Native and exotic coniferous species in Europe – possible host plants for the potentially invasive Siberian moth, *Dendrolimus sibiricus*[1] Tschtv. (Lepidoptera, Lasiocampidae)

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The performance of young larvae of the potentially invasive Siberian moth *Dendrolimus sibiricus* Tschtv. has been studied for the first time on the native and exotic coniferous species which are widely distributed and of considerable commercial value in Europe. *Picea*, *Abies*, the introduced *Pinus* species (five-needle pine only), and species from the exotic genera *Pseudotsuga* and *Cedrus* (all Pinaceae) are found to be suitable hosts for pest development. Two-needle pines and species from non-native *Tsuga* (also Pinaceae) are poor hosts in terms of larval performance though they may support growth of neonates (most sensitive to food quality). Coniferous species from other families: Taxaceae and Cupressaceae are inedible for the pest. The fact that the Siberian moth is able to survive and develop on all the tested genera of Pinaceae and that some of them constitute two thirds of the European forests underline how harmful this defoliator could be in the case of its introduction into European countries.

Introduction

The Siberian moth *Dendrolimus sibiricus* Tschtv. (Lepidoptera: Lasiocampidae) has recently been declared as a pest recommended for regulation by European and Mediterranean Plant Protection Organization (EPPO) member countries (EPPO, 2005). Being the most destructive pest of conifers in Russia it inhabited the huge territory: from the Pacific Ocean (Russian Far East) across Siberia to the Ural Mountains (Okunev, 1955; Rozhkov, 1963). A recent record of the pest west of the Urals strongly supports the assumption that it could invade Europe in the future (Gninenko & Orlinskii, 2002). The risk that the moth could be established in European countries, particularly those in the north and centre of the region (Belarussia, Baltic and Scandinavian countries etc.), is considered as very high (EPPO, 2006a). In the last version of data sheets on pests recommended for regulation the Siberian moth is identified as a potential hitchhiker, being associated with the coniferous plants moving in trade (EPPO, 2006a). During outbreaks, eggs and larvae of the pest can in particular be transported with wood with bark, or isolated bark, and may also be present as a contaminating pest on other products.

It is believed that accidental introduction of the Siberian moth could result in the devastation of large areas of European forest stands (EPPO, 2006a). Within its natural range, the moth has caused serious damage to thousands of hectares of forests (Baranchikov & Kondakov, 1997). Thus, during the last outbreak alone, in 1999–2002 in the Republic of Yakutia (Russia), more than 8 million hectares of larch stands were damaged (Vinokurov & Isaev, 2002). Weakened and stressed trees are attacked by secondary pests, which ultimately results in forest death and subsequent predisposition to fires (Furiaev, 1966; Isaev *et al*., 1988).

In its natural habitat, the Siberian moth damages coniferous species from Pinaceae (Rozhkov, 1963). The performance of the pest larvae on North Asian hosts has been extensively studied both in laboratory and field observations (Boldaruev, 1955; Rozhkov, 1963; Vshivkova, 1976, 2004; Kirichenko & Baranchikov, 2007). Despite the serious threat posed by the moth to the coniferous species of Eastern and Central Europe, no specific report concerning European hosts for the pest has been published so far (EPPO, 2006a). No data exists on the ability of the pest to develop on non-native coniferous species. However, these data are mandatory for the invasion risk assessment, particularly for the evaluation of potential host plants, that may result in establishment and spread of the moth in EPPO member countries (Kirichenko *et al*., 2007).

Our study aimed at the evaluation of the performance of the Siberian moth neonates on a spectrum of coniferous species widely planted in European countries which also have a relatively

[1] Notes on taxonomy and nomenclature: Many Russian scientists believe that there exists a species *Dendrolimus superans* (coniferous silk moth) with two subspecies: *Dendrolimus superans sibiricus* Tschetverikov (Siberian silk moth) widely spread in continental Russia and *Dendrolimus superans albolineatus* Matsumura (Sakhalin silk moth) which occurs on Sakhalin and Kunashir islands (Rozhkov, 1963; Epova, Pleshanov, 1995). But, according to the main international opinion (CABI, 1996), *Dendrolimus superans sibiricus* corresponds to the species *Dendrolimus sibiricus* (Siberian silk moth), and *Dendrolimus superans albolineatus* to the species *Dendrolimus superans*.

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high economical significance. In addition to indigenous European coniferous species from the same genera attacked by the pest in its range, we also tested species from exotic genera belonging to Pinaceae and to two other families (Taxaceae and Cupressaceae).

Material and methods

The experiment was carried out on the newly-hatched Siberian moth larvae. In Lepidoptera the first instar larvae appear to be the most sensitive to the food quality (Podgwaite, 1981; Slansky & Scriber, 1985). The young larvae were a daughter generation of the pest's population originated from larch shelter-belts in Shipunovskii Forestry of the Republic of Altai (Russia). The population has recently increased there (Pudovkin, personal communication).

To obtain the new generation, old larvae of the parental generation collected from the forest in June 2007 were reared in laboratory until they became imago which mated and laid eggs. Transported from the forest larvae of penultimate and ultimate instars were kept in the insectarium of V.N. Sukachev Institute of Forest SB RAS (Krasnoyarsk, Russia) under stable conditions (temperature 21–23°C, relative humidity (RH) 50–60%, photoperiod 18:6-h L:D). They were reared in 7 plastic containers (300 larvae per 10 L container) provided with cut branches of Siberian larch *Larix sibirica* Ledeb. collected in the Institute's arboretum. Branches always bore much more needle than larvae could consume. Fresh food was provided daily. Pupated larvae continued their development individually in plastic glasses (250 mL). Emerged adults were transferred in pairs one female per one male per cage into 40 cages ($18 \times 18 \times 35$ cm) covered with plastic net and supplied with cut Siberian larch branches as a substrate for laying eggs.

In the beginning of June when oviposition started, eggs were collected and immediately transported to the quarantine facilities of the *Laboratoire de Lutte biologique et Ecologie spatiale, Université Libre de Bruxelles* (Belgium) for the following experiment.

Newly hatched (<10-h old), randomly selected non-fed larvae were placed in Petri dishes (50 mm in diameter) in groups of ten to fit their natural behaviour (Kirichenko & Baranchikov, 2004a). They were kept at constant conditions (20–23°C, 55–60% RH, 18:6-h L:D) till moulting onto the second instar. To maintain the group size, dead insects were replaced with live ones kept in the same experimental regime in additional Petri dishes and reared on the same experimental hosts.

Indigenous coniferous species of prime commercial interest in Europe were used as host plants: Scots pine *Pinus silvestris* L., European black pine *P. nigra austriaca* Arnold, Norway spruce *Picea abies* (L.) Karst. and European silver fir *Abies alba* Miller. These species belong to Pinaceae and are related to those damaged by the pest in its natural habitat (Boldaruev, 1955; Rozhkov, 1963; Kirichenko & Baranchikov, 2004b). Another native conifer used in the trial was European Yew *Taxus baccata* L. (Taxaceae). Coniferous species were also tested which are non native but are widely planted in Europe: Sitka spruce *Picea sitchensis* Bong. Carr., Grand fir *Abies grandis* (Dougl. ex D. Don) Lindl., Eastern white five-needle pine *Pinus strobus* L., Douglas-fir *Pseudotsuga menziesii* (Mirbel) Franco, Eastern hemlock *Tsuga canadensis* (L.) Carr., Blue Atlas cedar *Cedrus atlantica glauca* Manetti (all from Pinaceae), and Mediterranean cypress *Cupressus sempervirens* Mill. (Cupressaceae). It is important to mention that the species from genera *Pseudotsuga*, *Tsuga*, *Cedrus* and *Taxus* do not occur in the pest's range. Four to six year old branches of the host plants were collected every second day and kept separately in plastic bags in the refrigerator at approximately 5°C. All plants were from the Tervueren Arboretum in Brussels.

Larvae were kept in Petri dishes in 15 replications per coniferous species. They were provided with one-year-old needles of all species. Food was always provided in larger quantities than daily larval consumption. The insects were inspected daily: dead larvae were counted and removed, together with the food remains and the faeces; thereafter dishes were disinfected with 90% ethanol/water (v/v) solution.

Larvae were weighed individually at the beginning the experiment (after hatching) (W1) and immediately after moulting to the second instar (W2), on torsion balances (accuracy ± 0.1 mg). Relative growth rate of larvae (RGR) expressed in fresh weight (mg/mg/day) was computed from formula: $RGR = (\ln W2 - \ln W1)/(t2 - t1)$, where $t2 - t1$ is the period between the two measurements: W1 and W2. Larval survival was calculated as the proportion of larvae alive to the beginning of the second instar per Petri dish. For the subsequent inspections the numbers of surviving or dead larvae were encoded as 1 or 0, respectively.

Z-test was applied to analyze the significance of differences between host plants on the basis of larval survival. Larval relative growth rates on different host plants were compared using ANOVA (LSD test) (Sheskin, 2004) using the software *Statistica 7.0 for Windows*. For all results means ± SE are reported; the significance levels were set at $P < 0.05$. Cluster analysis was performed to rank the coniferous species on their suitability for the neonates on the basis of both RGR and larval survival. Before the analysis, the mean of each parameter on a particular host was computed. Then RGR on each coniferous species was standardized to the highest RGR among all hosts. The tree clustering method was used where the similarities between the hosts were measured by Euclidean and City-block (Manhattan) distances (Stuetzle, 1995) and the single linkage dendrogram was drawn using the software *Statistica 7.0 for Windows*.

Results and discussion

It was supposed that larvae of the Siberian moth *D. sibiricus* that attack species of *Larix*, *Abies*, *Pinus* and *Picea* in its natural range, should be able to damage other species of the same genera growing in European countries (Davis *et al.*, 2005). This hypothesis has been confirmed in our experiment (Table 1).

In our study neonates fed with the needles of indigenous European species from *Abies*, *Pinus* and *Picea* passed the first instar and moulted onto the second one. Norway spruce and European silver fir provided relatively high growth rate though larvae reared on fir suffered from high mortality (Table 1). The two-needle pines were least suitable hosts. However, larvae reared on Scots

Table 1 Relative growth rate (± SE) and survival (± SE) of the Siberian moth neonates on the coniferous species planted in Europe

Coniferous species tested	Region of origin	Parameters of larval performance	
		Relative growth rate, mg/mg/day	Survival, %
Pinaceae			
Pinus strobus	Eastern North America	0.245 ± 0,001a	86.5 ± 4.7a
Abies grandis	North America	0.233 ± 0,002b	64.5 ± 6.7b
A. alba	Europe	0.223 ± 0.002c	57.7 ± 6.9b
Picea sitchensis	North America	0.236 ± 0.002b	88.5 ± 4.4a
P. abies	Europe	0.231 ± 0.002b	90.4 ± 4.1a
*Cedrus atlantica**	Mediterranean region	0.221 ± 0.003c	92.3 ± 3.7a
*Pseudotsuga menziesii**	Western North America	0.209 ± 0.002d	94.2 ± 3.2a
*Tsuga canadensis**	Eastern North America	0.194 ± 0.002e	69.2 ± 6.4b
Pinus silvestris	Europe	0.189 ± 0.002e	72.1 ± 6.2b
P. nigra	Southern Europe	0.170 ± 0.008f	32.7 ± 6.5c
Taxaceae			
*Taxus baccata**	Central Europe	–†	0
Cupressaceae			
*Cupressus sempervirens**	Medeterranean region	–†	0

*The genera of these species do not exist in the pest range. †There were no data obtained on these coniferous species because of 100% larval mortality during the first instar.
Means within a column followed by the same letter are not significantly different ($P > 0.05$, LSD test); in other cases $P \leq 0.05$.

pine experienced less mortality and grew significantly better than those fed on European black pine needles. Larvae were also able to develop on *Abies*, *Picea* and *Pinus* species introduced some time ago from North America to Europe and widely planted there now: Sitka spruce, Grand fir and Eastern white five-needle pine. Suitability of the former two species appeared to be similar to those of native fir and spruce, accordingly. The five-needle pine, in contrast to the native two-needle pines, provided highly suitable diet for neonates. Larvae which consumed Eastern white pine needles had the highest relative growth rate in the trial.

Although we did not test European larch in the given experiment we suppose that this conifer can be served as a host of a high favorability for the Siberian moth larvae. In our previous study European larch *Larix decidua* P. Mill. was the best host for the neonate performance in comparison with the other native European coniferous species. Early instar larvae experienced the highest growth rate and survival either they were reared on cut branches collected from matured trees (Kirichenko *et al*., 2006) or on potted 3–4 years old larch trees (Kirichenko *et al*., 2007a).

These results complement laboratory experiments and field observations in the natural range of the Siberian moth. Among North Asian coniferous five-needle pines (*Pinus sibirica* De Tour., *P. pumila* Rgl.), firs (*Abies sibirica* Ledeb., *A. sachalinensis* Fr. Schmidt. and *A. nephrolepis* (Trautv.) Maxim.) and spruces (*Picea obovata* Ledeb., *P. ajanensis* Fisch.) are the appropriate hosts for larvae performance. The two-needle Scots pine is the poorest host although it may support larval development (Boldaruev, 1955, Rozhkov, 1963, Kirichenko & Baranchikov, 2004b). The most suitable hosts for the pest in its range are larches (*Larix sibirica* Ldb., *L. kurilensis*, *L. gmelinii* (Rupr.) Rupr., *L. sukaczewii* Dyl. Mayr. and *L. cajanderi* Mayr.). Consuming the foliage of these species larvae grow fast and reach large larval and pupal weights resulting in a high fecundity in adults (Kirichenko & Baranchikov, 2004b). Within the current home range of the moth, widespread outbreaks typically occur in pure larch or fir forests and, to a lesser extent, in mixed stands of fir, spruce, and five-needle pine, whereas two-needle pine stands are rarely affected (Rozhkov, 1963).

Our study demonstrated that larvae were also able to grow and survive on the Pinaceae species from genera exotic to both Europe (where they are widely planted now) and Northern Asia. At least two coniferous plant species: Douglas-fir and Blue Atlas cedar, were of high suitability for the neonate development. Fed on their needles, neonates had a high survival similar to that on the best host in the test (Eastern white pine) and grew at a rate comparable to that on firs. Suitability of another tested non-native conifer plant Eastern hemlock (Pinaceae) was lower than that of Douglas-fir and cedar and close to Scots pine. Nevertheless this coniferous plant could support neonate growth and provided 70% survival rate of larvae in the experiment.

Thus, all genera of Pinaceae tested in this study: *Abies*, *Pinus*, *Picea* and non-native *Pseudotsuga*, *Cedrus* and *Tsuga*, and earlier tested *Larix* could be host plans for the Siberian moth larvae, supporting to various extents their development. In its range the Siberian moth exclusively damages coniferous species from Pinaceae family (Boldaruev, 1955; Rozhkov, 1963; Vshivkova, 1976, 2004; Kirichenko & Baranchikov, 2007). Conifers from other families are poorly distributed in Northern Asia. In European countries, besides plants from Pinaceae, coniferous species from other families are widely planted. Among them the conifers from Taxaceae and Cupressaceae are of high importance as ornamental trees. Phylogenetically these families are distant from Pinaceae (Quinn & Price, 2003). Representatives of these families: European Yew and Mediterranean cypress were found to be inedible for the larvae (Table 1). Neonates offered the foliage of these plants never started feeding and died on the second and third days of the test. Inability of *D. sibiricus* to feed on conifers from other families confirms that the pest's trophic niche is limited to Pinaceae.

Our data were used to rank the threatened species that could adversely be affected by the Siberian moth in the case of its accidental introduction into Europe (Fig. 1). Using cluster analysis all tested hosts were differentiated into several groups and the main ones were identified. The group of the conifers that may potentially provide the highest pest performance included Eastern white five-needle pine, spruces, Douglas-fir and Blue atlas cedar. The next group was formed by the firs, however, despite the high relative growth rate neonates experienced high mortality (Table 1). The third group consisted of Eastern hemlock and Scots pine. Black pine was classified as the poorest host for the Siberian moth larvae. Nevertheless as we found earlier this two-needle pine species may support larval development

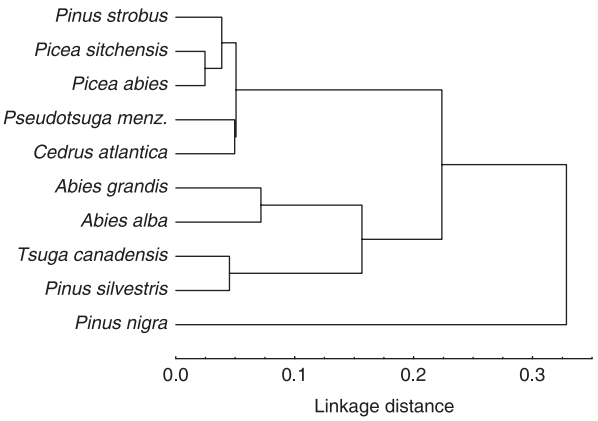

Fig. 1 Clustering of potential hosts for the Siberian moth in Europe on the basis of growth rate and survival of young larvae.

till pupation (N. I. Kirichenko, unpublished data). We believe that European larch not included in the present test would enter the first group of most appropriate possible hosts.

Conclusions

Our study provides evidence for the invasive potential of the Siberian moth, should it be either accidentally introduced or actively spread to Central Europe. According to the EPPO decision-support scheme for quarantine pests, the occurrence of at least one host, in a pest risk analysis area, is regarded as important circumstance for the pest's potential establishment and dispersal (EPPO, 2006b). In Europe, including the western part of Russia where the pest is believed to disperse (Gninenko & Orlinskii, 2002), more than 60% of the forest area consists of coniferous stands composed of *Pinus*, *Picea*, *Abies* and *Larix* species (Köble & Seufert, 2001; Baines, 2004). Once introduced into Europe, the moth could become an invasive pest in forests dominated by these species. However, it could also become a pest on the recently introduced Douglas-fir – the most commercially important non-indigenous coniferous tree species in Central Europe nowadays (Essl, 2005). The fact that this exotic species is also a highly favorable host for the moth larvae is of special interest for the North American forests, where this coniferous species is native. The risk of an introduction of the Siberian moth to North America is considered to be likely (Orlinskii, 2001; Davis *et al*., 2005); however, the resulting ecological and economic consequences have yet to be evaluated. In spite of two-needle pines being found to be poor food plants for the moth larvae in this laboratory study as compared to other potential hosts, damage by this pest might still take place.

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Espèces de conifères indigènes et exotiques en Europe –plantes-hôtes possibles pour l'espèce potentiellement envahissante *Dendrolimus sibiricus* (Lepidoptera: Lasiocampidae)

Les performances de jeunes larves de l'espèce potentiellement envahissante *Dendrolimus sibiricus* ont été étudiées pour la première fois sur des espèces de conifères indigènes et exotiques qui sont largement répandues et ont une valeur commerciale considérable en Europe. Les *Picea,* les *Abies,* les espèces introduites de *Pinus* (seulement à cinq aiguilles), et les espèces des genres exotiques *Pseudotsuga* et *Cedrus* (toutes Pinacea) se sont révélées être des hôtes adaptés au développement du ravageur. Les pins à deux aiguilles et les espèces du genre non indigène *Tsuga* (également Pinacea) sont de mauvais hôtes en termes de performance larvaire même s'ils peuvent accueillir la croissance des premiers stades (les plus sensibles pour la qualité de l'alimentation). Les conifères d'autres familles (Taxaceae et Cupressaceae) ne sont pas comestibles pour le ravageur. Le fait que *D. sibiricus* est capable de survivre et de se développer sur tous les genres de Pinaceae testés et que certains d'entre eux constituent les deux tiers des forêts européennes souligne le danger que peut représenter ce défoliateur s'il était introduit dans les pays européens.

Аборигенные и чужеродные виды хвойных в Европе – возможные кормовые растения для потенциально инвазийного сибирского шелкопряда, *Dendrolimus sibiricus* Tschtv. (Lepidoptera, Lasiocampidae)

Впервые изучено развитие молодых гусениц потенциально инвазийного сибирского шелкопряда на аборигенных и экзотических хвойных растениях, имеющих широкое распространение и значительную коммерческую ценность в Европе. Наиболее благоприятными для развития личинок первого возраста (самых чувствительных к качеству) признаны виды из аборигенных родов *Picea* и *Abies*, а из иноземных – *Pseudotsuga* и *Cedrus* (все относятся к семейству Pinaceae). Интродуцированный вид пяти-игольчатой сосны оказался высокоблагоприятным, тогда как аборигенные представители двух-игольчатых сосен и представитель иноземного рода *Tsuga* (так же из семейства Pinaceae) – малоблагоприятными, но способными поддерживать развитие молодых гусениц. Представители хвойных из семейств Taxaceae and Cupressaceae

– несъедобны для личинок сибирского шелкопряда. Учитывая широкое распространение представителей протестированных родов в лесах Европы, а так же способность вредителя развиваться на абсолютно новых кормовых породах, легко представить остроту проблемы, которая может возникнуть при появлении вредителя в европейских странах.

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