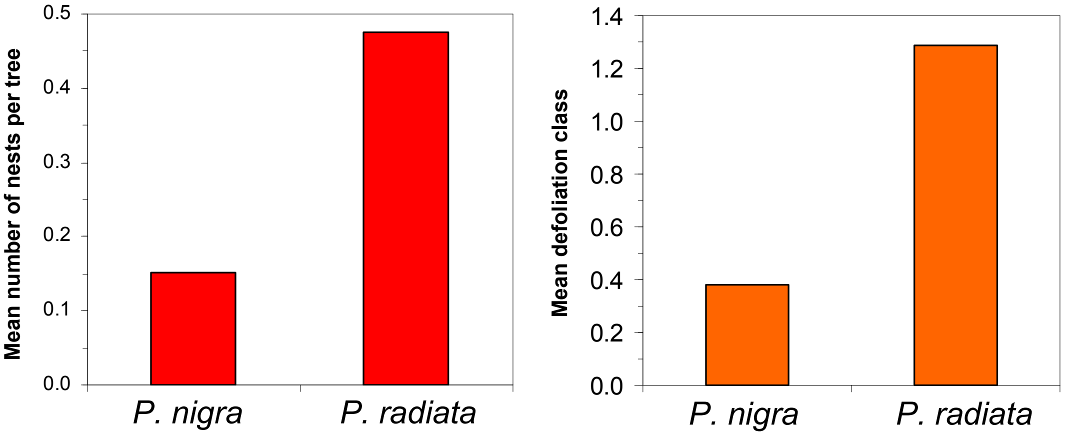

Figure 6: Mean number of pine processionary nests and defoliation of *Pinus radiata* and *P. nigra* in a young, mixed stand at Esolamakil. **Legend**: 0 = no defoliation, 1 = < 10% defoliation, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-100% defoliation.

Because *P. radiata* trees were on average of slightly greater height than the *P. nigra* in this stand, there could have been a bias towards attack of *P. radiata* as the tallest trees in a stand are generally most susceptible. To separate this potential effect, we used the Esolamakil data set from young trees for another analysis with tree height as another variable. This analysis confirmed that *P. radiata* had overall significantly more damage (*P* < 0.0001) but there were also a significant height and species x height interaction effects (Fig. 7).

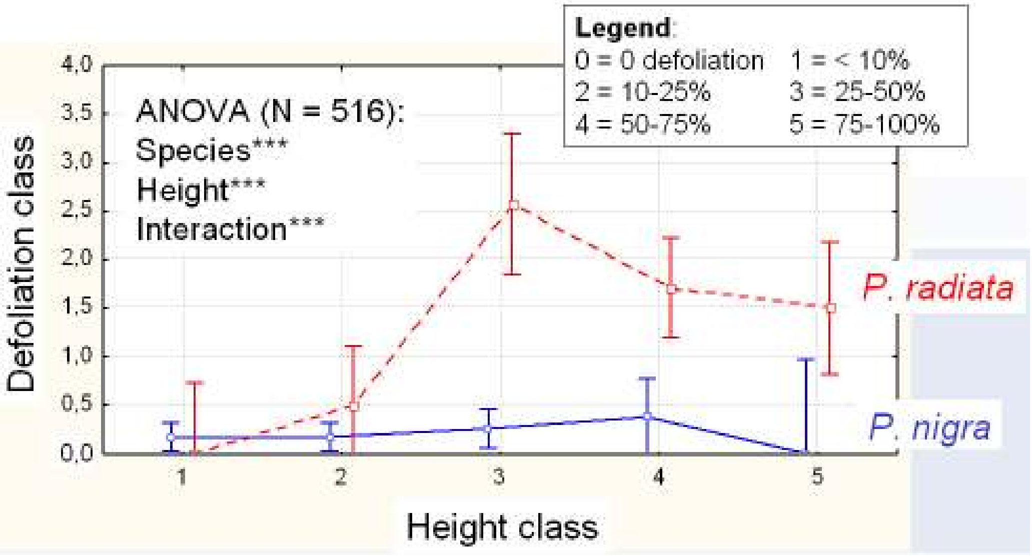

Figure 7: Mean level of defoliation of *Pinus radiata* (red) and *P. nigra* (blue) in a young, mixed stand at Esolamakil. Here only trees of similar height were compared. Damage classes are as in Fig. 6. Height classes are (1) 1.2–1.3 m, (2) 1.4–1.5 m, (3) 1.6–1.7 m, (4) 1.8–1.9 m, (5) 2.0–2.1 m. Note: taller *P. radiata* were excluded because there were no matching *P. nigra*.

San Roke – open stand of 5 – 10 m *P. pinaster* and *P. radiata*

A mixed stand of *Pinus pinaster* and *P. radiata* was found near San Roke, between Bilbao and Vitoria. There was much evidence of pine processionary attack in this stand and in the whole area. To compare the attack and damage from pine processionary moth we assessed groups of trees where both pine species were adjacent. The same pattern of greater susceptibility of *P. radiata* was apparent (Fig. 8). We assessed 78 trees (33 *radiata*, 45 *pinaster*) of which 2 *P. radiata* were removed from the analysis to ensure similar tree height between species. This analysis showed that *P. radiata* had significantly more nests (up to five per tree and on average 1.4 nests per tree) than *P. pinaster* (0.3 nests per tree on average) ($P < 0.0001$). The analysis of damage by height class showed that *P. radiata* was much more affected, and overall this was highly significant ($P < 0.0001$) (Fig. 9). There was also a significant height effect (P =.0.03) which confirmed that taller trees are more likely to be damaged, but the species by height interaction was not significant.

Figure 8: Study site at San Roke (Basque Region, Spain) in a mixed stand of *Pinus pinaster* and *P. radiata*. Trees ranged from about 5 – 10 m in height.

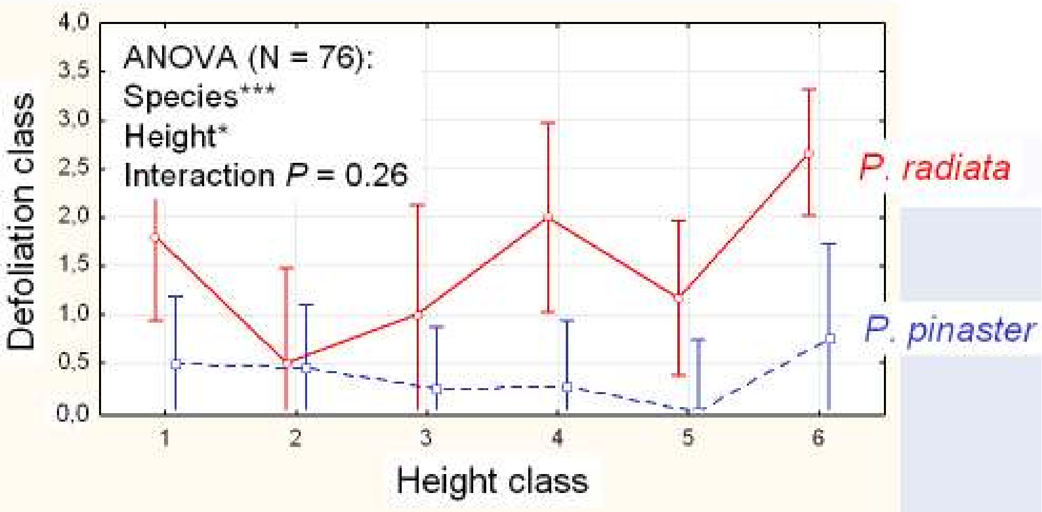

Figure 9: Mean level of defoliation of *Pinus radiata* (red) and *P. pinaster* (blue) in stand of 5- 10 m tall trees at San Roke. Only trees of similar height were compared. Damage classes are as in Fig. 6. Height classes are (1) 4.4–5.7 m, (2) 5.8–6.4 m, (3) 6.5–7.1 m, (4) 7.2–8.1 m, (5) 8.2–8.6 m, (6) 8.7-10.0 m. Note: Two taller *P. radiata* were excluded because there were no matching *P. nigra.*

San Roke –stand of older mixed *P. pinaster*, *P. radiata*, and other pines

A mixed stand of mature *P. pinaster* and *P. radiata* with some smaller *P. sylvestris* and *P. nigra* was suitable for a comparison of attack of older trees (Fig. 10).

Figure 10: Study site at San Roke (Basque Region, Spain) in a mixed stand of *Pinus pinaster*, *P. radiata*, and other pines. Trees ranged from about 22 – 34 m in height.

The age of these trees ranged from about 37 to 57 years, according to cores taken from all the 32 trees we assessed. The level of attack was remarkable with up to 35 nests on one *P. radiata* and considerable defoliation of these big trees (Fig. 10). This stand was comparatively small, which limited the possible sample size at this site, and another constraint was that the assessments of these tall trees (up to 34 metres) were more time-consuming. During the data analysis it became apparent that we had to exclude the smaller trees because there were no matching *P. radiata* available. The final data set we analysed consisted of 10 *P. radiata* and seven *P. pinaster* of matching tree height in height classes between 22 and 34 m (Fig. 11). The species effect was significant ($P = 0.01$), and *P. radiata* was again shown to be more susceptible than *P. pinaster*. The height effect and species x height interaction were not significant, but the sample size here was relatively small.

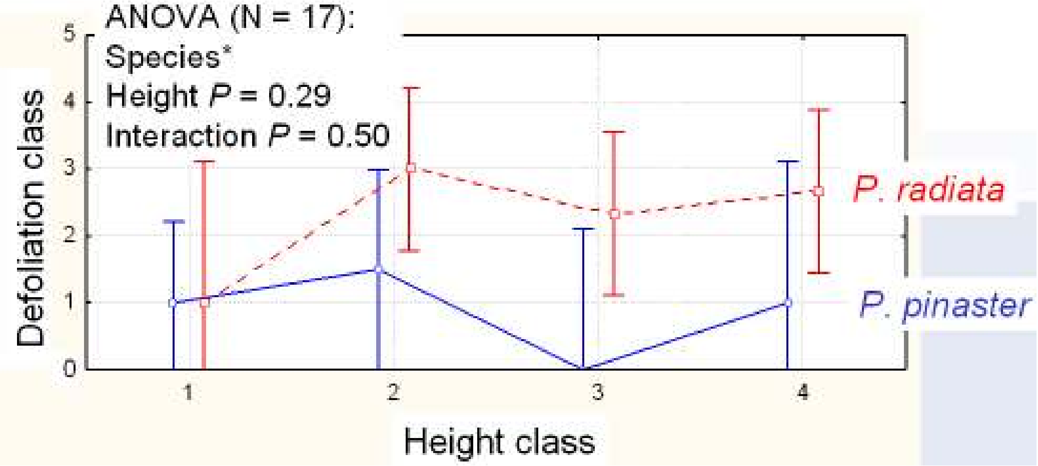

Figure 11: Mean level of defoliation of *Pinus radiata* (red) and *P. pinaster* (blue) in stand of 5- 10 m tall trees at San Roke. Only trees of similar height were compared. Damage classes are as in Fig. 6. Height classes are (1) 22-23 m, (2) 27-28 m, (3) 29-32 m, (4) 33-34 m.

Overall comparison of defoliation of *P. radiata* and other pines

Our experiments showed that *P. radiata* was consistently more attacked and defoliated than *P. nigra* and *P. pinaster*, the two principal native pines in the region. There was a significant height effect, with taller trees typically being more attacked, and we conducted our analyses to separate this height effect from the species effect. If this height effect is *not* taken into consideration, then the comparison between *P. radiata* and the native pines would show an even greater attack of *P. radiata* because of its greater height growth. There can be no doubt that pine processionary moth is a serious pest of *P. radiata*, and that the incidence of serious defoliation would be much worse were it not for the widespread use of insecticides to protect stands, particular in the Basque region of Spain.

Reasons for the susceptibility of *P. radiata* to pine processionary moth attack

Our study clearly showed that *P. radiata* is more attacked by pine processionary moth and that it suffers more damage from this defoliator than the principal native pine species. Several previous studies observed this, although this was often based on anecdotal evidence. A study by Tiberi et al. (1999) examined the role of various monoterpenes that characterise the odour of different pine species and are likely to be used during host location by the female moths. They suggest that the presence of (S)-(-)-limonene, which occurs in needles of *P. radiata*, is partly responsible for the attractiveness to pine processionary moth, whereas other pines, with lower (S)-(-)-limonene concentrations, are less attractive. The superior height growth of *P. radiata* also increases the risk of attack. Needles of *P. radiata* appear to be more nutritious than those of European pines such as *P. pinaster* and *P. nigra*. Buxton (1983) found that the growth rate of pine processionary caterpillars was greatly increased when they fed on *P. radiata* than when they fed on *P. pinaster*. Not only did this potentially increase their fitness and reproductive capacity, they were also less likely to be attacked by parasitoids because of reduced synchrony of their life cycles. The higher growth rate of pine processionary caterpillars from *P. radiata* leads to their earlier pupation, compared with those from *P. pinaster*. A tachinid fly, *Phryxe caudata*, emerges too late to parasitise the majority of pine processionary caterpillars from *P. radiata* whereas those from *P. pinaster* are still in their larval stage that can be attacked by the parasitoid. Therefore, it appears that the increased susceptibility of *P. radiata*, compared with European pines, to the pine processionary moth is caused by several factors: *P. radiata* attracts more pine processionary moths that are seeking hosts for oviposition, it appears to be more nutritious and allows faster development, and it indirectly assists with protection from natural enemies.

Bark beetles – Ips sexdentatus *and other species*

Biology

Ips sexdentatus, the six-spined engraver beetle (Coleoptera, Scolytinae), is a serious pest of pines in its native region in Europe, North Africa, and parts of Asia. It creates tunnels (known as galleries) under the bark where the larvae feed on the phloem. The initial colonisation by a male beetle often leads to a mass-attack that is mediated by the release of a species-specific aggregation pheromone that attracts both females and other males to the same log or tree (and surrounding area). This mass attack helps to overcome defensive reactions by trees such as resin flow, and it allows the beetles to colonise live trees, in addition to logs and dead trees. As other bark beetles, *Ips sexdentatus* can vector many fungal associates, including some that are significant tree pathogens or that affect wood quality. A more detailed description of its biology and other information is given in the Appendix B.

Damage observed in stands of *P. radiata* and other pines

Ips sexdentatus is often considered to be less damaging than the closely related *Ips typographus*, which is typically found on spruce (*Picea* spp.) where it has frequent outbreaks in parts of Europe. However, a recent serious outbreak of *Ips sexdentatus* in the pine plantations (over 1 million ha of mainly *P. pinaster*) of the Landes Region in south-west France, that followed a storm in December 1999, shows that *Ips sexdentatus* can also have very damaging outbreaks and kill live trees over large areas. The recent outbreak in the Landes Forest occurred because bark beetles were able to breed in the abundant fresh logs that had fallen during the storm. Beetle populations during the peak of the outbreak were so abundant that they were able to attack many live trees, especially those that were stressed.

There are only a few small stands of *Pinus radiata* in the Landes Forest but we located more substantial plantings further south in the French Basque region where we encountered some substantial attack by *Ips sexdentatus*. Near Moleon, we visited a ca. 30-year old *P. radiata* stand that had been damaged by hail and was subsequently attacked by *Ips sexdentatus*. This attack affected nearly all the trees, and the entire stand had to be salvage harvested (Fig. 12a). Individual logs we examined showed extensive galleries of *Ips sexdentatus*, and it was obvious that such attacks inevitably cause tree mortality (Fig. 12b).

Figure 12a: A stand of ca. 30-year old *P. radiata* killed by bark beetles (*Ips sexdentatus*) after it had been damaged by hail (near Mauleon, France).

Figure 12b: Galleries and larvae of the bark beetle *Ips sexdentatus* that infested and killed a stand of ca. 30-year old *P. radiata* after it had been damaged by hail (near Mauleon, France).

Attack of billets of *P. radiata* and other pines

The trial we set up in October 2004 with billets of *P. radiata*, three other exotic, North American pines [*P. contorta* (lodgepole pine), *P. palustris* (longleaf pine), *P. taeda* (loblolly pine)], and four native, European pines [*P. nigra nigra* (black pine or Austrian pine), *P. nigra laricio* (Corsican pine), *P. pinaster* (maritime pine), *P.* sylvestris (Scots pine)] to compare the relative susceptibility of these species (Figs. 13, 14), showed that all were readily attacked by *Ips sexdentatus*. Within days frass was noticeable on some billets (Fig. 15), but the overall attack rate was relatively low, probably because the local outbreak had already collapsed and local populations were smaller. The pooled data from the no-choice and multiple choice experiments showed that although *P. radiata* had received some attacks (about one attack per two billets), it appeared to be the least favoured of the pines in the trial (Fig. 16). The European *P. pinaster* and *P. sylvestris* as well as the North American *P. palustris* were significantly more attacked (Fig. 16). Despite the fact that *Ips sexdentatus* appeared to have a lower preference for *P. radiata* in this study, it is known from field observation by us and others that it can be a major pest of *P. radiata*.

Subsequent dissections of a subset of logs revealed that *P. radiata* had also been attacked by the bark beetles *Hylastes ater*, *Hylurgus ligniperda*, *Orthotomicus erosus*, *Pityogenes bidentatus*, and by the pine weevil *Hylobius abietis*. Particularly the records of *H. ater* and *H. ligniperda* were of interest because these species have already become established in New Zealand and several other countries where they attack *P. radiata* and other pines (Brockerhoff et al. 2006). These observations indicate that trials such as this can reveal which insects should be classed as potential biosecurity threats to pine plantations in New Zealand, particularly if there is a pathway that could facilitate their invasion. Most of the bark beetles we encountered in *P. radiata* were also recorded in a recent study in the Spanish Basque Country (Romón et al. 2007a), and in addition they also recorded *Hylurgops palliatus*, *Hylastes attenuatus*, *Dryocoetes autographus*, *Tomicus piniperda*, *Pityogenes calcaratus*, *Pityophthorus pubescens*, *Hypothenemus aspericollis*, *Xyleborus dispar*, *X. dryographus*, and *Xylosandrus* sp. Among these species, *Tomicus piniperda* causes much economic damage in the Basque Country and other Spanish regions (e.g., Amezaga 1993). Furthermore, many of these Scolytinae have associations with fungal pathogens (Romón et al. 2007b), and they may also vector pitch canker. More comments regarding the risk assessment of these species are given below.

Figure 13: Billets of *P. radiata* and three other exotic pine species and four native pine species (or subspecies) that were subsequently used to assess attacks by *Ips sexdentatus* and other bark beetles (on the grounds of the INRA laboratory at Pierroton, France, with Hervé Jactel and Pierre Menassieu).

Figure 14: Multiple choice experiments with billets of *P. radiata*, three other exotic pine species and four native pine species, with a lure for the bark beetle *Ips sexdentatus* (attached to the stake in the centre) (INRA grounds, Pierroton, France).

Figure 15: Frass produced by *Ips sexdentatus* that initiated galleries in billets of *P. radiata* and other pines. (INRA grounds, Pierroton, France).

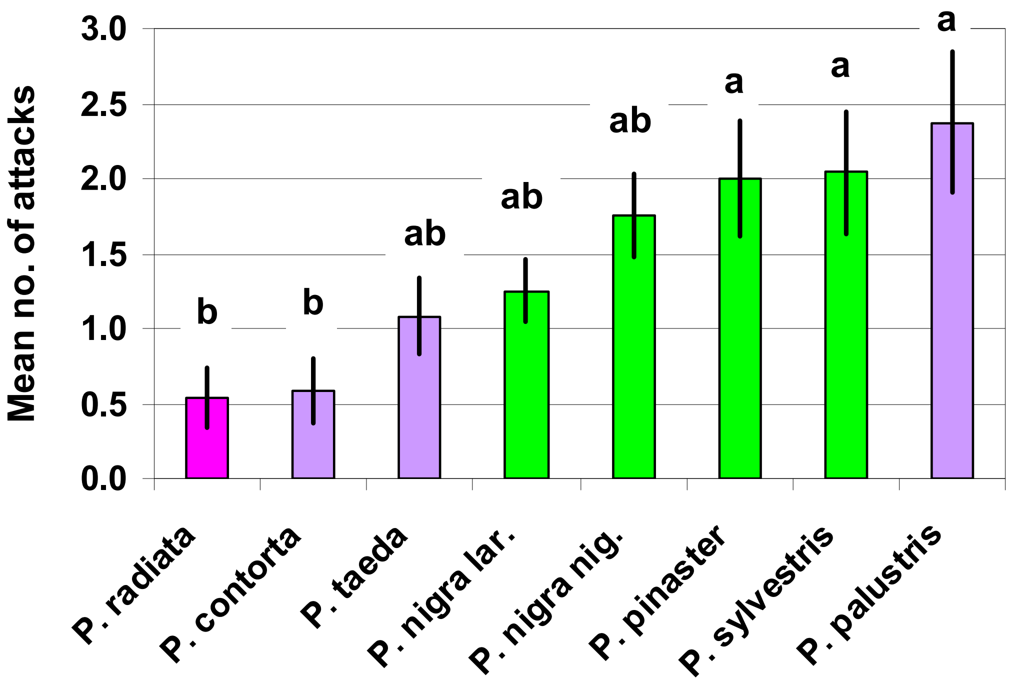

Figure 16: Mean (± SE) number of attacks of pine billets by *Ips sexdentatus*. Columns not sharing a letter were significantly different according to an ANOVA and a Tukey multiple comparison test (Note: Green columns represent native European pine species and purple columns represent introduced pines).

Other pests

Dioryctria sylvestrella

Attacks by the pine shoot borer, *Dioryctria sylvestrella* (Lepidoptera: Pyralidae), were noticed in a *P. radiata* stand near Mauleon, in the French Basque Country. This insect is considered a major pest in *P. pinaster* (maritime pine) stands in the Landes Forest (Jactel et al. 1994). Tunneling on the main stem of younger trees can cause breakage of the leader and stem deformation which devalues the log significantly. Although the level of damage we noticed on *P. radiata* was limited in this particular instance, it is an indication that *D. sylvestrella* attacks *P. radiata*, and that is has considerable pest potential. A more thorough assessment of this species could be worthwhile.

Literature records of other potential or actual species attacking P. radiata

Although we did not encounter any other significant insect pest damage during the study we conducted in Europe, it is known that several other European insects are threats to *P. radiata*.

The wood wasp *Sirex noctilio* is a European species that became a significant pest of *P. radiata* in New Zealand following its introduction in the late 1800s. Biological control and silvicultural improvements of stands have reduced this problem in New Zealand (Zondag and Nuttall 1977).

The European pine shoot moth, *Rhyacionia buoliana*, was introduced to Chile and first detected there in the mid-1980s (Toro and Gessel 1999). It has become a major pest in pine plantations there, and a wide range of control options have been explored to reduce its impact.

The nun moth, *Lymantria monacha*, a close relative of the gypsy moth, is a European defoliator of pines and other conifers that has recently been shown to have considerable pest potential on *P. radiata* (Withers and Keena 2001).

An annotated bibliography on numerous other, mostly more minor, insect pests that were recorded from *P. radiata* in Europe and other parts of the world was prepared by Ohmart (1982). This bibliography contains summaries of 295 publications on insects recorded from *P. radiata*.

A comprehensive review of insect pests and diseases of *P. radiata* in Spain was prepared by Cobos-Suarez and Ruiz-Urrestarazu (1990) [in Spanish]. This review focuses on the Basque Region, where the majority of Spanish radiata plantations are located, but problems recorded from other regions are also reported. Their review classes the pine processionary moth as the most important pest of *P. radiata* in Spain, a conclusion that we would support based on our observations and studies. Other species considered to be of significant pest concern are the pine weevil *Hylobius abietis* (which we also recorded in our billet study) and *Rhyocionia duplana* in nurseries and young plantations, the weevil *Pissodes notatus* in older stands, and the bark beetles *Ips sexdentatus* and *Tomicus piniperda* in mature stands, where weakened trees are at a particular risk.

The authors of the present report have collected numerous additional publications that were not covered by previously published reviews, and these are available on request.

CONCLUSIONS AND RECOMMENDATIONS

Implications for forest biosecurity in New Zealand

Actual and potential impact of European pests on *P. radiata*

Based on the results of our study and our review of the literature, *P. radiata* appears to be highly susceptible to a wide range of European insect pests of pines. Many of these European species, which have not received as much attention in New Zealand as pests known from North America, are potentially significant pests and should be regarded as major biosecurity threats. The greater impact on *P. radiata* than on native pines that was observed for some of these European pests is likely to be related to the fact that there was no opportunity for adaptation to evolve in the case of the new association. This could also indicate that European pests of pines may be more damaging to *P. radiata* than the North American pests of pines. The pine processionary moth as well as several of the bark beetle species can be ranked as the most damaging species which probably reflects their pest potential in New Zealand, should they become established here. In addition to the direct impact of these insects, there is the additional impact of associated pathogens that are vectored by some of these species. For example, the pitch canker pathogen, *Fusarium circinatum*, is known to be vectored by species in the bark beetle subfamily Scolytinae. Pitch canker has been introduced accidentally into the Spanish Basque Country, and it is possible that *F. circinatum* could be dispersed with bark beetles over longer distances. It is also worth noting that the effects of European insects could potentially be worse than in their native region where they are associated with their various natural enemies, whereas in New Zealand they are likely to encounter far fewer effective natural enemies that could exert control.

Risk of arrival in New Zealand – pine processionary moth

In terms of the risk of arrival of these species, the pine processionary moth is considered to be a poor disperser, and to our knowledge it has not yet become established anywhere outside its native region. Although pathways such as accidental shipment of egg masses or of mated females with containers originating from infested regions, or accidental transport by tourists, there have not been any recorded arrivals in New Zealand of any life stage of the pine processionary moth. There are numerous arrivals of gypsy moth egg masses, mainly with imported cars and containers originating from Japan and adjacent countries, gypsy moth females lay their eggs relatively indiscriminately on inanimate objects (e.g., cars, containers) whereas the pine processionary moth lays its eggs only on pine needles. Air cargo containing a live, mated female is another potential, and perhaps more probable, pathway. However, one would consider that the arrival in New Zealand of viable propagules of the pine processionary moth is comparatively low-risk. Nevertheless, there are frequent outbreaks of pine processionary moth in southern Europe which suggests that there is a high propagule pressure in its native region. These outbreaks often affect pines in urban and semi-urban areas in close proximity to industrial sites with shipping container activity, and therefore it is conceivable that needles carrying egg masses or mated females could accidentally be transported on the surface or inside a container. Other lepidopterous defoliators that were considered low risk have become established in New Zealand.

Risk of arrival in New Zealand – bark beetles

The risk of arrival of *Ips sexdentatus* and other European bark beetles is probably much higher. Bark beetles and wood borers travel well because they develop under bark or inside wood, and wooden packaging that may contain such insects is still widely used for packaging. Numerous interceptions of such species have been recorded at New Zealand’s borders and in other countries, including most of the bark beetles observed on *P. radiata* in Europe (Brockerhoff et al. 2003, 2006). Furthermore, many of these species have already become established outside their native range (Brockerhoff et al. 2006), including several cases in New Zealand.

Risk of arrival from bio-geographically related regions

Although our trade with Europe is comparatively less important (in terms of the relative amount of trade with other regions) and perhaps not as much a biosecurity risk as trade with other regions, many of these insects have a geographic distribution that extends eastwards beyond Europe into parts of Asia where we have significant trading partners. Numerous recent incursions in North America and elsewhere of forest pests originating from these regions in (e.g., Asian longhorn beetle, emerald ash borer), prove that this threat to forest biosecurity should be taken seriously. Pine processionary moth does not occur in eastern Asia, but some of the European bark beetles, or closely related species, occur in eastern Asia as well.

Risk of establishment

When viable stages any of these insects arrive in New Zealand, the risk of their establishment is relatively high. Although the majority of arrivals of exotic species clearly do not become established (due to Allee effects, etc.), insects of pines find a sizeable and widespread resource of pine trees in New Zealand, which should assist their colonisation. Interestingly, there is some evidence that ‘aggressive’ bark beetles such as *Ips sexdentatus*, which are capable of attacking and killing live trees, are less successful as invaders than secondary bark beetles that attack dead wood (dead trees, logs, etc.) (e.g., Brockerhoff et al. 2006), although there are some precedents of the former (e.g., *Scolytus multistriatus* in New Zealand, which could be considered ‘aggressive’ because it often kills trees, by way of infection with pathogens during maturation feeding, that are subsequently colonized).

Recommendations

Based on the potential risk to New Zealand’s forest biosecurity of insect pests originating from Europe and adjacent regions, we recommend that border surveillance for such species should be increased. This can be done by targeted examination of high risk goods and pathways and by using specific pheromones that are readily available for the pine processionary moth (Jactel et al. 2006), *Ips sexdentatus*, and other species we studied. For example, lures with the pheromone of the pine processionary moth could be added to gypsy moth traps without sacrificing the effectiveness for either species (Brockerhoff et al. 2007 in B3 M1.3

report). Similar approaches could be investigated for multiple-species traps for combinations of species that have not yet been explored. An improved understanding of what risks are associated with particular pathways can be used to implement improved safety measures for such pathways.

ACKNOWLEDGEMENTS

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APPENDICES

Appendix A – Information on pine processionary moth

Thaumetopoea pityocampa

[from: Data Sheets on Quarantine Pests (Prepared by CABI and EPPO for the EU under Contract 90/399003)]

IDENTITY

Name: *Thaumetopoea pityocampa* (Denis & Schiffermüller)
Taxonomic position: Insecta: Lepidoptera: Thaumetopoeidae
Common names: Pine processionary (English)
Processionnaire du pin (French)
Pinienprozessionsspinner (German)
Procesionaria del pino (Spanish)
Processionaria dei pini (Italian)

Notes on taxonomy and nomenclature: The species was described by Denis & Schiffermüller in 1776 in the genus *Bombyx*. In 1822, Hübner created the genus *Thaumetopoea* for all species now included in the family Thaumetopoeidae (raised to this category in 1990). Some authors have followed Stephens who, in 1928, included all species of Thaumetopoeidae in the genus *Cnethocampa*, which he placed in the family Notodontidae (Agenjo, 1941).

Bayer computer code: THAUPI
EU Annex designation: II/B

HOSTS

All species of *Pinus* and *Cedrus* and occasionally *Larix decidua* are attacked. Different species vary in susceptibility, partly because of physical factors such as needle morphology and dimensions, which determine suitability for oviposition (Demolin, 1969a). The following list places species in decreasing order of susceptibility:

Pinus nigra var. *austriaca*
Pinus sylvestris
Pinus pinaster
Pinus pinea
Pinus canariensis
Pinus halepensis

Cedrus atlantica

Larix decidua

The host plant also influences larval development. Survival is greater on *P. sylvestris* and *P. nigra* var. austriaca than on *P. pinaster* and *P. halepensis* (Montoya, personal communication). In field trials in the Thessalonika area of northern Greece, larvae developed faster on *P. radiata* than on *P. pinea* (Avtzis, 1986). Such differences must not be assumed to apply outside the regions where they were observed. For example, *P. pinaster* is not much attacked in Corsica, southern France or Spain but suffers significant damage in Les Landes (France). [Note: These comments about regional variation in attack should be viewed with caution. There have been records of substantial damage on *P. pinaster* in SE France (H. Jactel., unpublished)]. *Cedrus* is undamaged in the Mont Ventoux area (France), but carries high population levels in North Africa (Geri, 1980).

GEOGRAPHICAL DISTRIBUTION

EPPO region: Albania, Algeria, Austria, Bulgaria, Croatia, Cyprus, France (including Corsica), Greece (including Crete), Hungary, Israel, Italy (including Sicily and Sardinia), Lebanon, Libya, Morocco, Portugal, Spain (including Balearic Islands, but not Ibiza), Switzerland (Genève, Tessin, Valais), Syria, Tunisia, Turkey and Yugoslavia.

Asia: Cyprus, Israel, Lebanon, Syria, Turkey.

Africa: Algeria, Libya, Morocco, Tunisia.

EU: Present.

Distribution map: See CIE (1977, No. 366).

BIOLOGY

The life cycle of T. pityocampa is normally annual but may extend over 2 years at high altitude or in northern latitudes for part or the whole of the population. The life cycle has two phases, the adult, egg and caterpillar being aerial and the pupa hypogeal.

Development lasts 6 months under the most favourable conditions, but the 4th and 5th instars may be prolonged in the winter. The pupal stage can be prolonged considerably by diapause which adjusts, at a given location and within certain limits, to ensure constant adult emergence dates each year. Effects of altitude and latitude are discussed by Demolin (1969b), explaining the variation in behaviour at different sites.

Daily average sunshine plays an important role in defining the northern limit of distribution. Androic (1957) proposed the isohelia of 2000 h for the northern border; this is a good aproximation but varies with other climatic factors. Adult emergence dates are earlier at northern latitudes and at higher altitudes. In general, the emergence period lasts less than 1 month for vigorous populations and 1.5 months for weakened populations in regression. In most ecological conditions, the adults fly in July.

A few hours after emergence and mating, the females oviposit on the nearest pines. They can, however, fly several kilometres, and quickly extend outbreaks over large areas. The eggs are laid in cylindrical masses in a helicoid arrangement around pairs of needles. A large proportion of the egg masses are generally laid on the peripheral shoots of the crown and contain 70-300 eggs, according to the feeding conditions of the caterpillars (Geri, 1980).

After 30-45 days the young larvae bore an opening in the chorion that can be recognized easily. They aggregate in colonies and spin silken nests which enlarge until the 4th instar when the definitive winter nest is built. In general, this is situated at the branch tips in the upper part of the crown. The caterpillars change colour at each moult and at the 3th instar urticating hair patches appear (Demolin, 1963). If the autumn is warm and sunny, the caterpillar can reach the 5th instar in early winter.

The pupation 'processions', which occur in late winter and early spring, are a spectacular expression of the social behaviour. The caterpillar at the head of the procession is commonly a future female, leading the colony in a file searching for a suitable site to tunnel underground and pupate in the soil. The processions occur at temperatures of 10-22°C; at lower temperatures the colonies regroup and at higher temperatures they bury themselves wherever soil texture allows. Consequently, the cooler the soil, the more extensive is the spread of pupation sites at forest edges. At higher temperatures, the procession moves towards trunk bases in the shade of trees and may even bury itself close to the base of the original tree (Demolin, 1969c). A colony was observed to travel 37 m in 2 days in a cold mountainous area of Spain, the first 35 m being covered during the first day (Robredo, 1963).

Pupation takes place at a depth of about 10 cm and the pupae enter diapause, which always breaks 1 month before adult emergence. Some pupae or the whole colony may not yield adults in the year of pupation, the diapause period extending until the following year or longer.

DETECTION AND IDENTIFICATION

Symptoms

In infested pine forests, it is easy to detect the presence of T. pityocampa by the cylindrical egg masses laid on the low branches of trees and by the early damage caused by the 1st- and 2nd-instar caterpillars. They feed on the needles of twigs close to the silken nest; these partially eaten twigs remain on the tree with their brown and yellowing needles. During the winter, defoliation increases and the white nests stand out plainly.

Morphology

Eggs

The typical cylindrical egg masses range in length from 4 to 5 cm. They are covered with the scales of the female anal tuft, which mimics the pine shoots.

Larva

The larvae develop through five instars, recognized by differences in head capsule size. The average head width of the 5th-instar caterpillar is 4.8 mm for the male and 3.4 mm for the female. The full-grown caterpillar is about 40 mm in length. The head capsule is black. The body of the 1st-instar caterpillar is dull apple-green. After the second moult, the caterpillar assumes its definitive appearance and the reddish dorsal urticating hair patches on each body segment appear arranged in pairs. The integument and hairs that clothe the body vary considerably with different provenances. In general, the integument is darker in colder areas and varies from dull bluish-grey to black. The pleural hairs vary from white to dark-yellow; the dorsal hairs range from yellow to dull orange.

Pupa

Pupation takes place in the soil in an oval, ochreous-white silken cocoon. The obtect pupae are about 20 mm in length, oval, and of a pale brownish-yellow colour that later changes to dark reddish-brown.

Adult

The female moth has a wing-span of 36-49 mm. The wing-span of the male is 31-39 mm. The antennae are filiform in females and pectinate in males. Both have a hairy thorax. The abdomen is stout and its last segments are covered with a tuft of large scales; the abdomen of the male is brushy and sharp. The forewings are dull ashen-grey; the veins, margins and three transverse bands are darker. The hindwings are white, grey-fringed, with a characteristic dark spot in the anal region.

For further details, see also MAPA (1981).

MEANS OF MOVEMENT AND DISPERSAL

Females of T. pityocampa are able to fly some kilometres and the pupation processions may cover up to 37 m. Pupae may be transported with plants in attached growing medium which may be infested by buried insect pupae. Any plant cultivated near infested trees could harbour pupae.

PEST SIGNIFICANCE

Economic impact

In the Mediterranean region, T. pityocampa is considered one of the most important forest pests (Cadahía et al., 1975) and is commonly observed in pine forests; it is also common in the cedar forests of North Africa. Defoliation damage is extremely serious in young reforested areas where it may lead to death of trees, directly or as a consequence of attack by bark beetles or other wood-boring insects. In mature forests trees are rarely killed but significant losses occur in volume growth.

Calas (1897) estimated a 60% reduction in height growth of Pinus nigra trees. In young reforestations of P. radiata, Cadahía & Insua (1970), by controlling infestations on young trees, demonstrated losses of wood volume increment between 14 and 33% for light and high infestations, respectively. Bouchon & Toth (1971) showed by dendrochronological techniques that forests of P. nigra periodically subject to heavy attacks lost about 45% of their volume in 50 years. Lemoine (1977) found a reduction of 30% in circumference growth after an attack on P. pinaster in Les Landes (France). Defoliation of P. nigra subsp. nigricans on Mont Ventoux by T. pityocampa caused a missing growth ring the year after a severe attack, resulting in radial growth reductions of 35% (Laurent-Hervouet, 1986). In Corsica, radial growth losses on P. nigra subsp. laricis were 20% for the 28 years studied, but the attacks only took place every other year.

Defoliation damage and the presence of caterpillars are important on amenity trees in recreational and residential areas, where defoliation may also cause severe deterioration and greater maintenance costs. In addition, the caterpillars have urticating hairs from the 3rd instar onwards (Demolin, 1963), which may cause allergies resulting in conjunctivitis, respiratory congestions and asthma (Ziprkowski & Roland, 1966). These effects occur not only when the caterpillars are present, but also during the following summer because of the persistence of allergenic hairs in the remains of winter nests. This problem not only affects recreational and residential areas but also hinders sylvicultural operations and grazing in forests (Marti Morera & Barri Baya, 1959).

Control

Chemical and biological control treatments are mainly applied by ULV aerial spraying with rotary atomizers at 5 litres/ha, with petroleum oil or vegetable oils as solvents. Dosages of the active ingredients are as follows (Robredo, 1980; Robredo & Obama, 1987): 45-56 g/ha of the insect growth regulator (IGR) diflubenzuron; 1.7-2.6 g/ha of the pyrethroid cypermethrin; 0.65-1.00 g/ha of the pyrethroid deltamethrin; and different formulations of Bacillus thuringiensis at the rate recommended by each manufacturer. All larval instars are susceptible to these treatments, but the 4th and 5th instars need the highest dosages. At this stage of development, during the winter months, the impact of pyrethroids on the beneficial insect fauna is minimized (Robredo & Obama, 1991).

In small areas or at low population density, mechanical control is also recommended, by cutting and burning of winter nests. Sex pheromone traps may be used, both for monitoring and for mass trapping (Cadahía et al., 1975; Montoya, 1984; 1988).

The major parasitoids and predators of T. pityocampa are as follows (Biliotti, 1958; Biliotti et al., 1965; Cadahía et al., 1967; Demolin & Delmas, 1967; Demolin, 1969c; Du Merle, 1969).

On eggs: The parasitoids Tetrastichus servadei (Hymenoptera: Eulophidae), Oencyrtus pityocampae (Hymenoptera: Encyrtidae), Trichogramma sp. (Hymenoptera: Trichogrammatidae), Anastatus bifasciatus (Hymenoptera: Eupelmidae), and the predators Ephippiger ephippiger (Orthoptera: Tettigoniidae), Barbitiste fischeri (Orthoptera: Tettigoniidae).

On larvae: The parasitoids Phryxe caudata (Diptera: Larvaevoridae), Compsilura concinnata (Diptera: Tachinidae), Ctenophora pavida (Diptera: Tachinidae), Erigorgus femorator (Hymenoptera: Ichneumonidae), Meteorus versicolor (Hymenoptera: Braconidae) and the predator Xantandrus comtus (Diptera: Syrphidae).

On pupae: The parasitoids Villa brunnea (Diptera: Bombyliidae), V. quinquefasciata (Diptera: Bombyliidae), Coelichneumon rudis (Hymenoptera: Ichneumonidae). The most important diseases (Vago, 1958; Atger, 1964) are caused by the viruses Borrelina sp. and Smithiavirus pityocampae, the bacteria Bacillus thuringiensis and Clostridium sp., and the fungi (mainly on pupae) Aspergillus flavus, Beauveria bassiana, Cordyceps sp., Metarhizium anisopliae, Paecilomyces farinosus, P. fumoso-roseus and Scopulariopsis sp.

Phytosanitary risk

T. pityocampa is not listed as a quarantine pest by EPPO or by any other regional plant protection organization. Within the EPPO region it is likely to be a damaging pest only in the pine and cedar forests in the Mediterranean area. At present only a few areas are still free from the insect; for example, the Canary Islands are being protected by phytosanitary measures taken by the Spanish Department of Agriculture.

PHYTOSANITARY MEASURES

Plants for planting of the genera Pinus and Cedrus should be inspected for the presence of egg masses and caterpillar colonies of T. pityocampa. Likewise, nursery plants with attached growing medium should be inspected for the presence of pupae. Ideally, consignments of plants for planting, in particular those with attached growing medium, should come from an area found free, together with its immediate vicinity, from T. pityocampa.

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Appendix B – Information on the bark beetle Ips sexdentatus

Ips sexdentatus

[from: Data Sheets on Quarantine Pests (Prepared by CABI and EPPO for the EU under Contract 90/399003)]

IDENTITY

Name: *Ips sexdentatus* (Börner)
Synonyms: *Dermestes sexdentatus* Börner
Ips typographus De Geer
Bostrichus pinastri Bechstein
Tomicus stenographus Duftschmidt
Taxonomic position: Insecta: Coleoptera: Scolytidae
Common names: Six-toothed bark beetle (English)
Stenographe (French)
Grosser 12-zähniger Kiefernborkenkäfer (German)
Tolvtannet barkbille (Norwegian)
Bayer computer code: IPSXSE
EU Annex designation: II/B

HOSTS

In northern Europe, *I. sexdentatus* is found on *Pinus sylvestris*, and in central and southern Europe also on *P. pinaster*, *P. heldreichii* and *P. nigra*. In Turkey, Georgia and southern Russia, it occurs on *Picea orientalis*. It is occasionally recorded on species of *Larix*. In Asia, it occurs on *Pinus armandii* and other species of *Pinus*.

GEOGRAPHICAL DISTRIBUTION

EPPO region: *I. sexdentatus* occurs in *Pinus* forests throughout Europe, but in Scandinavia it is only found north of the Arctic Circle: Austria, Bulgaria, Czech Republic, Finland (north of Arctic Circle only), France, Germany, Greece, Hungary, Italy (mainland, Sardinia), Lithuania, Macedonia, Norway (north of Arctic Circle apart from some small local populations in southern Norway), Poland, Portugal, Romania, Russia (central Russia, southern Russia, Western Siberia, Far East), Spain, Sweden (north of Arctic Circle only), Slovakia, Switzerland, Turkey, UK (England, but absent from Northern Ireland), Ukraine, Yugoslavia.

Asia: China (Hebei, Heilongjiang), Korea Democratic People's Republic, Korea Republic, Russia (Siberia, Far East), Thailand, Turkey.
EU: Present.

BIOLOGY

The species has only one annual generation north of the Arctic Circle, two generations in central areas of Eurasia and four to five generations in the Mediterranean area and in other areas with a long, warm summer season. The spring flight starts when the temperature exceeds about 20°C; in the north this is in May/June, in southern areas in March/April. The male beetle initiates the boring and releases an aggregation pheromone consisting mainly of ipsdienol (Vité *et al*., 1974). Brood development from the start of gallery construction until the emergence of the new generation adults may take 2-3 weeks at a constant laboratory temperature of 27°C and 3-4 weeks at 22°C. No gallery construction and brood production succeeds at a constant temperature of 12°C. Overwintering is in the adult stage. The supercooling point in hibernating adults is about -19°C, whereas in larvae it is only -9°C (Bakke, 1968).

DETECTION AND IDENTIFICATION

Symptoms

Reproduction occurs under thick bark of pines. The gallery system has two to four female galleries up to about 1 m in length, half of them in each of two opposite directions. Larval galleries are 8-10 cm long. The wood under the gallery is stained blue from fungi transferred by the beetles (Chararas, 1962). As in the case of other conifer bark beetles, *I. sexdentatus* acts as a vector for a bluestain fungus (*Ophiostoma brunneo-ciliatum*) which also damages the tree (Lieutier *et al*., 1989).

Morphology

This is the largest beetle of the genus *Ips*, 7-8 mm in length. Both sexes have six spines at each side of the elytral declivity. The fourth is the largest and is capitate. Only the female has a longitudinal stridulatory organ on the upper hind part of the head (Balachowsky, 1949; Chararas, 1962; Grüne, 1979).

MEANS OF MOVEMENT AND DISPERSAL

Laboratory experiments have shown that adult *Ips* spp. can fly continuously for several hours. Jactel & Gaillard (1991) found, for example, that in a sample of 38 beetles, 98% could fly >5 km, 50% >20 km and 10% >45 km. The speed of flight was constant and equalled 1.3 m/s. In the field, however, flight has only been observed to take place over limited distances and then usually downwind. Beetles have been found in the stomach of trout in lakes 35 km from the nearest spruce forest, probably carried by the wind (Nilssen, 1978). Dispersal over longer distances depends on transportation under the bark of logs.

PEST SIGNIFICANCE

Economic impact

This species is of no significance as a pest in northern and central Europe, where it breeds only in fresh logs or in weakened or dying trees. It has caused death of *Pinus sylvestris* and *P. radiata* suffering from drought stress in central and southern France, northern Spain and Portugal (Goix, 1977; Perrot, 1977; Lieutier, 1984; Ferreira & Ferreira, 1986; Lieutier *et al*., 1988; Paiva *et al*.,1988; Cobos-Suarez & Ruiz-Urrestarazu, 1990), often in association with other pests (*I. acuminatus*, *Tomicus piniperda*). Outbreaks have occurred on *Picea orientalis* in Turkey (Schimitschek, 1939; Schönherr *et al*., 1983).

Control

The most effective control measure is to remove infested trees before the new generation of adult beetles emerge.

Phytosanitary risk

I. sexdentatus is not considered to be a quarantine pest by EPPO or any other regional plant protection organization. It is not generally a primary pest and is only capable of attacking trees already suffering stress, either environmental or from other pests. It is already very widespread in Europe. The island of Ireland remains the principal area facing a certain risk from this pest. *I. sexdentatus* is unlikely to spread there naturally, so that phytosanitary measures could be justified. However, it should be stressed that *I. sexdentatus* is a much less important pest than *I. typographus* (EPPO/CABI, 1996), and so presents a much lesser risk than that species.

PHYTOSANITARY MEASURES

If it is judged necessary to take phytosanitary measures against *I. sexdentatus*, measures equivalent to those taken against *I. typographus* would be effective.

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